UGBY-02

BLOCK - 1

GYMNOSPERMS

Uttar Pradesh
Rajarshi Tandon Open University

UGBY -02
PLANT DIVERSITY II

Block

1

GYMNOSPERMS

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COURSE INTRODUCTION

Some kind of awareness of the diversity of plants must be almost as old as mankind. Experience taught early men how to distinguish plants that were wholesome or benign from those that were poisonous or injurious. Through trial and error, he must have gradually realised that plants not only raised in their utility, but also in seasonal occurrence and distribution. After man learnt how to cultivate useful plants at one place rather than move around gathering or hunting, the discovery of the staple crops and new plants for survival began. In 17th century the emerging scientific community began to take an interest in collection of dried plants and seeds, occasionally living plants, from far and wide. In 18th century modern studies of plant taxonomy came into existence. In the late 18th and early 19th centuries the knowledge, information and speculation on plant distribution began to take shape of the sciences which are known today as plant sciences. The knowledge of form and composition of diverse plants, their interrelationships and reproduction has formed the basis of the evolution and progress of modern man. In this course of plant diversity you will study about morphology, anatomy, reproduction, and life-cycle of Algae, Fungi, Bryophytes, Pteridophytes, Gymnosperms and Angiosperms.

You have already gone through Plants Diversity-I Course. You have studied about algae, fungi, bryophytes and pteridophytes which are often termed as lower plants. Now in Plant Diversity-II you will study about Gymnosperms, Angiosperms and Economic Importance of Plants.

In this group of plants there is enormous diversity, the plants have aquired a tree like structure to a full fledged tree. There is variation in habitat, leaf structure, flower structures, ways of reproduction, in fruits, in their dispersal and seed structure. The Gymnosperms, which have magestic and beautiful trees but possess naked seeds and single fertilization, are less evolved than the more versatile angiosoperms. When you are studying the Blocks starting from gymnosperms to angiosperms you will go through a variety of topics such as anatomy, economic botany and taxonomy related to both of them.

This is a 4 credit course containing 4 Blocks in which the third Block consists of two parts - Block III A and III B. This course also includes lab work of 2 credits. This makes 6 credits of Plant Diversity II or LSE 13.

Plant Diversity II

Block I	-	Gymnosperms
Block II	-	Flowering Plants
Block III A	-	Economic Botany
Block III B	-	Economic Botany
Block IV	-	Families of Angiosperms

Block I with 5 units is fully devoted to gymnosperms in which you are going to study morphology, anatomy and life cycles of *Cycas*, *Pinus*, *Ephedra* and *Gnetum*. You will also study how gradually gymnosperms aquire some characters of angiosperms but still retain their own identity as gymnosperms. You will also study about the various uses of gymnosperms as timber, medicine, food and as raw material in various industries.

Block II has 5 units which give you a broad idea about angiosperms. It also describes various tissues found in angiosperms in detail. You will also study about the structure, anatomy and modifications of root, stem and leaf. You will also learn about the origin, evolution and structure of flower, fruit and seed. A very important event pollination is also described in the unit on pollination biology.

Block III, which is subdivided into two parts, deals with the economic importance of some cultivated plants on which the human race is dependent for food, shelter and clothes. Block III A deals with cereals, millets, legumes, pulses, fruits and nuts, vegetables, oils, sugar and starch, while Block III B deals with spices and condiments, beverages, medicinal and aromatic plants and forest produce.

Block IV presents a glimpse of the families of angiosperms, both monocot and dicot, and a unit where some plants of special interest are discussed.

We hope that you find this course interesting and informative and inspires you to develop further interest in plant science.

BLOCK 1 GYMNOSPERMS

One of the most significant events in the long evolutionary development of the plant kingdom was the origin of the first land plants. The dominant land plants of the earth, despite their extraordinary diversity in habit, organography and method of reproduction, share one important character : the presence of a vascular system. This anatomical character is the basis for designating such plants as "Tracheophytes".

You have already studied about one group of vascular plants—the Pteridophytes. The other group comprises the seed bearing plants (also referred as Spermatophyta). The Spermatophytes are sub-divided into two major sub-divisions: Gymnosperms and Angiosperms, on the basis of protection afforded to the ovule. The gymnosperms have their ovules freely exposed, whereas in the angiosperms the ovules are enclosed in the ovary. It shall be our endeavour to reveal in the Unit 1 the salient features of morphology, anatomy and reproductive biology of gymnosperms in general. In the subsequent Units 2, 3 and 4 of the Block I, we have tried to give you an account of the diversity in the structure and reproduction of the naked seeded plants.

Unit 1 deals with a general account of the gymnosperms, their distribution, general morphology and reproduction and their life cycles. Beside this we have also discussed some gymnosperms of special interest such as the living fossil *Ginkgo* and *Welwitschia*, that is unique as it is found in formidable terrain of Namib desert.

Unit 2 deals with Cycadopsida with *Cycas* as the representative genus. This is because it is the only genus of Cycadales found in this subcontinent.

Unit 3 deals with *Pinus* the most important and widespread genus of the Coniferopsida. It is very well represented in India and is also the source of timber and resins.

Unit 4 deals with Gnetopsida comprising members with high order of specialisation in their vegetative and reproductive structures. Three families—Ephedraceae, Gnetaceae and Welwitchiaceae form the class Gnetopsida. This Unit is subdivided into two subunits. Subunit 4A pertains to the only representative genus of the family Ephedraceae, that is, *Ephedra*. This genus is both important and interesting because it is strikingly different in appearance from the other gymnosperms. In subunit 4B we have taken up yet another sole representative member of family Gnetaceae—*Gnetum*. This genus too is important for study as it has several features resembling the angiosperms.

Unit 5 The gymnosperms constitute a group which is economically very important. In this Unit you will study about various uses of gymnosperms as source of timber, pulp for paper industry, resins, medicines, and as minor source of food. It is also favourite of horticulturists because of their evergreen nature and attractive foliage.

After studying this block you will be able to:

- describe the distribution, main morphological and anatomical features of gymnosperm and some typical gymnosperms.
- describe classification of gymnosperms.
- describe in detail the characteristics and life histories of *Cycas*, *Pinus*, *Gnetum* and *Ephedra*.
- list the economic importance of gymnosperms.

UNIT 1 INTRODUCTION OF GYMNOSPERMS

Structure

1.1 Introduction
Objectives
1.2 General Characters of Gymnosperms
1.2.1 Distribution
1.2.2 Morphology
1.2.3 Anatomy
1.2.4 Reproduction
1.3 Embryogeny
1.3.1 Polyembryony
1.3.2 Mature Seed and Germination
1.4 General Patterns of Life Cycles
1.5 The Living Fossil — *Ginkgo biloba*
1.6 The Genus *Welwitschia*
1.7 Classification of Gymnosperms
1.8 Summary
1.9 Terminal Questions
1.10 Answers

1.1 INTRODUCTION

The seed plants (spermatophytes) are generally divided into two groups, gymnosperms and angiosperms. Theophrastus, a pupil of Aristotle, used the word "Gymnosperm" for the first time. As the name suggests (gymnos = naked, sperma = seed), the gymnosperms unlike the angiosperms have ovules that are exposed.

The gymnosperms comprise of only a small portion of the plant kingdom (about 70 genera and more than 700 species). In spite of being represented by such a few members, they are distributed throughout the world and, on many mountainous areas, they form a dominant part of the vegetation.

The group has a long history which dates back to atleast 200 or 300 million years. Their long evolutionary history contains many examples of organisms that existed and flourished for some duration and then became extinct as a result of changes in climate, topography and biological competition. Of the living (extant) gymnosperms, some have a long fossil history and are aptly called **"living fossils"**.

Gymnosperms as a group are most fascinating not only because they stand between the cryptogams and flowering plants (phanerogams), but also because of their great importance in forestry. In the earlier course you have studied about the various "lower plants" from algae to pteridophytes. In order to have a complete picture about the diversity ranging in the plant kingdom, it is necessary to learn about the gymnosperms, which constitute a small but important part of this range.

Objectives

After studying this unit, you should be able to :

- describe the distribution of gymnosperms,
- enlist their main morphological features,
- describe their anatomical characters,

- explain the mode of reproduction and depict the typical life-cycles diagrammatically,
- name some living fossils,
- categorise the various gymnosperms and write the classification,
- understand the difference between angiosperms and gymnosperms.

1.2 GENERAL CHARACTERS OF GYMNOSPERMS

Gymnosperms are a group of plants that differ from the angiosperms in many ways. They occur mostly in the temperate regions of the world and include mostly evergreen trees and shrubs that look extremely captivating. They are an asset to horticulturists and landscape architects. Their evergreen nature bestows on them the unique advantage of an year round appeal.

A large number of gymnosperms are economically important, particularly in forestry, horticulture and as a source of resins, drugs, essential oils and even edible seeds. The economic importance of gymnosperms will be dealt in Unit 5 of this course.

The seed plants (spermatophytes, which include both gymnosperms and angiosperms) are characterized by a very complex, large, independent sporophytic generation and a much reduced gametophytic generation which is dependent on the former. But first we must study some salient features of Gymnosperms and Angiosperms so that you will be able to appreciate the difference between them.

Characteristics of Gymnosperms:

1. Plants are sporophytes, having true roots, stems and leaves.
2. Sporophytes large, perennial with active cambium producing secondary xylem most of them lack vessels.
3. Sporangia borne on sporophylls which together form cones.
4. All forms heterosporous, and the two kinds of spores produce male and female gametophytes.
5. True seeds (single megaspore retained inside a megasporangium, which in turn is enclosed by an integument) young sporophyte (embryo) retained inside older sporophytes.
6. Gametophytes small, dependent.
7. Pollen tube forms; pollination occurs by wind or insects.
8. Ovules and seeds borne naked (uncovered).
9. Archegonium with neck, VCC/VCN and egg.
10. Single fertilization i.e. one sperm involved in fertilization.
11. Free nuclear proembryo.
12. Endosperm is haploid.

Salient Features of Angiosperms (Flowering Plants)

1. Microsporangia borne on microsporophylls (anthers and filaments respectively) comprising the androecium.
2. Characterized by megasporangia (ovules) enclosed within one or more carpellary sporophylls which comprise the ovary. Ovary together with style and terminal stigma constitutes gynoecium (pistil).
3. Subsequent to pollination and double fertilization, Endosperm is triploid. Ovules develop into seeds within the ovary wall; leads to formation of fruit.
4. Presence of vessels in the xylem. Secondary xylem produces porous wood (some exceptions known).

Box 1.1 Living Fossils

The living representatives of the Ginkgophyta and Cycadophyta are called **living fossils.** *Ginkgo biloba* is the sole living member of the group and exists in the wild state only in certain mountains in south-east China. The cycads are also relicts from the past age and are confined to some areas in the tropics and subtropics. The Cycadophytes (cycadeoids and cycads) were abundant during the Jurassic period (of geologic time scale) and it was during this time that the dinosaurs flourished. Hence, the cycads are also called as **"dinosaurs of the plant kingdom."**

SAQ 1

1. How will you define gymnosperms? How will you distinguish them from angiosperms (Give any 5 points).

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SAQ 2

Complete the sentence by matching column A with column B.

Column A	Column B
1. The gymnosperm that has vessels	(a) haploid endosperm
2. The seeds of gymnosperms	(b) conifers
3. Gymnosperms have single fertilization and form	(c) *Gnetum*
4. Presently the largest group of gymnosperms distributed all over the globe is	(d) are exposed and uncovered

SAQ 3

List three major differences between angiosperms and gymnosperms.

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1.2.1 Distribution

The gymnosperms are represented in nearly all parts of the world. The extant Cycadales and Ginkgoales are very ancient and with a long fossil history. For this very reason and few other characters, they are called "living fossils". Though these orders were well represented in the past, but presently the cycads are represented by only 11 genera and Ginkgoales by a single species, *Ginkgo biloba*. They now show only limited distribution in the tropical and subtropical regions. They do not form a major part of the vegetation on the earth.

The conifers (Coniferales) are the most conspicuous and largest group of gymnosperms and contain many economically important plants. The conifers are represented by over 50 genera and these are distributed in nearly all parts of the globe. Araucariaceae and Podocarpaceae families are represented mainly in the Southern Hemisphere. Taxodiaceae and Cupressaceae are equally represented in both Northern and Southern Hemispheres. Taxaceae (which at times are not considered a true conifer because of their distinct reproductive morphology) occur mostly in North America, Europe and Asia.

The orders Ephedrales. Gnetales and Welwitschiales are monotypic, represented by the genera *Ephedra, Gnetum* and *Welwitschia,* respectively. These plants not only show restricted distribution but also many interesting features in their morphology and reproductive biology. *Ephedra* occurs only in arid regions and in tropical and temperate Asia and America. *Gnetum* grows in tropical rain forests of Africa, Asia and S. America. *Welwitschia* is restricted to South West Africa.

Nearly 20 genera of gymnosperms have been reported from the Indian subcontinent. Of these 14 genera are native. These include conifers namely *Abies, Cedrus, Larix, Pinus, Picea, Tsuga, Cephalotaxus, Cupressus, Juniperus, Podocarpus* and *Taxus*. Besides these, *Cycas, Ephedra* and *Gnetum* are also found in the wild state.

Several genera, introduced from outside, have also established well in the hills and plains of India, these include *Ginkgo, Biota, Thuja, Cryptomeria, Agathis, Araucaria, Cunninghamia* and *Taxodium.*

1.2.2 Morphology

The gymnosperms include both large trees and woody shrubs. A few may be lianas or climbers (*Gnetum)* or rhizomatous (*Stangeria paradoxa, Encephalartos villosus, Macrozamia* sp.). Most gymnosperms are evergreen; a few such as *Larix and Taxodium* are deciduous. A large number of plants exhibit xerophytic characters.

The tallest trees in the plant kingdom belong to the gymnosperms. In California the two species of living red woods are renowned for their size, height and longevity. It is not uncommon for *Sequoia sempervirens* (coastal or California redwood) to attain a height of 90 meters (295 feet) and one tree in Humboldt County, California with a height of 111.6 meters (366.2 feet) is believed to be the tallest tree in the world. The other species *Sequoiadendron giganteum* usually referred to as "Big Trees" or Giant Redwood (and confined to the eastern slopes of California) does not become quite as tall as the coastal redwood but exceeds it in total size. The "General Sherman" tree in Sequoia National Park, for example is, 31 meters (101.5 feet) in circumference 83 meters tall it weighs an estimated 5,5,94 metric tons (6167 tons). The tree is over 3,500 years old. "Pine Alpha" is a 4,300 years old specimen of bristlecone pine (*Pinus longaeva*) growing in California.

The smallest recorded gymnosperm is a cycad. *Zamia pygmaea,* merely 3 to 4 cm tall.

Morphology of Root, Stem and Leaves

Root : The gymnosperms possess a tap root system. Some genera such as *Cycas* also show the development of coralloid roots while *Pinus* and other conifers show the presence of mycorrhizal roots. Both of these are symbiotic associations (with blue green algae and fungi respectively) that help in the nutrition of the plant. In mycorrhizal roots the mycelium of fungus forms an enveloping sheath called "Hartig net". You will read about them in detail in Unit 2 and Unit 3.

Stem: Aerial trunks are branched (as in most plants) or unbranched as in cycads shoots may be dimorphic having long and dwarf shoots, latter showing restricted growth as in *Pinus* and *Ginkgo* – long shoots and dwarf shoots. Dwarf shoots bear leaves at their apices, and the whole structure is called a spur shoot in *Pinus.*

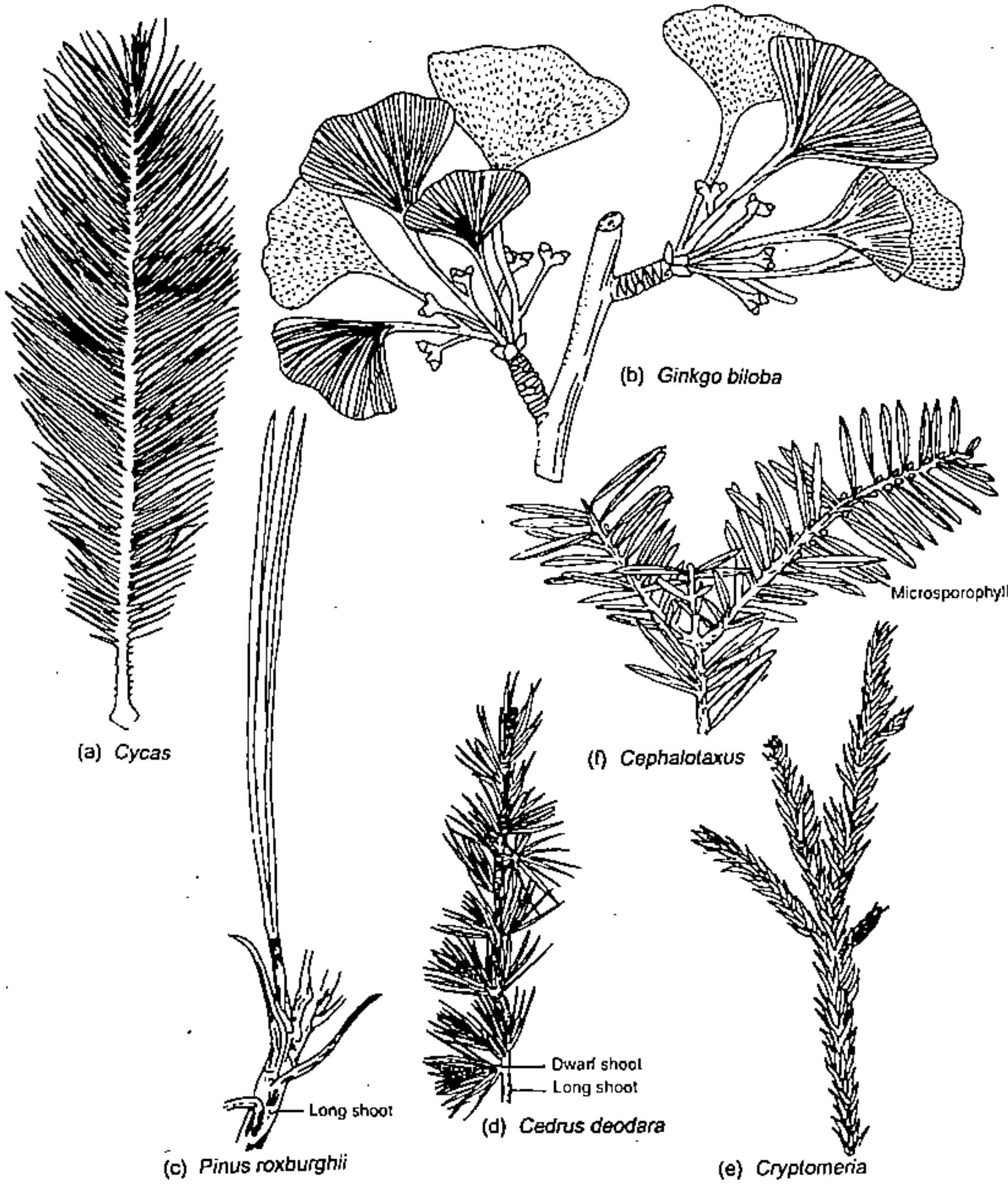

Fig 1.1 : Variations in leaf morphology amongst gymnosperm (Note these are not drawn to the same scale).

Leaves: Leaves show great variation in form and arrangement. The leaves may be large (megaphylls) or small (microphylls). Both simple and compound leaves occur: the shape also ranges from pinnate or fern-like in cycads to needle-like in *Pinus.* Leaves of *Ginkgo* are fanshaped, and those of *Gnetum* superficially resemble dicots. In *Welwitschia* they are strap shaped and persist throughtout the life of the plant. In gymnosperms the foliage leaves are usually evergreen and protected by a thick cuticle. Besides foliage leaves, scale leaves may also be present.

Arrangement of leaves on the stem is highly variable. They are generally spirally arranged but may be whorled as in *Cedrus* or opposite decussate as in Cupressaceae and *Gnetum*.

The venation also ranges from single veined in most genera to reticulate (*Gnetum*), parallel (*Agathis* and *Welwitschia*) and even dichotomous (*Ginkgo*). Resin canals occur in all coinfers except *Taxus*. Stomata are usually sunken (most gymnosperms show xerophytic characters), being present on both the surfaces or only on the lower side of leaf.

SAQ 4

Match column A with the words/names given in column B.

	Column A	Column B
1.	Only 2 leaves are formed	(a) *Zamia pygmaea*
2.	Leaves are fan-shaped	(b) *Cedrus*
3.	Mycorrhizal roots are present	(c) Almost all the conifers.
4.	The smallest gymnosperm	(d) *Welwitschia*
5.	Leaves superficially resemble dicots.	(e) *Taxus*
6.	Needle like leaves arranged in whorls	(f) *Sequoia*
7.	Tallest tree	(g) *Ginkgo*
8.	Resin ducts are absent	(h) *Gnetum*

1.2.3 Anatomy

In the young stem (primary) open, collateral, endarch bundles occur in a ring. Secondary growth takes place due to the activity of cambium. The wood is characterized by absence of vessels in most cases (exceptions are *Gnetum, Ephedra* and *Welwitschia*). The wood comprises tracheids and parenchyma; xylem fibres are absent and, therefore, the wood is referred to as "softwood" in contrast to "hardwood" in dicots (angiosperms). There are two types of wood namely manoxylic and pycnoxylic (see box). Phloem lacks companion cells and instead shows albuminous cells.

In roots the xylem is di- to polyarch. Tracheids constitute the major part of xylem. An important feature of gymnosperm leaf anatomy is the transfusion tissue.

Box 1.2 : Manoxylic and Pycnoxylic wood

There are two types of wood, namely manoxylic and pycnoxylic, depending on the amount of wood parenchyma present in it, and the size of the pith. The pycnoxylic wood is compact, has narrow xylem rays and contains small cortex and pith. On the other hand, manoxylic wood has lesser xylem and more parenchyma present in wider rays, large pith and cortex. Pycnoxylic wood forms the main component of the trunk, hence such wood is commercially important. Manoxylic wood is not important commercially. There is another aspect: the manoxylic wood is found in forms with megaphylls and radially symmetric seeds (radiospermic) e.g. cycads; pcynoxylic wood is associated with microphyllous leaves and bilaterally symmetric seeds (platyspermic) e.g. conifers.

1.2.4 Reproduction

Vegetative methods of reproduction are rare in gymnosperms, but cycads do propagate through bulbils. You will study about bulbils in Unit 2 of this block where *Cycas* will be dealt in detail.

Sexual Reproduction

Gymnosperms are heterosporous producing two kinds of spores in different spore-bearing structures (megasporangium or ovule and microsporangium or pollen sac). See Fig. (1.2 & 1.3) for details.

The gymnosperms may be monoecious (*Pinus, Cedrus*) or dioecious (*Cycas, Ephedra, Ginkgo*), and bear male and female cones, except in *Cycas* (female plant). The size of the male cone ranges from 1mm (*Zamia pygmaea*) to 60 cm (*Encephalartos coffer*). The position of the strobili on the plant varies from terminal to lateral. In *Cycas* the megasporphylls are loosely arranged between successive crowns of foliage leaves. There is great variation in the arrangement of female cones or strobili which you will study in coming units of this block. Microsporangia are borne on the abaxial or lower surface of the microsporophyll. Ovules are generally borne on the adaxial or upper surface of the megasporophyll or the ovuliferous scale. The ovule is generally orthotropous. The spore mother cells contained in the sporangia undergo meiosis to form respectively the microspores and megaspores that represent the first cell of the haploid or gametophytic generation. The microsporangium contains numerous microspores whereas the megasporangium contains only one megaspore. The gametophytes are endosporic, i.e., they develop within the respective spore walls. The microspore forms the microgametophyte (pollen grain) that produces the male gametes (sperms). The megaspore develops into megagametophyte (female gametophyte) that bears archegonia containing the female gamete (egg).

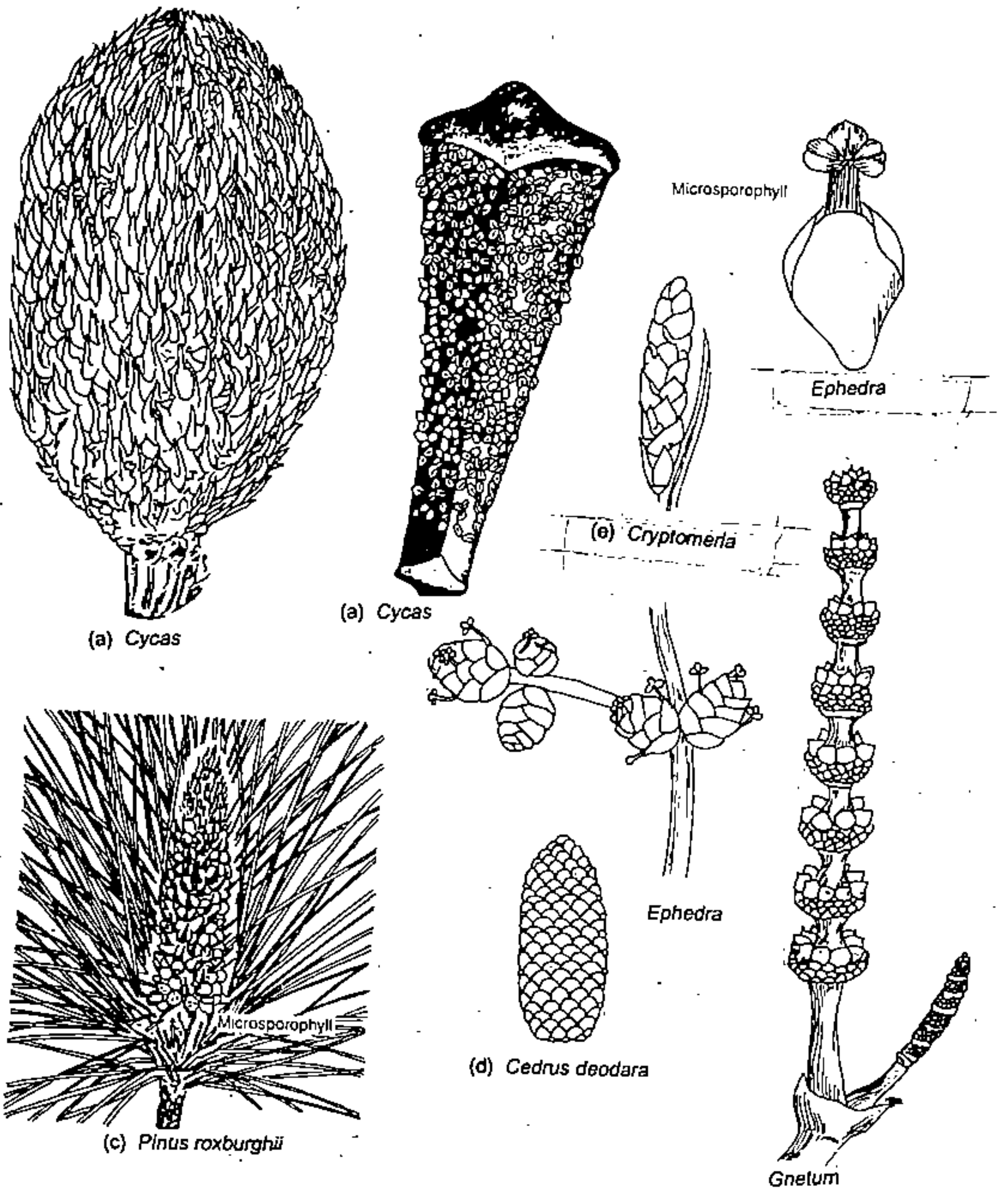

**Fig. 1.2 : Various types of male reproductive structures in gymnosperms.
(Mote these are not drawn on same scale)**

Microsporangia and Male Gametophyte

Microsporangia are borne on the abaxial surface of the microsporophyll. The development of the microsporangium is as follows. The initials form archesporial tissue that leads to formation of wall layers and sporogenous cells. The latter give rise to microspore mother cells which divide meiotically to form tetrads of microspores. The microspore is the first cell of the male gametophyte. This usually undergoes division to form one or more prothallial cells, and an antheridial initial. The latter finally forms the male gametes.

The development of male gametophyte being endosporic, it takes place partly in the microsporangium and partly in the pollen chamber of the ovule.

The development of male gametophyte is summarized below :

Each step represents a division of a cell.

- Microspore
  - Central cell
    - Antheridial initial
      - Antheridial cell
        - Spermatogenous (body) cell
          - Male gamete
          - Male gamete
        - Stalk cell
      - Tube cell
    - Prothallial cell
  - Prothallial cell

There is variation in the number of prothallial cells, size and motility of male gametes and their time of formation and discharge.

Male cells are formed in Cupressaceae, Taxodiaceae, Araucariaceae and Gnetaceae while nuclei are formed in *Ephedra*, *Cephalotaxus* and Pinaceae. In *Cycas* and *Ginkgo* male gametes are motile (spermatozoids) and this feature is characteristic of lower vascular plants (Pteridpohyta). In these two plants the pollen tube is not a carrier of sperms but merely acts as an haustorial agent by invading the nucellus. The discovery of motile sperms in *Ginkgo* was made in 1896 by Hirase.

At the time of shedding, the pollen grains are usually multicelled and contain one, two or more prothallial cells, tube nucleus and antheridial cell. In Cupressaceae, Taxodiaceae, Cephalotaxaceae and Taxaceae, pollen are shed at the uni-nucleate stage and the gametophyte development continues after pollination.

The pollen grains are winged (*Pinus, Podocarpus*) or non-winged (*Cycas, Ginkgo*). Either the male gametophyte lacks a prothallial cell (*Taxodium, Cephalotaxus*) or the number ranges from one (*Cycas*) to 32 (*Agathis, Araucaria*). The male gametes are flagellate (*Cycas, Ginkgo*) or non-flagellate (*Pinus, Cedrus*).

Ovule and Female Gametophyte

The ovules as you know are naked (i.e. they are not enclosed by megasporophyll or the subtending structures) and are borne on the adaxial surface of the megasporophylls which, in turn, are generally arranged spirally around a central cone axis. The ovules are sessile and orthotropous and each consists of a parenchymatous mass of cells called the **nucellus** or the **megasporangium**. The nucellus becomes enveloped by a single massive **integument** that grows around it leaving a small opening or the **micropyle** at the tip. The megasporangium enclosed by the integument is called an ovule. The nucellus contains a single diploid **megaspore cell** that undergoes meiosis to form a tetrad of **haploid megaspores** of which only one remains functional and the other three degenerate. The **functional megaspore,** which is usually the chalazal megaspore, enlarges and undergoes **free nuclear divisions.** Thus the young gametophyte develops within the megaspore. Centripetal wall formation (wall formation starts from periphery and proceeds inwards) starts around the free nuclei of the female gametophyte (alveolus formation see Unit 3) and goes on until the whole gametophyte becomes cellular. This is the female gametophyte. The integument in gymnosperm ovules consists of three layers. You will study this in more detail later in units of *Cycas* and *Pinus* of this Block.

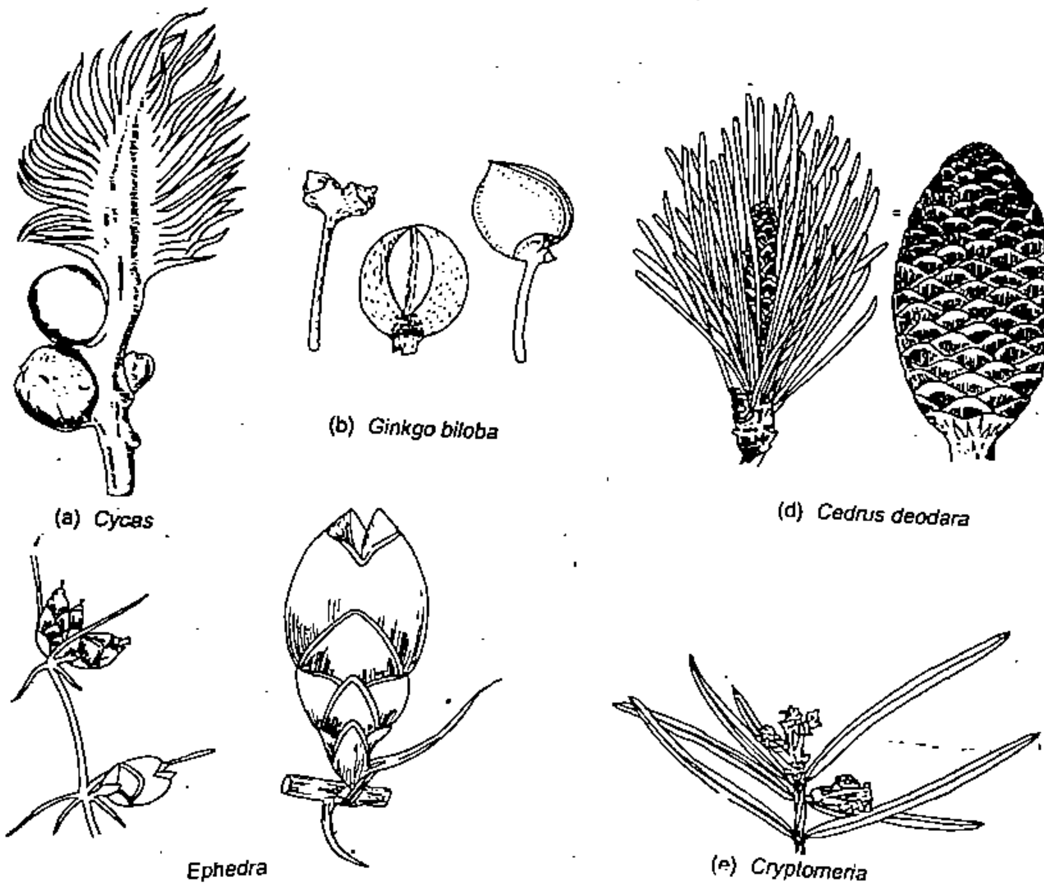

Fig. 1.3 : Various types of female reproductive structures in gymnosperms.

The apical region of the nucellus degenerates to form a **pollen chamber** in which the pollen grains will come and lie until further growth. Female sex organs or **archegonia** develop towards the micropylar end of the female gametophyte. The archegonia may occur singly or in **archegonial complexes.** The archegonia are large and elongated and lack neck canal cells. *Gnetum* and *Welwitschia* lack distinct archegonia, egg nuclei and prothallial tubes containing egg nuclei; respectively.

Pollination and Fertilization

Pollen grains are carried to the ovule and this is followed by fertilization. The male gametes are carried to the egg by means of the pollen tube. Syngamy (or fertilization) between two haploid gametes (male and female) restores the ploidy level of 2n. The new sporophyte is first represented by the zygote that later develops into embryo. Thus the cycle is complete. There is distinct alternation of generations.

Pollination in gymnosperms usually takes place by means of wind and abundant pollen production ensures pollination. Most conifers have winged pollen and wings help the pollen to reach the ovule. In pines, when the male cones dehisce and pollen is shed, the area all around is covered with the yellow pollen grains and this phenomenon is referred to as *"Sulphur showers"*. Entomophily has been reported in *Cycas, Ephedra, Gnetum* and *Welwitschia.*

A pollination drop is secreted by the ovule at the tip of the micropyle and this captures the wind-borne pollen. The partially developed male gametophytes are drawn or sucked into the ovule by the drying of the pollination drop. The exudate not only receives the pollen but also places them close to the nucellus. The pollen now lie in the pollen chamber or on the nucellus, in close proximity to the archegonia.

In the gymnosperms pollination may not be immediately followed by fertilization: sometimes a very long interval elapses between the two phenomena. During this intervening phase (called as resting phase), the ovule shows many changes and gets ready for fertilization. The micropyle is closed and the ovule enlarges in size. The pollen grains on reaching the nucellus germinate immediately or after a resting period. The pollen tube reaches the female gametophyte and finally makes contact with the neck of the archegonium.

In some gymnosperms, a well-defined depression forms at the tip of the nucellus. This pollen chamber receives the pollen grains. Today it is found only in cycads, *Ginkgo* and *Ephedra.*

Box 1.3 : Siphonogamous and Zooidogamous plants

The term "siphonogamous" has been used to collectively designate plants in which the sperm are directly transported to the egg by means of a pollen tube. Lower vascular plants, by contrast, have been designated as "zooidogamous" because the motile flagellated sperm are freely liberated from the antheridium into water through which they must swim (often for some considerable distance) to reach and fertilize the eggs. The evolutionary steps in the transition from zooidogamy to siphonogamy are by no means very clear, but the development of sperm-carrying pollen tubes typical of higher gymnosperms and of all angiosperms was surely a significant achievement. By means of the pollen tube the considerable chances and hazards of the aquatic zooidogamous method were eliminated and much greater assurance of fertilization was made possible. Among living gymnosperms, cycads and *Ginkgo* appear to have a primitive type of pollen tube which serves primarily as an haustorium. It seems significant in this connection that these are the only known living seed plants to have retained the flagellated type of sperm. (Gifford 1989)

The pollen grain produces a more-or-less tubular outgrowth, the pollen tube. In *Cycas* and *Ginkgo* the pollen tube acts mainly as the haustorial organ. It grows for several months into the nucellar tissue and absorbs food and transfers it to the developing pollen grains at the lower end of the tube. It also helps to transfer the male gametes into the archegonial chamber. During fertilization the basal end of the pollen tube bursts and liberates the multiflagellate sperm and some fluid into the cavity. The sperms swim to the archegonial neck, shed the flagella and enter the archegonium; the male nucleus fuses with the egg to form the zygote.

In conifers the pollen tubes act only as sperm carriers. The male gametes alongwith the tube and stalk nuclei migrate to the tip of the pollen tube, which grows through the nucellus. The pollen tube reaches the archegonial neck, pierces it, bursts and then liberates the male gametes, one of which brings about fertilization.

In *Welwitschia* the female gametophyte gives out tubular prolongations that meet the pollen tube tips. The intervening wall dissolves and fertilization takes place. There is no archegonia in *Welwitschia* and *Gnetum*.

Double fertilisation is absent in gymnosperms. The only exceptions are *Ephedra* and *Gnetum*, but even there the endosperm is haploid.

SAQ 5

Fill in the blanks :

1. Large scale shedding of Pine pollen covering the whole area is known as ....
2. The wind borne pollen are captured by .... secreted by ovule.
3. In *Cycas* and *Ginkgo* pollen tube acts mainly as ....

SAQ 6

Summarize the development of male gametophyte only by flow diagram.

SAQ 7

The formation of female gametophyte in gymnosperms.

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1.3 EMBRYOGENY

Proembryogeny in gymnosperms is quite variable. In gymnosperms (except *Sequoia* and *Welwitschia*) the initial phase of embryo development is free nuclear. In *Pinus* there are only eight free nuclei; in cycads as many as 256 or 572 free nuclei may be formed. Later wall formation starts and a cellular embryo is produced. It differentiates (at maturity) into suspensor, radicle, hypocotyl, plumule and cotyledons. The shoot end of the embryo is away from the micropyle, so that embryogeny is endoscopic.

1.3.1 Polyembryony

Formation of many embryos in a single gametophyte is of common occurrence among gymnosperms. Simple or archegonial polyembryony is very frequent because more than one archegonium may be fertilized. In conifers there is **cleavage polyembryony**. Here the four cells of the young proembryo separate and each develops into the embryo. Physiological competition eliminates all but one embryo that reaches maturity.

1.3.2 Mature Seed and Germination

The formation of seed is the result of fertilization and consequent enlargement of the ovule. The zygote develops into an embryo, and the endosperm is formed from the persisting female gametophyte (which provides nutrition). The nucellus gets disorganised and is visible at the micropylar tip of the seed as a thin cap. The integument forms the seed coat.

The seed is a remarkable combination of two sporophytic and one gametophytic generation.

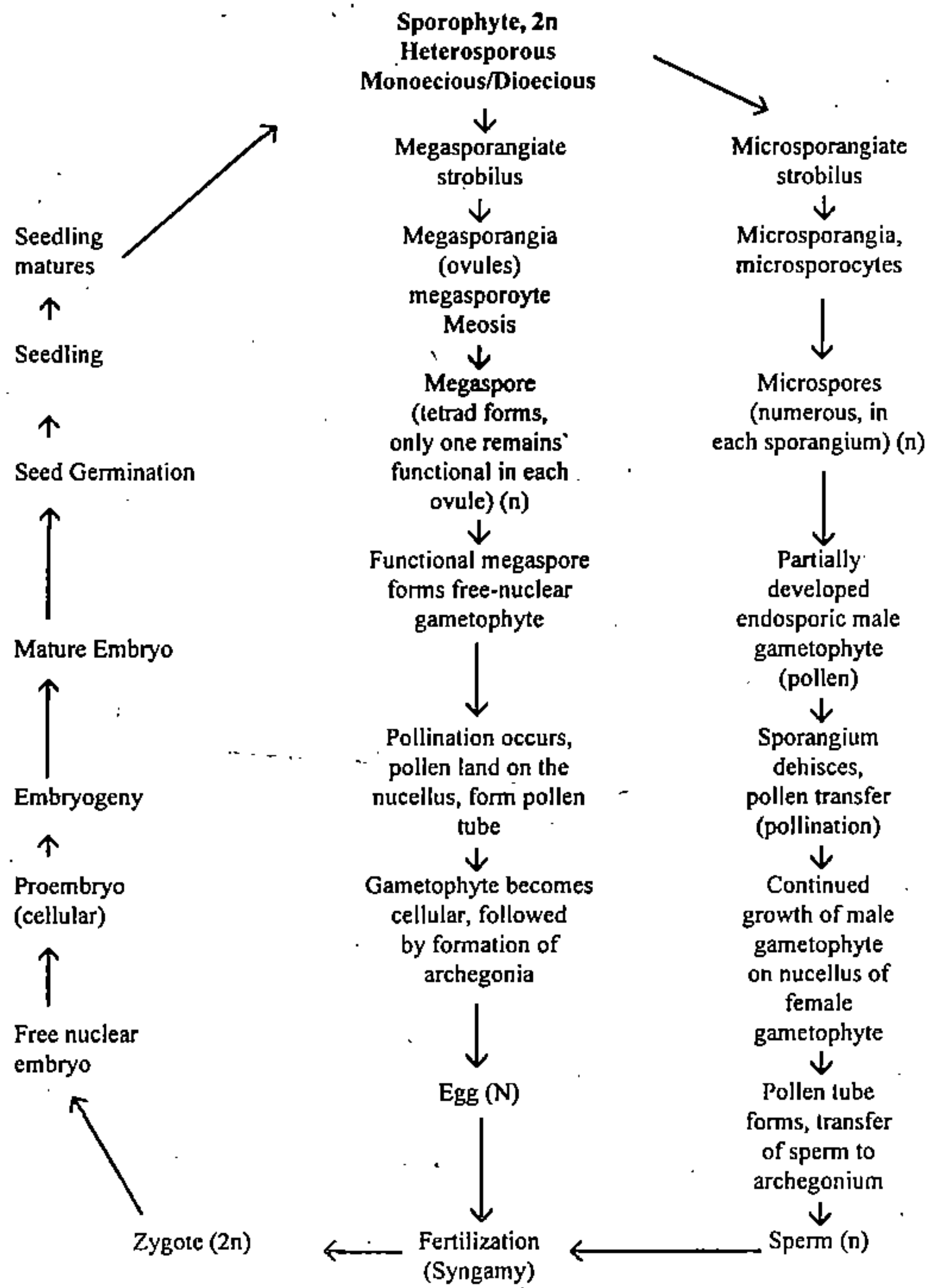
i) The seed coat is the old sporophyte

ii) The embryo is the new sporophyte

iii) The endosperm is the persistent female gametophyte

The number of cotyledons varies from two to many. The detached seeds of gymnosperms remain dormant and undergo a prolonged period of rest. With the onset of favourable conditions the embryo again resumes its growth and rupturing the hard seed coat and develops into a new plant. Germination is epigeal in most genera, i.e., the cotyledons come above the ground.

In *Cycas* and *Ginkgo* the seeds show no dormancy, they germinate immediately on falling on a suitable substrate or else they lose their viability.



Write whether the statement is true or false in the given brackets. Write T for true and F for false statement.

i) The gymnosperms are heterosporous i.e. produce two types of spores [ ]

ii) In gymnosperms male and female spores are produced in the same strobili. [ ]

iii) The gametophytes in gymnosperms develop within their respective spore wall. [ ]

iv) *Cycas* has the largest ovule in the plant kingdom. [ ]

v) In *Cycas* pollen tubes are carrier of sperm. [ ]

vi) In gymnosperms the megaspores are diploid, whereas microspores are haploid [ ]

SAQ 9

Write a short note on polyembryony in Gymnosperms.

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SAQ 10

What characteristics do all modern gymnosperms share with ancient forms?

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1.4 GENERAL PATTERNS OF LIFE CYCLES

The reproductive phases in gymnosperms are spread over a long period of time. Information on this aspect is important to foresters and plant breeders. Since many gymnosperms belong to the temperate areas, their activity is slowed down during the winter period. As a result, not only cambial activity comes to a halt, but development of reproductive structures also gets restricted, and this activity is renewed in spring.

Duration of Reproductive Cycle

The male cones of most temperate or subtropical conifers take less than a year from initiation to shedding (pollination). Unlike the angiosperms where time lag between ovule initiation and seed maturity is short (few weeks), in gymnosperms the same process may take a much longer duration. The only exception appears to be *Ephedra* where the process is completed in about 3-4 months. Most other gymnosperms show 1-, 2-, or 3-year type of reproductive cycle. The counting of years is based on the number of winter rests followed by renewed growth in spring, that the ovule passes through. Most species of a genus show a similar type of reproductive cycle, but some exceptions do occur (*Podocarpus, Juniperus* and *Pinus*).

The cycads do not easily fit into this scheme of cycles partially because of lack of detailed information and more importantly because most of them are tropical or subtropical, and thus do not undergo winter rest.

A convenient method to represent the life cycle of gymnosperms with regard to time of the year using certain symbols is shown in the figure below. These symbols have been used in all subsequent diagrams. The numbers represent the months of year. The seasons of the year have also been indicated since they vary in the Northern and Southern Hemispheres.

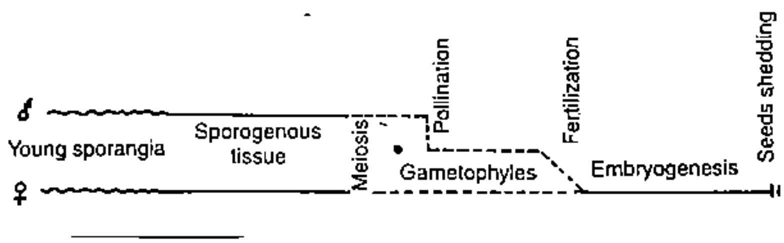

Fig. 1.4 : Major events/stages in the reproductive cycle of a gymnosperm represented by different types of lines (wavy, straight, broken and parallel). These lines have been used in the subsequent four diagrams of life cycles in this chapter (after Singh, 1978).

A generalised type of one-year cycle showing male cone initiation in summer and female cone in autumn, overwintering in the sporogenous stages, pollination during spring, fertilization in summer and seed matures before onset of next winter.

One-year Type of Reproductive Cycle. In the reproductive cycle of *Cedrus deodara* as it occurs in the Western Himalayas. Pollination occurs in autumn and development of gametophytes also starts at the same time (Fig. 1.5 a).

One-year Type of Reproductive Cycle. In *Gnetum ula* life cycle as it occurs in the Western Ghats. In this case embryogeny continues after seed shedding in summer (Fig. 1.5 b).

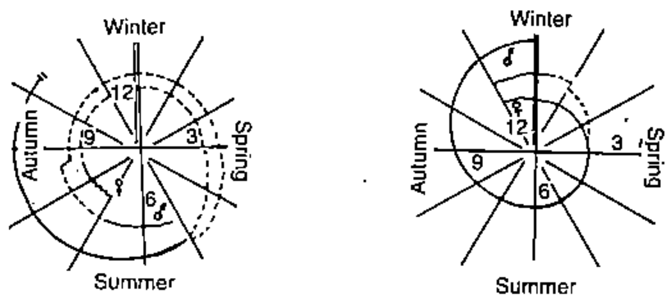

Fig. 1.5 : One-year type life cycle represented by *Cedrus deodara* a) and *Gnetum ula*. b) as occurring in Western Himalayas and Western Ghats of India, respectively. The numbers represent the months of the year. Pollination and development of gametophytes in *Cedrus* take place in autumn. The seeds in *Gnetum* are shed in summer but the embryogeny continues. (after Singh, 1978).

Two-year Type of Reproductive Cycle

This type of reproductive cycle occurs in *Ginkgo biloba* where pollination takes place in the spring of first year and fertilization takes place in the early autumn of the same year but embrypgeny lasts much longer and continues even after the seeds are shed.

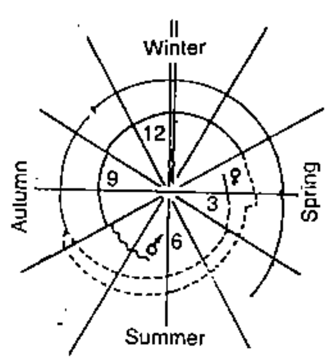

Fig. 1.6 : Two-year type of life cycle in *Ginkgo biloba*.

Three-year Type Reproductive Cycle

In *Pinus roxburghii* the ovules are pollinated in spring of first year and get fertilized in the spring of third year. Thus the time lapse is of two years. Seed shedding occurs in autumn.

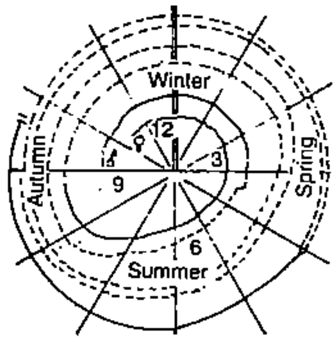

Fig. 1.7 : Three-year type of life cycle in *Pinus roxburghii.*

Reproductive Cycles in Cycads

Cycas circinalis occurs in S. India. *Cycas* shows pollination in first year winter, fertilization in second year summer i.e., after five months, and seed shedding in third year summer and embryogeny continues even after the seeds are shed.

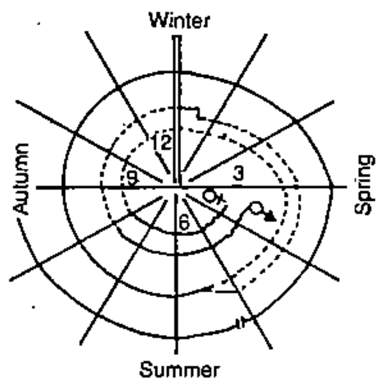

Fig. 1.8 : Three-year type of life-cycle on *Cycas circinalis.*

1.5 THE LIVING FOSSIL — *Ginkgo biloba*

Some living (extant) gymnosperms have a very ancient fossil history and for this reason and few other characters, they are often referred to as "living fossils".

Metasequoia glyptostroboides is an example where the genus was first reported in fossil records from various parts of North America and Asia and later discovered alive by Chinese botanists from Szechuan province.

The sago-palm (*Cycas*) and the maidenhair tree (*Ginkgo biloba*) are living fossils, and the latter may be the oldest living genus of seed plants. Fossils of *Ginkgo* like plant have been found from Jurassic beds all over the world. Its decline started in the Mesozoic and presently China is the only natural home of this tree. It is doubtful whether this genus exists in the wild state. It is widely cultivated as a park and avenue tree in many temperate areas of the world. The plant is dioecious and it is not possible to distinguish the two sexes in the young stage. The seeds emit an odour that is like stale butter and hence female plants are highly undesirable. The kernel of the seed is used as food in Japan and China. It is also used in Chinese medicine as tonic for heart and lungs, and treatment of other diseases like asthma. Alzheimer's disease, and circulatory disorders.

Box 1.4 : The maiden hair tree

The word *Ginkgo* is derived from Chinese words meaning "silver apricot". It is also called as the maidenhair tree because of the similarity of the notched, broad, fan-shaped leaves to the individual pinnae of maidenhair fern.

The trees are frequently found growing in the vicinity of temples in China and Japan and it is likely priests played a significant role in their spread and keeping them alive.

The tree of *Ginkgo* has a pyramidal form, with fan-shaped deciduous leaves. The leaves resemble those of *Adiantum* (maidenhair fern) and hence the name maidenhair tree (Fig. 1.9 a) is given to *Ginkgo*.

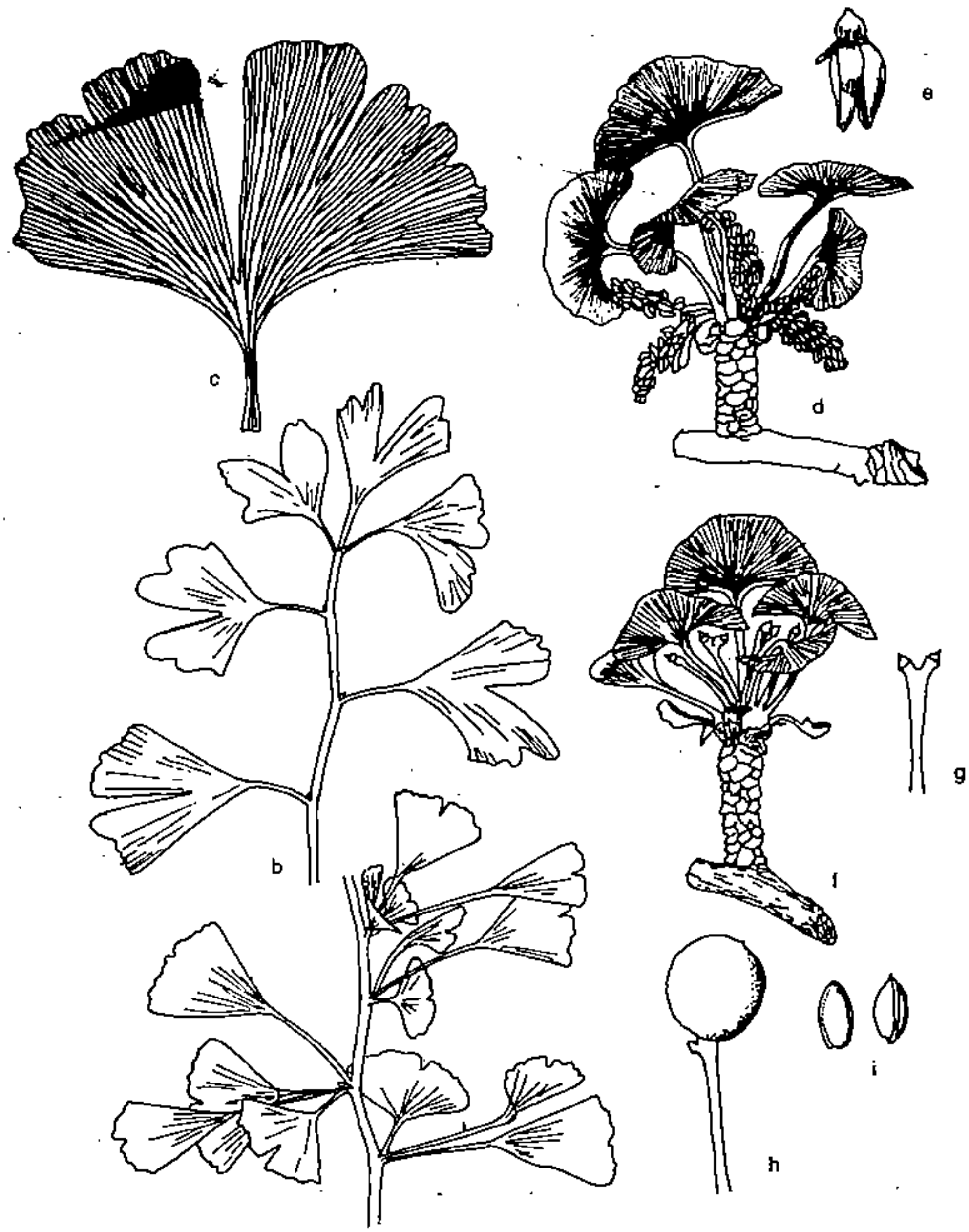

Fig. 1.9 : *Ginkgoaceae. Ginkgo biloba.* a) Dwarf shoot, b) Long shoot. c) Leaf. d) Dwarf shoot with female "flowers", e) Microsporophyll, f) Dwarf shoot with female "flowers", g) Stalked ovules, h) Seed, i) Seed with the fleshy envelope removed (a-c from de Wit 1964; d, f from Bold et al. 1980; e from Lawrence 1951; g-i original Götz).

The plant shows shoot dimorphism i.e. it has two types of shoots : (i) long shoots of unlimited growth, and (ii) dwarf or spur shoots of limited growth, with a cluster of leaves the apex. The leaves are wedge-shaped or fan-shaped and distinctly lobed and the venation is conspicuously dichotomous. The leaves change colour to golden yellow before they are shed in autumn.

Reproductive structures of *Ginkgo* are considered as primitive. *Ginkgo* is dioecious. Male strobili occur in leaf axils on the spur shoot. Each strobilus is a loose structure resembling an angiosperm inflorescence. The ovulate strobilus is also borne on the spur shoot leaf axils. It has a short peduncle which bifurcates at tip, each bearing a sessile erect ovule, with a collar-like outgrowth at the base.

The pollen tube is haustorial and spreads out in the nucellus. After the male gemetophyte development is complete, and it reaches the archegonium, the fertilization occur. The discovery of motile sperms in gymnosperms was by Hirase in 1896 from this plant.

Another note-worthy feature of *Ginkgo* is its pattern of embryogeny which is a continuous process from the time of fertilization till seed germination. Seeds get detached from the parent plant at an early stage of development and most of the embryo growth occurs while they lie on the ground. The seeds are shed even prior to fertilization (but after pollination has taken place) and it takes approximately 7 months for the embryo to attain maturity and be ready for germination.

1.6 THE GENUS *WELWITSCHIA*

The most bizarre and geographically restricted gymnosperm is the African genus *Welwitschia* consisting of only one species, *W. mirabilis.* The epithet "mirabilis" is quite correct because the plant is marvellous in the sense that the adult plant has a small disc or woody crown that bears only two huge strap-shaped leaves and these persist for a life time.

The plant occurs in the Namib Desert in S.W. Africa and Angola in regions where rainfall is very low. The genus is named after Dr. Frederic Welwitsch who discovered it in 1860.

The estimated life-span of *Welwitschia* is 400-1500 years. As the plants grow in regions of extreme dryness (rainfall 0-100 mm per year), they depend upon night fog or dew. The mature plant resembles a giant turnip or carrot with the diameter of the top reaching one metre or more. The part of the stem above the leaves is the crown; the region between crown and root is the stock. A periderm covers the whole plant. The vegetative organography of *Welwitschia* is unique among vascular plants. The shoot tip loses its meristematic activity and degenerates at an early stage of development. Two short-lived cotyledons are produced during the seedling phase which remain photosynthetically active up to 1/2 to 1½ years, and the permanent photosynthetic organs are represented by only one pair of strap-shaped leaves. These persistent leaves grow indefinitely by a basal meristem. A mature leaf attains up to 3m length and 1m width: it shows numerous parallel veins, and towards the tip the leaves are torn into ribbons or shreds. *Welwitschia* is reported as having CAM photosynthesis. Two scale-like leaves engulf the shoot apex.

Plants are dioecious and both the male and female strobili ("inflorescences") are borne terminally on branched stalks.

Welwitschia, has been called as a persistent seedling. It is also described sometimes as a "handicapped plant" that has actually lost its head.

Welwitschia is a neotenic plant, i.e. one in which the reproductive phase arises while the plant is still in the juvenile form.

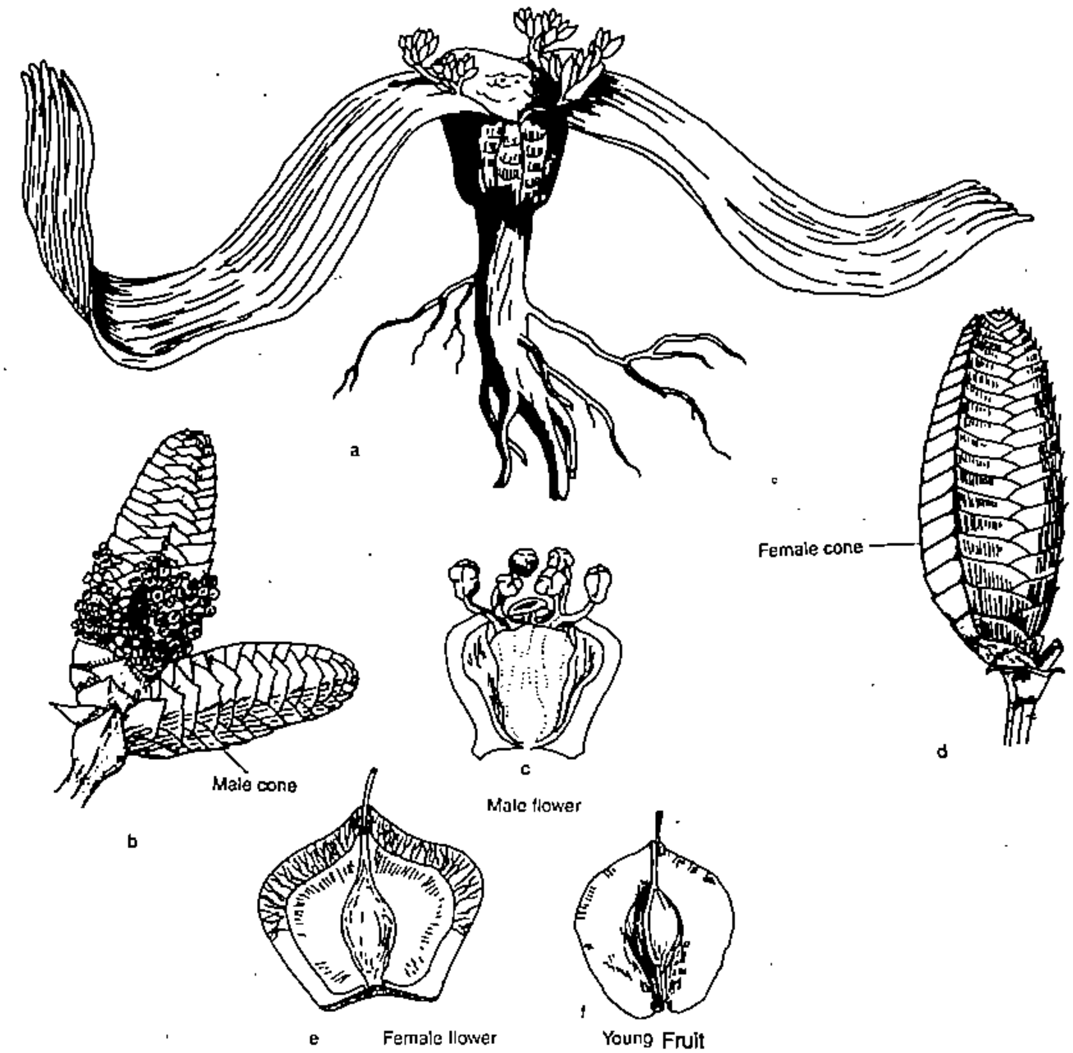

Fig. 1.10 : Welwitschiaceae, *Welwitschia mirabilis,* a) Habit, b) Male cone, c) Male flower, d) Female cone, e) Female flower, f) Young fruit (a,d, f from Le Maout and Decaisne 1876; b, c, e from Engler's syllabus 1954).

Box 1.5 : Common and botanical names of various Gymnosperms

List of names :		
Pines	*Pinus sp.*	*P. roxburghii* = Chir, pine
		P. wallichiana = Kail, pine
		P. gerardiana = chilgoza pine
Cedar	*Cedrus* sp.	
Yew	*Taxus* sp.	
Cypress	*Cupressus* sp.	
Cycads	*Cycas* and other members of Cycadales	
Maidenhair tree	*Ginkgo biloba*	
Araucaria	*Araucaria* sp.	
Giant Redwood	*Sequoiadendron giganteum*	
California Redwood	*Sequoia sempervirens*	
Juniper	*Juniperus*	

(contd.)

Larch	*Larix*
Fir	*Abies*
Spruce	*Picea*
Bald Cypress	*Taxodium*
Hemlock	*Tsuga*

1.7 CLASSIFICATION OF GYMNOSPERMS

Gymnosperms being an important group of plants have been variously classified by different workers. The classification being followed in this unit is after Bhatnagar and Moitra (1996). Details of these are given below :

Gymnosperms comprise both living (extant) and fossil (extinct) groups. This classification lists the various families of this group. You do not have to memorise this classification. It is given because you must have an idea about all the classes, order and families of gymnosperms.

Class I : Progymnospermopsida

Order	Aneurophytales	(Only fossils)
Family	Aneurophytaceae	
Order	Archaeopteridales	
Family	Archaeopteridaceae	
Order	Protopityales	
Family	Protopityaceae	

Class II : Cycadopsida

Order	Pteridospermales	Only fossils
Family	Calamopityaceae, Lyginopteridaceae Medullosaceae, Callistophytaceae	
Order	Glossopteridales	
Family	Glossopteridaceae	
Order	Caytoniales	
Family	Caytoniaceae, Corystospermaceae Peltaspermaceae	
Order	Cycadales	
Family	Cycadaceae, Zamiaceae (Living and fossil)	
Order	Cycadeoidales (= Bennettitales)	(Only Fossils)
Family	Williamsoniaceae, Wielandiellaceae Cycadeoidaceae	
Order	Pentoxylales	
Family	Pentoxylaceae	

Class III : Coniferopsida

Order	Ginkgoales	
Family	Ginkgoaceae	
Order	Czekanowskiales	(Only fossils)
Family	Czekanowskiaceae	
Order	Cordaitales	
Family	Cordaitaceae	
Order	Voltziales	
Family	Voltziaceae	
Order	Coniferales	

Families : Pinaceae, Taxodiaceae, Cupressaceae, Podocarpaceae, Araucariaceae, Cephalotaxaceae, Taxaceae.

Class IV : Gnetopsida

Order	Ephedrales	
Family		Ephedraceae
Order	Gnetales	
Family		Gnetaceae
Order	Welwitschiales	
Family		Welwitschiaceae

Box No. 1.6 : Conservation of Gymnosperms

The gymnosperms comprise only a very small portion of the flora of the world. The conifers are mostly restricted to temperate regions where they form large belts of forest area. This group consists of tall, perennial trees prized for their timber and other products like resin and pulp. The need today is to identify and propagate "elite" (or superior) trees with desired characteristics, i.e. better yield, disease and pest resistance. Screening and conservation of natural germplasm is thus essential.

The cycads and *Ginkgo* are some of the most ancient groups of plants present on the Earth. Their natural habitats are facing pressures from civilization and are rapidly diminishing in size. These "Living fossils" would be gone if they are not conserved by man. Both in situ and ex situ measures are required for this.

Gymnosperms have been screened for their medicinal and food value and some like *Taxus* have shown promise as a cure for cancer. In future other members of the group may also prove to be economically important. Hence there is an urgent need to conserve them.

1.8 SUMMARY

In this unit you have studied that :

- Gymnosperms differ from Angiosperms in their morphology, anatomy and mode of reproduction.
- Ovules and seeds are naked and uncovered.
- The sporophytes are large and perennial; whereas gametophytes are highly reduced and dependent on sporophyte.
- Single fertilization (exceptions *Ephedra* and *Gnetum*) i.e. one sperm involved in fertilization.
- The tallest trees are redwoods and Big trees, both are gymnosperms.

1.9 TERMINAL QUESTIONS

1. Enumerate differences between Gymnosperms and Angiosperms.

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2. Describe pollination and fertilization in gymnosperms and how it is different from Angiosperms.

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3. Why the seed of gymnosperms is considered of having remarkable combination of two generations.

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4. "Gametophytic generation is dependent on the sporophytic generation in gymnosperms". Comment upon this statement.

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. Write short notes on the following

i) Distribution of gymnosperm.

ii) manoxylic and pycnoxylic wood.

iii) Siphonogamous and zooidogamous.

iv) Polyembryony in gymnosperms.

v) Pollen Pollination drop.

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6. Describe the genus *Welwitschia*.

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7. Describe the living fossil of gymnosperms and also comment why it is called so.

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8. Describe cycles in gymnosperms with proper diagrams.

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1.10 ANSWERS

Self-assessment Questions

1. See—Characteristics of Gymnosperms and Angiosperms and write any 5 points.
2. 1 (c)

   2 (d)

3 (a)

4 (b)

3. Refer to section 1.2.
4. See salient features of Angiosperms

1	d
2	g
3	c
4	a
5	h
6	b
7	f
8	e

5. 1. Sulphur showers
   2. *Welwitschia*
   3. Pollination drop
6. See section 1.2.4 – microsporangia and male gametophyte
7. See section 1.2.4 – ovule and female gametophyte
8.

1	T
2	F
3	T
4	F
5	T
6	F

9. See section 1.3 – embryogeny.
10. 1. naked seed
    2. single fertilization
    3. haploid endosperm

Terminal Questions

1. See section 1.2 – General characters of gymnosperms
2. See section 1.2 – and subsection 1.2.4 – Reproduction
3. See sub-section 1.3.2 Mature seed and germination point of reference.
   i) Sporophytic tissues and gametophytic tissues both found in seed. Describe them in detail.
4. See sub-section 1.2.4. Reproduction. Describe in detail how gametophytic generation is totally dependent on sporophytic generation in gymnosperms. In Plant Diversity – I, you have already studied that gametophytic generation may be a free living photosynthetic plant or subterranean and apparently dependent upon the presence of an endophytic fungus for its existence.
5. See section – 1.2.1, Box 1.1. Box 1.3, Subsection 1.2.4
6. See section 1.6 – The Genus *Welwitschia*
7. See section 1.5 – The living fossil – *Ginkgo biloba*
8. See section 1.4 – General pattern of life cycles.

UNIT 2 CYCADOPSIDA : *CYCAS*

Structure

2.1 Introduction
Objectives

2.2 Distribution, Habitat and General Features

2.3 Vegetative Structures
2.3.1 Root
2.3.2 Stem
2.3.3 Leaf

2.4 Reproductive Structures
2.4.1 Male Cone and Gametophyte
2.4.2 Female Strobilus and Gametophyte

2.5 Pollination, Fertilization and Embryogeny

2.6 Distinctive Features and Conservation Concerns

2.7 Summary

2.8 Terminal Questions

2.9 Answers

2.1 INTRODUCTION

In Unit 1 you have studied that Cycadopsida consists of six orders : Pteridospermales, Caytoniales, Cycadeoideales, Cycadales, Pentoxylales and Glassopteridales. Of the above mentioned orders, members of five orders are extinct and Cycadales is the only one with living members.

Cycadales have a very ancient fossil history. They were common during the mid-Mesozoic era, and some of them are present even today. They are, therefore, also called 'living fossils'. On a casual glance all cycads resemble palms. The term 'cycads' refers to all the members belonging to Cycadales. They have a stocky, cylindrical stem bearing a crown of large, coarse, palm-like leaves. They, in fact, are true gymnosperms as their seeds are naked and are borne on modified leaves called sporophylls. Some scientists consider cycads as transitional stages between ferns and gymnosperms. The retention of ciliate sperms, which are characteristic of the lower plants, lends support to this assumption.

The Cycadales consist of 11 genera categorized by Johnson (1959) in three families, viz. Cycadaceae, Stangeriaceae and Zamiaceae. But Bhatnagar and Moitra (1996) have retained the 11 genera under one family – Cycadaceae, because there is uniformity in the overall morphology, anatomy and reproductive biology of these genera. In this course too, we shall follow the latter system of classification. Most of the description in this Unit is based on *Cycas*, reference to features of special interest of the remaining genera will be made wherever necessary.

Objectives

After studying this unit, you should be able to :

- list the cycad genera,
- identify cycads in general and *Cycas* in particular, on the basis of their gross morphological, anatomical and reproductive characters,
- illustrate and describe the life cycle of *Cycas*,
- discuss the structural peculiarities of *Cycas* vis-a-vis the lower vascular plants, particularly the Filicales, and
- give reasons for the decline in the number of cycads all over the world and enlist the measures taken.

2.2 DISTRIBUTION, HABITAT AND GENERAL FEATURES

The eleven genera belonging to Cycadales have been listed in Table 2.1. Though the cycads have existed for about 250 million years and were then widely distributed, at present each genus has a restricted distribution. More than 100 species belonging to these genera are distributed both in the Eastern and Western Hemispheres.

Table 2.1 : The global distribution pattern of Cycads.

Genus	Region/Country	Hemisphere
Dioon, Ceratozamia	Mexico	Western Hemisphere
Microcycas	Cuba	
Zamia	Mexico, West Indies, North-Western South America, and Florida	
Chigua	Colombia	
Encephalartos, Stangeria	South Africa	Eastern Hemisphere
Lepidozamia Macrozamia, Bowenia	Australia	
Cycas	Madagascar, Australia, Indian Subcontinent, China and S. Japan	

Of the genera mentioned in Table 2.1. Only *Cycas* is found in the Indian subcontinent. In addition to India, it is found in neighbouring countries such as Nepal, Myanmar and Sri Lanka. *Cycas* species that occur in India are listed in Table 2.2.

Table 2.2 : Distribution of *Cycas* in India.

Species	Place of occurrence
C. beddomei Dyer	Hills of Cuddapah district of Tamil Nadu and Eastern Andhra Pradesh
C. pectinata Griff.	In the Sal Forests of Sikkim and Assam, Khasi Hills and Manipur
C. circinalis Linn.	In the deciduous forests of Western Ghats ; and Orissa
C. rumphii Miq.	In the beach forests of Andaman and Nicobar Islands
C. revoluta Thunb. and *C. siamensis* Miq.	Cultivated in gardens

Cycas is both cultivated and found growing wild. Its natural habitat is rather xeric and includes well-drained soil exposed to sun, and the sunny hill slopes.

In its habit *Cycas* appears like a palm (Fig. 2.1a). It possesses a columnar aerial trunk with a crown of pinnately compound leaves. The stem is normally unbranched but, sometimes, older trees do exhibit branching. A branch starts as a small bulbil (Fig. 2.2) which is actually an adventitious bud. The bulbil arises from the lower, fleshy region of the leaf base. Initially bulbil shows only scale leaves but with further growth, it starts producing a crown of leaves just like the main trunk and subsequently appears as a branch. The bulbils also serve as a means of vegetative propagation of plant, both artificially and in nature. Factors like physical injury enhance branching and one comes across highly branched *Cycas* trees in parks, whereas in an undisturbed condition they remain unbranched or poorly branched.

Fig. 2.1: a) A few plants of *Cycas revoluta* growing in front of the Museum of Kagoshima Prefecture in Kagoshima city of Japan. The explanatory plate in the picture means that "This tree of *Cycas revoluta* is a memorial one from which Professor Ikeno discovered spermatozoids in 1898, so we must keep it carefully". b) A part of the trunk magnified. Note the alternating bands of large and small leaf bases. Courtesy : a) Professor Tetsuo Nakajima; b) Bhatnagar & Moitra, 1996.

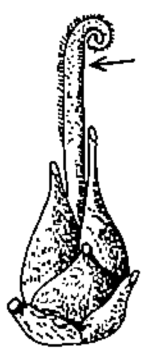


Fig. 2.2 : Bulbil of *Cycas* sp. Amongst the scale leaves a circinately coiled rudimentary leaf pinna (arrow) can be seen (from Pant, 1973).

An armour of alternating bands of large and small leaf bases covers the aerial stem in a spiral manner (Fig. 2.1b). The large leaf bases are the foliage leaves and the smaller ones are the scale leaves. The features of both these leaves are discussed in the following section. The leaf bases persist for many years, but abscise in the old trees. The trunk in such trees looks thinner in the lower region than in the upper portion.

Two crowns of leaves are produced annually, one in spring and the other during monsoon coinciding with the favourable seasons of growth. The age of a *Cycas* plant can be determined by counting the number of leaf bases on the trunk, and dividing their number by half the number of leaves in the crown, as the growth of two seasons is present any time of the year.

SAQ 1

Which of the items (i-viii) are relevant to Cycadales?

i) Living fossils

ii) True gymnosperms

iii) Ferns

iv) Three genera

v) Herbaceous plants

vi) Mesophytic

vii) Palm-like appearance

viii) Xeric

Choose the correct answer from the choices given below :

a) ii, iv, vi, viii

b) i, iii, v, vii

c) iii, iv, v, vi

d) i, ii, vii, viii

SAQ 2

Match the items given in Column A with those of Column B. Choose the correct answer from the choices given below:

A		B	
1.	Number of genera in Cycadales:	i)	*Chigua*
2.	Cycad genus in Indian subcontinent:	ii)	recent origin
3.	Cycad history:	iii)	scale leaves
4.	Asexual propagation by:	iv)	3 genera
5.	Crown(s) of leaf(ves) produced per year:	v)	*Cycas*
		vi)	bulbil
		vii)	two
		viii)	common in mesozoic era
		ix)	11 genera
		x)	one

Choices for answer

	1	2	3	4	5
a)	ix	i	viii	vi	x
b)	iv	v	ii	iii	x
c)	ix	v	viii	vi	vii
d)	iv	i	ii	vii	viii

2.3 VEGETATIVE STRUCTURES

In this section the salient morphological and anatomical features of vegetative structures namely root, stem and leaves are described. You are advised to devote some time to observing the figures to grasp their details.

2.3.1 Root

The primary root is a tap root which dies early and, in its place, an adventitious root system comprising large fleshy roots develops. Some of the roots near the soil grow upwards and form apogeotropic roots. These branch copiously by repeated dichotomy forming dense, greenish or brown masses known as **coralloid roots** (Fig. 2.3).

Fig. 2.3 : a) *Cycas* sp. a bunch of coralloid roots. b) A part of a coralloid root enlarged (from Pant, 1973).

Being apogeotropic, the coralloid roots also come out of the soil. It is believed that these roots, besides aiding in atmospheric nitrogen fixation, also act as aerating organs. In addition to the coralloid roots, non-coralloid aerial roots also occur in some species of *Cycas.* Such roots arise from the base of the bulbils or the leaf bases, and are positively geotropic. Both normal and coralloid roots have abundant lenticels on their surface.

Normal Root – The anatomical structure of a young, normal root of *Cycas* (Fig. 2.4 a, b) is similar to that of a dicotyledonous angiosperm. The xylem and phloem are radially arranged. The vasculature varies from diarch to triarch to polyarch condition, and the protoxylem is exarch. The centre of the root may be occupied by a small parenchymatous pith or it may be occupied by metaxylem elements. The vasculature is surrounded by pericycle, which is often multi-layered. It is made up of thin-walled cells with abundant starch grains. An inner periderm often differentiates in this region. On the outer side is a single-layered endodermis. The endodermal cells are characterised by casparian thickenings. Next to the endodermis lies the cortex, which is several-layered and consists of parenchymatous cells with abundant starch grains. Occasionally sclerenchymatous cells and tannin-filled cells are interspersed in the cortex region. In addition, cells containing variously shaped crystals are also commonly seen distributed in the cortex. The outermost layer is the epidermis. It develops root hairs behind the growing apex as in other roots. Secondary growth begins with the development of arcs of cambium on the inner side of the phloem. The pericycle cells in between these arcs too become meristematic and join the arcs of cambium to form a complete cambial ring. The activity of the cambial ring generates the secondary xylem towards inside and the secondary phloem towards outside.

Coralloid Root – Anatomically the coralloid root is quite similar to the normal root except that it has a wider cortex with a well-defined algal zone almost in its middle (Fig. 2.4 c,d). This zone consists of thin-walled, radially elongated cells that are loosely arranged, having large intercellular spaces occupied by cyanobacteria such as *Anabaena* and *Nostoc*; some reports indicate the presence of algae such as *Ulothrix, Chroococcus* and *Calothrix*. The cortex consists of parenchymatous cells. A phellogen (cork cambium) and a few layers of cork cells are present on the periphery.

2.3.2 Stem

The stem has an irregular outline due to the persistent leaf bases. In a transverse section, a large, parenchymatous pith occupies most of the central region and forms a major portion of the entire stem. The pith cells contain large amounts of starch – sago, which is commercially extracted from some species. Pith is surrounded by a ring of numerous small vascular bundles which are collateral and open. The protoxylem is endarch. Outside the vascular ring lies a wide cortex which is connected with the pith by broad medullary rays. The stem of *Cycas* is mostly parenchymatous with a scanty amount of xylem. This condition is referred to as **manoxylic** (also see Section 1.2.3). In such a situation mechanical strength to the stem is provided by the thick and rigid armour of leaf bases and periderm. Some cells of the pith and medullary rays contain calcium oxalate crystals. In addition, mucilage cells are also present both in the pith and the cortex, and these form a network that extends into the branch and leaf traces as well. Mucilage helps in the conservation of water and this is a xerophytic character.

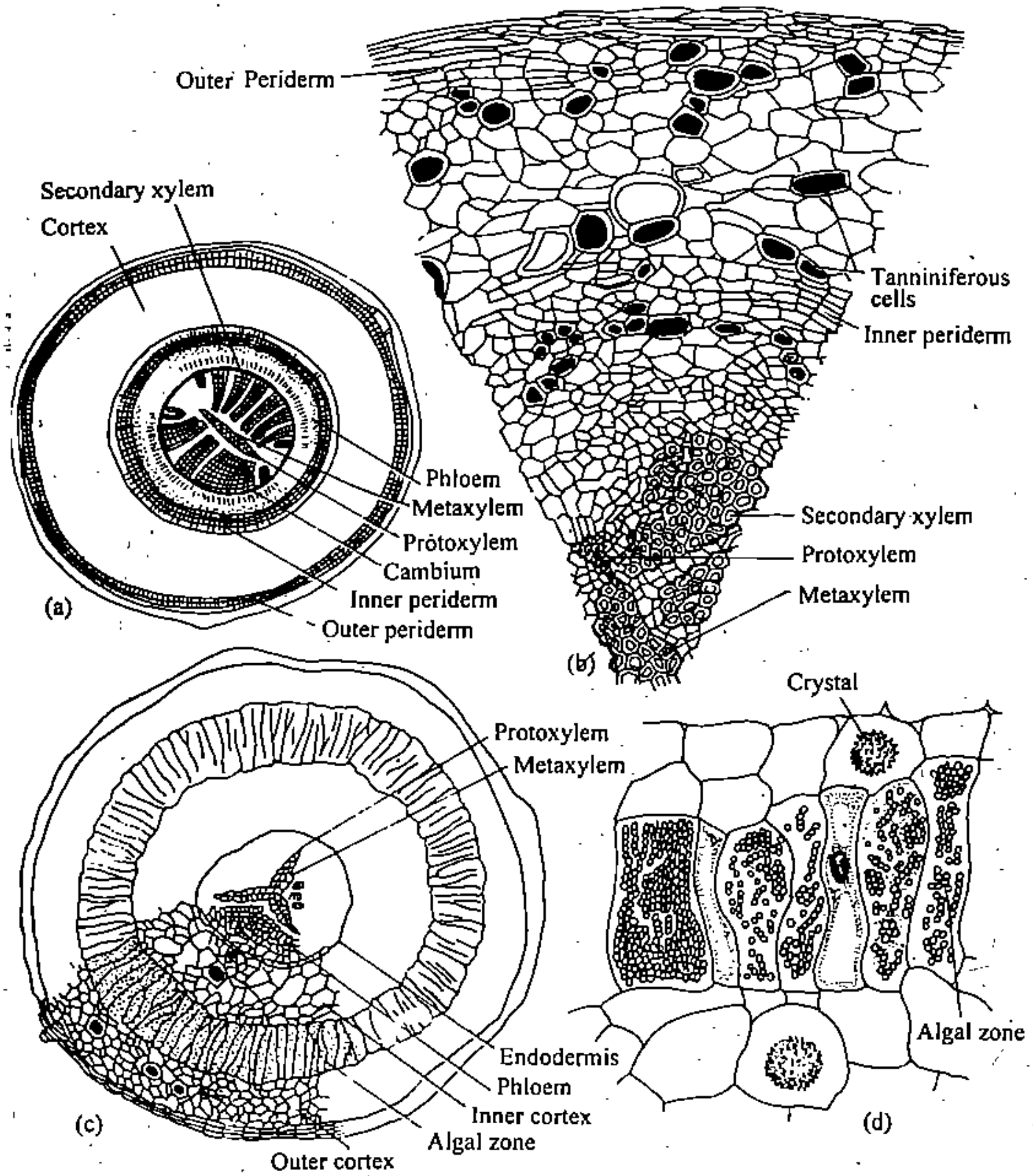


Fig. 2.4 : *Cycas* **sp. normal root (a, b) and coralloid root (c, d). a) Outline diagram of a transverse section of a normal root. Note the diarch condition. b) A sector of the normal root enlarged to show the cellular details. c) Outline diagram of a transverse section of a coralloid root. Mark the position of the algal zone. d) A part of the algal zone magnified to show the radially elongated cells containing the alga (a-c, after Pant, 1973; d, after Wettstein, 1935).**

Secondary growth takes place quite early. The interfascicular cambium develops and joins the intrafascicular cambium. The cambium cuts xylem towards inside and phloem towards outside. To begin with, the stem of *Cycas* is **monoxylic**, i.e., with one ring of vasculature, but becomes **polyxylic** later as a result of accessory rings of cambia that arise in the cortex (Fig. 2.5a). Numerous leaf-traces are seen in the cortex (Fig. 2.5b).

Box 2.1 : The leaf traces in Cycadales

Leaf traces are the strands of vasculature that enter the leaves. In cycads, each leaf is supplied by two types of traces both arising from the primary vascular bundles. These are **girdle traces** and the **radial** or **direct traces.** The girdle traces arise on the side of the stele opposite the leaf which they will ultimately enter. In their course through the cortex, they girdle the stele on two sides just like the curved prongs in a pair of tongs, and become completely reversed while passing through the cortex. These girdle traces are characteristic of Cycadales. The radial or direct traces do not girdle the stele but take a straight path through the cortex, before entering the leaf.

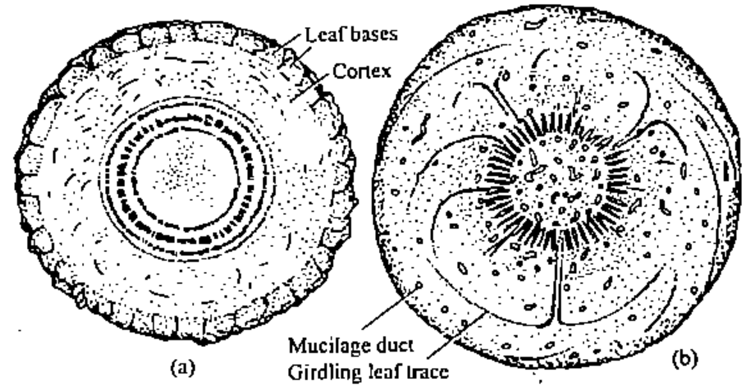


Fig. 2.5 : a) ***Cycas*** **sp., outline diagram of a stem in transection. Note the armour of leaf bases, large cortex, pith, and the polyxylic condition. b)** ***Zamia*** **sp., outline sketch of stem in transverse section. Prominent leaf trace girdles are seen in the cortex. Also note the manoxylic wood. A large number of mucilage ducts are scattered all over the stem, (From Bhatnagar & Moitra, 1996).**

2.3.3 Leaf

Cycas produces two types of leaves, that is, it exhibits dimorphism. There are large, green foliage leaves and small, brown cataphylls or scale leaves. The scale leaves appear brown due to a heavy coating of bicelled hairs known as the **ramenta.** Crowns of foliage and scale leaves alternate regularly.

Revolute-folded downwards

The foliage leaves (Fig. 2.6a) are unipinnately compound with numerous leathery, opposite or alternately arranged leaflets (= pinnae, pinna-singular) which are spine-tipped. The leaves possess a long rachis and a short petiole. At the base of the petiole are present two rows of small stiff spines (Fig. 2.6a, arrows). The margin of the leaflet is either revolute as in *C. revoluta* and *C. beddomei*; or flat, as in *C. circinalis, C. rumphii, C. pectinata,* and *C. siamensis.* A prominent midrib runs the entire length of the leaflet. The plant possesses fern-like characters such as straight or circinate rachis and circinate vernation of leaflets (Fig. 2.6b, c).

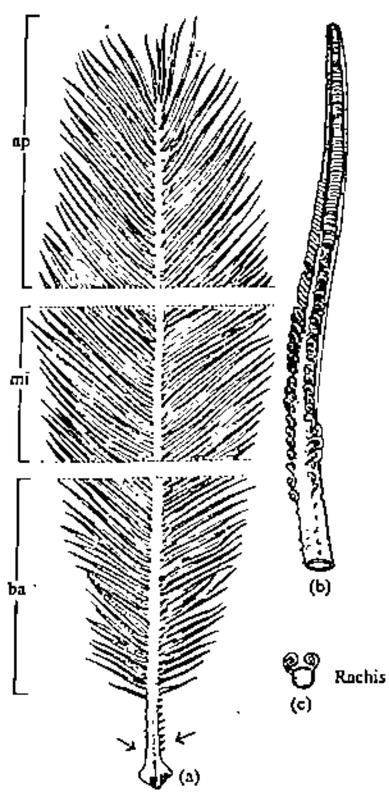


Fig. 2.6: ***Cycas revoluta.*** **a) A leaf showing the apical (ap), middle (mi), and basal (ba) portions. b) Same, at younger stage showing unrolling of rows of circinate leaflets from base upwards, i.e., in acropetal succession. c) T.S. young leaf showing two circinate leaflets on the rachis (a, After Pant, 1973; b and c, after Gifford & Foster, 1989).**

The leaf anatomy of *Cycas* is discussed under two subheadings – rachis and leaflet.

Rachis – The rachis is cylindrical and bears leaflets inserted on the adaxial (dorsal) side; this makes the outline appear like a shield. The epidermis is thick-walled and covered with a thick cuticle except in the region of stomata. The hypodermis consists of a mixture of sclerenchyma and collenchyma followed by parenchymatous ground tissue, in which are interspersed the vascular bundles. These are arranged in an arc that appears like a 'U' with arms, or like the inverted Greek letter Ω (Omega). Mucilage canals are present both on the inside and the outside of the vascular arc.

The vascular bundles of the rachis demonstrate an interesting behaviour. You may recall that two bundles of a leaf trace enter the base from the stem. At this juncture the bundles are endarch or centrifugal, i.e., the protoxylem is inside and the metaxylem is towards the periphery of the rachis. The vascular bundles, as they enter the leaf, split into a number of strands and get arranged in the form of an inverted omega (see Fig. 2.7a). At this level, the xylem elements remain entirely endarch or centrifugal. After traversing some distance in the rachis, the centripetal xylem elements appear on inner side of the protoxylem. Subsequently, formation of centrifugal xylem is reduced gradually on moving towards the tip. Therefore, near the tip of the rachis the centripetal xylem is more abundant than the centrifugal xylem (Fig. 2.7b). These peculiar, diploxylic vascular bundles having both the centripetal as well as the centrifugal xylem (Fig. 2.7c) are also termed **pseudo-mesarch**. As the bundles move further into the leaflets, they become exarch with no traces of centrifugal xylem.

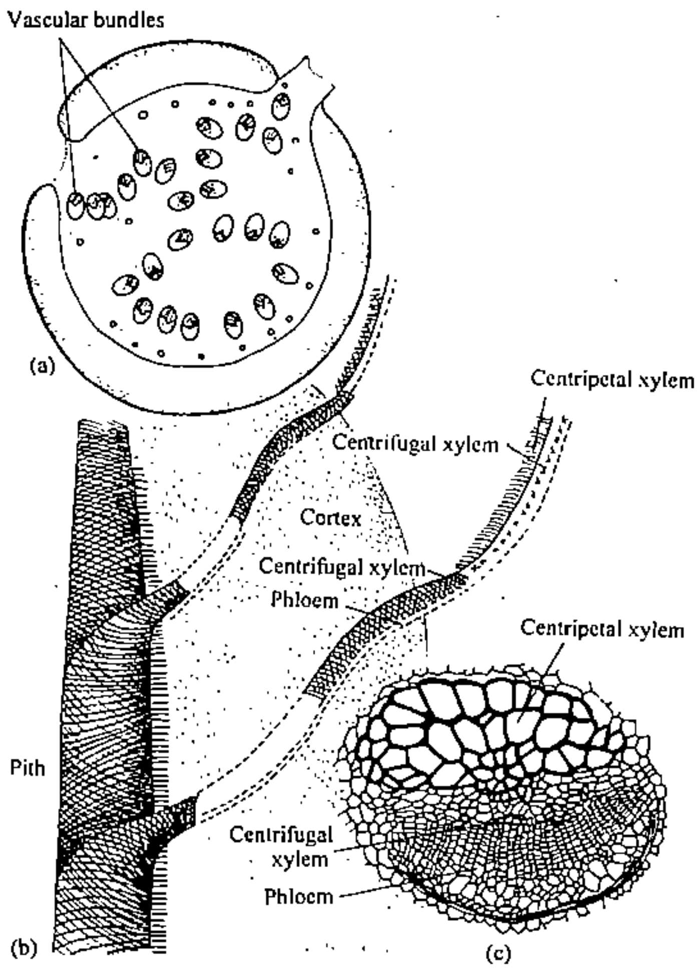


Fig. 2.7: *Cycas* sp. a) Outline diagram of rachis in transection. Note the inverted omega-shaped arrangement of vascular bundles. b) Diagrammatic representation of a part of stem with two petioles, showing the course of vascular bundle from the stem to the petiole, and the relationship of the centripetal and centrifugal xylem. c) An enlarged view of a diploxylic vascular bundle. (a, After Pant, 1973; b, after Le Goc, 1914; c, after Maheshwari, 1960).

Leaflet – The entire leaf of *Cycas* exhibits a number of xerophytic characters. Each leaflet is dorsiventral and the epidermis comprises thick-walled cuticularized cells with simple pits. The hypodermis is one -, or two-layered and its cells are also cutinized and lignified.

The mesophyll is differentiated into a single-layered palisade, and multi-layered spongy parenchyma (Fig. 2.8 a,b). The vascular bundle is diploxylic. Isolated thick-walled cells extend from it to the hypodermal cells. Some tracheid - like cells with reticulate thickenings or bordered pits on their walls are present on either side of the centripetal metaxylem. These constitute the **transfusion tissue**, which is connected to the surrounding parenchymatous cells. Additionally, between the palisade and spongy parenchyma lie a few layers of empty, tracheid-like cells with reticulate thickenings and pits on their walls. These cells are arranged at right angles to the longitudinal axis of the leaf, and are present from mid rib to the margins of the lamina. These are designated as the **accessory transfusion tissue** and function as lateral conducting tissue. The stomata are sunken and occur only on the lower side (Fig. 2.8c).

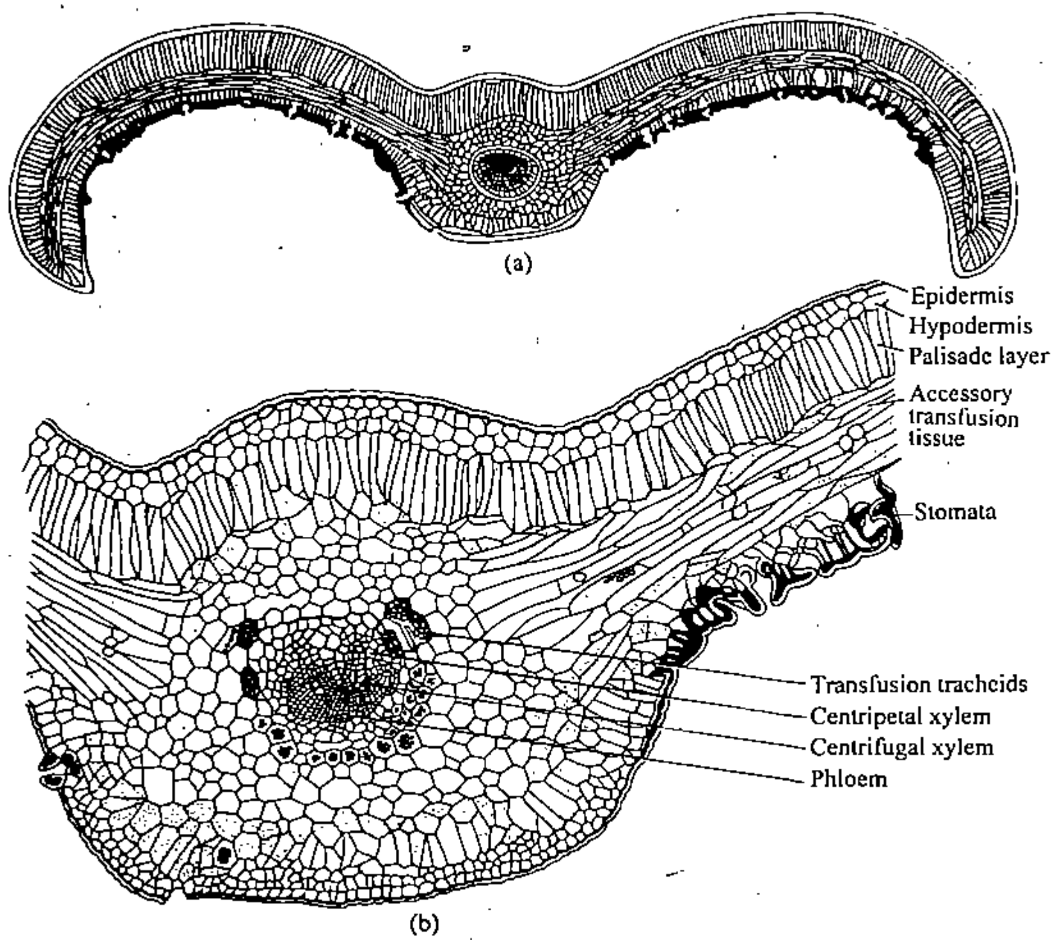


Fig. 2.8 : ***Cycas*** **sp. a) Vertical section of a leaflet showing thick-walled epidermis with cuticle, and stomata on the lower region. b) A portion of the same enlarged to show the diploxylic vascular bundle, and transfusion tissue (a and b, after Pant, 1973).**

SAQ 3

Tick the correct word(s) given in parentheses.

a) The primary root system consists of (tap/fibrous) root(s).

b) The (coralloid/aerial) roots are apogeotropic, and help in fixing atmospheric nitrogen.

c) The coralloid root differs from normal root in having (narrow/wider) cortex region and the (presence/absence) of an algal zone.

d) The irregular outline of the stem is due to (unusual secondary growth/persistent leaf bases).

e) (Mucilage/Sago) is a commercially exploitable product derived from the stem.

f) The stem derives its mechanical strength from (massive xylem/leaf base armour).

g) The accessory transfusion tissue functions as (secretory tissue/conducting tissue) in the leaflets of *Cycas*.

2.4 REPRODUCTIVE STRUCTURES

Cycads are dioecious, i.e., the male and female reproductive structures are borne on separate plants. The *Cycas* plants undergo vegetative growth for about ten years and then start bearing the reproductive structures. One cannot distinguish between the two sexes until the plants have borne the male and female reproductive structures. Even the bulbils meant for vegetative propagation develop into the plant of the same sex as the parent.

2.4.1 Male Cone and Gametophyte

The male cone is very large, oval or conical in shape (Fig. 2.9a) and usually occurs singly in the centre of the crown surrounded by scale leaves. The surface of the young cone is covered totally by brown scales. The mature cone emits a strong characteristic odour that can be smelled even from a distance.

The cone has a central axis on which the microsporophylls are arranged in a spiral manner. Each sporophyll (Fig. 2.9b) is a hard, horizontally flattened, woody structure consisting of a wedge-shaped portion with a tapering upcurved apex. Numerous **sporangia** (sporangium - singular) are borne on the abaxial (lower) surface (Fig. 2.9b), and these are clumped together in groups of 3, 4 or 5 to form **sori** (sorus – singular). Each sorus is surrounded by single-celled soral hairs. Each sporangium has a massive stalk and dehisces by a longitudinal slit (Fig. 2.9d) that forms on the wall. About 700 sporangia per sporophyll are found in *C. circinalis* and there are around 1160 in *C. media*.

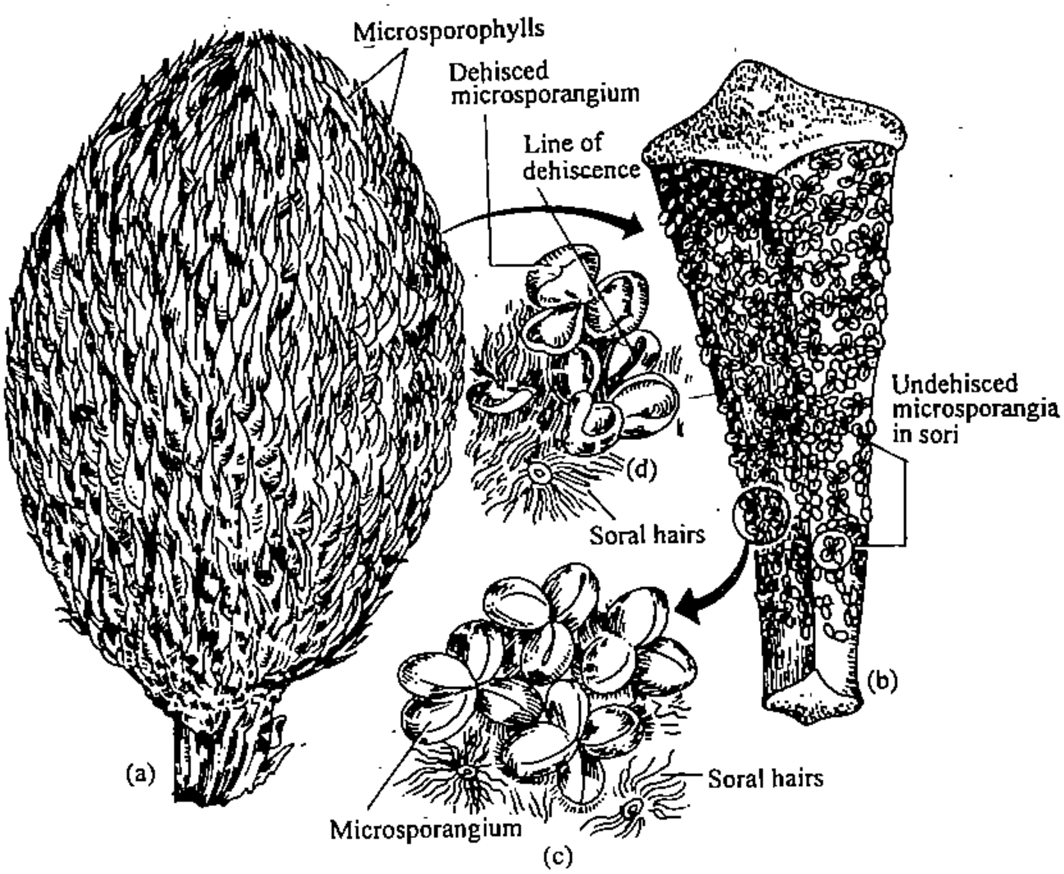


Fig. 2.9: *Cycas circinalis*. a) A mature male cone. Note the spirally arranged microsporophylls. b) A microsporophyll in abaxial view showing numerous microsporangia arranged in sori. c) Undehisced microsporangia arranged in groups forming sori. Note the soral hairs surrounding the sori, d) Dehisced microsporangia. (Redrawn from : a, Maheshwari, 1960; b-d, redrawn from Wieland, 1906).

The male cones are terminal in position, but from the base of the peduncle arises a lateral bud that pushes the cone to one side. The new shoot apex thus formed soon produces a crown of leaves and scales, and ultimately bears another male cone. This type of growth is termed **sympodial.**

The cellular details of a microsporophyll are depicted in Fig. 2.10a,b. In addition to the vascular bundles, mucilage ducts are interspersed in the ground tissue. On the lower or abaxial side are the sporangia. Each sporangium has a characteristic **exothecium.** Inner to it lie the **tapetal** tissue and the **microspores** (Fig. 2.10b).

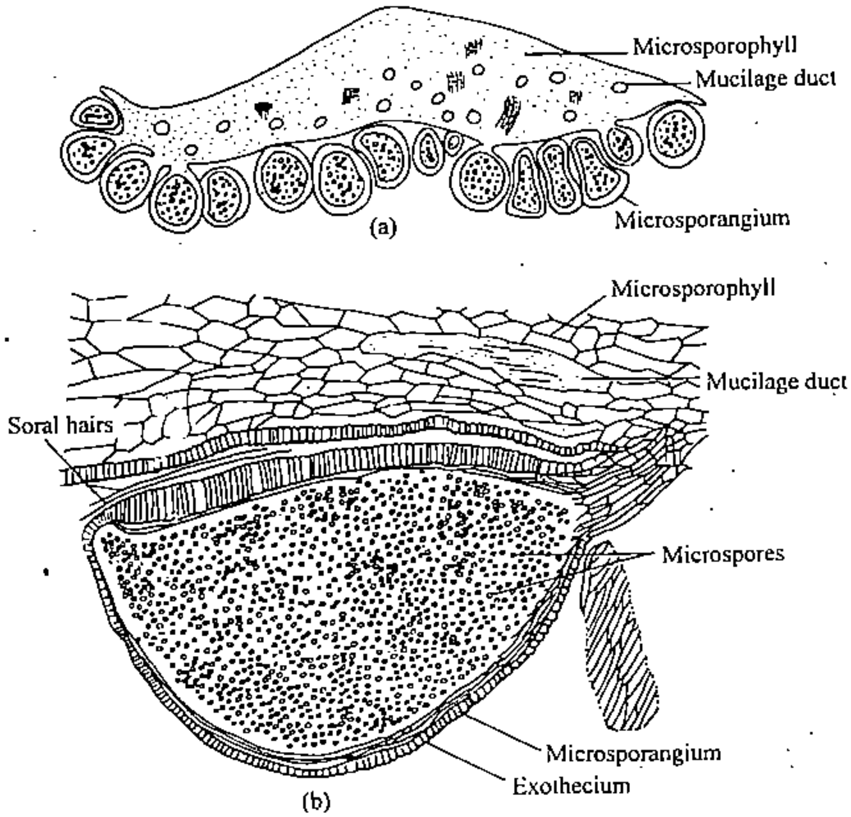


Fig. 2.10 : *Cycas revoluta* **a) V.S. microsporophyll showing abaxial microsporangia. b) Same, a part enlarged. The microsporangium shown here has got cut longitudinally (a, b, After Pant, 1973).**

The microspores or the pollen grains develop from microspore mother cell (Fig. 2.11a) as a result of microsporogenesis. The microspores at various developmental stages are depicted in Fig. 2.11. The mature pollen grain is boat-shaped due to a depression on one side. They are shed at the 3-celled stage, i.e., one prothallial, an antheridial and a tube cell.

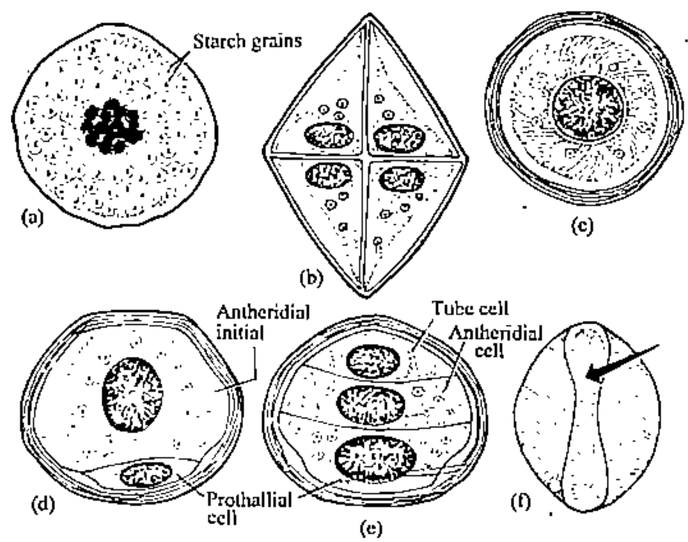


Fig. 2.11 : *Cycas* **sp. Developmental stages of the male gametophyte. a) A microspore mother cell before meiosis; note abundant starch. b) After meiosis, microspore tetrad is formed. c) Uninucleate microspore. d) Two-celled microspore with antheridial initial and prothallial cell. e) Mature pollen grain at shedding stage consists of three cells. The tube cell and the antheridial cells are the products of the antheridial initial shown in d. f) Mature pollen in side view showing a prominent furrow marked by an arrow. (After Pant, 1973).**

2.4.2 Female Strobilus and Gametophyte

The genus *Cycas* is unique amongst other cycads in not having a compact female cone (Fig. 2.12). The female plant bears successively the foliage leaves, cataphylls and then megasporophylls. This sequence keeps on repeating. From the point of view of origin, the megasporophylls have been compared to the foliage leaves and the two are considered to be homologous. In *C. revoluta* they appear like modified and reduced foliage leaves that are copiously covered with brown ramenta (Fig. 2.12c).

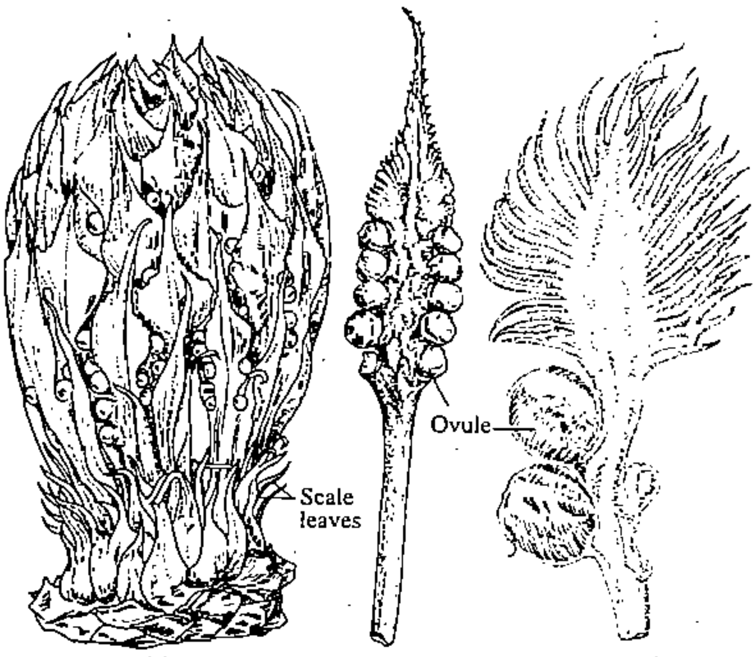


Fig. 2.12 : a, b) *C. circinalis;* c) *C. revoluta.* a) A cluster of megasporophylls. Sterile scale leaves are present at their base. b) A megasporophyll enlarged. Note ovules in two rows, and oppositely arranged. The tip (arrow) portion of the megasporophyll is sterile. c) Another megasporophyll. Mark the same features as in b. The sterile tip portion is larger, flattened and fan-like. (a, b, after Maheshwari, 1960; c, redrawn from Gifford and Foster, 1989).

Each megasporophyll is about 30 cm or more in length, and it bears 2 to 12 ovules arranged in two rows. The ovules are orthotropous, short-stalked and are either oppositely or sub-oppositely arranged (Fig. 2.12 b, c). *Cycas* is known to produce the largest ovules in the plant kingdom ranging between 6-7 cm in length. In a young ovule a distinct megaspore mother cell is seen (Fig. 2.13a). It undergoes meiosis to form a linear tetrad of megaspores, of which only the lowermost is functional. This undergoes a series of mitotic divisions to first form a free nuclear female gametophyte which eventually becomes cellular. Formation of archegonia begins soon after the gametophyte becomes cellular. As the female gametophyte develops, the micropylar surface of the gametophyte which bears archegonia separates from the covering cells to form a space called the archegonial chamber. Various developmental stages of the female gametophyte and archegonium are depicted in Fig. 2.13. Study this figure carefully.

The mature archegonium has a neck made up of a single tier of two cells; there are no neck canal cells and the ventral canal nucleus also degenerates. The egg nucleus is large, up to 500μ in *Cycas revoluta* and is visible to unaided eye. It takes about 2 months for the archegonia to mature.

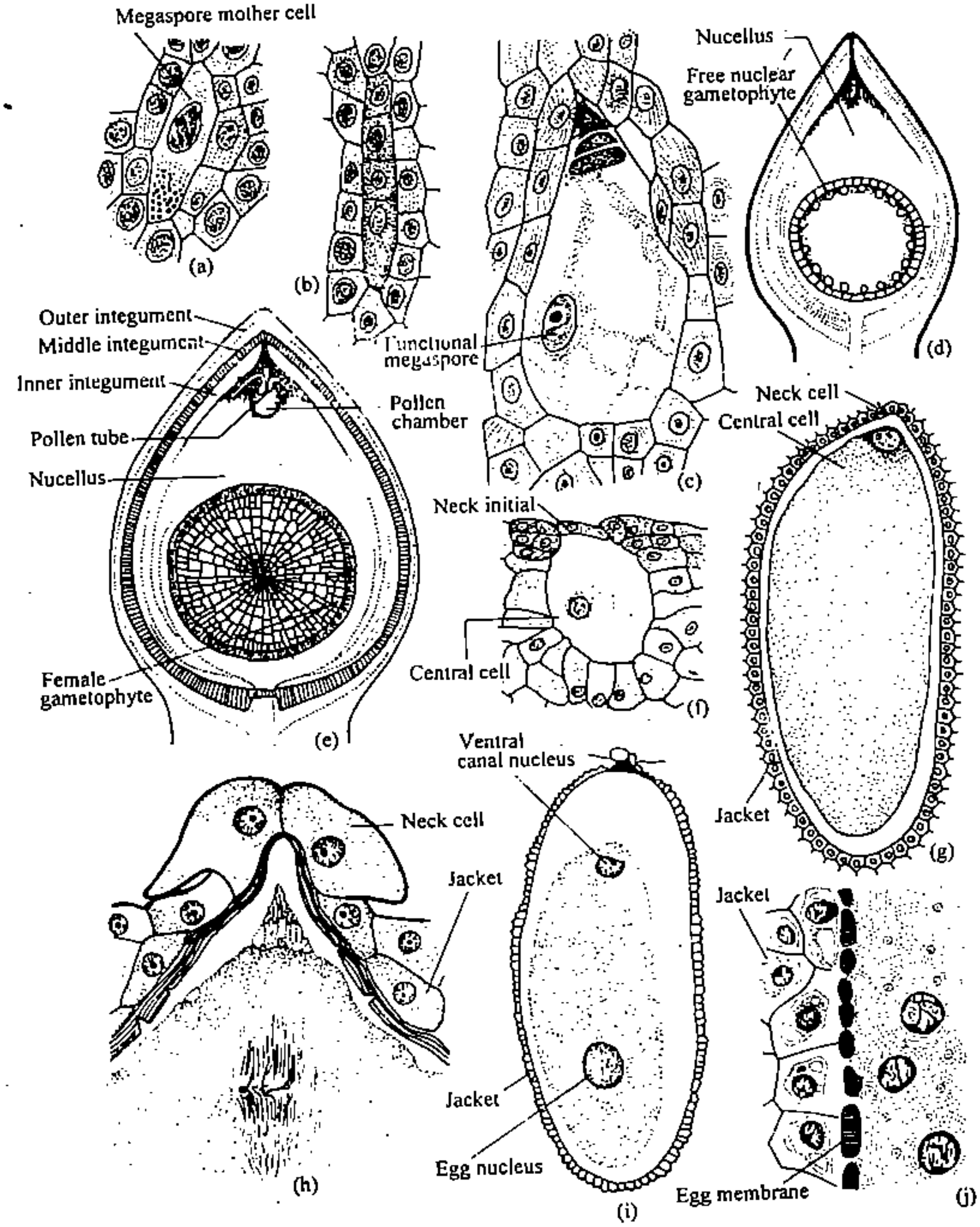


Fig. 2.13 : Developmental stages of female gametophyte in cycads. a-c, f-j) *Cycas* spp.; d, e) *Dioon* sp. a)A megaspore mother cell. b) A tetrad formed after meiosis in megaspore mother cell. c) The functional megaspore is a large, distinct cell, whereas the remaining three degenerated megaspores are present as dark masses. d, e) Stages showing formation of numerous nuclei after division of the functional megaspore. The free nuclei gradually acquire cell walls around them, as shown in e. Note the radial arrangement of cells. In e, also note three layers – outer, middle and inner, of the integument enclosing the nucellus that has a prominent pollen chamber at the tip. Further, archegonial initials differentiate from amongst micropylar cells of the female gametophyte. This and the subsequent stages of archegonium are depicted in f to j. f) Archegonial initial divides to form a neck initial and a central cell. g) A young archegonium has a central cell, two neck cells and a distinct jacket. h) The central cell nucleus undergoes division. Note prominent neck cells at this stage. i) Mature archegonium has egg, ventral canal nucleus, and degenerated neck cells. The egg nucleus enlarges and often reaches up to 500 µm in size, and occupies central position in the archegonium. j) Part of free nuclear embryo and surrounding jacket cells. The thick egg membrane shows large pits through which cytoplasmic connection is maintained. (a-c, after De Silva and Tambiah, 1950; d, e after Chamberlain, 1935; f, h, after Swamy, 1948; g, i, j, after Maheshwari, 1960).

SAQ 4

Which of the following statements are **not** true for cycads? Choose the correct answer from the choices given below.

i) A bulbil borne by a female plant would also produce a female plant.

ii) Most cycads bear several male cones and a single female cone.

iii) A mature female cone emits a strong characteristic smell to attract pollinators.

iv) Cone, sporangia, microsporophylls and sori is the order in which the structures are to be handled to have access to the male gametophyte.

v) The reproductive structures are devoid of mucilage ducts.

vi) The female plant sequentially bears first the foliage leaves, followed by cataphylls and then the megasporophylls.

vii) The megasporophylls are considered as the modification of the foliage leaves.

viii) Cycads are known to produce the smallest ovules in the whole plant kingdom.

Choices of Answers

a) i, ii, iii, vii

b) iii, iv, vi, vii

c) iv, v, vi, vii

d) ii, iv, v, viii

2.5 POLLINATION, FERTILIZATION AND EMBRYOGENY

After the development of male and female gametophytes, further development can take place only after these two are brought together through **pollination,** and subsequently fertilization. The pollen grains are transported to the female plants by means of wind or insects. They are caught in the pollination drop secreted at the tip of the ovule, and are subsequently 'sucked in' through the micropyle to the pollen chamber. The pollen chamber is then sealed from the outside world to prevent invasion by pathogens and to provide a congenial environment to the developing embryo. In the meanwhile, the pollen grain germinates to form a pollen tube at the end opposite to the prothallial cell and it is haustorial in nature. The antheridial cell divides into stalk and spermatogenous cell. Two sperms are formed by the division of the spermatogenous cell (see Figs 2.11, 2.14). The continued growth of the haustorial pollen tube leads to the degeneration of nucellar tissue. The spermatozoids of cycads are the largest male gametes of the plant kingdom, and can be seen with naked eyes. The sperms are top shaped and have a spiral band which makes six turns on the body, and to it the flagella are attached. The sperms are released in the archegonial chamber from the pollen grain through tubular growth on the side of the prothallial cell. It eventually casts off its flagellar band and its nucleus approaches the egg and sinks into it. This marks the completion of fertilization. Zygote is the product of this process. Of the two sperms produced per pollen, only one participates in fertilization, whereas the second sperm degenerates. Embryogeny begins by the division of the zygote. In early stages, the development is free-nuclear and the nuclei arrange themselves around a vacuole in the archegonium. Later, most of the nuclei move towards the base, and the upper portion has few nuclei. Wall formation starts from the base and these form the proembryo. The upper cells elongate to form the suspensor. Complete cellularization does not take place. The zone of cells separating the suspensor and free nuclear zone is called the buffer zone. Polyembryony, occurs in the initial stages, but ultimately the most vigorous embryo takes the lead and matures. The growth of embryo in the seed is very slow and it takes over a year for the embryo to mature after fertilization. Since there are several ovules per megasporphyll, one may ask, how many develop into seeds? Many of the ovules remain unpollinated and abort or remain small. Ripe seeds are broad, elliptical or egg shaped, somewhat flattened laterally and are bilobate. Young seeds are copiously covered with brown hairs. By the time the seeds become mature, these hairs are shed. The ripe seeds are fleshy and become bright orange or red in colour. Being tropical or sub-tropical plants, cycads do not undergo winter rest. Seed germination is hypogeal (Fig. 2.15).

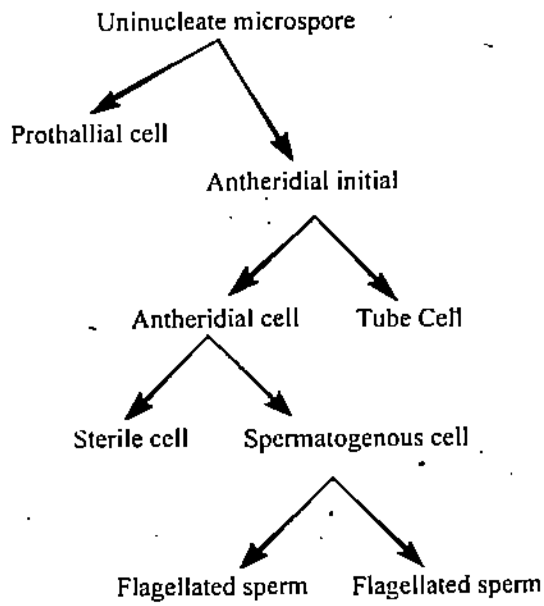


Fig. 2.14 : Schematic diagram depicting stages in the development of male gametophyte in cycads.

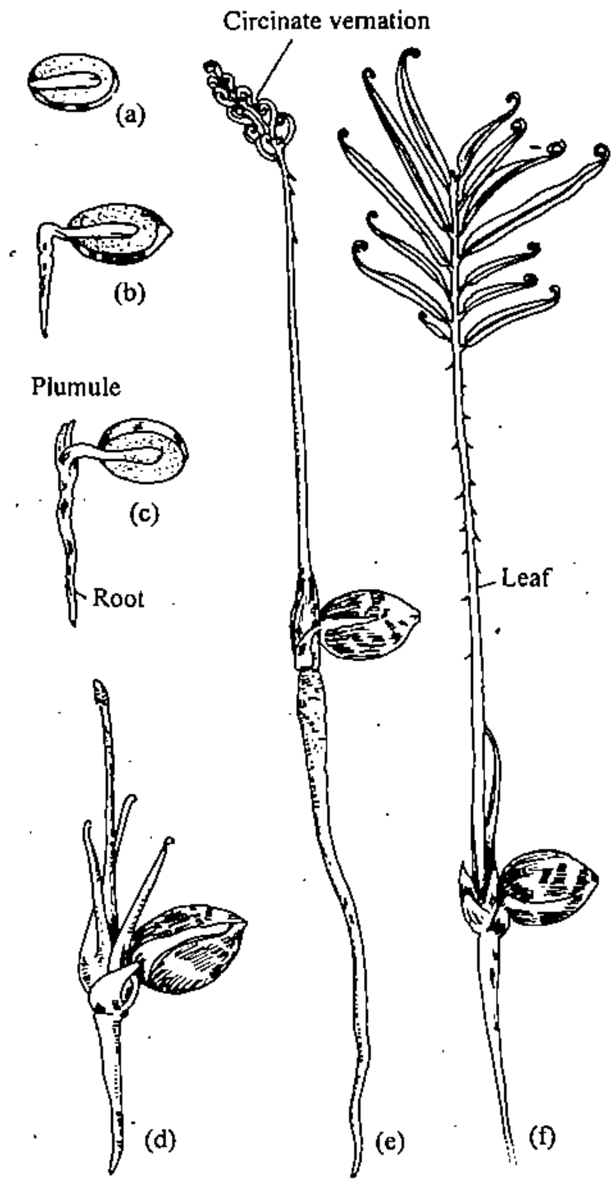


Fig. 2.15 : a-f) Stages of development of a *Cycas* seedling, (a-f, after Maheshwari, 1960).

2.6 DISTINCTIVE FEATURES AND CONSERVATION CONCERNS

Cycads were common during the mid-mesozoic era, and their antiquity is established by the large number of fossil cycads reported from many parts of the world. Present day cycads have a very limited distribution. Most cycads contain certain glycosides (cycasin and macrozamin) that are poisonous, or some other physiologically active substances. It is believed that the presence of these substances might have helped this group to survive up to the modern era (also see Unit 5, Economic Importance of Gymnosperms).

Box 2.2: Reasons for Decline and Conservation Measures for Cycads

Cycads are under a lot of pressure because : (i) their natural habitats are being indiscriminately spoilt/destroyed; and (ii) they are being continuously removed for sale or as collectors' items. The IUCN (International Union for Conservation of Nature and Natural Resources) currently recognizes 26 species as endangered worldwide. It is important to conserve the cycads at the international as well as local level. The CITES (Convention of International Trade in Endangered Species) prohibits/restricts trade in endangered species, and some cycads are listed under these categories. Cultivation in Botanic Gardens has played a major role in the conservation of cycads. Increasing awareness about the importance of cycads may help ensure their survival in natural habitats also.

The Cycadales, like the pteridosperms, show a number of filicean characters combined with the seed-bearing habit along with gymnospermous features. However, unlike the seed ferns, their sporangia are borne on specialised lateral structures – the sporophylls. The sporophylls in turn are organised into groups called terminal male and female cones. *Cycas* is the only exception in that it has lax arrangement of leaf-like megasporophylls. The anatomical characteristic feature of cycads is the presence of girdle traces in the stem.

The extinct group Pteridospermales or the pteridosperms existed from the Carboniferous period to the Permian. They had features of both ferns and gymnosperms, i.e., foliage like the ferns and formation of seeds like the gymnosperms.

This group of plants has survived as remnants of a line of plants that once dominated the earth's vegetation. But they are now decreasing rapidly, partly due to their natural decline and more because of man's indiscriminate intrusion into their natural habitats. The time may not be very far when probably all the species may disappear if they are not protected from man's onslaught.

In India as well as in other parts of the world, cycad species find themselves on the verge of extinction and are listed in the Red Data Book. There is thus an urgent need to conserve these ancient plants. In fact, reintroduction of saplings into the habitats from where they have been depleted is one conservation measure. The second conservation measure involves *in vitro* propagation using biotechnological tools. You may also think of some ways of conserving this fascinating group of plants.

SAQ 5 Make a concept map of the events associated with pollination in cycads?

SAQ 6 Draw parallels between the cycads and the Filicales.

2.7 SUMMARY

In this unit you have studied that :

- Cycadales were prevalent during the mid-mesozoic era. At present, over 100 species grouped in 11 genera are found in restricted locations, both in the Eastern and the Western Hemispheres.

- *Cycas* has a palm-like appearance with columnar, aerial trunks and a crown of leaves. The bulbils which are adventitious buds develop into branches and also contribute to the vegetative propagation of the plant. Two crowns of leaves are produced annually during the favourable seasons

- In *Cycas*, the primary root system comprising a tap root is replaced by adventitious roots. Some of these roots branch dichotomously, turn apogeotropic and perform the role of nitrogen fixation, and are termed as coralloid roots. Anatomically young roots resemble those of angiosperms. The coralloid root anatomy is similar to the normal root. but it additionally has a distinct algal zone in the middle of the cortex.

- The stem is characteristic of xerophytes. The abundant mucilage cells help in conserving water. Pith is prominent, and it occupies nearly one third area of the stem. The wood is manoxylic and stems derive mechanical strength from the persistent leaf bases present on the surface. The girdling leaf traces are the other characteristic feature of cycad stem.

- *Cycas* bears dimorphic leaves – the scale leaves and the foliage leaves produced in an alternate manner. The scale leaves have a dense coating of the ramenta: and the foliage leaves are unipinnately compound having circinate vernation, rachis and leaflets. Both rachis and the leaflets exhibit xerophytic characters. The vasculature of the rachis shows distinct diploxylic (pseudomesarch) bundles.

- *Cycas* bears male and female reproductive organs on separate plants, i.e., they are dioecious. Male cone is a large terminal structure, borne singly and has a peculiar odour. The male cone consists of a large number of microsporophylls, each bearing numerous sporangia present in groups on its underside. The female plant bears several megasporophylls, each bearing many ovules arranged in two rows.

- Pollination is effected by means of insects or wind. The sperms are flagellate and are the largest male gametes in the plant kingdom. The product of fertilisation is zygote. It undergoes embryogeny and forms the seed. The seeds do not undergo dormancy, and exhibit hypogeal germination.

- It is believed that the presence of certain physiologically active substances in cycads have enabled them to survive up to the modern times. This group also presents marked similarities with the seed-ferns.

2.8 TERMINAL QUESTIONS

1. What promotes branching in cycads?
2. Why is it that some cycads have thinner trunks near the lower region as compared to the upper part?
3. Given a *Cycas* tree, how would you determine its age?
4. Compare the normal and the coralloid roots of *Cycas.* Draw labelled figures to mark the differences.
5. With the help of labelled outline diagrams only, depict the structure of rachis at two levels in the leaflet, one, near the point it connects the leaflet, and the second, near its tip.
6. Compare the male and female reproductive structures of *Cycas.*
7. List the anatomical features that are characteristic of cycads.
8. Devise a strategy for the conservation of cycads.

2.9 ANSWERS

Self-Assessment Questions

1. d
2. c
3. a) tap
   b) coralloid
   c) wider, presence
   d) persistent leaf bases
   e) sago
   f) leaf base armour
   g) conducting tissue
4. d
5. See Section 2.5

   Hint : Pick out the pollination related key terms from the section, arrange them in a logical sequence and connect them with arrows. You may use connecting words for linking these terms.
6. **Hint** : Read Section 2.6. and compile all the relevant points given in the Unit.

Terminal Questions

1. Physical injury is an important factor leading to branching in cycads.
2. As the trees age, the older leaf bases, which obviously are near the lower region abscise. Therefore the lower trunk appears thinner than the upper region.
3. Count the number of leaf bases, divide by half the number of leaves in the crown. See Section 2.2.
4. Refer to Section 2.3.1.
5. Read the descriptions given in Section 2.3.3 and make outline diagrams.
6. See Subsections 2.4.1 and 2.4.2.

   Hint: It would be a good idea to bring out these differences in a tabular form. Outline diagrams can enhance the clarity of your answers. So make as much use of them as possible.
7. **Hint** : Write the anatomical peculiarities of the vegetative structures.
8. Write your viewpoint.

   Hint : You can include the following aspects in your answer: spreading awareness, *in situ* conservation, use of the biotechnological breakthroughs.

UNIT 3 CONIFEROPSIDA: *PINUS*

Structure

3.1 Introduction
Objectives

3.2 Distribution, Habitat and General Features

3.3 Vegetative Structures
3.3.1 Root
3.3.2 Stem
3.3.3 Leaf

3.4 Reproductive Structures
3.4.1 Male Cone and Gametophyte
3.4.2 Female Cone and Gametophyte

3.5 Pollination and Fertilization

3.6 Embryogeny and Seed Development

3.7 Summary

3.8 Terminal Questions

3.9 Answers

3.1 INTRODUCTION

You have read a general account of gymnosperms and have also studied about *Cycas* in detail in Unit 3. In this Unit you are going to study about Coniferales and in particular *Pinus*.

Coniferales constitute about 75% of all the extant gymnosperms, and form an important component of the world flora today. This order has seven families comprising 52 genera and 550-600 species.

The Conifers : Some genera are widely distributed all over the globe while several taxa are endemic and show restricted distribution. This indicates that this is an ancient group which was once widely scattered (mid-Mesozoic era) and extensive forests occurred in Europe. Subsequent decline led to their disjunct distribution.

The temperate regions of the world are home to the conifers, only few genera are tropical. The height of the plants is much variable.

General Characters of Conifers

1. Woody perennials with long and dwarf shoots, presence of foliar and scale leaves.
2. Tap roots associated with ectotrophic or endotrophic mycorrhizae.
3. Wood pycnoxylic, secondary xylem lacks fibres.
4. Reproductive organs found in unisexual compact cones.
5. Pollen grains (winged/non-winged) produce non-motile sperms.

You have learnt in Unit 1 that Coniferales consist of seven families viz. Pinaceae, (Abietaceae) Taxodiaceae, Cupressaceae, Podocarpaceae, Araucariaceae, Cephalotaxaceae and Taxaceae.

Pinaceae constitutes the most widely represented family of the conifers. Here we shall familiarise you with the Pinaceae in general and the genus *Pinus* will be described in detail.

Pinaceae

The family Pinaceae, has 10 genera: *Abies, Cathaya, Cedrus, Keteleeria, Larix, Picea, Pinus, Pseudolarix, Pseudotsuga* and *Tsuga*.

It comprises highly resinous shrubs or trees. Leaves are evergreen or deciduous, usually with resin canals, needle like or oblong, solitary and spirally arranged or grouped together on spur shoots.

Male and female cones occur on the same tree. Male cones have an axis with numerous spirally arranged microsporophylls. Female cones have bract scales and ovuliferous scales; seeds are winged or unwinged, two per scale.

Six genera are found in the Indian subcontinent. These are *Pinus, Tsuga, Picea, Abies, Cedrus* and *Larix*. Now we are going to describe the genus *Pinus* and give a detailed account of its morphology, anatomy and reproduction.

Objectives

You have already become acquainted with the cycads. After studying this unit you will be able to :

- state the general characters of conifers,
- list the various genera belonging to Pinaceae,
- state the distribution of various species of *Pinus* in India,
- describe the morphology and anatomy of the vegetative structures,
- give an account of the structural and developmental details of male and female cones, and the gametophytes contained therein,
- give an account of pollination and fertilization, and
- describe proembryo formation and subsequent embryogeny.

3.2 DISTRIBUTION, HABITAT AND GENERAL FEATURES

The genus *Pinus* is the most well known representative of this family and has been known to mankind since times immemorial. Pines are distributed mainly in northern Europe, North and Central America, subtropics of North Africa, the Canary Islands, Afghanistan, Pakistan, India, Myanmar and the Philippines, and spread up to Indonesia after crossing the Equator. In tropical areas they occur at sub-tropical or high temperate altitudes. *P. merkusii* is the only pine that crosses the Equator.

The genus *Pinus* is represented by over one hundred species of evergreen trees. The pines form extensive pure forests or contrastingly form mixed forests in association with broad leaved trees. Seven species of *Pinus* occur in India, of which four are restricted to the Himalayas.

Pinus is a beautiful tall tree, with horizontal branches arranged in whorls, giving the tree a pyramidal appearance but in later stages the trees start losing their symmetry.

Box 3.1 : Distribution of *Pinus* in the Indian subcontinent and neighbouring countries

Species	Place of Occurence
P. wallichiana	(From Pakistan to Arunachal Pradesh through Nepal & Bhutan, Kashmir, Himachal Pradesh, Kumaon, Sikkim, Arunachal Pradesh)
P. armandii	Arunachal Pradesh, C. & W. China & Taiwan
P. bhutanica	Arunachal & Bhutan
P. gerardiana	N.W. Himalayas, Afghanistan to Kashmir, Himachal Pradesh
P. kesiya	Khasi & Naga hills, Manipur, Myanmar & Philippines
P. roxburghii	Pakistan to Arunachal Pradesh at 450-2300 mt. (Absent in Kashmir where full force of monsoon not felt).
P. merkusii	In Myanmar, Thailand, China, Indonesia, Phillipines recently reported from Arunachal Pradesh.

3.3 VEGETATIVE STRUCTURES

3.3.1 Root

Pinus exhibits two types of root system — the long roots having potential for indefinite growth constitute the main root system, while the branches with restricted growth and relatively short life are the short or dwarf roots.

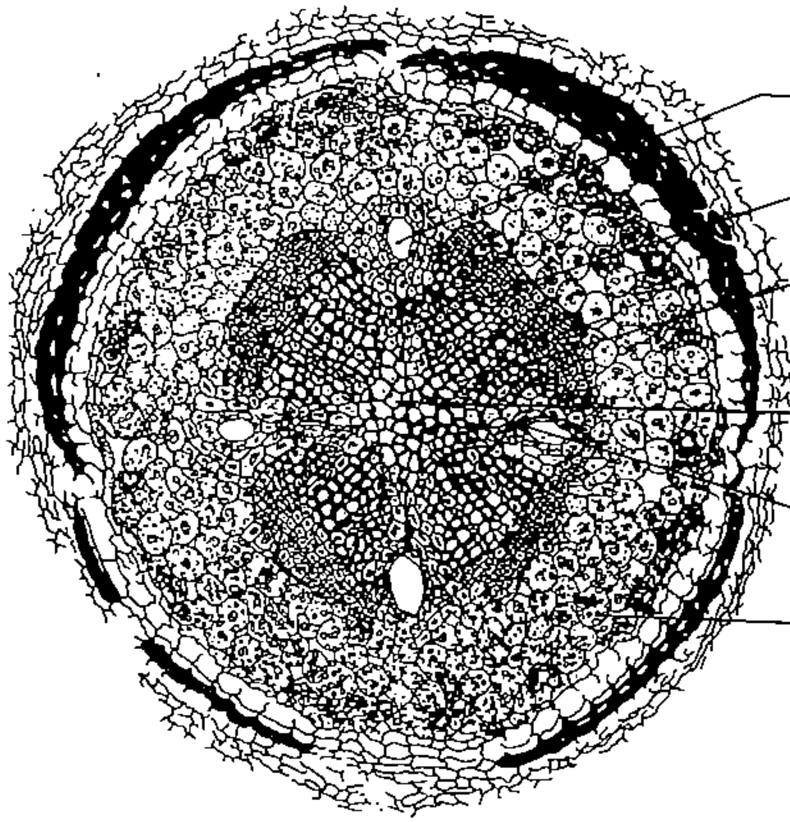


Fig. 3.1 : *Pinus* sp. Transverse section (T.S.) of a young root after secondary growth has been established. The outer part is scaling off in plates. There is a resin duct opposite each of the four protoxylem points. The crushed protophloem is still visible, and outside it are cells rich in starch, and just beneath the scaling off layers are numerous resin cells.

In *Pinus* both long and short roots are diarch or tetrarch (Fig. 3.1). The structure from outside inward is epidermis followed by starch-filled cortex having an outer zone of small and an inner zone of large parenchymatous cells. The endodermis is single-layered with Casparian strips and is followed 6 or 7-layered pericycle. The xylem and phloem show radial arrangement. Each protoxylem point is associated with a resin duct (Fig. 3.1). The metaxylem elements are made up of pitted tracheids. The phloem alternates with xylem and consists of sieve cells and parenchyma.The pith cells are rich is starch. Occasionally some of them are tanniniferous too.

Secondary growth starts very early and the structure of the root, in later stages, is much like that of the stem.

The dwarf root of *Pinus* is anatomically similar to the long root. It, however, differs from the long root in the absence of a root cap, resin ducts, starch in cortical cells and secondary growth. The cortex is smaller in the dwarf root than in the long root.

Mycorrhiza occurs in several conifers. In *Pinus* it is well developed, and has also been extensively studied. It exhibits well developed ectotrophic mycorrhizal association with over 50 different species of fungi belonging to families Boletaceae and Agaricaceae of the Basidiomycetes. The dwarf roots divide dichotomously (Fig. 3.2) and become modified into

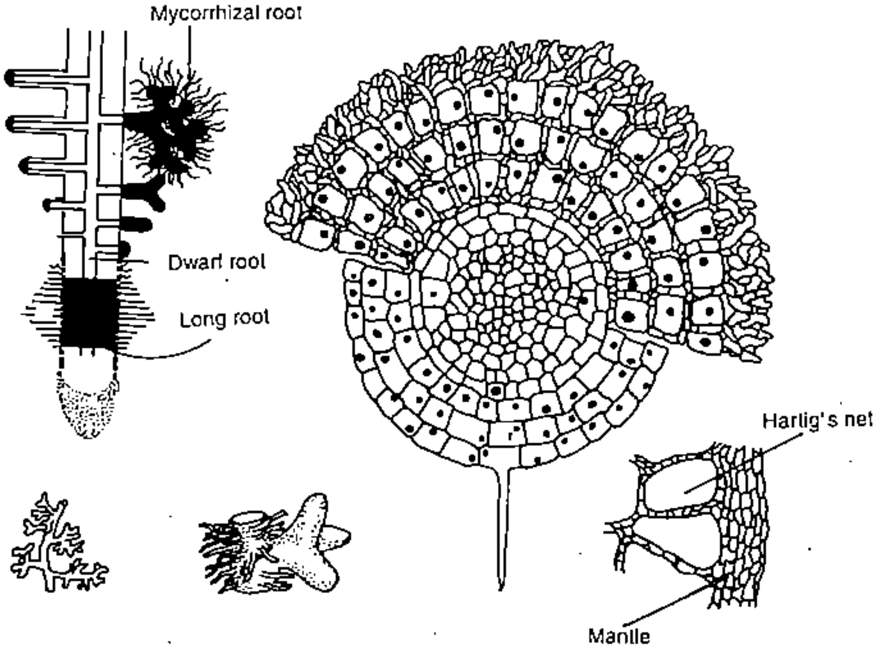


Fig. 3.2 : ***Pinus*** **sp. a) Diagrammatic representation of a young root. Root hair zone K (in block) is near the tip. Note that the absorbing surface (In black) on the infected side (a-d) is greater than on normal side (e-j). b) T.S. root whose one half is normal and the other half (upper portion in the figure) is mycorrhizal. Cortical cells are hypertrophied and enveloped by fungal filaments forming an ectotrophic mycorrhiza In the infected part. c) Short lateral roots in infected condition branch dichotomously. d) Mycorrhiza in an enlarged view. e) Ectotrophic mycorrhiza with the characteristic Hartig's net and mantle. (a, c, d after Hatch, 1937; b, e, after Hatch and Doak 1933).**

mycorrhizal system after fungal infection, when the entire rootlet is enclosed by mycelium (Fig. 3.2). The fungal hyphae penetrate the intercellular spaces in the cortical cells of the root forming the Hartig's net (Fig. 3.2).

The pine-fungal relationship is symbiotic, the pine tree benefits by the increased absorbing area of mycorrhizal roots and enhanced absorption of soil nutrients.

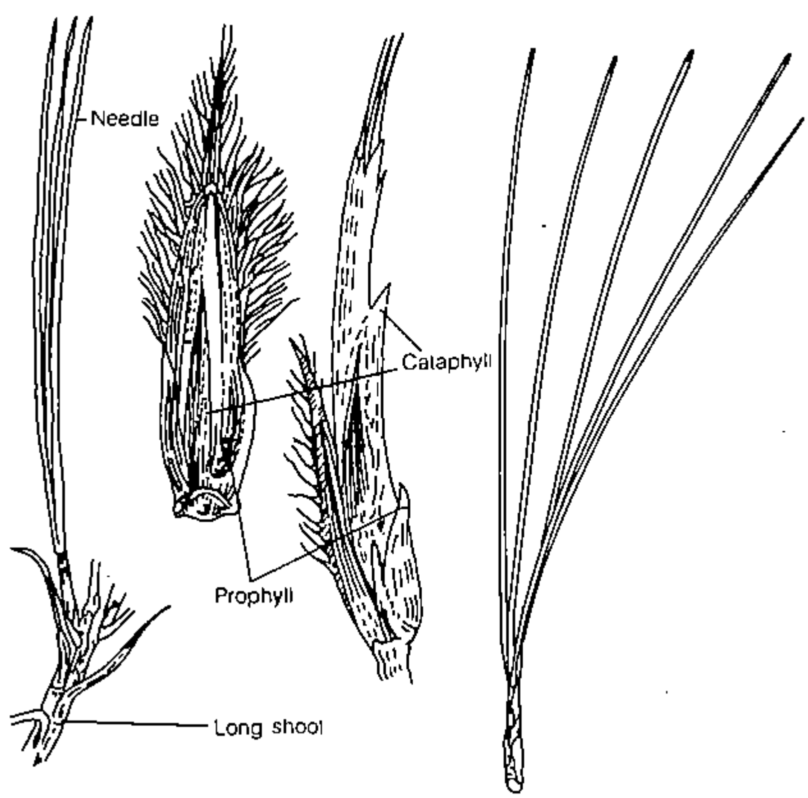


Fig. 3.3 : a-c) ***Pinus*** **sp. a, b) Young dwarf shoots showing stages in the unfolding of needles. c) Part of long shoot bearing a dwarf shoot with three needles. d) Dwarf shoot bearing five needles. (a-c, after Maheshwari & Konar, 1971; d, after Konar & Ramchandani, 1958).**

3.3.2 Stem

The stem is erect, woody and covered with rugged scaly bark which peels off. The branches are of two types; (i) the long shoots, and (ii) the dwarf shoots. The long shoots or branches of unlimited growth bear an apical bud enclosed in bud scale. Each long shoot arises as a lateral bud in the axil of a scale leaf. These lateral buds grow horizontally on the main stem to a certain length and this is referred to as nodal growth. The spur shoots, when they fall off, leave a scar on the stem. The dwarf shoots or branches of limited growth, also called short shoots, brachyblasts or foliar spurs, are borne on long shoots and arise in the axil of scale leaves (Fig. 3.3 a-b). Each dwarf shoot bears two opposite scaly leaves, called prophylls followed by 5-13, spirally arranged scaly cataphylls in 2/5 phyllotaxy.

The pine tree grows as a result of the activity of an apical meristem. In T.S. of a young stem of *Pinus* you can see ridges and furrows formed due to adpressing of surrounding leaves. Epidermis is followed by a broad parenchymatous cortex, a ring of discrete collateral and open vascular bundles, and pith. Bundles are separated from each other by broad medullary rays. Resin ducts with an inner lining of thin walled, epithelial cells are present. After a wound is inflicted, many resin ducts are formed around it. Prior to secondary growth, the fascicular cambium and interfascicular cambium join up forming a complete ring. The

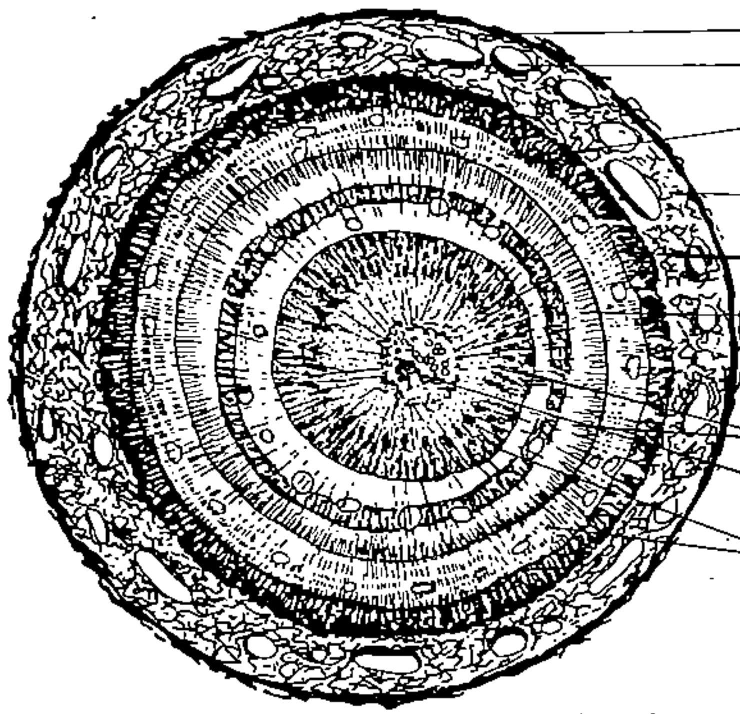


Fig. 3.4 : T.S. of a two-year old stem of *Pinus* with growth rings and pycnoxylic wood (After Foster 1989).

cambium cuts off two types of cells– the fusiform and the ray initials. The fusiform initials are elongated with tapering ends and are tangentially flattened. They give rise to the axial system i.e., xylem and phloem. The ray initials are small and isodiametric, and form the radial system which is composed of rays.

The cambium produces a continuous cylinder of secondary xylem towards inside and secondary phloem towards outside (Fig. 3.4). The cambium also cuts off parenchyma cells which give rise to secondary medullary rays. The tracheids of secondary xylem have bordered pits (Fig. 3.5).

The secondary phloem has sieve elements the most characteristic feature of the which is the occurrence of sieve plate, on the radial walls throughout its length. The sieve plates consist of numerous narrow channels lined with callose.

The rays are of two types: (i) uniseriate rays, and (ii) multiseriate or fusiform rays. Most of the rays are of the uniseriate type; in height, the ray varies from 1 to 12 cells. The multiseriate ray is always more than one cell wide and several cells in height. It is associated with a centrally situated resin canal (Fig. 3.5b). The detailed structure of ray can be best understood by examining sections cut in all the three planes. You must study Figure 3.5 carefully. The transverse section (T.S) shows the width and the length of the ray. The longitudinal sections should be cut in the radial (RLS) as well as in the tangential (TLS planes). If one began cutting tangential sections and continued to cut inwards, section passing through the pith would be radial (see Fig. 13.5). It should be understood clearly that a radial section cuts along the radius and also along the vascular rays while the tangential section cuts at right angles to vascular ray. The TLS shows the height and width of the ray. The RLS depicts the length and height of the ray. There are two kinds of cells in the rays — the inner, starch filled, living ray parenchyma and the peripheral, non-living ray tracheids. The ray parenchyma has simple pits while the ray tracheids show bordered pits.

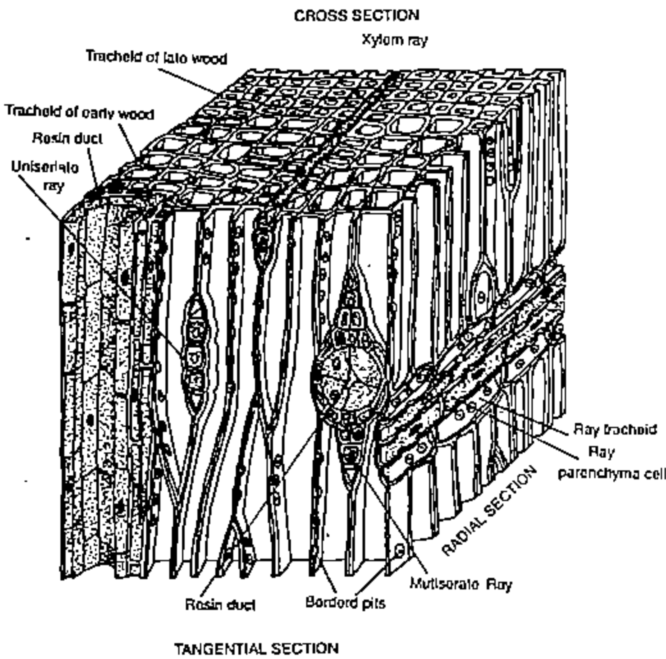


Fig. 3.5 : Three-dimensional diagram of a cube of secondary xylem of *Pinus* sp.

The wood structure of *Pinus* is much simpler as compared to the wood of dicotyledons. The wood consists mainly of tracheids and characteristic feature is the absence of vessels. The cork cambium differentiates in the first or second layer of the cortex. It cuts off cork on the outer side and secondary cortex on the inner side.

Anatomically the dwarf shoot resembles the long shoot except for its diameter.

3.3.3 Leaf

The leaves on the dwarf shoots are of two types: 2-5, long, needle-like foliage leaves, and, the scale leaves of protective nature. **The needle number is constant for a species** and is used as a taxonomic character, eg. *P monophylla* has one. *P. sylyestris* has two, *P. roxburghii* has three (Fig. 3.3c) and *P. wallichiana* has five needles (Fig. 3.3d).

The primary (deciduous) leaves, which are always single, appear soon after germination and function as foliage leaves. The secondary (permanent) leaves, or the needles, are borne on short shoot or brachyblasts in bundles in the axils of scale leaves.

In *P. monophylla* the solitary needle is round (Fig. 3.6a), in the 2-needle pine (*P. merkusii*) it is semicircular, and in three needle pines as in *P. roxburghii*, it is triangular (Fig. 3.6 b). The internal structure of needle is explained in (Fig. 3.6c). The dermal layer (epi–and hypodermis) is followed by mesophyll surrounding the diarch/monoarch stele. The epidermis is a single layer of isodiametric lingnified cells covered with a thick deposit of cutin. The hypodermis consists of 2 or 3 layers of cells which could be uniformly thin or thick. The mesophyll is chlorenchymatous with varying number of plate-like or peg-like infoldings of the wall projecting into the cell cavity. Resin ducts are also present in the mesophyll.

The endodermis is a single continuous layer of barrel-shaped cells. The pericycle is parenchymatous, interspersed with transfusion tracheids. A sclerenchymatous sheath is present around the vascular bundle. In *P. roxburghii* there are two vascular bundles, placed at an angle to each other. The xylem consists of protoxylem elements and metaxylem elements. Phloem consists of sieve cells and parenchyma. Transfusion tissue consisting of tracheids and parenchyma cells occurs on both sides of the vascular bundle; it plays a part in lateral conduction of water and nutrients. The stomata are situated in longitudinal rows and are sunken. The walls of the subsidiary cells and the guard cells are partly lignified.

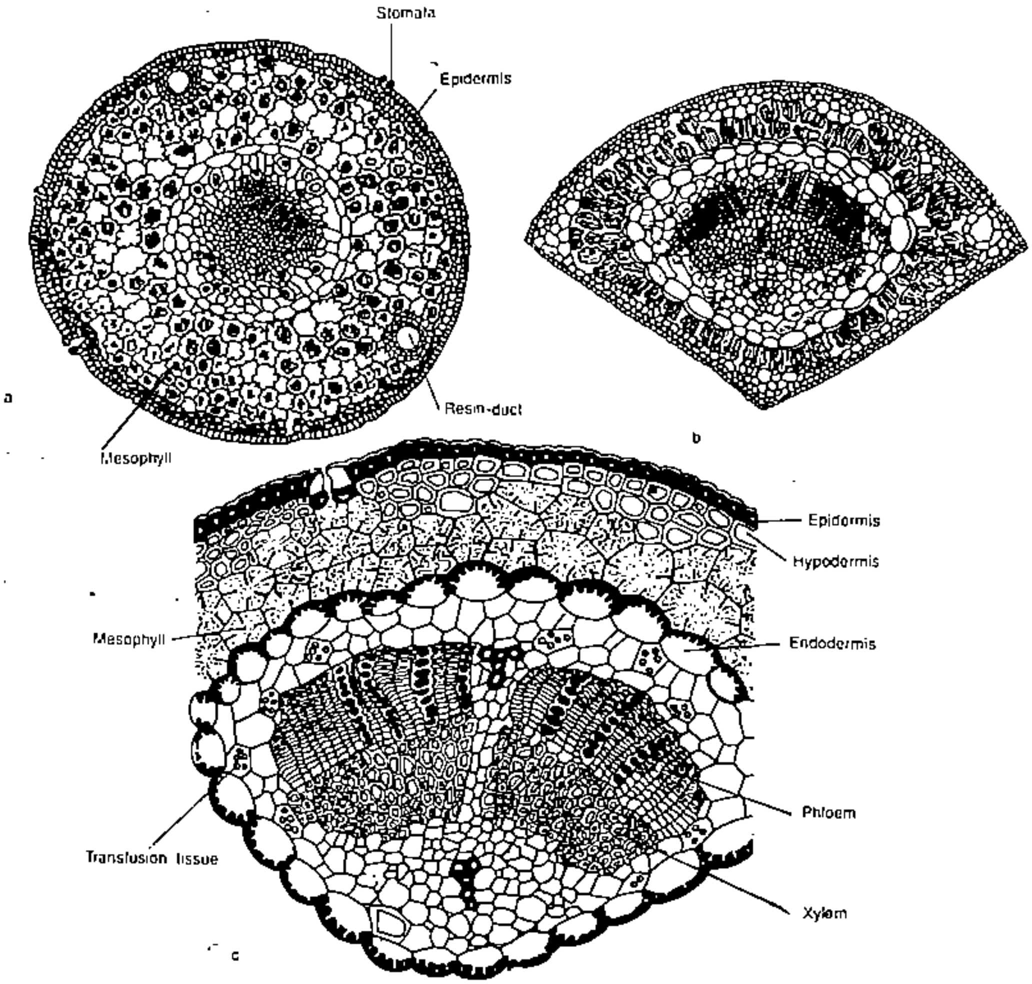


Fig. 3.6: *Pinus* sp. a,b) T.S. needle. c) Part of a needle in T.S. enlarged to show lignified epidermis, hypodermis, mesophyll with cells showing infolding of walls, endodermis with thickened outer walls, transfusion tissue and two vascular bundles placed at an angle. (a redrawn from Gifford & Foster, 1989, b after Konar 1963 a).

SAQ 1

State whether the following statements are true or false. Write (T) for true and (F) for false in given brackets.

1. The family Pinaceae has only 7 genera. [ ]
2. The pines form extensive pure forest or mixed forest in association with broad leaved trees. [ ]
3. Six species of *Pinus* are indigenous to Himalayas [ ]
4. The needle number of *Pinus* is constant for a species and is used as a taxonomic character. [ ]

SAQ 2

Fill in the blanks with the appropriate words.

1. The cells of the cortex are filled with ....
2. The phloem consists of .... and parenchyma.
3. In *Pinus* .... mycorrhizal association is well developed.

4. The pine-fungal relationship is ....
5. In *Pinus* vascular bundles are .... and ....
6. The sieve cell has .... on the wall through out the length of cell.
7. In the wood of *Pinus* there is absence of ....
8. In *P. roxburghii* the needles are .... in T.S.
9. In *P. roxburghii* the two vascular bundles are placed at an .... to each other.
10. The stomata in Coniferales are ....

3.4 REPRODUCTIVE STRUCTURES

3.4.1 Male Cone and Gametophyte

The tree is monoecious, but the male and female cones are borne on separate branches. The male cones arise on the lower and the female cones on the upper branches. The male cones, which replace the dwarf shoot, occur in clusters (Fig. 3.7a-c). The number of male cones in a cluster varies from 15 (*P. wallichiana*) to about 140 (*P. roxburghii*). Each male

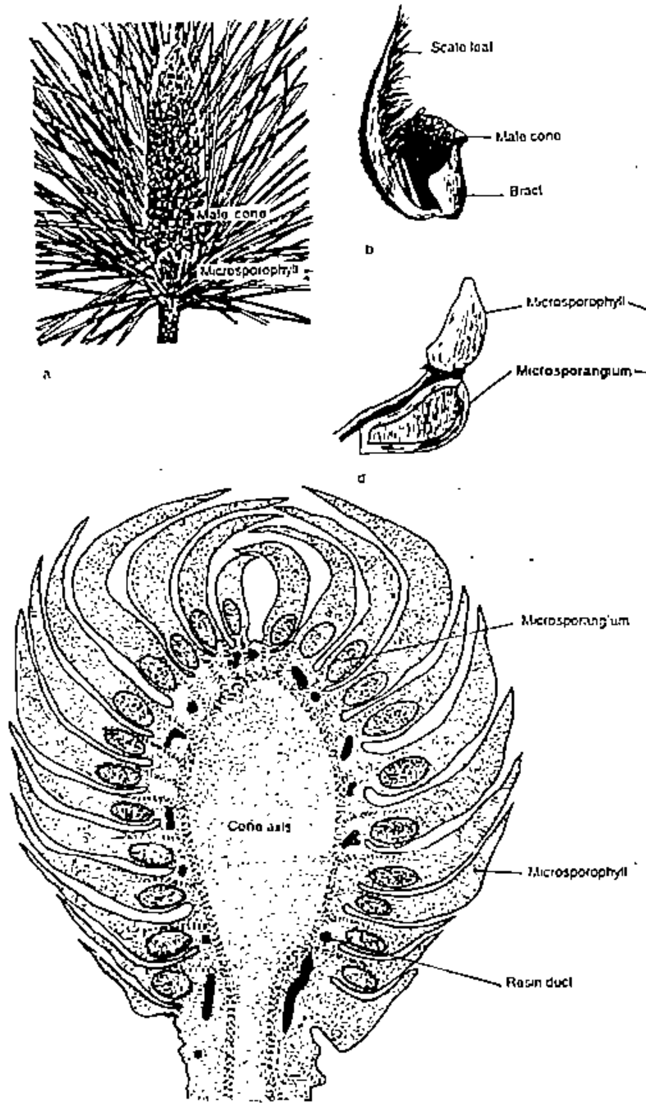


Fig. 3.7 : *Pinus* sp. a) Shoot bearing cluster of male cones. b-c) Early and late stages of the male cone. d) Lateral view of microsporophyll. e) Microsporophyll bearing two sporangia on abaxial side. f) L.S. male cone.

consists of a central axis on which the microsporophylls are spirally arranged (Fig. 3.7 f). Each microsporophyll bears two sporangia on the lower or the abaxial surface (Fig. 3.7 d-f). The cone axis elongates exposing microsporangia which dehisce longitudinally.

Microsporangium

You are already familiar with the structure of the male cone of *Pinus*. Now you will study in detail the developmental changes that lead to the formation of male gametophyte.

One or more hypodermal cells differentiate as archesporial cells which divide repeatedly to form an archesporial tissue (Fig. 3.8a). The peripheral cells of the archesporium divide periclinally to give rise to a primary parietal layer and primary sporogenous cells (Fig. 3.8b). The former divides both periclinally and anticlinally forming a wall of 3 or 4 layers, the innermost of which differentiates as tapetum (Fig. 3.8c). The remaining 2 or 3 layers are the middle layers, which degenerate with the maturation of the sporangium (Fig. 3.8d). The primary sporogenous cells, on the other hand, divide in all planes producing a mass of sporogenous tissue, the last cell generation of which is known as microspore mother cell stage.The epidermal cells, in later stages, develop fibrous thickenings except for a few cells

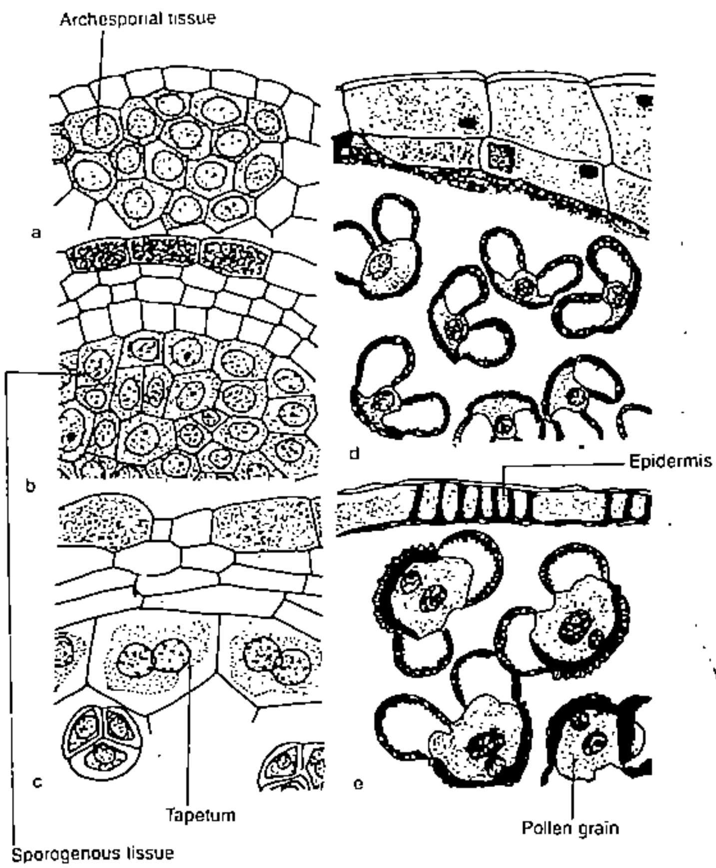


Fig. 3.8: *Pinus* a) L.S. young microsporangium to show hypodermal archesporial cells. b) Same, at a later stage; wall layers and sporogenous cells have differentiated. c) Microsporangium at tetrad stage, note binucleate tapetal cells. d) Slightly older microsporangium showing young bisaccate pollen grains. The tapetal layer and inner wall layers have degenerated. e) Same, at maturity with pollen grains at shedding stage. Epidermal cells have developed fibrous thickenings (a-c, after Konar, 1960; d, e after Konar Ramchandani, 1958).

in a row, which mark the suture of dehiscence. The development of tapetum and sporogenous cells is simultaneous in gymnosperms (Fig. 3.8e).

Microsporogenesis

Prior to meiosis the cytoplasm of microspore mother cells and tapetal cells looks alike. The nucleus of the mother cell undergoes reduction division which is followed by simultaneous wall formation to give rise to a tetrad of microspores (Fig. 3.8c, 3.9 a-d). At the end of this division, the callose sheath is dissolved by enzymatic action and the young haploid microspores are set free. The uninucleate pollen grain is the first cell of the male gametophyte. The tapetal cells and other wall layers finally degenerate when the pollen is formed (Fig. 3.9e).

Male Gametophyte

The microspore nucleus cuts off a small lens-shaped prothallial cell towards the proximal end and large central cell on the distal end (Fig. 3.9f). The central cell cuts off a second prothallial cell and an antheridial initial (Fig. 3.9g). The antheridial initial now divides to give rise to a small antheridial cell and a large tube cell. The pollen grains are shed at the four-celled stage, showing two prothallial cells, an antheridial cell and a tube cell (Fig. 3.9 h). In the microspores a thin layer of callose first develops at two sides where wings are destined to be formed, and later spreads and covers the proximal end of the pollen grain. The pollen is now mature and ready to pollinate the ovule. You shall learn about that at a later stage.

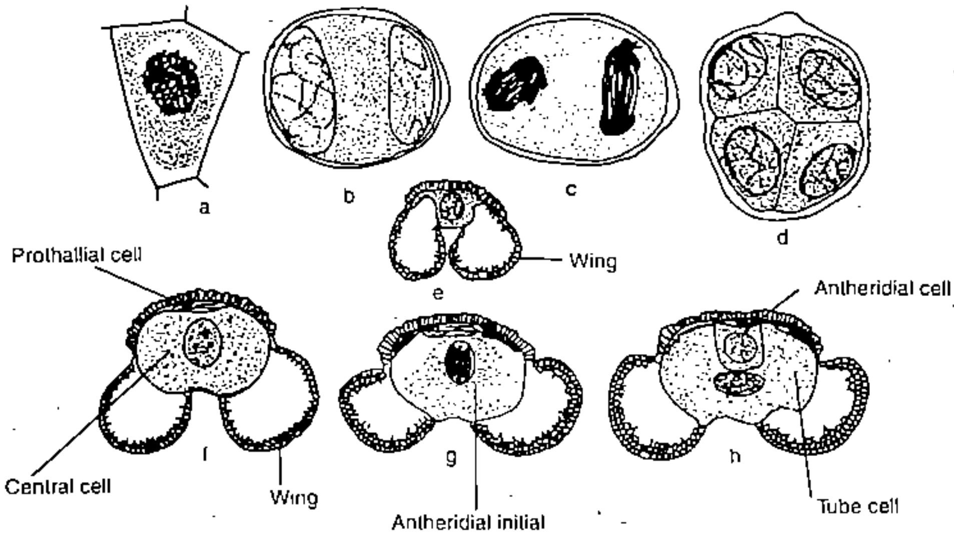


Fig. 3.9 : *Pinus* sp. Details of microsporogenesis a) Microspore mother cell. b, c) Meiosis I and II, respectively. d) Microspore tetrad. e) Uninucleate pollen grain. f, g) Stages in the development of male gametophyte. In g, both prothallial cells have been cut off and the antheridial initial is undergoing division. h) Mature, four-celled (two degenerating prothallial cells, an antheridial cell and a tube cell) pollen grain at shedding stage (after Konar & Ramchandani, 1958).

3.4.2 Female Cone and Gametophyte

The female cones (Fig. 3.10a) replace the long shoots and the number is variable but the number may be up to six. Each female cone consists of a central axis on which 80 - 90 megasporophylls (ovuliferous scales or ovule-bearing scales), are arranged in a spiral fashion (Fig. 3.10 b, c). The bract and the ovuliferous scales together form a seed-scale-complex (Fig. 3.10 e, f). Each megasporophyll bears two ovules on the upper or the adaxial surface (Fig. 3.10d). The ovules are inverted with micropyle facing the axis of the cone. The ovuliferous scale is initially much smaller than the bract scale, but in post-pollination stages it overgrows the latter (Fig. 3.10 e, f).

Megasporangium and Megasporogenesis

The ovules of *Pinus* are unitegmic and crassinucellate. The integument is free from the nucellus for most part of its length, except at the chalazal end. It forms a fairly broad micropylar tube which is curved in during pre-pollination stages, but is curved-out at the time of pollination.

A hypodermal archesporial cell (rarely more) is formed at the micropylar end of the broad nucellus. It divides periclinally to form a primary parietal cell towards micropylar end and a primary sporogenous cell towards chalazal end. The former divides both anticlinally and periclinally so that the megaspore mother cell is pushed deep into the nucellus (Fig. 3.11a). It forms a linear tetrad of megaspores after meiosis (Fig.3.11b). The lowermost cell acts as the functional megaspore and upper three megaspores degenerate.

Female Gametophyte

The functional megaspore enlarges considerably; its nucleus divides mitotically to give rise to the free nuclear gametophyte (Fig.3.11c, d).

The number of nuclei in the free nuclear gametophyte is constant for a particular species. When the free nuclear gametophyte has to become cellular, the first walls are laid

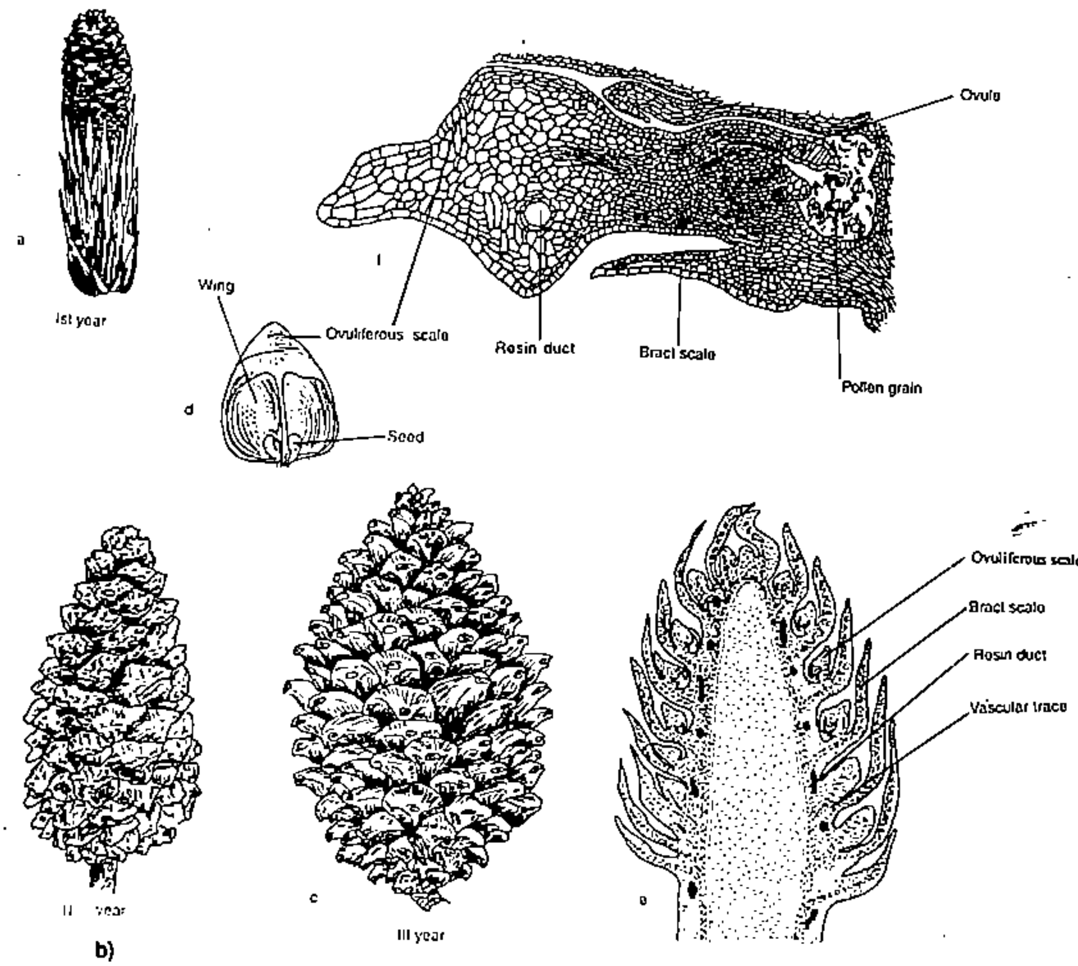


Fig. 3.10: ***Pinus* sp. : a) Female cone at the time of pollination (1st year). b, c) Same during the (IInd and IIIrd year) post pollination phase and at time of seed-shedding. d) Ovuliferous scale with two seeds borne on adaxial surface. e) Longisection of a young female cone at the time of pollination.**

perpendicular to the megaspore membrane and extend to the middle of the central vacoule. These cells are like long tubes that are open towards the inside and are called "alveoli". As a result of laying down of walls towards the center the gametophyte becomes cellular (3.11e).

A few cells (generally two or four) at the micropylar end of the female gametophyte become large and prominent, and function as archegonial initials (Fig. 3.12a). Each archegonial initial soon divides into a large central cell and a small primary neck initial (Fig. 3.12b). The latter divides by two vertical walls at right angles to each other to form a neck of four cells arranged in a single tier. The central cell enlarges very rapidly so that numerous vacuoles are formed. This is referred to as the 'foam stage' of the archegonial development (Fig. 3.12c). The central cell nucleus, meanwhile, divides into an ephemeral ventral canal cell and a large egg cell (3.12d).

The gametophytic cells near the apical end of the individual archegonium grow vigorously resulting in the sinking of the latter. Thus each archegonium has its own archegonial chamber. Cells surrounding the archegonium form a special covering layer, the jacket (Fig. 13.12d). Numerous pits are present on the inner thickened wall (facing the archegonium). The archegonium maintains contact with the surrounding gametophytic tissue through these pits. When the pit membrane breaks down, various organelles, and even whole nuclei pass from the jacket to the egg cytoplasm.

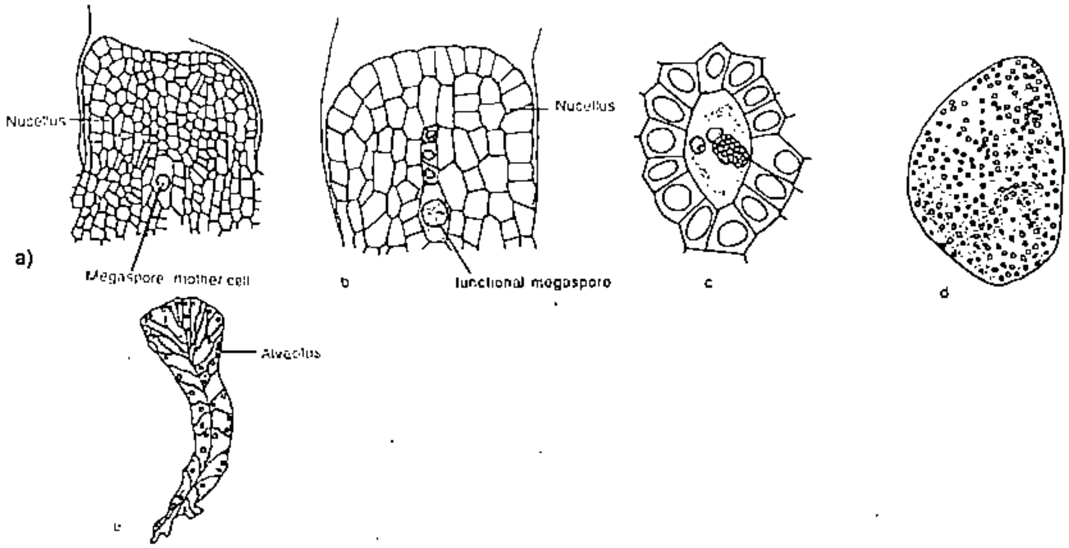


Fig. 3.11 : a-c) *Pinus roxburghii.* d-e) *P. wallichiana* a) L.S. nucellus with a deep-seated megaspore mother cell. b) Linear tetrad of megaspores; the chalazal one is functional and the upper three are degenerating. c) Four-nucleate female gametophyte. d) Whole mount of gametophyte at free nuclear stage. e) Walls have been laid down through alveoli. (after Maheshwari & Konar, 1971).

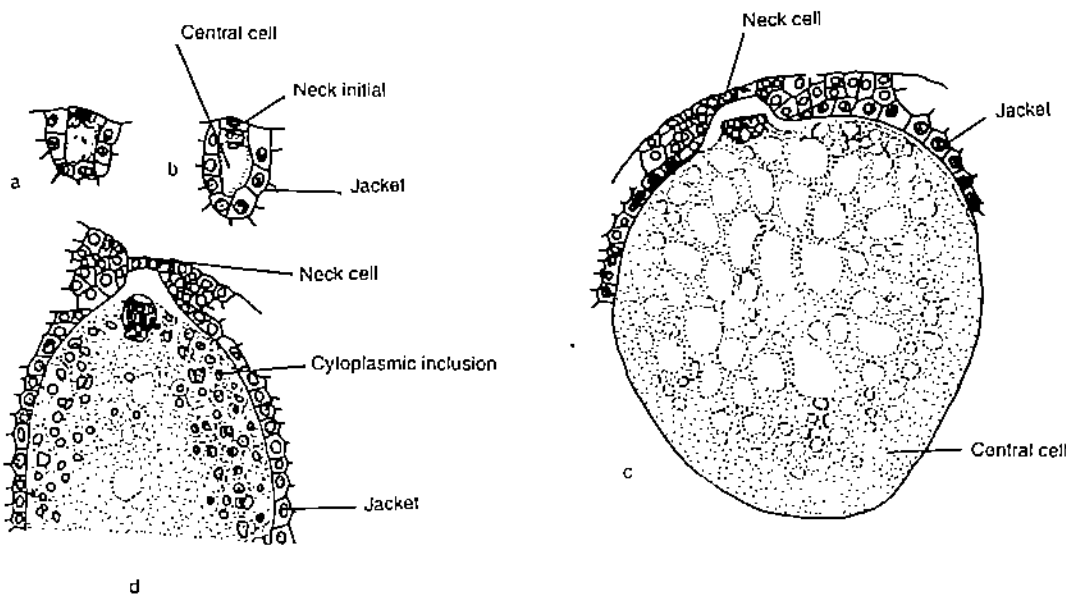


Fig. 3.12 : a-d, *Pinus* sp. : a) Newly formed archegonial initial and its jacket. b) The archegonial initial has been divided into neck initial and central cell. c) The central cell has undergone rapid enlargement; its cytoplasm shows numerous vacuoles. The neck initial has been divided into two neck cells. d) L.S. upper part of archegonium showing neck cells and central cell nucleus undergoing division which will result in the formation of ventral canal cell and egg cell; note cytoplasmic inclusions, after Konar & Ramchandani, 1958.

SAQ 3

State whether the following statements are True or False.

1. The *Pinus* tree is monoecious and male and female cones are borne on same branch. [ ]
2. Seed crops in *Pinus* are not annual and occur at the interval of two or even more years. [ ]
3. The ovuliferous scale in post-pollination stages overgrows the bract scale. [ ]

SAQ 4

Suppose that in certain species of *Pinus* the chromosome count in a leaf cell is 12 ? What chromosome count do you expect in each of the following cells of this species of *Pinus* ?

a. cell in a microsporophyll ....

b. megaspore ....

c. male gamete ....

d. cell of a megasporangium ....

e. ventral canal cell ....

f. megaspore mother cell ....

g. gamete ....

h. tapetal cell ....

i. cell of jacket ....

SAQ 5

Indicate what each of the following items becomes or develops into.

a. megaspore mother cell ....

b. ovule ....

c. microspore ....

d. embryo ....

e. integument ....

f. functional megaspore ....

g. zygote ....

h. cover scales in pine cone ....

i. ovuliferous scales in pine cone ....

3.5 POLLINATION AND FERTILIZATION

Pinus is wind-pollinated. The yellow pollen is produced in such great abundance that in a pine forest it is called 'sulphur shower'. At this time the female cone is still open (see Fig. 3.10 a, e) and the winged pollen grains easily *sift* in, roll down the obliquely tilted scales and finally come to rest in the vicinity of the micropyle. At this stage, the ovule secretes a drop of sugary liquid, the 'pollination drop', which fills the micropylar cavity and exudes out at the flared tip of the integument.

The secretion of the drop is reported to be a cyclic (24 hr cycle) phenomenon, which occurs at night or in the early hours of morning.

The wings help to orient the pollen in such a manner that the germinal pore of the grain contacts the drop and it gets sucked inside.

The pollen tube arises from the intine. While moving through the nucellus the pollen tube secretes enzymes dissolving the nucellar cell walls. As the tube emerges, the tube nucleus is

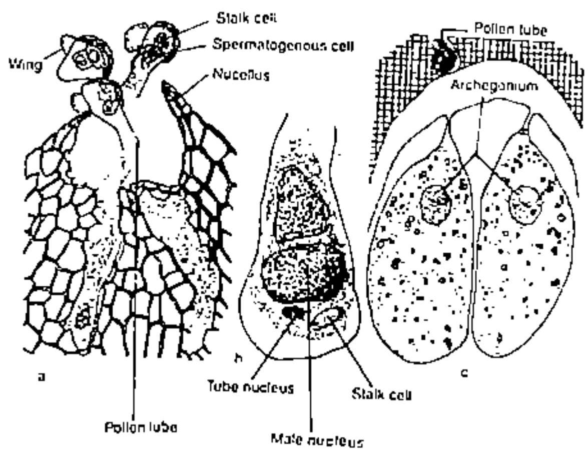


Fig. 3.13 : ***Pinus* sp. : a) L.S. nucellar tip with three germinating pollen grains. In one of the pollen grains, stalk and spermatogenous cells are separating prior to their entry into the pollen tube. b) Same, part of ovule showing a fertilized (left) and an unfertilized (right) archegonium. A portion of the pollen tube is seen in the nucellar tissue. c) Pollen tube from b enlarged to show the two unequal male gametes, the stalk cell and the tube nucleus (after Konar, 1962).**

the first to move into it followed by spermatogenous cell and stalk cells (Fig.3.13a). The spermatogenous cell eventually divides into two unequal male nuclei (Fig. 3.13b, c).

Fertilization

The union of the male and the female gametes which results in the formation of zygote is known as fertilization. The pollen tube enters the archegonium forcing itself between neck cells. The pollen tube on bursting releases two unequal male gametes, stalk cell and the tube nucleus with associated cytoplasm. The male nucleus enters the archegonium and moves towards egg nucleus and eventually fuses with it forming the zygote (Fig. 3.14).

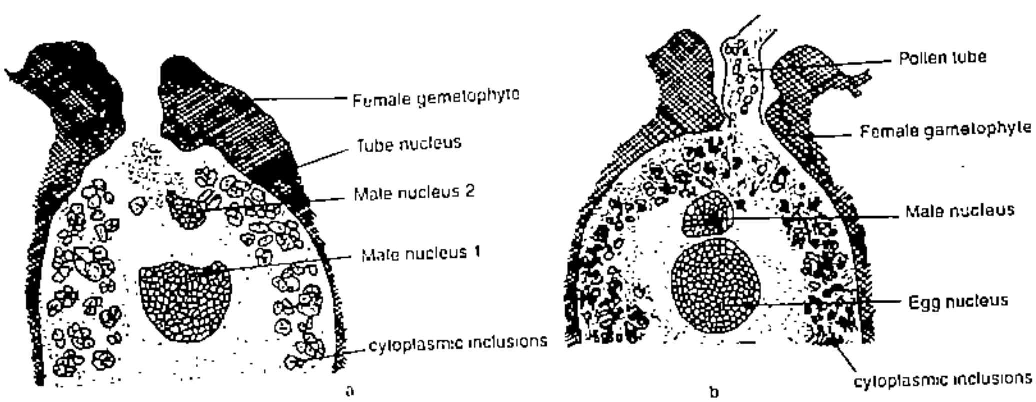


Fig.3.14 : ***Pinus* sp. Stages in fertilization. a) L.S. upper part of archegonium. The male nucleus is nearing the egg nucleus; part of the pollen tube is seen at the top. b) Same, showing fusion of the male and female nuclei to form the zygote. The second male nucleus and tube nucleus are visible in the upper part of egg cell. Cytoplasmic inclusions are prominent (after Konar & Ramchandani, 1958).**

Development of Proembryo

The zygote nucleus divides mitotically to give rise to two nuclei. The next division immediately follows and the resulting four nuclei move to the archegonium base (Fig.3.15a-c). A third synchronous division results in eight free nuclei. Wall formation gives rise to an upper group of cells, the primary upper tier (pU) and a lower group of cells, the primary embryonal tier (pE), each having four cells (Fig. 3.15d). One more division in both the tier (internal division) results in U, S and E. There are now 16 cells, arranged in 4 tiers. The upper tier has no wall towards the upper side and is thus open. The lower two tiers belong to the E group, followed by S and U tiers. The lowest tier (lower four cells of E group) gives rise to embryonal mass. Next tier (upper four cells of E group) elongates to form the embryonal suspensor (Es).

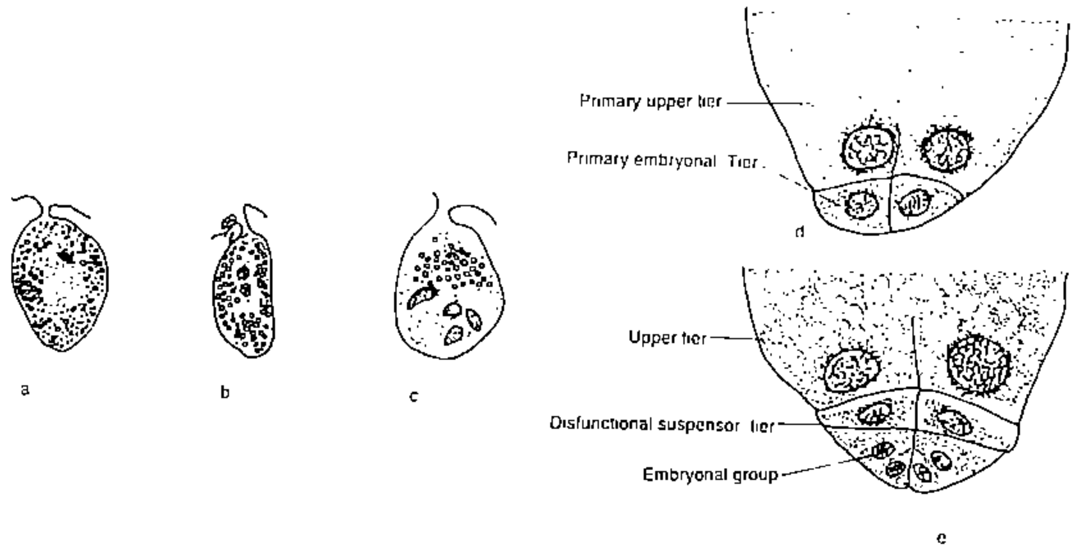


Fig. 3.15: *Pinus* sp. a) Archegonium showing zygote nucleus in metaphase. b-c) Two-and fournucleate proembryos, respectively. d) Eight-celled proembryo arranged in two tiers, primary upper (pU) and primary embryonal (pE), of four cells each. e) Proembryo comprising of upper (U) and disfunctional suspensor (dS) and embryonal group (E) of two tiers (after Konar & Ramchandani, 1958).

3.6 EMBROYGENY AND SEED DEVELOPMENT

The developing embryonal cells (Fig. 13.16 a-i) are pushed deep into the gametophyte by the several fold elongation of the embryonal suspensors. In *Pinus* several crops of embryonal suspensor (Es_1, Es_2 - Es_3 and ....) are produced (Fig. 13.16 a-d). Proximal cells of the embryonal mass elongate unequally forming the characteristic embryonal tubes. Four or more embryos start elongating. Both simple and cleavage polyembryony are evident. Only one embryo matures, whereas the growth of others is arrested at different stages of development.

The embryonal cell of the developing embryo divides in various planes to form a hemispherical apex at the lower (distal or chalazal) end and a suspensor system which is continuous with it at the upper (proximal or micropylar) end. Root cap develops at the suspensor end of the embryo and shows a central column and a peripheral region. During these changes in the root cap region of the embryo, the pith region begins to differentiate in hypocotyl shoot axis. The cells of the hypocotyl region, situated between epicotyl and root apex are large, vacuolate and transversely arranged. Then cortex is differentiated followed by procambium, and finally cotyledonary primordia. The shoot apex and cotyledons are last to differentiate. The cotyledons are 3-18 in number (Fig. 13.16h,i) and show the presence of procambial strands and mesophyll cells. The mature embryo, thus, has a distinct epicotyl root axis and a hypocotyl shoot axis with remnants of suspensor.

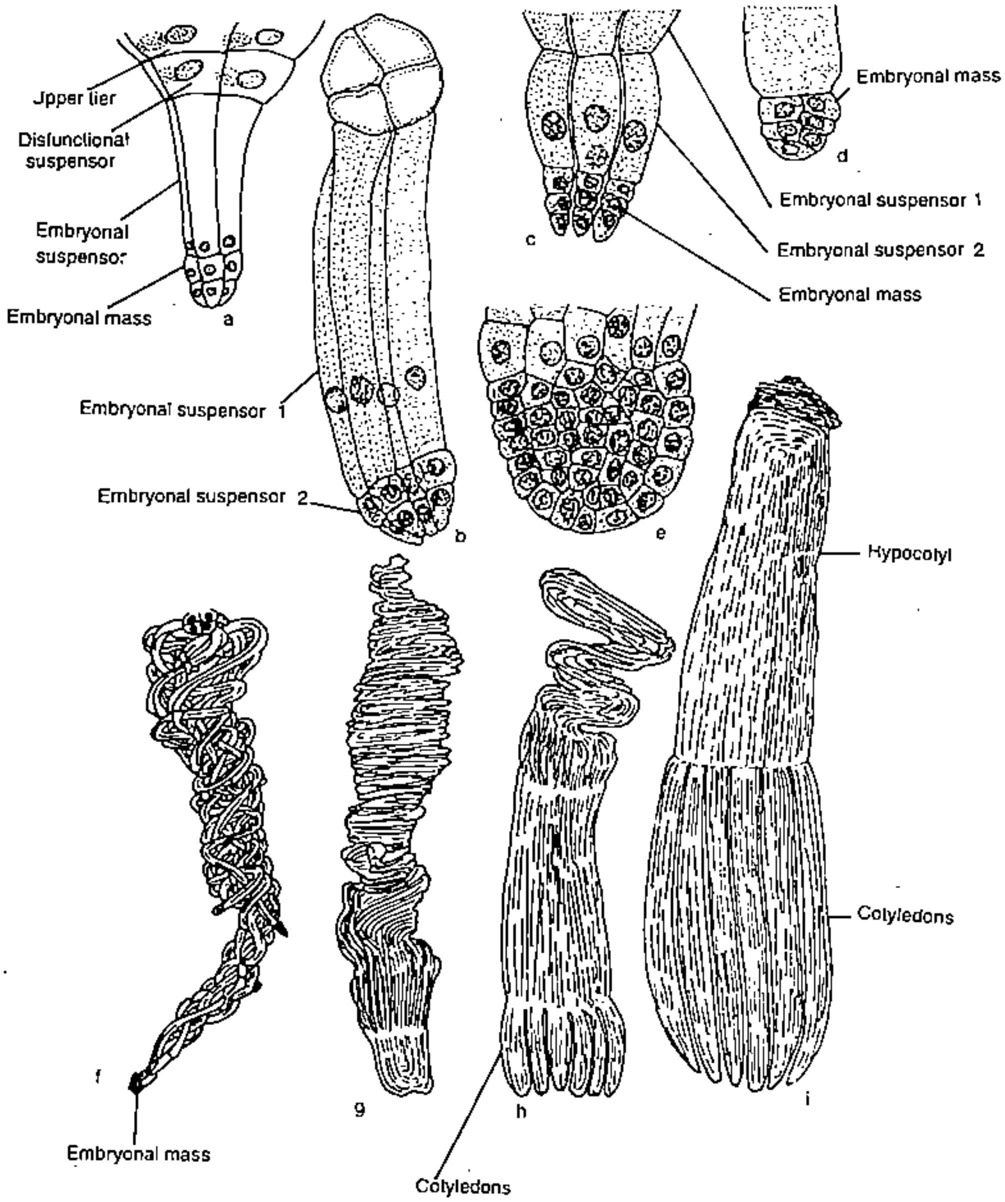


Fig. 3.16 : A. *Pinus* sp.; Progressive stages in the development of embryo. a) Diagrammatic representation of proembryo showing first crop of embryonal suspensor (Es_1). The suspensor tier of proembryo does not elongate and is disfunctional. Embryonal cells have undergone transverse division. b) The cells of the embryonal group have given rise to two crops of embryonal suspensor; note the great elongation of (Es_1). Disfunctional suspensor is seen above this tier. c-e) Further divisions in embryonal mass (e). f) Whole mount to show extremely coiled suspensor system and few proembryos at different levels. g, h) Whole mounts to show greater activity in embryonal mass (e); cotyledons have differentiated in h.i. Mature embryo showing polycotyledonous condition, a) after Buchholz, 1929; b-i) after Maheshwari & Konar 1970.

Seed Coat

In a young ovule the integument comprises three layers. As ovule matures the integumentary cells divide and become differentiated into three zones; outer fleshy, middle stony and inner fleshy (Fig. 3.17).

The seeds of almost all pines have well developed wings, however, some species possess rudimentary wings or are wingless.

The seed coat may be hard or papery, but it is permeable to water. The pine seeds are normally dispersed by wind to long distances. Cones may also roll down and help in establishing plants at lower elevations.

Seed crops are known in *Pinus.* These are not annual but occur at intervals of two or even more years. As the trees grow old, the seed-bearing capacity declines but does not stop entirely. Pines keep on producing seeds till their death.

A tree of *P. aristata* growing in Inyo National Park of California, USA, is more than 4,600 years old and occasionally produces cones.

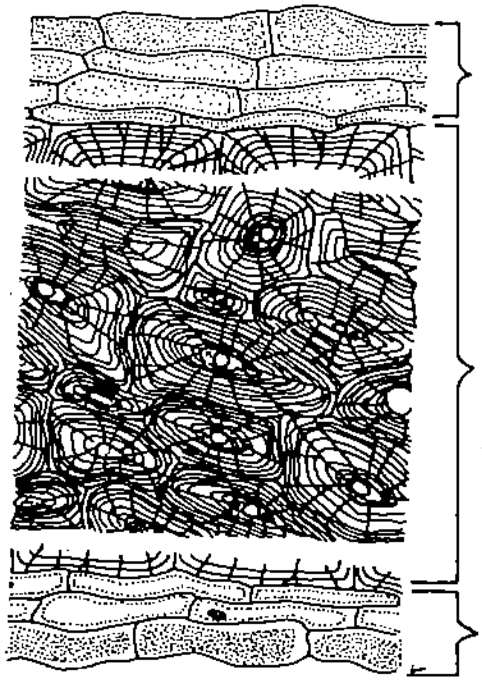


Fig. 3.17 : T.S. seed coat of *Pinus roxburghii* (After Konar, 1960).

Seed Viability and Germination

In *Pinus* where female cones remain closed at maturity the seeds remain viable for a long time. The germination of seed is epigeal (Fig. 13.18 a-h). The seeds germinate within 3-4 weeks after sowing. The radicle emerges and penetrates the soil. The hypocotyl elongates, straightens and carries the remnants of seed alongwith the cotyledons, thus pushing them above the ground. The cotyledons absorb nutrients from the endosperm and provide it to the seedling. The cotyledons are shed only after the juvenile leaves appear and long shoot has grown.

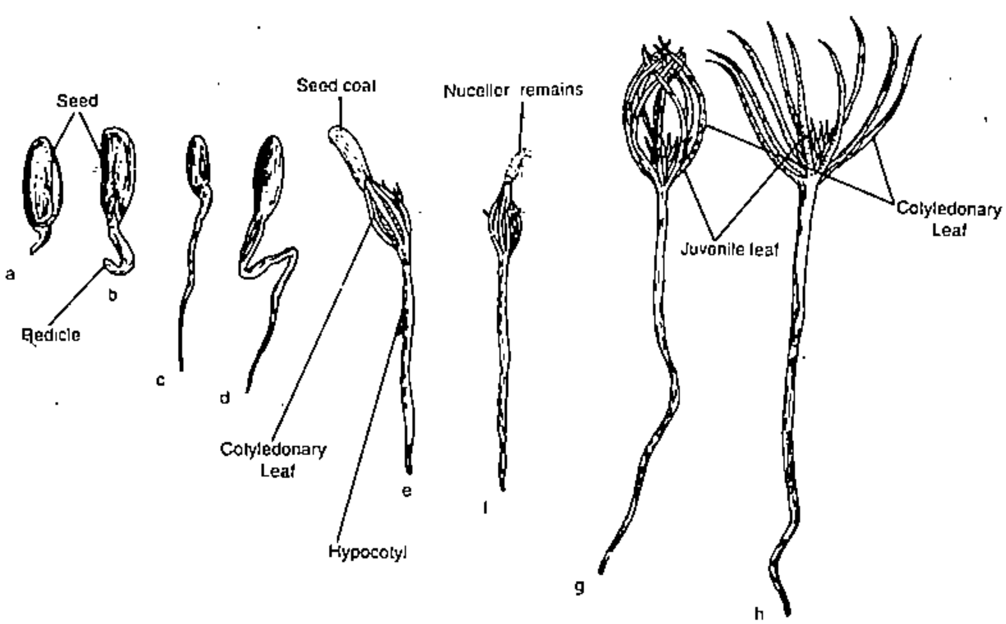


Fig. 3.18 : *Pinus gerardiana.* a-g) Stages in the germination of seed. h) Seedling with cotyledonary and juvenile leaves.

Life Cycle

The reproductive cycle in tropical and temperate pines is influenced by the environmental factors. The altitude at which the trees grow is also important. In trees growing at lower altitudes (e.g. *Pinus roxburghii*) male cones are initiated in September, and pollination occurs the following March. After germination the pollen tube undergoes rest for about 10 months (May to February-2nd year). Growth resumes in March followed by fertilization in April.

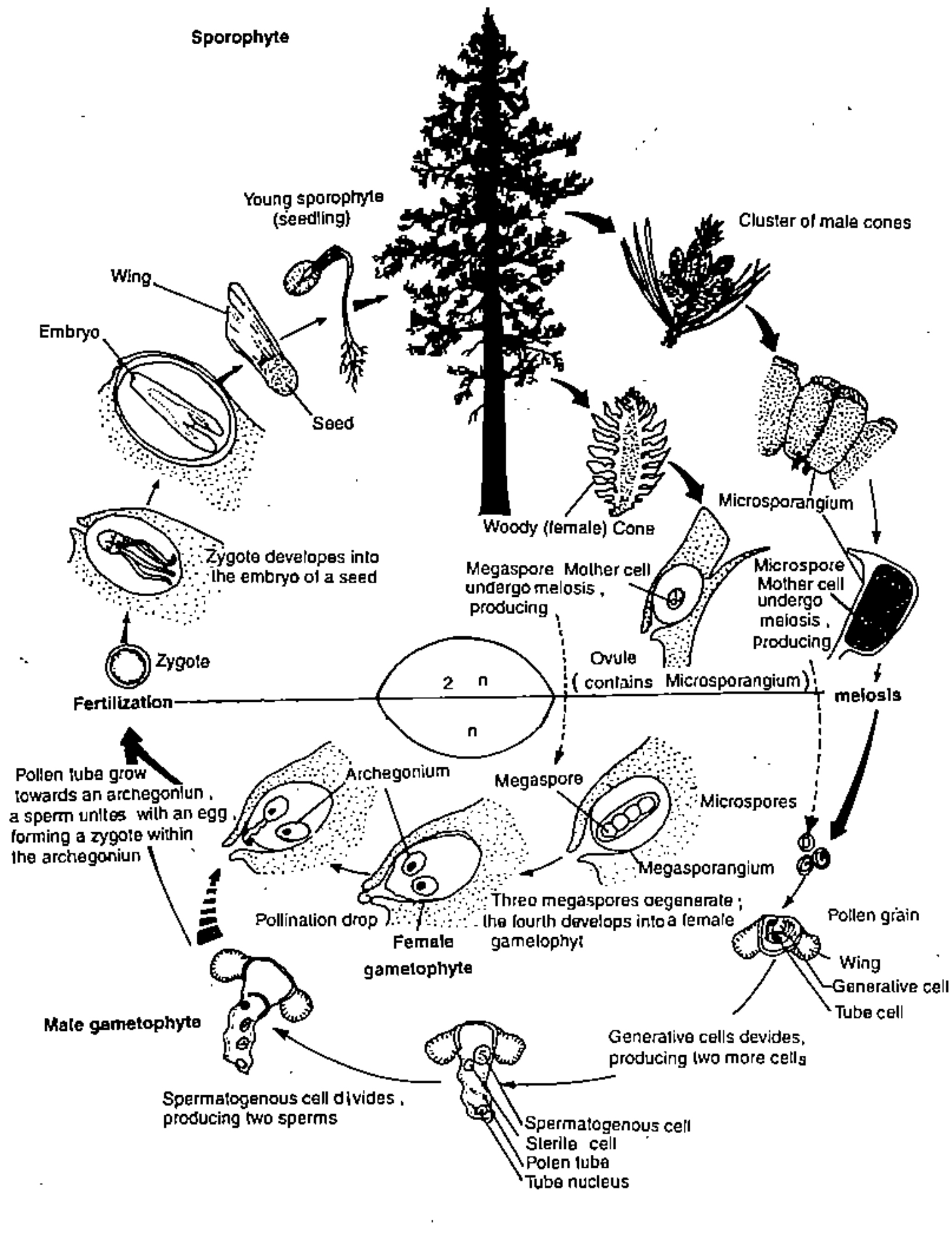
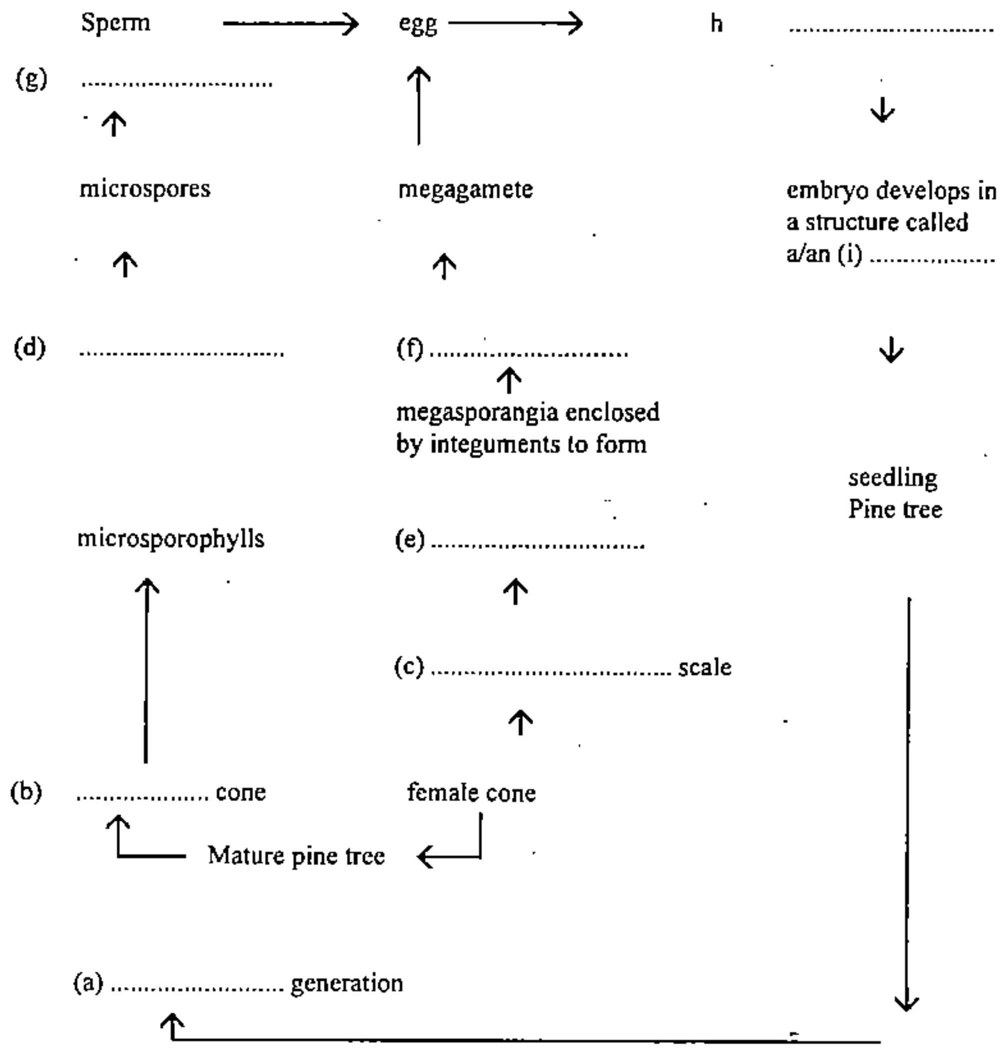


Fig. 3.19 : Diagrammatic representation of Life-Cycle of *Pinus*.

The female cones are initiated in February, pollinated in March and then undergo rest from April to January for 10 months. At the time of pollination the ovule contains a free-nuclear gametophyte. During the 2nd year when growth resumes in February, the gametophyte becomes cellular and the archegonia are formed. Fertilization take place in April and followed by embryo development and seed maturity. The cones dehisce and shed their seeds in April-May (3rd year).

SAQ 6

Summarize the life cycle of a pine, study the diagram below and fill in the names of the missing structures.



3.7 SUMMARY

- Coniferales are a large group consisting of 7 families. The genus *Pinus* is one of the most well known representative of the family. Seven species of *Pinus* are known from Indian sub-continent. *Pinus* is a beautiful tree with a pyramidal appearance. *Pinus* exhibits two types of roots: normal and mycorrhizal. The stem is erect and woody. Two types of branches (i) long shoots and (ii) dwarf shoots are found. The foliage leaves are needle-like and borne on dwarf shoots.

- The tree is monoecious, but male and female cones are borne on separate branches. The male cone occurs in clusters and the number varies from 15-140. The female cones replace the long shoots and 2-6 are borne on each node. 80-90 megasporophyls are spirally arranged along the central axis. The ovuliferous scales and the bract together form a seed-scale-complex.

- Mycorrhiza is found in several conifers. In *Pinus* there is well developed ectotrophic mycorrhizal association with 50 different species of fungi. The pine-fungal relationship is symbiotic. Secondary growth occurs both in root and shoot. The wood consists mainly of tracheids.

- The *Pinus* leaf may be round, semicircular triangular in transverse section. The leaves show xerophytic characters.

- Microsporogenesis occur in the microsporangium and winged pollen grains are formed. In the ovule (megasporangium) megasporogenesis occurs and haploid female megagametophyte is formed. The archegonium is situated at the apical portion of the gametophyte.
- In *Pinus* pollination is through wind and after fertilization zygote is formed. The embryo develops with a distinct epicotyl, root axis and a hypocotyl shoot axis with remnants of suspensor. The seeds of almost all pines have well developed wings; however, some species are wingless. The seedcoat comprises three layers. The seed germinates within 3-4 weeks after sowing. The reproductive cycle in *Pinus* is completed in three years.

3.8 TERMINAL QUESTIONS

1. Differentiate between long shoots and dwarf shoots.

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2. Describe male and female cones of *Pinus* with diagrams.

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3. What is mycorrhiza? Describe in detail who is benefitted in this relationship.

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4. Describe anatomical structure of stem.

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5. Describe microsporangium, microsporogenesis and male gametophyte in detail.

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....

6. How do pollination and fertilization take place in *Pinus* ?

....

....

....

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....

7. Depict the life cycle of *Pinus* through diagrams.

3.9 ANSWERS

Self-assessment Questions

1) 1. F
   2. T
   3. F
   4. T

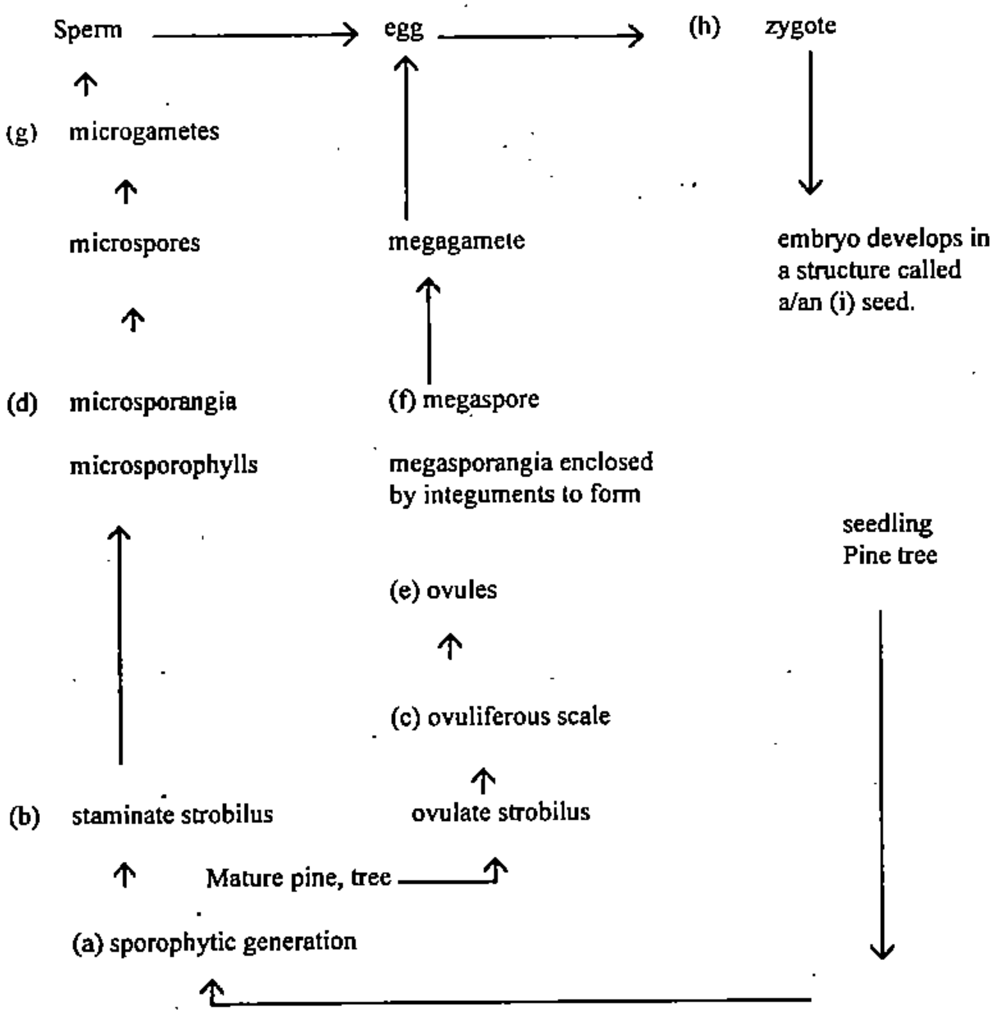
2) 1 starch
   2 sieve cell
   3 ectotrophic
   4 symbiotic
   5 open, collateral
   6 sieve plate
   7 vessels
   8 triangular
   9 angle
   10 sunken

3) 1 F
   2 T
   3 T

4) a 72
   b 36
   c 36
   d 72
   e 36
   f 72
   g 36
   h 72
   i 72

5) a four megaspores
   b seed
   c microgametophyte
   d seedling, sporophyte eventually mature in sporophyte
   e seed coats
   f megagametophyte
   g embryo
   h woody scales of mature ovulate pine cones.
   i wing like projection on pine seeds.

6)



Terminal Questions

1. See section 3.3 Morphology.
2. See section 3.3 Morphology and draw figures.
3. See section 3.4.2 and Fig. 3. Point for reference.
   i) ectotrophic mycorrhizal association
   ii) Over 50 species of Basidiomyectes
   iii) Hartig's net
   iv) relationship is symbiotic
4. See section 3.3, ...subsection 3.4.3 stem.
5. Refer to section 3.4 .... subsection 3.4.2; 3.4.3; 3.4.4.
6. Refer to section 3.5 .... Pollination.
7. Refer to Figure 3.19.

UNIT 4 GNETOPSIDA : *EPHEDRA* AND *GNETUM*

Structure

Introduction

Sub Unit 4A *Ephedra*

Sub Unit 4B *Gnetum*

You have already become familiar with the classification of gymnosperms (see Unit 1). The three families Ephedraceae, Gnetaceae and Welwitschiaceae, each represented by a single genus *Ephedra, Gnetum* and *Welwitschia,* respectively, have often been clubbed under the order Gnetales or the class Gnetopsida. There are certain features that are common to all the three genera, viz., i) secondary xylem contains vessels; ii) plants are usually dioecious; iii) male strobili are surrounded by bracts and hence these are called 'flowers'; and iv) ovules are also surrounded by envelopes that are often interpreted as perianth. Gnetopsida have more than one envelope in contrast to other gymnosperms that have only one integument. In spite of the common features, there have been changes in the taxonomic treatment of these three genera. However, detailed investigations have revealed significant differences in their morphology and reproduction. At present they are classified under different orders (also see Unit 1).

The three genera are highly specialised in reference to both vegetative and reproductive structures. *Gnetum* has many features which have resemblance to angiosperms. These angiospermic features make *Gnetum* an important genus especially from taxonomic viewpoint. We would like you to get acquainted with the plant *Gnetum* in detail as it is the only genus representing Gnetaceae. You will learn about this genus in the Sub Unit 4B. Before this you will study *Ephedra* in Sub Unit 4A. *Ephedra* is both important and interesting because this genus is strikingly different in appearance from other gymnosperms and is the source of the alkaloid ephedrine. About the third genus *Welwitschia* a mention has been made about it in Unit 1.

SUB UNIT 4A *EPHEDRA*

Structure

4A.1 Introduction
Objectives

4A.2 Distribution, Habitat and General Features

4A.3 Vegetative Structures
4A.3.1 Root
4A.3.2 Stem
4A.3.3 Leaf

4A.4 Reproductive Structures
4A.4.1 Male Strobilus and Gametophyte
4A.4.2 Female Strobilus and Gametophyte

4A.5 Pollination and Fertilization
4A.5.1 Pollination
4A.5.2 Fertilization

4A.6 Embryogeny

4A.7 Summary

4A.8 Terminal Questions

4A.9 Answers

4A.1 INTRODUCTION

Like Gnetaceae and Welwitschiaceae, the family Ephedraceae (Order Ephedrales) is also monotypic with only one genus – *Ephedra* which comprises 40 species. *Ephedra* is a small, much branched, erect, procumbent or occasionally a climbing shrub. It is distributed chiefly in the arid regions of the world. A widely used alkaloid ephedrine is extracted from some of its species. In this unit you will study the structural, reproductive and developmental aspects of this interesting genus.

Objectives

After studying this unit you should be able to:

- identify the *Ephedra* plant on the basis of its gross morphological and anatomical characters,
- describe the salient features of its vegetative and reproductive structures, and
- describe and illustrate the life cycle of *Ephedra.*

4A.2 DISTRIBUTION, HABITAT AND GENERAL FEATURES

The genus *Ephedra* has about 40 species that are distributed in the arid regions of New and Old Worlds from the Mediterranean and Black sea shores up to China including northern and north-eastern India. The Old World (France, Canary Islands, around the Mediterranean east to Iran, India and China) accounts for about 18 species whereas roughly 22 species are confined to the New World (North and South America).

The plants exhibit extreme xerophytic characters and are mostly shrubby, generally having a height of less than 2m. However, some species are lianas, others spread by underground rhizomes and one species, *E. triandra* is a small tree whose stem has a diameter of about 30cm. *Ephedra compacta,* as its name suggests is compact, profusely branching plant reaching a height of 30-50 cm. Another variation is exhibited by *E. campylopoda* which has pendulous branches. Five species of *Ephedra* found in India are indicated in Table 4A.1.

Table 4A.1: The species of *Ephedra* found in India (Source: Mehra, P.N. 1988).

S. No.	Species	Place of occurrence
1.	*E. foliata*	Drier tracts of the plains of Haryana, Rajasthan and Punjab.
2.	*E. intermedia*	Drier regions of temperate and alpine Himalayas especially in the crevices of rocks as perennial herbs.
3.	*E. gerardiana*	
4.	*E. saxatilis*	
5.	*E. likiagensis*	Central Himalayas.

On a casual look, one may mistake a plant of *Ephedra* (Fig. 4A.1) for *Equisetum,* as its internodes are longitudinally ridged, and also the ridges at successive internodes alternate. Similarly, the leaves on successive internodes also alternate. As in *Pinus,* there are two types of branches – **indeterminate** and **determinate** but the distinction is not as well marked as in *Pinus.* The indeterminate branches at each node have leaves in whorls of threes and sometimes in fours. The determinate branches are borne in the axil of some of the leaves of indeterminate branches, and these bear opposite and decussate leaves.

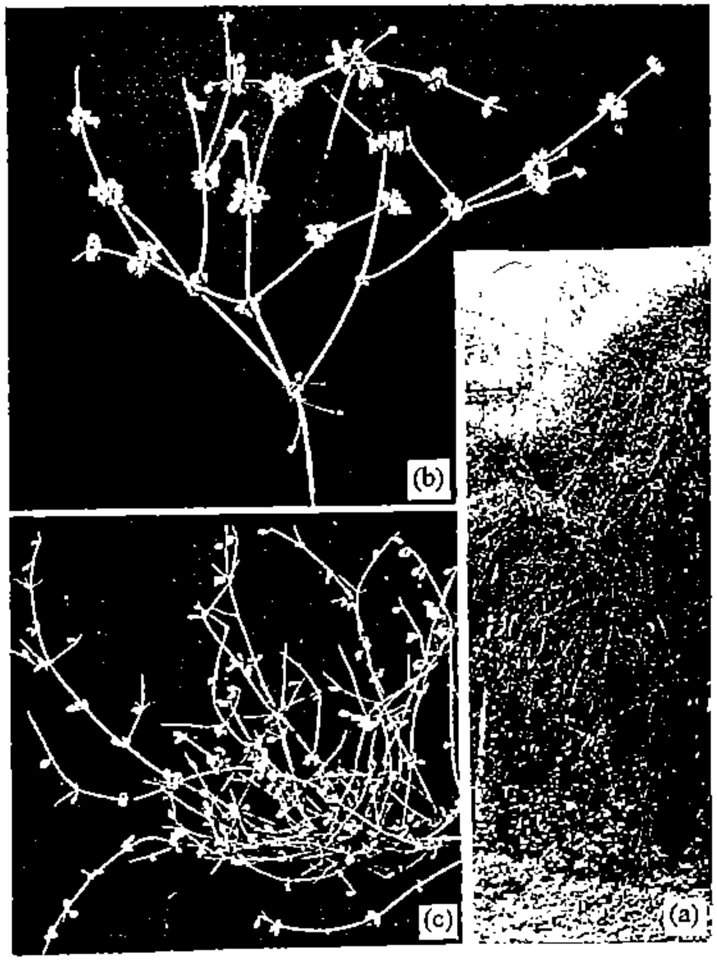


Fig. 4A.1 : *Ephedra foliata:* a) A part of the plant, note its bushy nature. b and c) Twigs bearing male and female strobili, respectively (Courtesy: Singh, M.N.).

4A.3 VEGETATIVE STRUCTURES

You will study the salient morphological and anatomical features of the vegetative structures namely root, stem and leaves in this section. You are advised to spend sufficient time in observing the detailed structures indicated in the diagrams.

4A.3.1 Root

The root of *Ephedra* shows a typical root structure in morphology as well as anatomy. The outermost layer is epidermis, which is followed by a well developed cortex. The cortex is differentiated into a compact outer region made up of thick-walled cells and an inner region composed of loosely-arranged thin-walled cells. Mucilaginous canals are distributed in the cortex. The cortex is limited by a single layer of thick-walled endodermis followed by a single-layered parenchymatous pericycle. There is a small diarch stele with exarch protoxylem elements. The pith is small but prominent. The roots undergo secondary growth in the usual manner.

4A.3.2 Stem

As mentioned earlier, the longitudinal ridges on the stem impart it a wavy outline. In a transverse section it shows the presence of ridges and furrows (Fig. 4A.2a). The epidermis has a thick cuticle which is interrupted in the furrows where stomata are present. The stomata are sunken, and each consists of two guard cells with a prominent substomatal cavity (see Fig. 4A.2b). The hypodermis is present only below the ridges and is composed of elongated sclerenchyma which provide mechanical strength to the stem. The cortex is differentiated into an outer single layer of compactly arranged, elongated palisade cells containing abundant chlorophyll and are thus capable of photosynthesis. The inner zone is made up of loosely-arranged cells containing fewer chloroplasts. The cortex is delimited by a single-layered endodermis. Vascular bundles are open and endarch. The centre of the pith consists of thick-walled tanniniferous cells. Xylem consists of tracheids, vessels and xylem parenchyma. The tracheids exhibit annular and spiral thickenings and bordered pits, whereas the vessels have only bordered pits. The phloem consists of sieve cells, phloem parenchyma and albuminous cells.

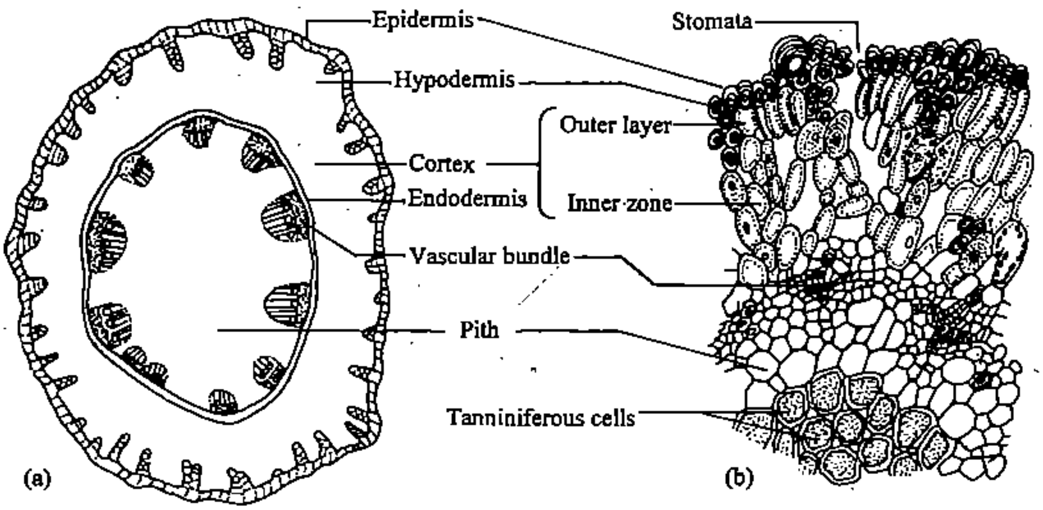


Fig. 4A.2: a) *Ephedra foliata.* Outline diagram of a young stem cut transversely. Note the wavy outline, regions of thick-walled cells under the ridges, wide cortex, pith and endarch vascular bundles. b) *Ephedra trifurca.* A part of stem in transverse section to show the cellular details. Mark the thick-walled cells below the ridges, stomata in furrows, outer and inner cortex, vascular bundles and thick-walled tanniniferous cells in the pith. a, Modified from Bhatnagar & Moitra, 1996: b, after Chamberlain, 1935).

The internodes of the stem of *Ephedra* are quite elongated. This is due to the activity of an intercalary meristem or meristematic plate which is present just above each node (see Fig. 4A.3a, b). After the active phase, the intercalary meristem either forms an abscission layer or matures into a band of sclerified parenchyma. The intercalary meristem is also known as the nodal diaphragm. This diaphragm at the base of each internode makes the stem easily separable at the nodes.

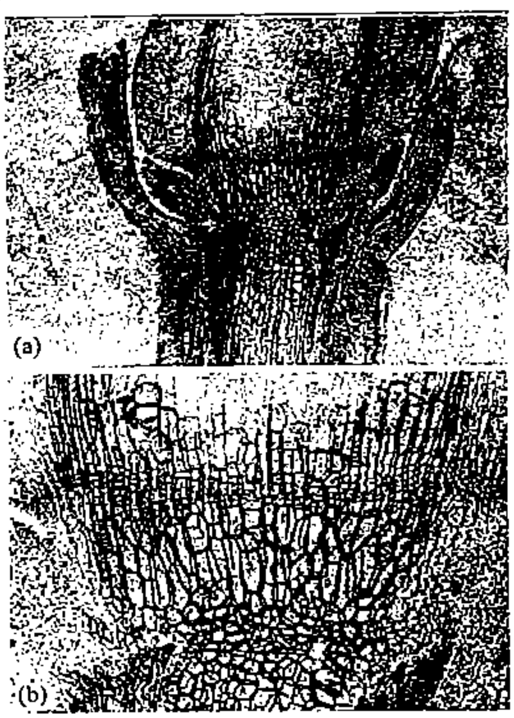


Fig. 4A.3 : *Ephedra foliata.* a) A part of stem at the nodal region in longitudinal section showing the meristematic plate. b) The intercalary region magnified. (from Bhatnagar & Moitra, 1996).

The stem undergoes secondary growth in the usual manner. The beginning of secondary growth is marked by the differentiation of interfascicular cambium. This joins with the intrafascicular cambium to form a ring. The cambial ring cuts off secondary xylem towards inner side and secondary phloem towards outer side. You may recall that the cambial cells are of two types: ray initials and fusiform initials. The former, as their name suggests, cut off xylem and phloem rays, whereas the latter give rise to vascular elements. The annual growth rings are visible with each year's secondary growth (Fig. 4A.4a, b). In a young stem the medullary rays are uniseriate, but in mature stems they become multiseriate (Fig. 4A.4d) by longitudinal division of the ray cells or by fusion of uniseriate rays. The tracheids show bordered pits (Fig. 4A.4c). Vessels are the most prominent feature of the stem (Fig. 4A.4a-c). The secondary phloem consists of sieve cells, phloem parenchyma, albuminous cells and rays. The albuminous cells which are found in the axial system, are cut off by fusiform initials.

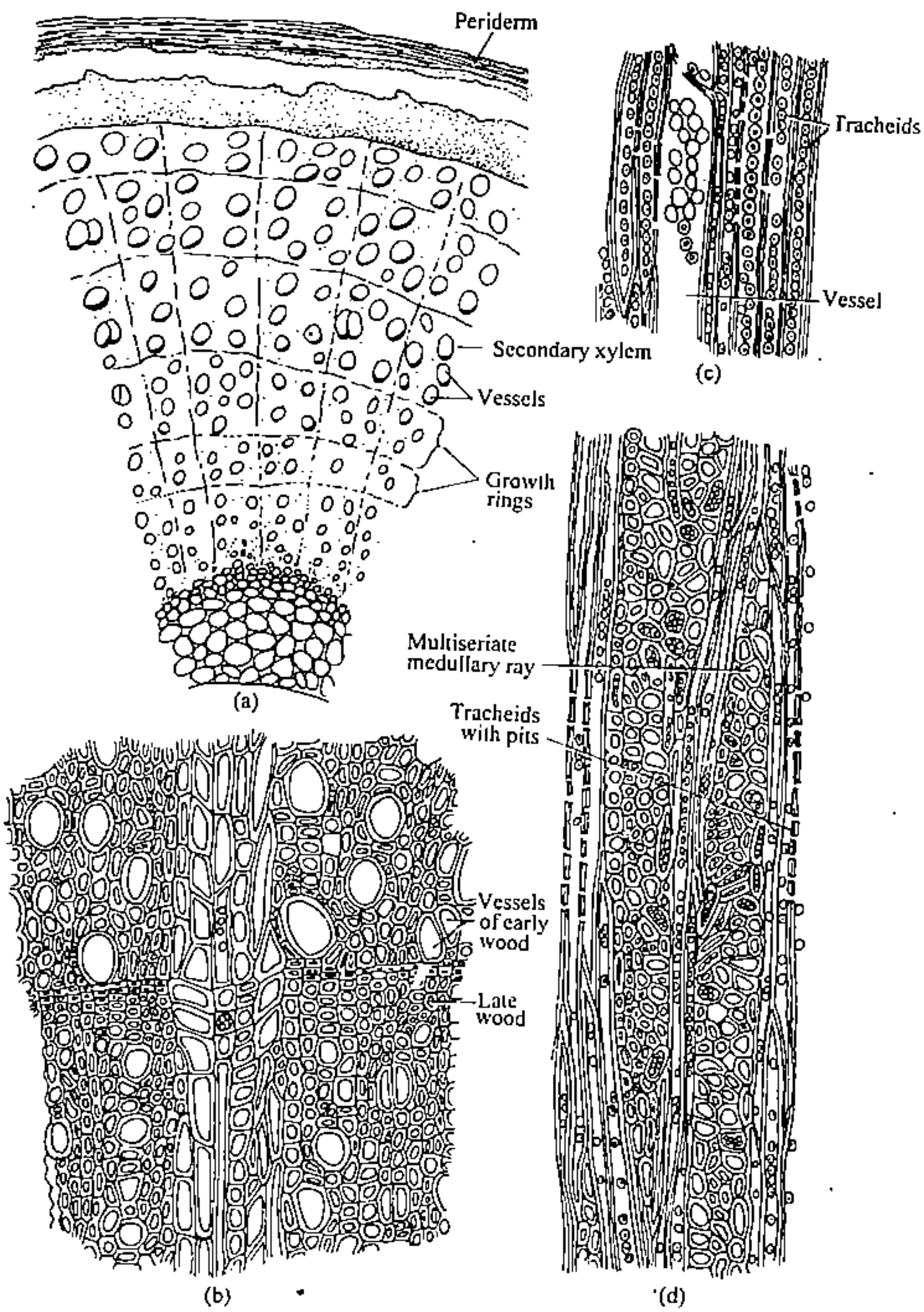


Fig. 4A.4: *Ephedra* spp. a) A part of mature stem in transverse section showing several annual rings. b) Part of figure a, magnified to show early and late wood elements. Note the early wood has large vessels whereas the late wood is composed of mainly tracheids. c) A part of stem cut in radial longitudinal section (RLS) showing a large vessel and many tracheids. d) A portion of stem cut in tangential longitudinal section (TLS) showing two wide multiseriate medullary rays and many tracheids. (a, redrawn from Bhatnagar & Moitra, 1996; b-d, after Chamberlain, 1935).

The leaves are connate and are fused into a basal sheath. They are small, scaly and thin. They are green when young but turn brown at maturity and are eventually shed. Accessory buds arise below and at the base of axillary shoots. Since the leaves are scaly and reduced, the carbon assimilation is done through stem which is green (see Subsection 4A.3.2). In a transverse section the leaves exhibit an oval outline. The epidermis bears a thick cuticle. A few deeply situated or sunken stomata interrupt the epidermis. The epidermis is followed by two or three layers of palisade cells containing chloroplasts. The remaining space is filled by spongy cells, which are devoid of chloroplasts. Two small vascular traces are embedded in the spongy parenchyma.

SAQ 1

Mention three key features that you would look for while identifying a plant of *Ephedra*.

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SAQ 2

Which of the following are not true for the roots of *Ephedra?* Select your answer from the codes given below.

a) It has a wavy outline due to the presence of longitudinal ridges.

b) Epidermis constitutes the outermost layer.

c) Cortex is poorly developed.

d) Mucilaginous canals span the cortex.

e) The endodermis and pericycle form the covering of the stele.

f) The stele is diarch with exarch protoxylem.

g) Secondary growth does not occur.

h) A prominent pith is present.

Codes

1) b, d, g

2) b, e, h

3) a, c, g

4) e, f, h

SAQ 3

a) This question is based on the stem structure of *Ephedra.* Match items of column I with those of column II.

I	II
1) Epidermis	i) Two zones
2) Stomata	ii) tannin-filled cells
3) Hypodermis	iii) Open, endarch
4) Cortex	iv) sieve cells, parenchyma and albuminous cells
5) Endodermis	v) thick cuticled
6) Vascular bundles	vi) deeply sunken

7) Xylem — vii) sclerenchyma below the ridges

8) Phloem — viii) one-layered

9) Pith — ix) tracheids, vessels and parenchyma

b) Which anatomical speciality is responsible for the long internodes of *Ephedra?* Discuss

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SAQ 4

You are given the following four features of the leaf structure. What would you deduce about the nature of the plant? Give reasons. The four features are: membranous leaves, cuticle-coated epidermal cells, sunken stomata, palisade cells packed with chloroplasts.

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4A.4 REPRODUCTIVE STRUCTURES

Ephedra is typically dioecious. The male and female strobili are borne in the axils of leaves of determinate shoots and also in whorls on the nodes of older branches (Figs 4A.1, 4A.5). They may be solitary but mostly arranged in dichasial cymes.

4A.4.1 Male Strobilus and Gametophyte

Male Strobilus – It consists of a central axis and a few (10 in *E. foliata*), opposite and decussately arranged bracts (Fig. 4A.5a) the lowest of which is sterile. In the axil of each fertile bract there arises a fertile shoot or a microsporangiate 'flower'. Each 'flower' consists of a pair of basally fused perianth leaves and a sporangiophore, which bears 2 to 6 bilobed, sessile, microsporangia at its tip (Fig. 4A.5b).

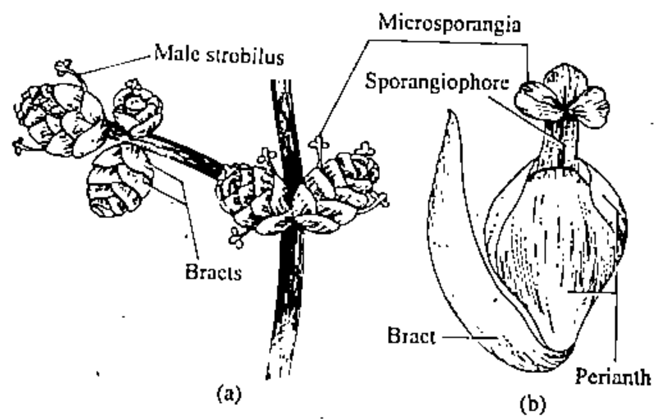

Fig. 4A.5: *Ephedra foliata.* **a) A part of twig with a cluster of male strobili. b) A male fertile shoot with three bilocular microsporangia at the tip. (After Tiagi, 1966).**

Microsporogenesis – A group of archesporial cells gets differentiated in the hypodermal region of the young sporangium (Fig. 4A.6a, b). Subsequently, differentiation of a band of sterile cells divides sporogenous cells into two chambers (Fig. 4A.6c). Even in the surface view the sporangium appears lobed. A primary parietal layer and a primary sporogenous layer are cut off by the periclinal division in the outermost layer of the archesporial cells. The former undergoes both anti- and peri-clinal divisions giving rise to wall layers, the innermost of which differentiates into tapetum (Fig. 4A.6d). The primary sporogenous cells, in turn, give rise to sporogenous tissue, whose cells eventually become the microspore mother cells (Fig. 4A.6d). The microspore mother cells undergo meiosis to give rise to tetrads of microspores embedded in a massive layer of callose. The microspores are set free after the dissolution of callose.

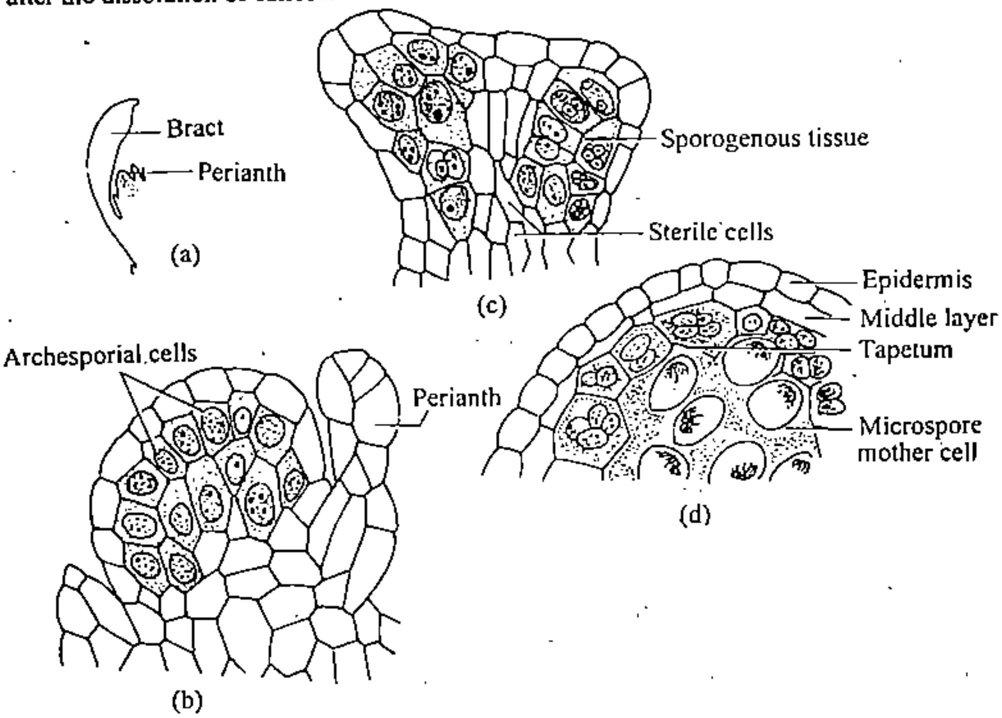

Fig. 4A.6: *Ephedra* sp. microsporogenesis, a) L.S. young male flower with subtending bract. Note the perianth and the initiating sporangium. b) Same, at an older stage showing perianth and hypodermal archesporial cells. c) Still later stage depicting the development of a band of sterile cells. Also seen are two groups of sporogenous cells. d) A sector of sporangium showing microspore mother cells undergoing meiosis and multinucleate tapetal cells (after Singh & Maheshwari, 1962).

Development of Male Gametophyte – The microspore nucleus moves to one end (Fig. 4A.7a) and divides to form two cells: a small, ephemeral, lens-shaped prothallial cell (designated as first prothallial cell) and a large central cell (Fig. 4A.7b). The central cell divides again in the same manner, forming a second prothallial cell and the large antheridial

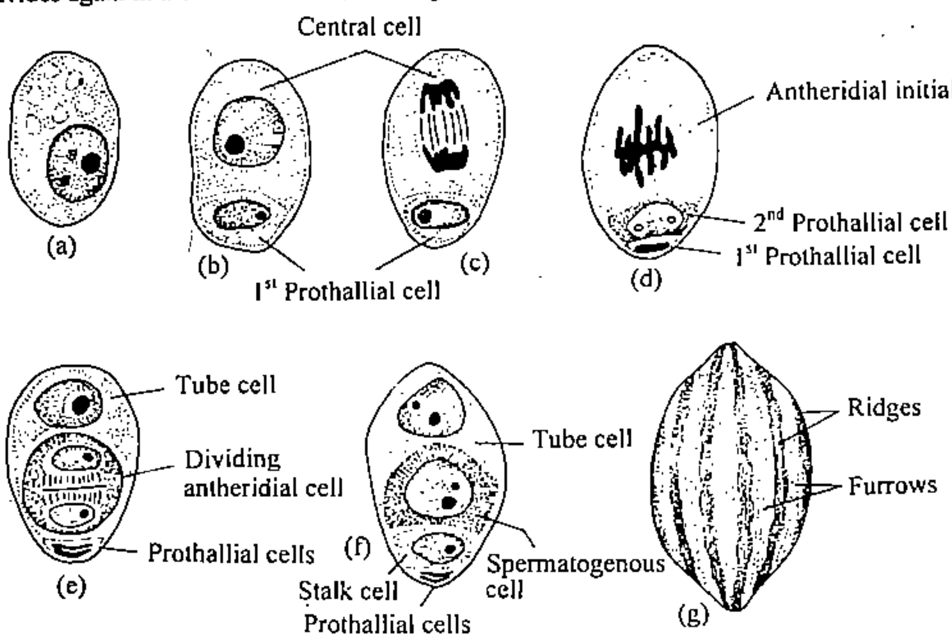

Fig. 4A.7: (a-g): *Ephedra* sp., developmental stages of male gametophyte. a) A microspore, b-e) Stages in the development of male gametophyte. f) A five-nucleate pollen grain. g) The surface view of a mature pollen grain showing ridges and furrows. (after Singh & Maheshwari, 1962).

initial (Fig. 4A. 7c, d). The antheridial initial undergoes division giving rise to a tube cell and an antheridial cell. The antheridial cell on division forms the spermatogenous cell and stalk cell (Fig. 4A.7e.f). The shedding of pollen thus takes place at 5-celled stage, having two prothallial cells, one tube cell, a stalk cell and a spermatogenous cell. The pollen wall is laid down concurrent to the release of microspores from the tetrads. It consists of two layers — an outer exine and an inner intine. The exine is coated with sporopollenin, that is autofluorescent, and is resistant to acetolysis. The intine is cellulosic in nature. The exine is ribbed, i.e., it consists of ridges and furrows (Fig. 4A.7g). About 16 such ridges run longitudinally in *E. foliata* whereas in *E. gerardiana* only eleven such ridges are present.

4A.4.2 Female Strobilus and Gametophyte

Female Strobilus – A female strobilus consists of four to seven pairs of opposite and decussate, green bracts, fused at the base forming a cup-like structure. In the axil of each of the uppermost pair of bracts there is an ovule (Fig. 4A.8a, b; 4A.9a). Each ovule consists of two envelopes. The inner envelope, which is the only integument, is thin and fused with the nucellus except in the upper region and protrudes to form a long micropylar tube (Fig. 4A.8b). The outer envelope also known as perianth, is thicker and completely free from the integument.

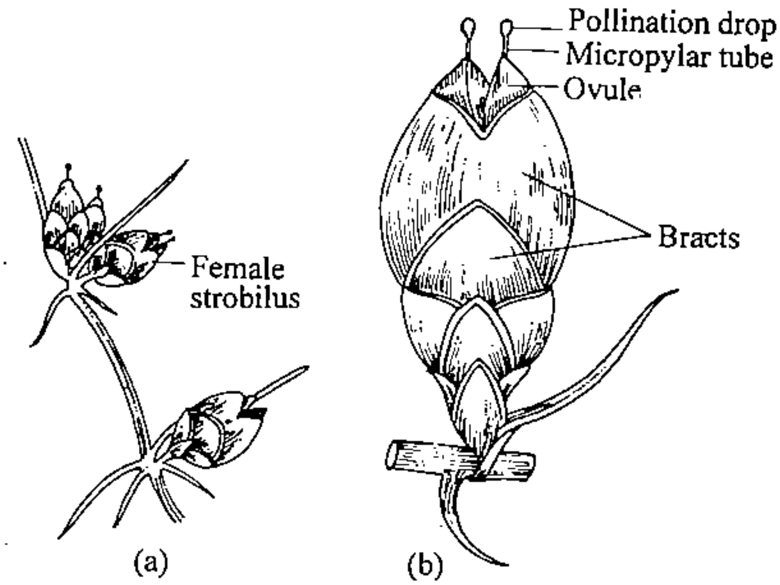

Fig. 4A.8 : ***Ephedra foliata.*** **a) A part of the twig bearing female strobili. b) A female strobilus in an enlarged view. It consists of two large ovules and six pairs of bracts. Each ovule shows a micropylar tube with a distinct pollination drop (after Tiagi, 1966).**

The apical meristem transforms into an ovule. The initiation of ovule is marked by periclinal divisions in the outermost layer of the lateral shoot meristem. The outer envelope (perianth) is formed by anticlinal and periclinal divisions in the epidermis. Immediately above the outer envelope, the integument arises as a protuberance. After initiation the integument becomes annular, but later shows one-sided growth or becomes asymmetric on the dorsal side. The integument remains asymmetric throughout and this is also reflected in the micropyle. Both the envelopes are inserted at almost the same level in a young ovule. Later, however, the integument, is seen at a much higher level than the outer envelope. This is probably because of the growth in the region below the nucellus and integument. The outer envelope grows by an independent meristem.

In most species, a massive nucellus arises as a result of periclinal divisions in the epidermis forming a nucellar cap; a parietal tissue is thus absent. However, in some species the nucellus is of dual origin having been contributed by the nucellar epidermis and parietal tissue.

Megasporogenesis – A single hypodermal archesporial cell differentiates, and then divides periclinally to produce a primary parietal cell and a sporogenous cell. The primary parietal cell gives rise to several layers of parietal cells (Fig. 4A.9b). Due to periclinal and anticlinal divisions in the cells of the nucellar epidermis, the megaspore mother cell is pushed deep in the massive nucellus. The megaspore mother cell enlarges and divides meiotically to form a linear tetrad of megaspores, of which the lowermost megaspore is functional and upper

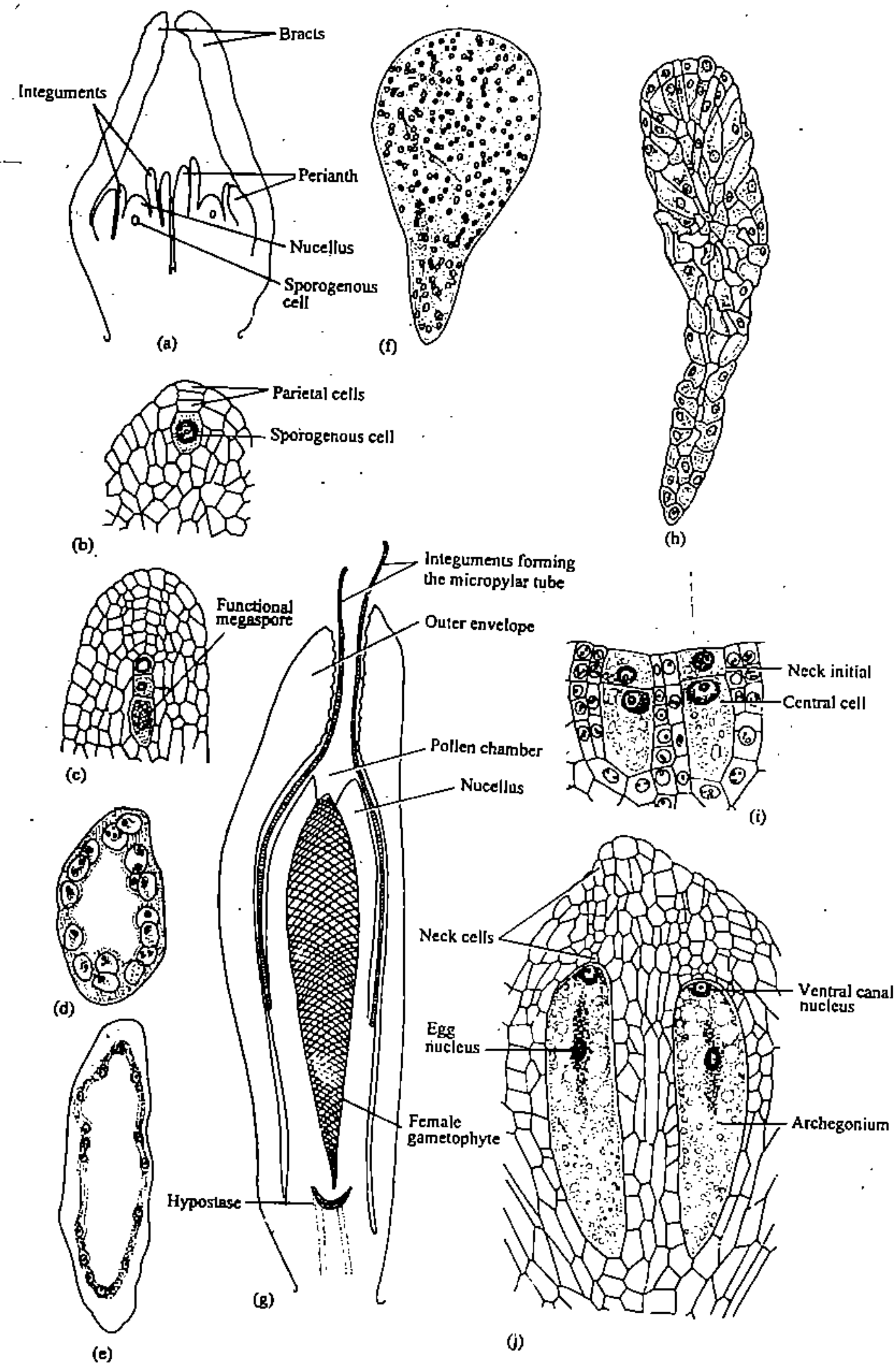

Fig. 4A.9: ***Ephedra*** **spp. a) Longitudinal section of a female cone showing two young ovules and the subtending bracts. b) A part of apical portion of the nucellus showing sporogenous cell and parietal cells. c) Same, with a triad of megaspores. Note, the lowermost cell is the functional megaspore. d, e) A young, free nuclear gametophyte in longitudinal section. f) Whole mount of the top-shaped female gametophyte at free nuclear stage. g) Longitudinal section of ovule at the cellular gametophyte stage; mark the hypostase. The integument forms the micropylar tube. h) Cellular gametophyte formed through alveolation, enlarged from figure g. i) L.S. female gametophyte showing two young archegonia, each with a neck initial and a central cell. j) Same, at a later stage of development. Each archegonium shows an egg nucleus, a ventral canal nucleus and a long neck whose cells merge with the surrounding gametophytic cells. [a, g, j) redrawn from Maheshwari, 1935; b, c, i) redrawn from Narang, 1956; d-f, h) after Singh & Maheshwari, 1962].**

three degenerate. Such a development is termed as monosporic. This is in contrast to tetrasporic development in *Gnetum* and *Welwitschia* where it is tetrasporic. However, sometimes, the upper cell of the dyad fails to divide resulting in a triad of cells (Fig. 4A.9c).

Development of Female Gametophyte – The functional megaspore enlarges considerably and a central vacuole appears in its cytoplasm. Its nucleus divides mitotically to give rise to as many as 256 or 512 free nuclei.The nuclei arrange themselves in a thin layer of cytoplasm around the central vacuole (Fig. 4A.9 d-f). The wall formation takes place through alveolation (see Unit 3). The cellular gametophyte (Fig. 4A.9g) can be demarcated into two zones: a broad micropylar zone of radially elongated, thin-walled, and hyaline cells with little cytoplasm; and a narrow chalazal zone of compact, small and polygonal cells with dense cytoplasm (Fig. 4A.9h). When the gametophytes are mature the chalazal part is distinguishable into an upper region of actively dividing cells and a lower region of large, densely cytoplasmic cells with prominent nuclei. The gametophyte which is conical at this stage has a long tubular process that goes deep into the chalazal region. It depletes the surrounding cells of nutrition, which eventually collapse. The mature gametophyte is thus divisible into three zones: an upper fertile zone that bears archegonia, middle storage zone and a lower haustorial zone.

Let us now talk about the development of the archegonia. Three or four (rarely more) cells at the micropylar end of the female gametophyte become archegonial initials. These are distinguishable from the neighbouring cells by their large nuclei and dense cytoplasm. The archegonial initials divide periclinally to form an outer, small primary neck initial and an inner, large central cell (Fig. 4A.9i). A distinctive feature of the archegonium is the formation of a long column of about 30 - 40 neck cells which generally merge with the surrounding gametophytic cells, so an exact count is difficult (Fig. 4A.9j). The long, columnar neck appears similar to the transmitting tissue in the style of angiosperms. The enlargement of the central cell is followed by division of its nucleus to form a ventral canal nucleus and an egg nucleus (Fig. 4A.9j). The ventral canal nucleus appears to degenerate soon after, but in some species it persists and remains intact near the upper part of the archegonium. The egg nucleus enlarges and comes to lie in the centre of archegonial cytoplasm.

SAQ 5

Given below are twelve terms pertaining to various structures and stages associated with the development of the male gametophyte. Arrange them in the proper order of placement/ development. (**Hint:** Start with male strobilus).

antheridial initial, sporogenous tissue, microsporangiate flower, archesporial cells, primary sporogenous cell, microspore mother cells, male strobilus, antheridial cell, pollen grain, microsporangia, primary parietal cell and microspores.

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SAQ 6

Which of the following statements pertaining to the structures and stages related to female gametophyte development are not true? Write them in the space provided below :

Statements

a) The ovule is formed by the transformation of the intercalary meristem.

b) There is an ovule each in the upper most pair of bracts of the female strobilus.

c) Each ovule has only one envelope.

d) The massive nucellus has a dual origin.

e) In an ovule, a group of archesporial cells form a large number of sporogenous cells.

f) The megaspore mother cell is deep-seated in the massive nucellar tissue.

g) A free-nuclear gametophyte is formed from the functional megaspore.

h) The mature gametophyte bears archegonia near its haustorial zone.

i) An egg nucleus, a ventral canal nucleus and a long neck are the chief components of an archegonium.

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4A.5 POLLINATION AND FERTILIZATION

4A.5.1 Pollination

The pollen grains of *Ephedra* are wingless and are airborne. These are caught in the pollination drop (Fig. 4A.10a) which is present at the micropylar tip and is subsequently sucked in. The pollen grains thus come to lie on the tip of the gametophyte. The pollination drop contains several amino acids, peptides, malic acid, citric acid, inorganic phosphates and sugars. The concentration of sucrose is as high as 25%. Wind-pollination is the common mode of pollen delivery. However, entomophily is prevalent in some species such as *E. aphylla* and *E. campylopoda*. In these species pollination takes place through the agency of ants and other insects that visit the strobili. Nectar, rich in sugars, is the chief attractant in both the male and the female strobili. The insects visiting these strobili feed on the nectar, and aid in the transfer of pollen grains that stick to their bodies to the ovules. The nucellus has a prominent pollen chamber into which the tip of the female gametophyte protrudes. Such a projection is called a 'tent-pole' (Fig. 4A.10b). The pollen chamber is broad and deep, and extends right down to the top of the female gametophyte (Fig. 4A.10b, 4A.11a) which is freely exposed.

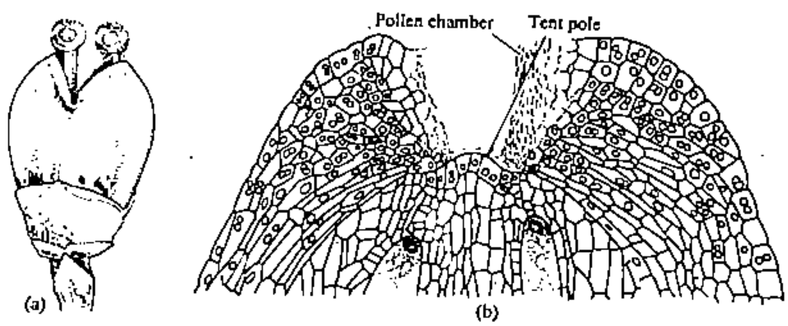

Fig. 4A.10 : *Ephedra* spp. a) A mature female strobilus with ovules showing prominent pollination drops. b) A portion of ovule cut in longitudinal section showing well developed pollen chamber and tent pole. (a, Courtesy Singh, M.N. : b, after Narang, 1956).

The pollen grains swell in the pollination drop resulting in the rupture of exine which is cast off before germination. The tube nucleus is first to move followed by the spermatogenous cell. The latter divides in the pollen tube to give rise to two male nuclei. Interestingly when the pollen grain germinates, the pollen tube enters the archegonium neck which is a gametophytic tissue, unlike in conifers where the pollen tube grows first through the nucellus which is a sporophytic tissue. Then pollen tube makes its entry into the egg cytoplasm and releases the two male gametes.

In post-pollination stages, the cells of the outer envelope show papillate projections which later elongate and become thick-walled (Fig. 4A.11 b). This results in closing the space between the two envelopes. The pressure so exerted on the micropylar tube seals off the micropyle. The cells lining the micropylar tube do not undergo any change.

There is a well-developed hypostase and the lower tapering end of the gametophyte lies very close to it. The cells of the hypostase are small, thin-walled and colourless. Some spiral and pitted tracheids are present below the hypostase (Fig. 4A.11c).

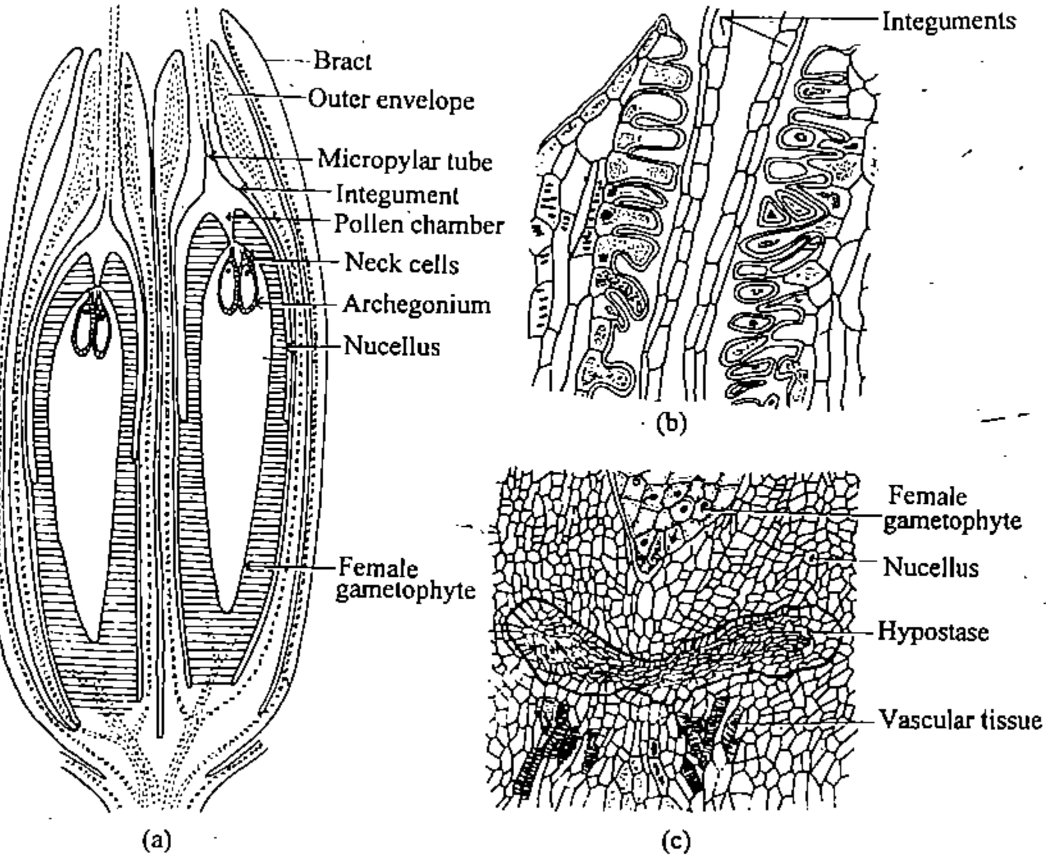

Fig. 4A.11 : *Ephedra* **spp. a) L.S. female cone showing two developed ovules, each showing two envelopes, a pollen chamber, long tapering female gametophyte bearing two archegonia with long prominent necks. b) L.S. micropylar part of ovule showing papillate projections from inner lining of outer envelope. c) A portion of nucellus from chalazal end with hypostase [a, after Narang, 1956; b & c, after Singh & Maheshwari, 1962].**

4A.5.2 Fertilization

The sperm nucleus approaches the egg nucleus and makes contact with it. Their nuclei fuse resulting in the formation of zygote. In *E. nevadensis* there is a regular occurrence of double fertilization. Both the male nuclei are released in the egg cell. One male nucleus moves down to meet the egg nucleus and fuses with it in the dense cytoplasmic zone forming the zygote nucleus designated as 'normal zygote nucleus' (Fig. 4A.12a-d). When the male and the egg nuclei are in an advanced stage of fusion, the ventral canal nucleus also moves down in the egg cell followed by the second male nucleus. Both these nuclei fuse forming the 'supernumerary zygote nucleus' (Fig. 4A.12b-f). This is the second fertilization, first one, being between the egg and the first male nucleus.

Whether the phenomenon of double fertilization in *Ephedra* and angiosperms could be considered homologous evolutionarily is difficult to determine at this stage. It is widely believed that it is a step in that direction. One could hypothesize that double fertilization arose in a common ancestor of both *Ephedra* and angiosperms.

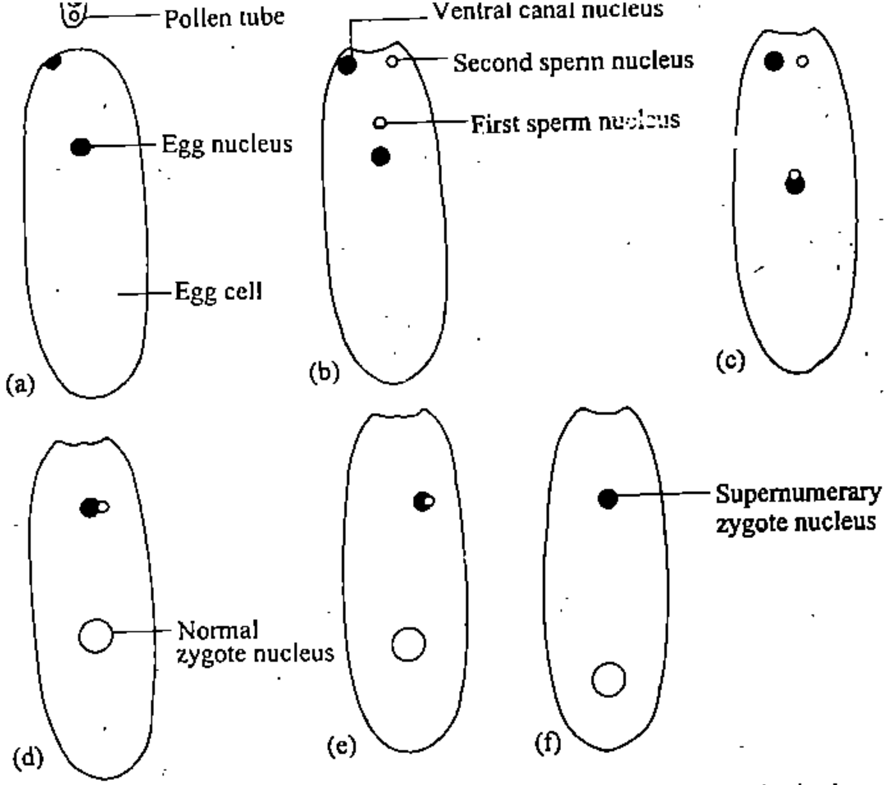

Fig. 4A.12. a-f) : *Ephedra* sp. Schematic diagrams depicting the various stages culminating in double fertilization. a) Diagrammatic representation of a pollen tube with binucleate sperm cell approaching egg cell. b-d) Stages of fertilization of egg nucleus by the first sperm nucleus forming a normal zygote nucleus. d-f) The zygote nucleus eventually migrates to the base of the former egg cell. The stages of fusion of the ventral canal nucleus and the second sperm nucleus are depicted in the figures b-f (see the upper region of the former egg cell). (Redrawn from Friedman, 1990).

4A.6 EMBRYOGENY

Division of the zygote nucleus marks the beginning of embryogeny. The synchronous division of the two zygote nuclei (Fig. 4A.13a) leads to the formation of two sets of daughter nuclei. Those derived from the normal zygote nucleus are situated at the base of the former egg cell and the other pair of nuclei is placed in the apical part of the former egg cell (Fig. 4A.13b). One more mitosis results in a total of eight nuclei typically arranged in two groups within the former egg cytoplasm: the basal four from the 'normal zygote nucleus' and the apical four arising from the 'supernumerary zygote nucleus' (Fig. 4A.13c). Subsequently cell walls are deposited around individual nuclei (Fig. 4A.13d). Thus two sets of four, unicellular, uninucleate proembryo cells or units are formed (Fig. 4A.13d) at both the apical and the basal end of the former egg cell. Each of these eight proembryonal cells or units is a potential embryo. The next step in the development is the appearance of a projection (tubular outgrowth) on one side, in each of the eight units. These projections grow towards the archegonial base. The nucleus in each of the eight units, then leaves the spherical bulb like-portion and comes to lie in the tube. It divides here by a transverse wall into an embryonal cell and a suspensor cell (Figs 4A.13e; and 4A.14a). Morphologically the latter is an embryonal suspensor which pushes the developing embryos deep into the female gametophyte. All the eight proembryos in an archegonium are potentially alike, but those present at the micropylar end gradually degenerate. One of the deep-seated, centrally placed, chalazal embryos finally develops into a mature embryo. The later stages of embryo development are depicted in Fig. 4A.14 b-d. The shoot apex is organized at the tip towards the chalazal end and the cotyledons arise as two small protuberances just below the shoot apex. Root apex differentiates near secondary suspensor cells.

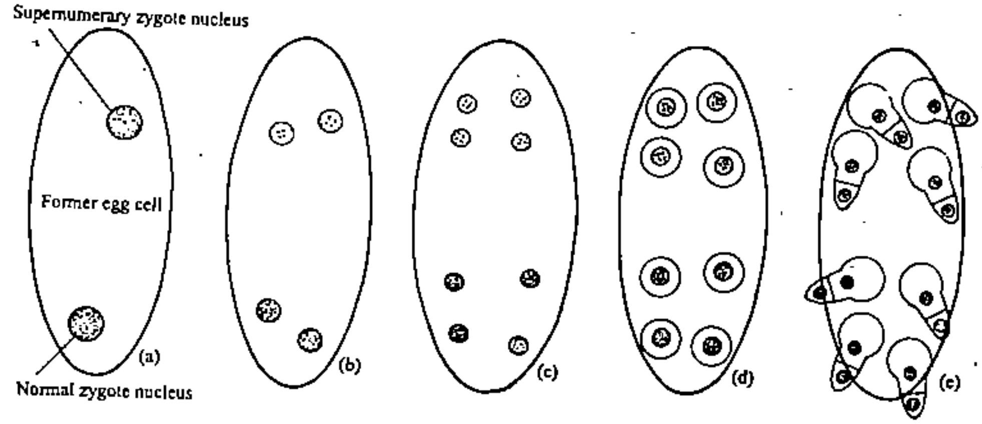

Fig. 4A.13: ***Ephedra*** **sp. Outline diagrams depicting stages of early embryogeny. a) The two products of double fertilization. b, c) The two fertilization products undergo mitotic divisions to form two groups of nuclei, each having four nuclei. d) Diagrammatic depiction of the cellularisation of free nuclei, consequently each nucleus acquires a cell wall. Thus two sets of unicellular/uninucleate proembryos are formed. e) Further, each proembryo begins a cellular pattern of development with filamentous growth (After Friedman, 1994).**

Seed

The two bracts of the megasporangiate strobilus in a mature seed form the outer fleshy envelope (Fig. 4A.15). Of the two envelopes, only the outer one which is vascularized, gives rise to the seed coat. The integument, remains papery. In the ovule at the pre-pollination stage, the nucellar cells around the pollen chamber become binucleate. These nuclei increase in size, becomes distorted and fragment after fertilization. In a mature seed, only the compressed remains of the nucellus persist. It is followed by a massive starch rich female gametophyte (=endosperm). The embryo is dicotyledonous. The germination of the seed is epigeal. The cotyledons now develop chlorophyll and represent the first two cotyledonary leaves.

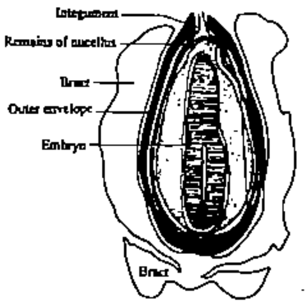

Fig. 4A.15: ***Ephedra*** **sp. Outline diagram of a seed cut longitudinally (Redrawn from Khan, 1943).**

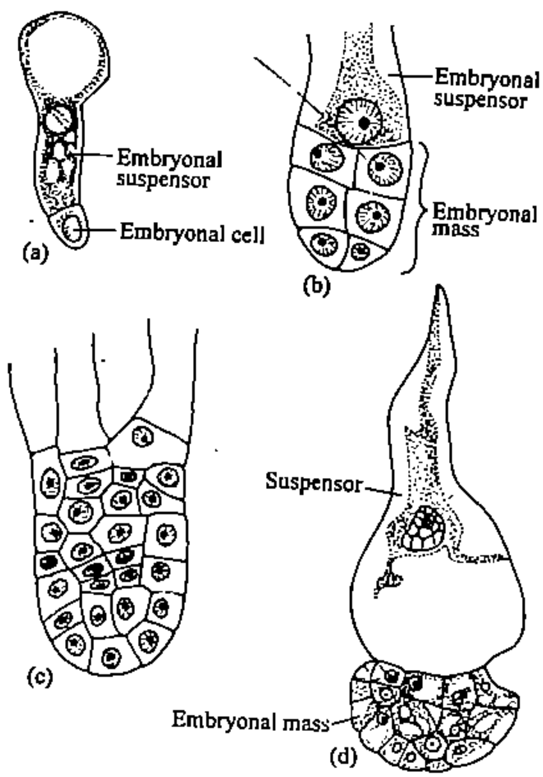

Fig. 4A.14: ***Ephedra*** **sp. Further stages in embryogeny, continued from Fig. 4A.13d. a) One embryonal unit at a later stage showing elongated embryonal suspensor and an embryonal cell. b-d) Later stages in embryo development. [Redrawn from: a, d, Khan, 1943; b, c, Lehmann-Baerts, 1967].**

SAQ 7

Answer the following questions briefly.

i) What are the modes of pollen delivery to the ovule?

ii) What is the role of the pollination drop?

iii) Which are the key participants in the 1st and 2nd fertilizations?

iv) Mention a peculiar feature of the embryonal development.

v) With the help of a diagram show the structure of a mature seed.

4A.7 SUMMARY

In this unit you have studied that:

- *Ephedra* is widely distributed in both the New and Old Worlds.
- It is well adapted to xerophytic conditions owing to a number of morphological and anatomical features.
- It has close resemblance to *Equisetum* in external morphology and has a typical root. The stem has ridges and furrows, deep-seated stomata and chlorophyll-packed palisade parenchyma. The leaves are highly reduced, and the stem is the site for photosynthesis. The intercalary meristem just above each node is a diagnostic feature of this genus.
- *Ephedra* is dioecious. The pollen grain at the time of shedding, is a 5-celled. Its exine has ridges and furrows, with their number varying with species. The mature archegonium contains a long neck an egg nucleus and a ventral canal nucleus.
- Pollination takes place through the agency of wind or insects. The pollen grains are caught in the pollination drop that later gets sucked in and the pollen grains come to lie on the gametophyte tip. Of the two male nuclei, one fuses with the egg nucleus forming the normal zygote nucleus. This is the first fertilization. The second fertilization involves fusion of the second male nucleus with the ventral canal nucleus to form the supernumerary zygote nucleus. *Ephedra* has a peculiar proembryogeny, and out of the eight proembryos in an archegonium, only one, which is centrally placed develops to maturity. The two bracts of the megasporangiate strobilus form the outer fleshy envelope in a mature seed. The embryo is dicotyledonous. Seed germination is epigeal.

4A.8 TERMINAL QUESTIONS

1. What diagnostic features would you look for in a plant to ascertain it is *Ephedra*?

....

....

....

....

2. Compare the structure of male and female strobili of *Ephedra* with their counterparts in *Pinus* and *Cycas*.

3. You are given a mixture of pollen grains of *Pinus*, *Ephedra* and *Cycas*. How would you identify the three types?

4. Describe the development of female gametophyte in *Ephedra*. How does it differ from that of *Pinus* and *Cycas*?

5. List the peculiarities related to pollination, fertilization and embryogeny in *Ephedra*.

....

....

....

4A.9 ANSWERS

Self-assessment Questions

1) Xerophyte, mostly shrubby habit, longitudinally ridged stem

2) 3

3) a) Connect 1 to v
   2 to vi
   3 to vii
   4 to i
   5 to viii
   6 to iii
   7 to ix
   8 to iv
   9 to ii

   b) **Hint** : Activity of the intercalary meristem.

4) Write your own analysis. You can think about the role that most leaves play and compare it with this plant. Also note the leaf structures of most leaves, see how different they are in this plant. What does this point to?

5) Male strobilus, microsporangiate flower, microsporangia, archesporial cells, primary parietal cell, primary sporogenous cell, sporogenous tissue, microspore mother cells, microspores, antheridial initial, antheridial cell, pollen grain.

6) a, c, e, and h

7) i) Through wind or insects.
   ii) Transports pollen onto the nucellus, provides a medium for pollen germination.
   iii) First fertilization – egg nucleus and first male nucleus; second fertilization – ventral canal nucleus and the second male nucleus.
   iv) **Hint**: Eight proembryos begin development, and only one develops into embryo.
   v) See Section 4A.6

Terminal Questions

1) Prepare a list of the morphological and anatomical features peculiar to *Ephedra*. Refer to Sections 4A.2 to 4A.4.

2) Reference – Section 4A.4 and Units 2 & 3.

3) See pollen structure of *Ephedra* in this unit, Section 4A.5. Refer to Units 2 and 3 for pollen of *Cycas* and *Pinus* respectively. Give diagrams to show structure of mature pollen grains of each to highlight the number of nuclei/cells present at the time of shedding.

4) Reference – Section 4A.4. and Unit 2 and 3.

5) Refer to Section 4A.5 and 4A.6.

SUB UNIT 4B GNETOPSIDA: *GNETUM*

Structure

4B.1 Introduction
Objectives

4B.2 Distribution, Habitat and General Features

4B.3 Vegetative Structure
4B.3.1 Root
4B.3.2 Stem
4B.3.3 Leaf

4B.4 Reproductive Structures
4B.4.1 Male Strobilus and Gametophyte
4B.4.2 Female Strobilus and Gametophyte

4B.5 Pollination and Fertilization

4B.6 Embryogeny and Seed Development

4B.7 Relationships
4B.8.1 Relationship with *Ephedra* and *Welwitschia*
4B.8.2 Relationship with Angiosperms

4B.8 Summary

4B.9 Terminal Questions

4B.10 Answers

4B.1 INTRODUCTION

In the previous sub unit you have studied *Ephedra,* and in this sub unit you will study *Gnetum* because it is the only genus representing Gnetaceae. *Gnetum* has many important feature which have resemblence with angiosperms.

Objectives

You have by now become familiar with the main categories of gymnosperms. In this unit you will be able to:

- state the distribution of *Gnetum* in world as well as in India,
- describe morphology of both vegetative and reproductive structures,
- distinguish between the anatomy of root, stem and leaf,
- describe the structure of micro-and megagametophytes,
- give an account of pollination, fertilization and seed development and
- compare relationship of *Gnetum* to other gymnosperms and with angiosperms.

4B.2 DISTRIBUTION, HABITAT AND GENERAL FEATURES

Most species inhabit the tropical rain forest below 1500 m altitude.

The genus *Gnetum* consists of thirty species, widely distributed in the tropical and sub-tropical humid zones of the world. Of these 7 occur in tropical America, 2 in western Africa and the remainder in tropical Asia, 5 species are found in India.

Gnetum resembles more an angiosperm than a gymnosperm. Most of the species are climbers with twinning stem.

G. ula, a woody climber, is most common and abundant, and occurs in the coastal regions of peninsular India. *G. contractum* and *G. montanum* both are also lianas, the former occurs in Kerala and Tamil Nadu, whereas the latter grows in Assam and Sikkim. Another climber, *G. latifolium* is found in Andamans. *G. gnemon* a tree is restricted to the north-eastern parts of India G. trinerve is reported as a parasite.

4B.3 VEGETATIVE STRUCTURE

4B.3.1 Root

The plant has a tap root system with well developed lateral roots. The outermost layer or epidermis is followed by many layered parenchymatous, starch-filled cortex. Thick walled fibre cells are common in the cortex. The endodermis encloses a multilayered pericycle. The primary xylem is diarch. The tracheids have uniseriate bordered pits. Phloem is composed of uniform cells. Secondary growth occurs in the normal manner.

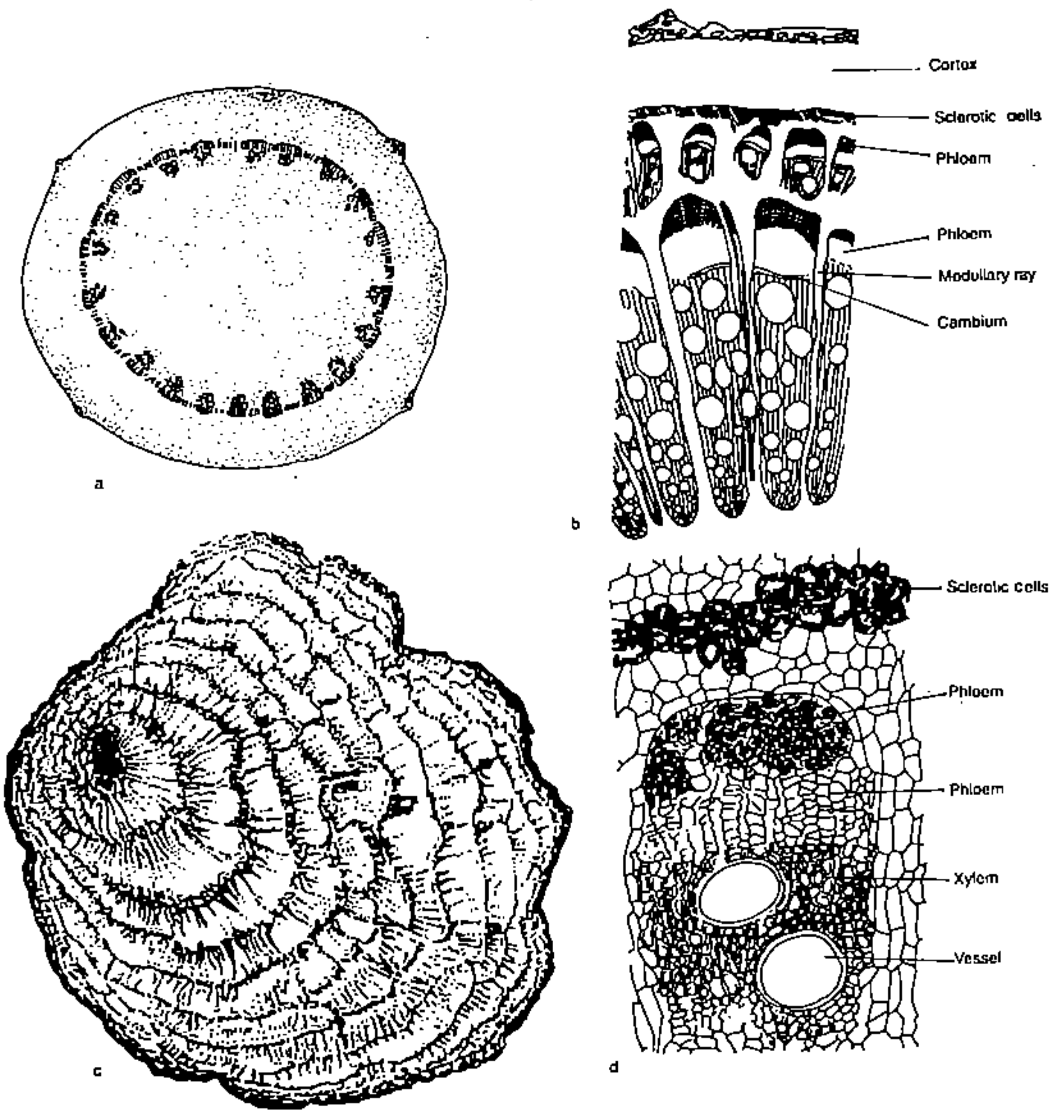

Fig. 4B.1 : *Gnetum* sp. a) T.S. of young stem (diagrammatic). b) T.S. stem showing accessory rings of vascular bundles. c) Same, a part enlarged to show two vascular rings. d) One vascular bundle from accessary ring enlarged. Note the presence of phloem fibres towards the periphery of the bundle forming a patch and a thick layer of sclerotic cells immediately above it. Two prominent vessels are seen in the xylem tissue (after Maheshwari & Vasil, 1961a).

4B.3.2 Stem

It exhibits two types of branches, viz, branches of limited growth and branches of unlimited growth. This distinction is not there in the shrub by or tree species of *Gnetum*, such as *G. gnemon.* Some species have articulate stems; the joints have two parts, one just above and the other below the node, and are separated by an annular groove.

A young stem shows a single layered epidermis of rectangular cells with a thick coating of cuticle and sunken stomata. The cortex consists of 12-16 layers of parenchymatous cells; some cells in the inner zone become fibrous with narrow lumen. In older stems, a ring of parenchymatous cells becomes sclerenchymatous in the inner cortex, and it is referred to as the ring of spicular cells. Endodermis and pericycle are not distinct. The vascular bundles (20-24) are collateral and endarch, and are arranged in a ring. The xylem consists of tracheids and few vessels. Medullary rays between vascular bundles are high and broad. The pith is parenchymatous. Laticiferous elements are seen in both pith and cortex (Fig. 4B.1a).

In tree species of *Gnetum*, such as *G. gnemon*, the secondary growth is normal. In the

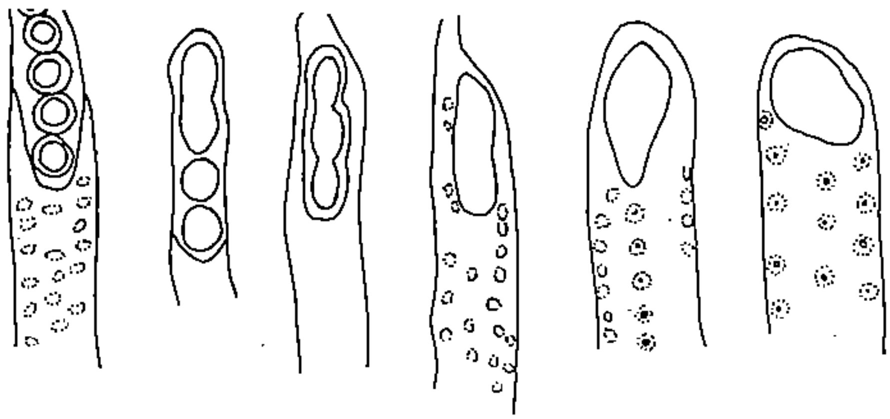

Fig. 4B.2 : Perforations in the end walls of the vessels of *G. africanum* (After Duthie, 1912).

climbing species, like *G. ula* and *G. africanum*, the secondary growth is normal to begin with but, later, due to the formation of new cambium, several rings of xylem and phloem, separated into wedge-shaped bundles because of medullary rays, are produced. You can see in Figure (4B.1b) that some of these accessory rings may be incomplete with the result that either the pith or the arrangement of vascular bundles is eccentric. The detailed structure of each vascular bundle is shown in Figure (4B.1c,d.).

The secondary phloem is composed of sieve cells and parenchyma. Both elements show great regularity in their arrangement – sieve cells in uniform rows and parenchymatous cells in angles between them. In their location, size and contents the parenchymatous cells resemble companion cells, although their origin is very different.

The wood of *Gnetum* is remarkable in showing vessels with a single pore on their end walls (Fig. 4B.2.a). Besides vessels, tracheids and xylem parenchyma are also present. The tracheids are long and show uniseriate bordered pits on both radial and tangential walls. The xylem parenchyma cells possess simple pits (Fig.4B.2b,c).

Stem apex: The shoot apex of *Gnetum* has assumed an angiospermous character. It exhibits a typical tunica-corpus organisation. The tunica is the outermost single layer of cells extending from the first pair of leaf primordia over the shoot apex. The corpus consists of subapical initials, central mother cell zone, flanking layers and pith rib meristem. You will read more about this in Unit-8.

4B.3.3 Leaf

The *Gnetum* plant resembles dicotyledons in the leaf shape and venation. The leaves are large, oval-shaped with reticulate venation and entire margin (Fig. 4B.3a). The short shoots are usually unbranched, and bear 9 or 10 decussately arranged leaves on each branch.

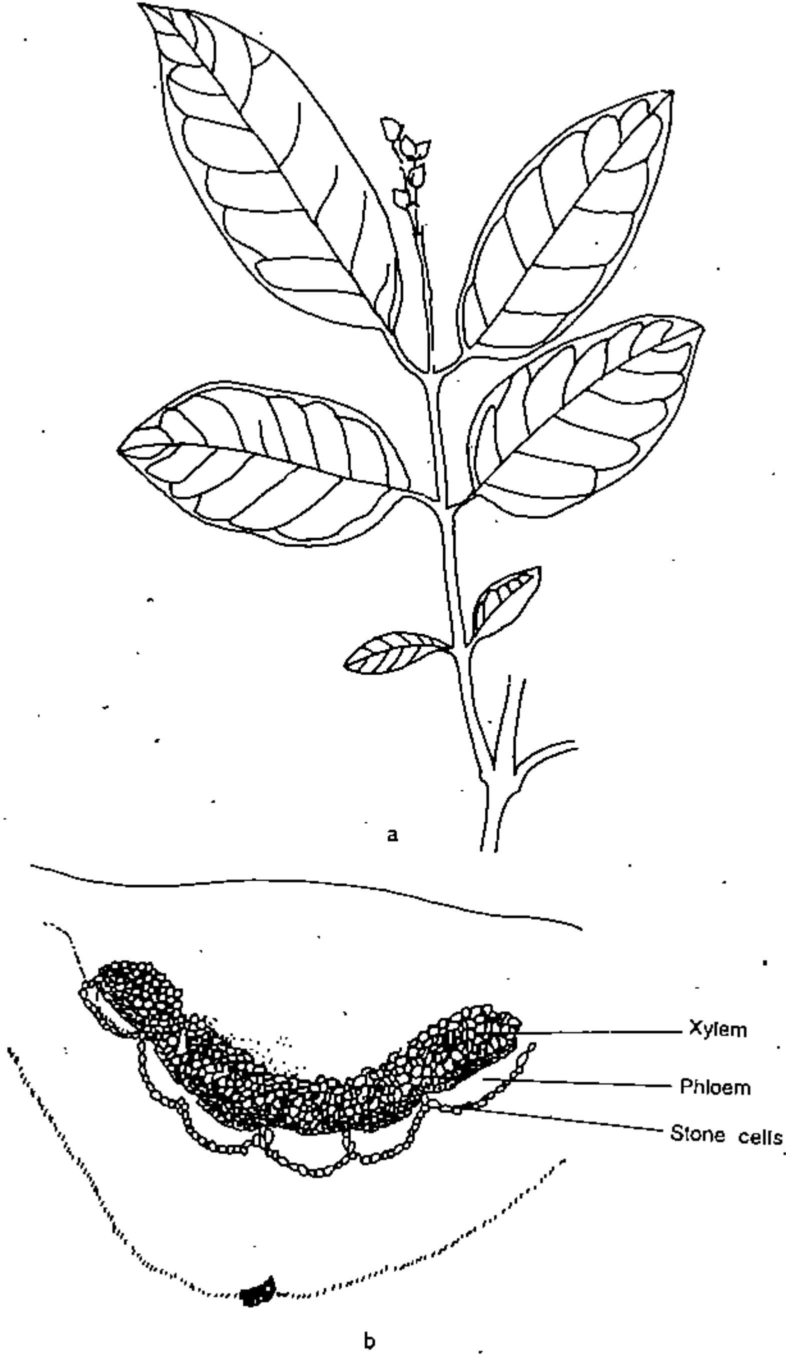

Fig. 4B.3: *Gnetum sp.* a) *Gnetum indicum:* Leaves with reticulate venation b) V.S. older leaf in the region of midrib. Note distinct patches of stone cells outside the phloem tissue (after Maheshwari &Vasil, 1961a).

In leaves the epidermis has undulating walls with a thick cuticle. The mesophyll is distinguishable into palisade and spongy parenchyma. The palisade consists of a single layer of compact cells which show the presence of stellately branched sclereids near the lower epidermis. Fibres and latex tubes are abundant, especially in the midrib region. Stomata occur only on the lower surface and are irregularly oriented. The pattern of stomatal development is haplocheilic. Vascular bundles are arranged in a curve (Fig. 4B.3b). Xylem consists of vessels, tracheids and parenchyma. The phloem is arranged in regular rows just beneath the xylem. Thick walled pitted cells form a patch outside the phloem.

SAQ 1

Fill in the blanks using the correct alternative.

1. *Gnetum* plants are found in .... (Kashmir/Kerala).

2. *Gnetum* is a plant of .... (arid/moist) tropical zones.

3. The leaves of *Gnetum* show .... (reticulate/parallel) venation.

4. *Gnetum* shows presence of .... (vessels/sclereids) and hence resembles angiosperms.

5. The presence of....................................(laticifers/resin ducts) is seen in the stem of *Gnetum*.

SAQ 2

1. Comment on the statement that "*Gnetum* shows an angiospermous shoot apex?"

....

....

....

....

....

2. Anamolous secondary growth occurs in some species of *Gnetum*. How does it differ from the normal growth?

....

....

....

....

....

....

3. What is characteristic of the wood of *Gnetum*?

....

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....

....

4B.4 REPRODUCTIVE STRUCTURES

4B.4.1 Male Strobilus and Gametophyte

Male and female strobili ("cones") develop on separate plants i.e *Gnetum* is dioecious. Figure 4B.4 shows the morphology of the male and female branches.

Male Strobilus : The "inflorescence" is a solitary or fascicled panicle. It is axillary on a short shoot and is unbranched. Apart from microsporangia it shows a whorl of sterile ovules. The strobilus consists of an axis with two sterile, connate opposite bracts at the base and a series of circular bracts (cupules or collars) which are superposed one above the other (Fig. 4B.5a). A young strobilus appears compact because of a reduced axis with very short internodes and the collars appear to be continuous. As the axis elongates the collars get separated. The upper two or three collars in *G. gnemon* are much reduced and sterile.

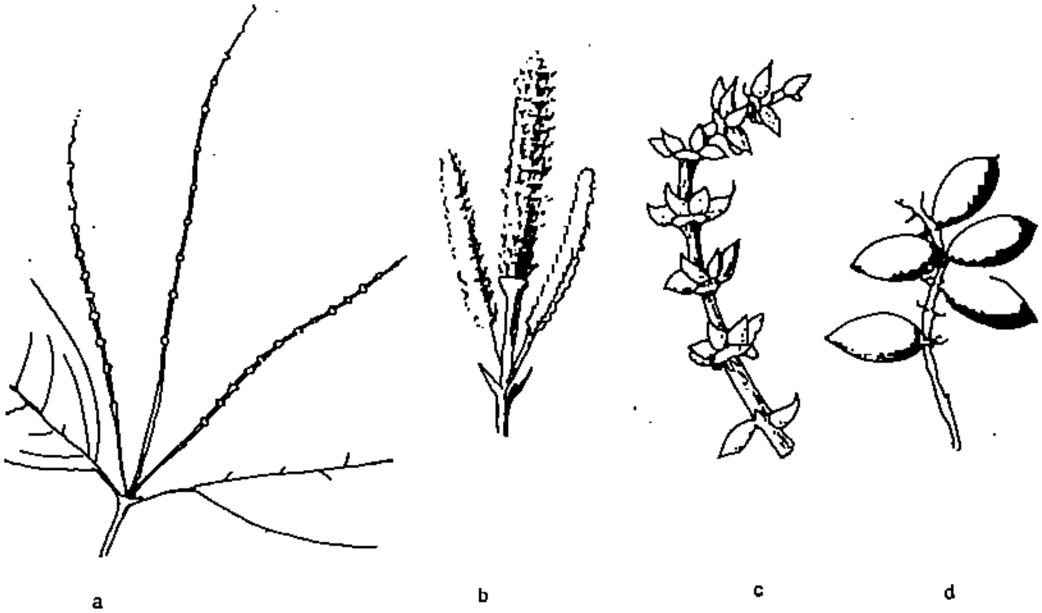

Fig. 4B.4: *Gnetum sp.*a) Reproductive branch. b) male strobilus. c) female strobilus. d) seed bearing branch (after Kubitzki, 1990).

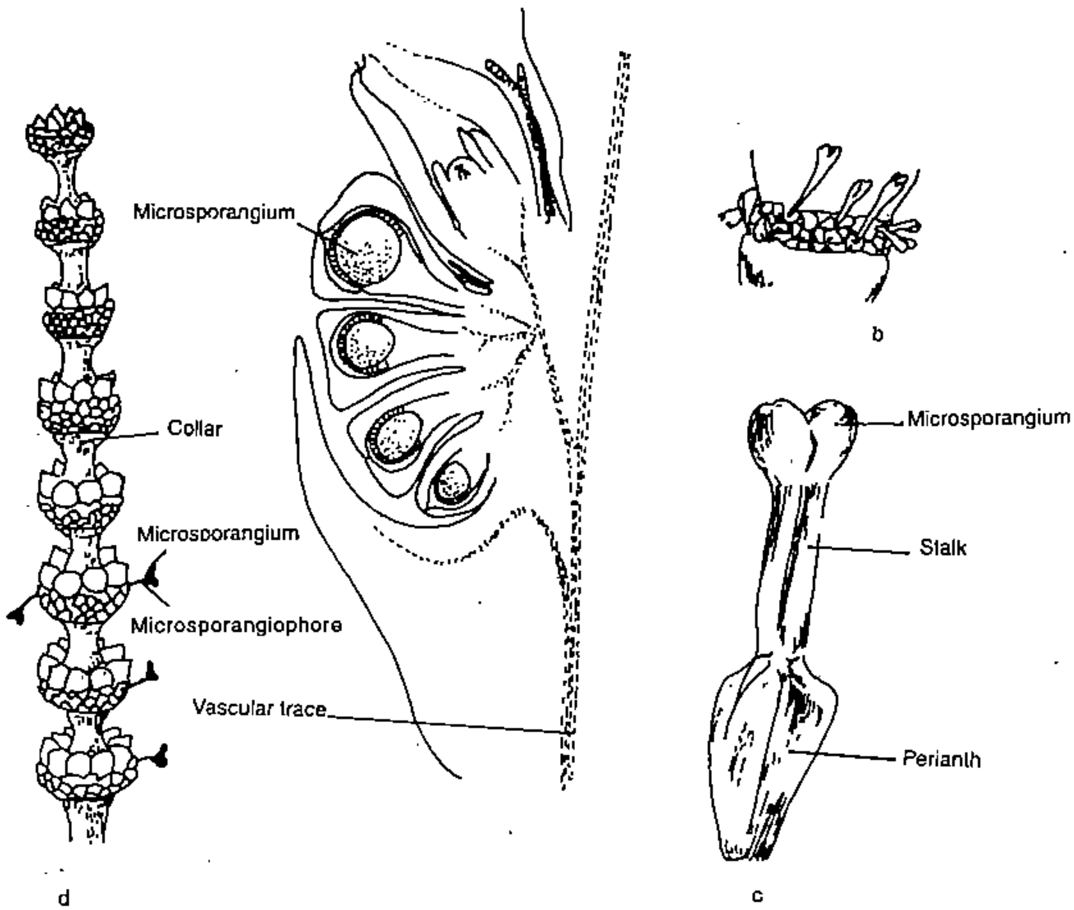

Fig. 4B.5 : a-c) *Gnetum* sp. : a) Branch bearing a panicle of male cones at dehiscense. At each collar, just above male flowers, there is a ring of imperfect female flowers or abortive ovules. b) Portion from an enlarged; male flowers are dehiscing. c) Elongation of stalk and emergence of anthers from perianth. d) L.S. part of male cone to show the position of sporangia and ovule and vasculature to collar, male flowers and ovule. (a-c, after Vasil, 1959 ; d-g, after Sanwal, 1962).

Each collar bears three to six rings of 12–15 male flowers and above them a single ring of 7–12 imperfect female flowers or abortive ovules (Fig. 4B.5a, b). Each male flower has two unilocular anthers on a stalk (antherophore) enclosed in a sheath of bracts or perianth (Fig. 4B.5d). The stalk elongates at maturity and the anthers come out of the perianth cover through a slit . (Fig. 4B.5c). During the development of the male strobilus, the collars are formed in an acropetal succession.

The shape of collars their number and internode length are of taxonomic importance.

A ring of meristematic cells differentiates at the base (axil) of each collar. The microsporangium is formed by a hump of tissue which becomes notched to form 2 anthers with a stalk. Two groups of hypodermal archesporial cells, by repeated divisions, give rise to multicellular archesporium (Fig. 4B.6a). The outermost layer of the archesporial cells divides to form the primary parietal layer and the sporogenous cells (Fig. 4B.6b). The primary parietal layer, by periclinal division, gives rise to a wall layer towards outside and tapetum towards inside. The wall layer is the first to degenerate. The tapetal cells become densely cytoplasmic and are normally binucleate; the nuclei may fuse and become polyploid. The tapetal cells start degenerating after meiosis and their remnants are discernible at uninucleate stage of microspores (Fig. 4B.6c). Übisch granules or orbicules are seen on the wall of the tapetal cells. The epidermis is the only layer which persists in the mature sporangium which dehisces by a median longtitudinal slit. The sporogenous cells divide and increase in number, the last cell generation of which differentiates into microspore mother cells. Broad cytoplasmic channels interconnect microspore mother cells or meiocytes forming a syncytium. A space is formed between the plasmalemma and the mother cell wall. The latter is gradually dissolved away followed by the rounding off of the protoplasm. As the mother cell enters meiosis, it is surrounded by a thick layer of callose. The meiosis results in the formation of decussate, tetrahedral or isobilateral tetrads still embedded in the callose cover. This covering is soon absorbed releasing individual haploid microspores. (See Fig.4B.6c).

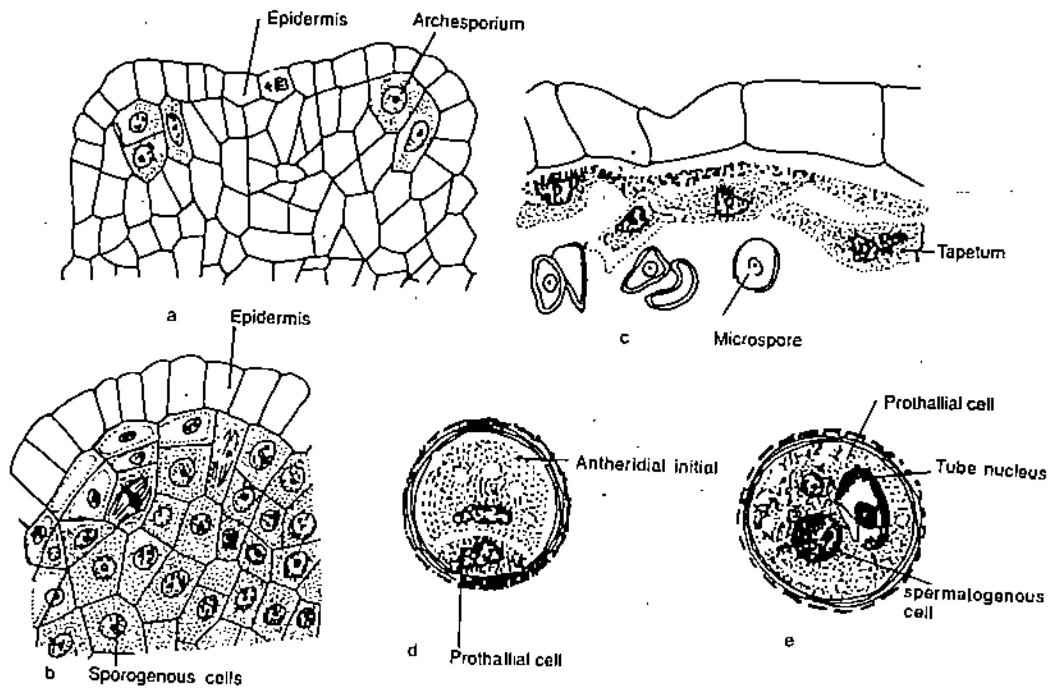

Fig. 4B.6 : *Gnetum* sp. Microsporogenesis and male gametophyte. a) L.S. very young male flower to show few hypodermal archesporial cells. b) Same, at a later stage; primary parietal layer has been cut off above sporogenous tissue. c) Part of sporangium showing degenerating tapetal cells and a few microspores. d) Two-nucleate pollen grain; prothallial cell has been cut off. e) Mature, three-celled (prothallial cell, tube cell and spermatogenous cell) pollen grain at shedding stage (after Sanwal, 1962).

The microspore nucleus divides to form a small lens-shaped prothallial cell and a large antheridial initial (Fig. 4B.6d). The prothallial cell rounds up and does not undergo any further division and degenerates as such. The antheridial initial divides forming an antheridial cell and a tube cell. Since a stalk cell is not formed in *Gnetum*, the antheridial cell directly functions as the spermatogenous cell. Pollen grains are shed at the 3-celled stage (Fig. 4B.6e). Double pollen grains have occasionally been observed in several species. They probably arise due to the non-separation of two or more cells of a tetrad. The pollen is sticky in nature.

4B.4.2 Female Strobilus and Gametophyte

Female Strobilus: The female strobilus resembles the male strobilus when young. However, as the strobilus grows, the distinction becomes clear. In a female strobilus, a ring of four to ten female flowers (ovules) is present above each collar. There are no male flowers. All the ovules look alike initially but, later, only a few grow to maturity. The upper few collars usually lack ovules and are thus sterile.

Nearly four to ten ovular primordia differentiate from an annular meristem or rim below each collar of the female cone. The ovular primordium lies on a cushion. The three envelopes (outer, inner and integument) arise in a centripetal manner. The ovule is stalked or subsessile. Of the three envelopes, the outer one differentiates first. Often called perianth, this envelope gets thickened and somewhat succulent at maturity (Fig. 4B.7a). The outer epidermis shows stomata.

The inner envelope is next to arise, and is sometimes called as the outer integument. The female flowers in the male cone lack this envelope. The apical part forms a tapering ring-shaped rim. Stomata differentiate in the outer epidermis. Laticifers are also formed at the time of pollination. The major part of the stony layer of the seed coat is formed by the fibrous elements and sclereids in this envelope.

The third envelope or the integument is last to be formed, and is fused with the nucellus in the lower part. It elongates considerably into a micropylar tube or the so-called "style" projecting beyond the apical cleft of the outer envelope. The exposed part is nearly one-third the length of the mature ovule. This part starts degenerating before or at the time of pollination. The apical lobes of this envelope become prominent and their number varies from 7 to 11. The lobes are large and irregularly twisted. Unlike the other two envelopes (Fig. 4B.7a), neither stomata nor sclereids develop in the integument.

Nucellus : The nucellus is well developed and quite massive. Its epidermis divides forming a nucellar cap.

Prior to meiosis in the megaspore mother cells, some nucellar cells below them divide to form a tissue wherein cells are arranged in radiating rows. This is termed as the **"pavement tissue"**, and its cells are densely stained when the female gametophyte is free nuclear. As the female gametophyte grows in the chalazal region, the pavement tissue gets absorbed. This tissue is thought to be nutritive in function.

Megasporogenesis and Female Gametophyte : Generally two to four hypodermal archesporial cells differentiate in the young nucellus (Fig. 4B.7b). They cut off primary parietal cells towards outside and primary sporogenous cells towards inside. As stated earlier, the parietal cells together with nucellar epidermis produce a massive nucellus. The primary sporogenous cells divide forming 8–16 sporogenous cells, that are linearly arranged and function as megaspore mother cells.

Since no walls are laid down after meiosis I and II (Fig. 4B.7d), a tetranucleate coenomegaspore is produced. To begin with, the four nuclei lie in the centre of coenomegaspore but later they move to the periphery. The development of the female gametophyte is, thus, **tetrasporic.**

Although several coenomegaspores develop in the same nucellus generally only 2 or 3 grow beyond 16-nucleate stage.

As the female gametophyte develops, a large vacuole appears in the centre and the nuclei in the peripheral cytoplasm undergo repeated divisions (Fig. 4B.7c). Later, as divisions

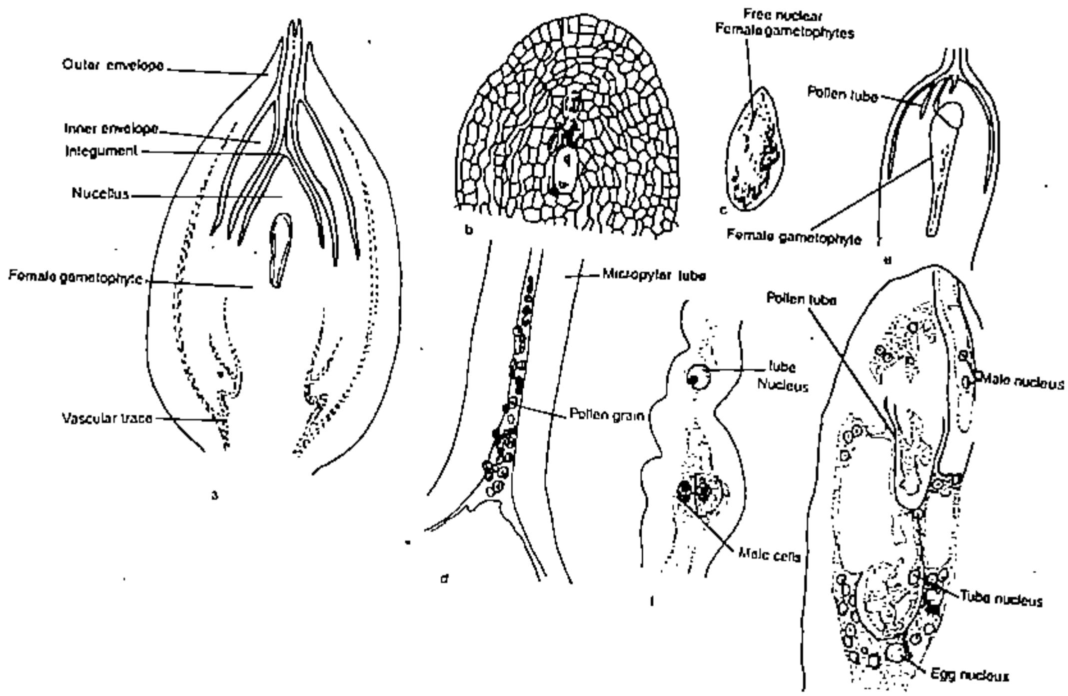

Fig. 4B.7: ***Gnetum*** **sp. a) L.S. ovule to show outer and inner envelopes, integument and well developed nucellus; the integument forms the micropylar tube. The female gametophyte is at the free nuclear stage. Dotted lines represent the vascular supply to various parts. b) A two nucleate megaspore mother cell. c) Free nuclear female gametophytes, d) L.S. part of micropyle showing entrapped pollen grains, e) L.S. ovule to show three pollen tubes in nucellar tissue. One of the pollen tubes is about to enter the lower female gametophyte. f) Portion of pollen tube showing tube nucleus and two equal male cells. g) L.S. upper part of female gametophyte with several pollen tubes. Two large nuclei with radiating cytoplasm near the lower pollen tube will function as egg nuclei, (c-e after Vasil, 1959; a-b after Madhulata, 1960; f-g after Sanwal, 1962).**

In *G. gnemon*, the pollen tube traverses laterally along the gametophyte and nuclei in the vicinity of the pollen tube enlarge several times and acquire dense cytoplasm around them. These are the egg nuclei.

continue, the gametophyte in the upper part widens and contains a vacuole, whereas, in its lower part the gametophyte shows accumulation of cytoplasm. With further growth, the gametophyte becomes elongated and acquires the shape of an inverted flask (Fig. 4B.7e).

An interesting feature of the female gametophyte is the absence of archegonia, a feature *Gnetum* shares with *Welwitschia*. When the pollen tube makes contact with the female gametophyte, one or more nuclei in the equatorial region of the dilated part, can be easily demarcated from the other nuclei by their large size and dense staining. These are the egg nuclei whose usual number is two but, rarely, one or three nuclei may also develop into eggs. The differentiation of the egg is stimulated by the presence of the pollen tube in the vicinity of the female gametophyte (Fig. 4B.7g). The most interesting part of the egg development is that all the eggs do not mature simultaneously nor all the pollen tubes reach the gametophyte at the same time. Differentiation of additional eggs continues even after fertilization of the first one. The gametophyte which, for most of its part, is free nuclear, starts becoming cellular in its upper portion soon after one of the eggs is fertilized. Eventually the upper part of the gametophyte becomes almost cellular.

4B.5 POLLINATION AND FERTILIZATION

The pollination takes place when the female gametophyte shows 250 nuclei in *G.ula* and 32 or 64 nuclei in *G.gnemon.* Pollination may be carried out by wind or insects. The tip of the micropylar tube becomes flared and lacerated. The pollination drop, which is rich in sugar, is exuded at the tip and collects pollen. As the fluid dries, the pollen grains are sucked into the micropylar canal and lodged in the pollen chamber (Fig. 4B.7d). Ants are known to visit the pollination drop which is formed by the degenerated cells of the nucellar tip.

The pollination biology of a dioecious (shrub) species, *G. gnemon* has been studied. During evening both male and female strobili emit a strong, putrid odour; pollination droplets are also secreted from the ovules. Evaporation of the exposed pollen droplet is very slow at night in the tropical rain forest. This nocturnal entomophily is attained by replacing showy petals with a strong odour.

At the time of pollen germination, the exine is cast off. The pollen grains are devoid of germ pores.The pollen grain puts out a tube which grows and traverses the nucellus through intercellular spaces. When the pollen tube has travelled almost half the length of the nucellus, the spermatogenous cell moves into the tube whereas the prothallial cell degenerates in situ. On division, the spermatogenous cell forms two male cells (Fig. 4B.7f). The male gametes move ahead of the tube nucleus and come to lie near the tip of the pollen tube (Fig. 4B.7g).

A **pollen chamber** develops at the apical portion of the nucellus. When megasporogenesis is complete, the cells in the upper region start degenerating. The degeneration of the cytoplasm is followed by the breakdown of nuclei and cell walls. Eventually, a shallow pollen chamber is formed into which pollen grains will be lodged. The cells between the pollen chamber and female gametophyte are gorged with starch grains. The growing endosperm (female gametophyte) nearly consumes the nucellus and, in a mature seed, the cells in the apical portion become cutinized and persist.

During post-pollination stages, a ring shaped swelling appears just above the insertion of inner envelope. Another swelling or proliferation develops in the apical part below the pollen chamber.

At the time of pollination, a circular rim or an umbrella-shaped structure, called "**flange**" develops from the integument. Its function is not clear.

Micropylar Closing Tissue : Another tissue (closing tissue) is formed by the proliferation of inner epidermis of integument at the level of the flange. This results in the closure of the micropylar canal.The closure is due to the elongation and interlocking of the inner epidermal cells. The micropylar closing tissue may grow downward filling the pollen chamber. The plugging tissue has been called "obturator" as it fits in the pollen chamber.

SAQ 3

1. If archegonia are absent in *Gnetum*, where is the egg nucleus present.

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2. Explain the process by which pollen is transferred from male strobilus to the ovule.

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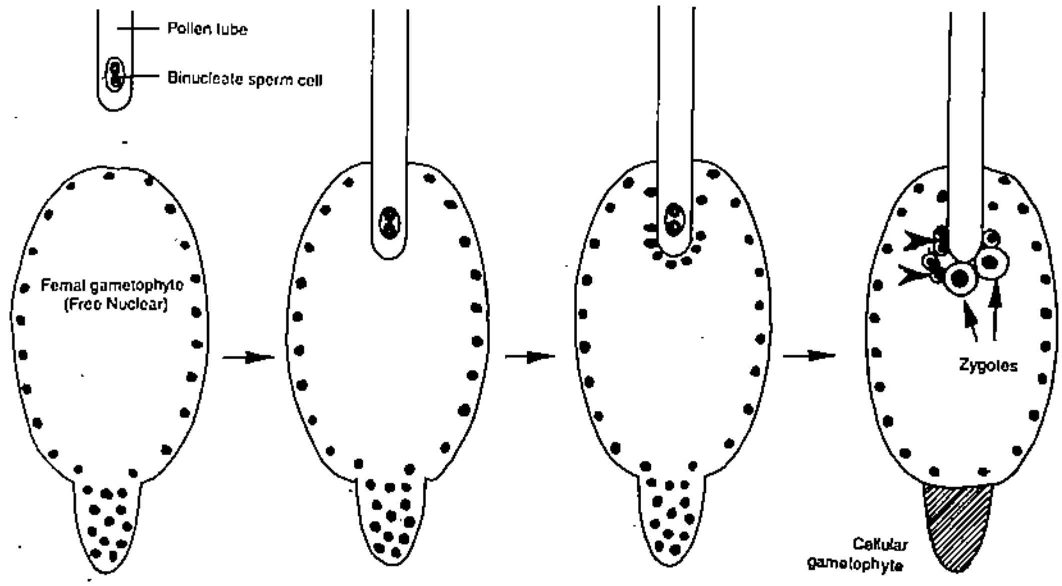

Fig. 4B.8: Diagram illustrating double fertilization in *Gnetum gnemon*. Binucleate sperm cells are produced within pollen tubes that enter a coenocytic female gametophyte. Shortly after pollen tubes enter, free nuclei within the female gametophyte migrate around the tips of pollen tubes. None of the female nuclei differentiate as eggs and all represent potential gametes. Pollen tubes discharge both sperm nuclei into surrounding female cytoplasm and each sperm nucleus fuses with a separate female nucleus. Double fertilization results in the formation of two viable zygotes. Although unfertilized female nuclei may become cellular (arrowheads), they are clearly distinguishable from diploid zygotes. Concurrent with fertilization, the chalazal region of the female gametophyte becomes cellular, will eventually enlarge and serve to nourish developing embryos. As many as six pollen tubes may fertilize a single female gametophyte, (after Friedman 1996).

SAQ 4

State whether the following statement is true or false. Write T for true and F for false in the given bracket.

1. In *Gnetum* the pollen grain is shed at three nucleate stage. [ ]
2. In *G. ula* the pollination take place when female gametophyte shows 250 nuclei. [ ]
3. The pollination drop is rich in protein and vitamins. [ ]
4. In the stem of some species of *Gnetum* several accessory rings of vasculature of which some may be incomplete are formed due to secondary growth. [ ]
5. The development of the female gemetophyte in *Gnetum* is tetrasporic. [ ]

There are reports of double fertilization in the genus *Gnetum*. It occurs regularly in *G. gnemon*, and is possible because two sperms per pollen tube have access to at least two fecundable female nuclei in the gametophyte. In *Gnetum gnemon* a binucleate sperm cell is formed in the pollen tube. In the free nuclear female gametophyte, undifferentiated female nuclei function as eggs. The two sperm nuclei are released in the surrounding female cytoplasm and each fuses with a separate female nucleus thus causing *double fertilization*, resulting in two diploid zygotes. After fertilization each zygote nucleus develops into an embryo, but usually only one attains maturity in the seed. You must study Fig. 4B.8 for the details

4B.6 EMBRYOGENY AND SEED DEVELOPMENT

The zygote may give rise to a small protuberance into which the nucleus moves (Fig. 4B.9a). It may even divide into two cells and both or one of the cells may give out a tube (Fig. 4B.9b).

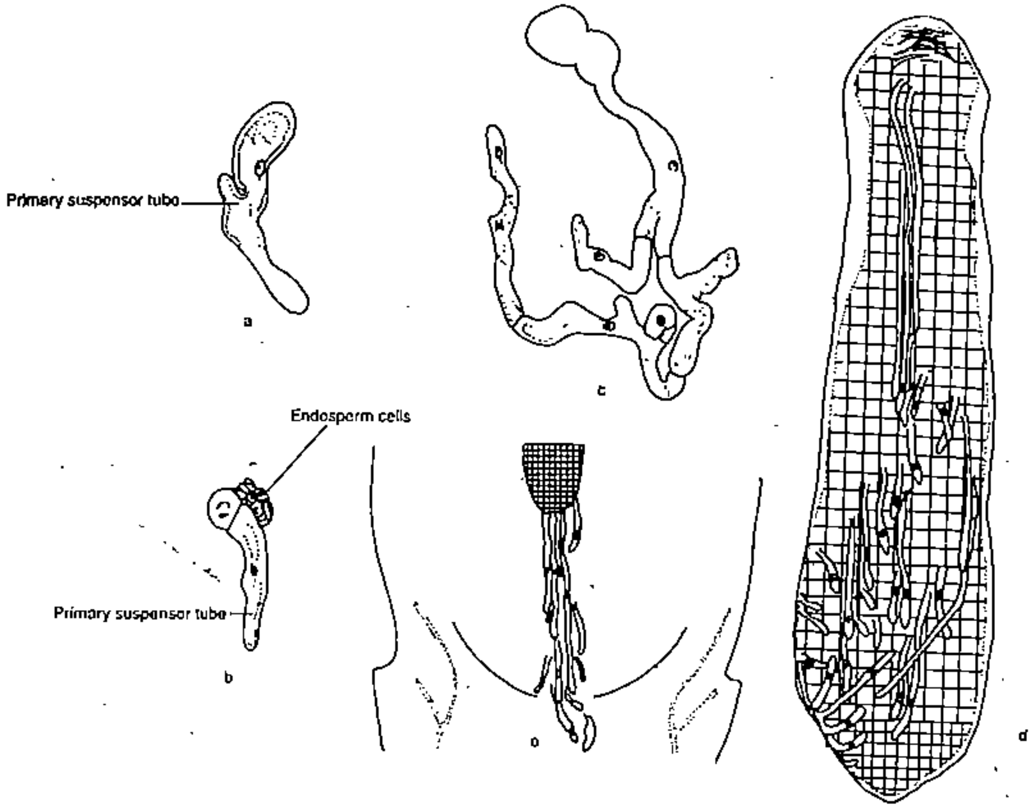

Fig. 4B.9a-e: Stages in development of embryo of *Gnetum gnemon*. a) Zygote giving out primary suspensor tube, b) Two-celled zygote; some endosperm cells are also seen. c) Branched primary suspensor tube. d) L.S. ovule showing numerous primary suspensor tubes penetrating the female gametophyte. e) Lower portion of ovule showing the primary suspensor tubes growing beyond endosperm in the nucellar tissues.

The tubes have variously been designated as primary suspensor tubes to differentiate them from the secondary suspensor which will be described later. The tubes become septate and much elongated and coiled, and penetrate the female gametophyte or endosperm (Fig. 4B.9c). These primary suspensor tubes always move downwards i.e., towards chalazal end (Fig. 4B.9 d, e).

Embryo development starts at the tips of some of these primary suspensor tubes. The nucleus of the primary suspensor tube migrates towards the tip and divides into two unequal nuclei (Fig. 4B.10a, b). The smaller one becomes rounded and divides twice producing four cells. Subsequent divisions are irregular forming a mass of cells, upper cells of which give rise to the secondary suspensor (embryonal tubes) (Fig. 4B.10c, d). Cells at the tip of the secondary suspensor are compact and form the embryo proper (Fig. 4B.10e). The secondary suspensor becomes quite massive appearing like a folded plate of cells. Some cells elongate producing long tubes growing on the sides of the primary suspensor tube which ceases to function (Fig. 4B.10f).

Embryo Development : Of the many primary suspensor tubes, only few continue to develop and the remaining embryos along with their primary suspensor system degenerate. The growing embryo exhibits a conical mass of cells with the shoot apex at the tip of the cone. On the sides of the embryonal mass tip, the cells divide actively to form two cotyledons covering the central zone of the shoot apex. The root tip is differentiated at the opposite end. The root cap cells are confluent with the massive secondary suspensor. After the formation of the shoot and the root apices, a small protrusion appears in the region between the two

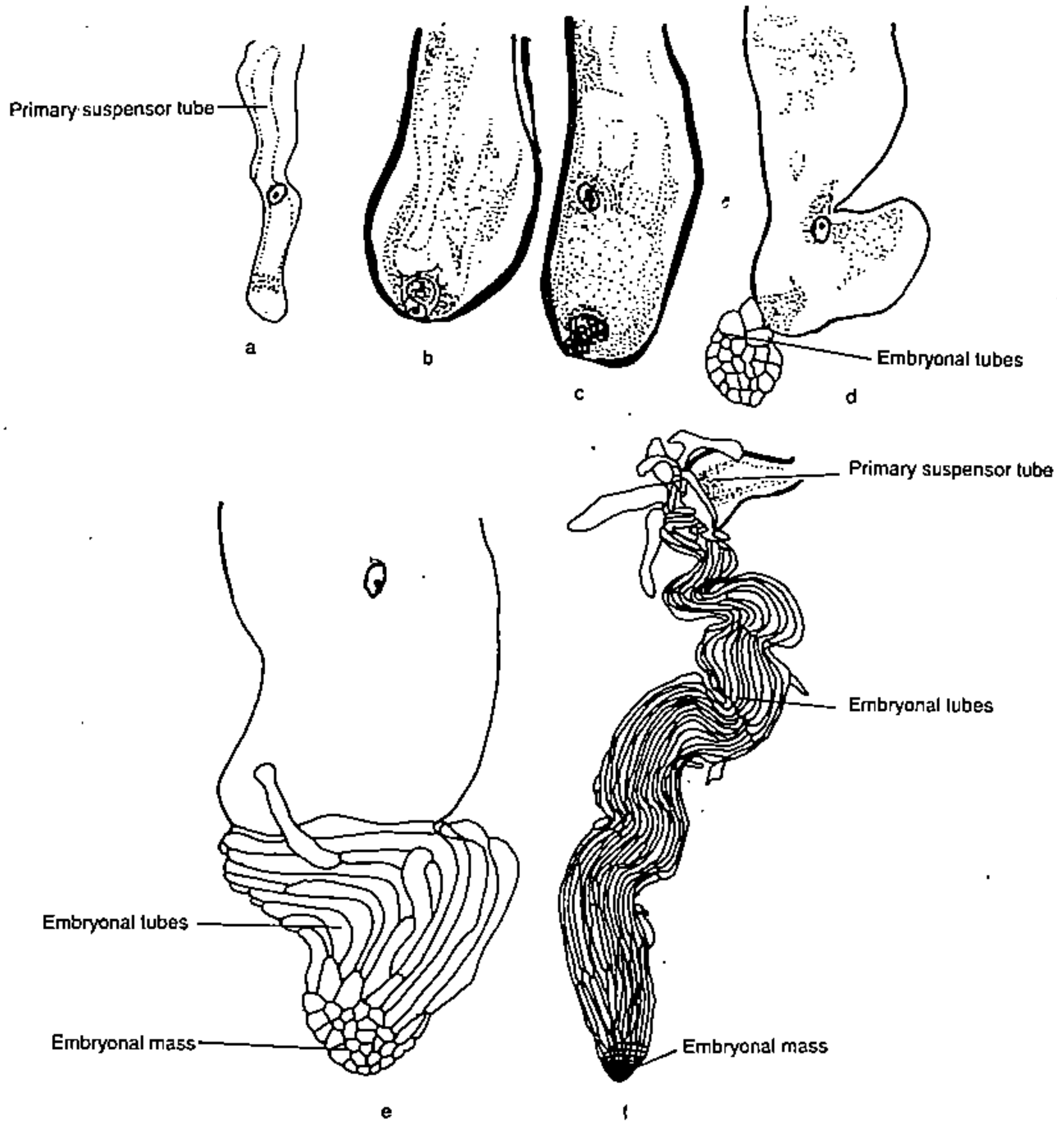

Fig. 4B.10: *Gnetum* sp. (et, embryonal tubes). a) Tip portion of primary suspensor tube. b, c) Same showing 2 and 8 celled stage; nucleus of primary suspensor tube is persistent. d, e) Upper cells of the cellular mass have enlarged and undergone division to give rise to secondary suspensor (embryonal tubes) f) Young embryo showing primary suspensor tube with long, coiled multicellular secondary suspensor. A few cells of secondary suspensor have elongated to produce long tubes growing on the sides of primary suspensor tube (after Vasil 1959).

apices. This is the beginning of the so-called "feeder". It shows epidermis, cortex, vascular bundles and pith. In the mature embryo the feeder is very prominent and is generally longer than the hypocotyl (Fig. 4B.11a).

Polyembryony is very common in *Gnetum* (Fig. 4B.11b). Both simple and cleavage polyembryony are recorded. The cleavage polyembryony may occur from the embryonal mass of the primary or the secondary suspensor tubes. Sometimes cells of the secondary suspensor may become meristematic and produce many embryos at the tip.

Endosperm : Unlike other gymnosperms where a cellular endosperm (female gametophyte) is formed before fertilization, in *Gnetum* although the cellularization begins before fertilization, a part of the gametophyte remains free nuclear. Wall formation results in multinucleate compartments. The nuclei in each cell eventually fuse forming a single polyploid nucleus.

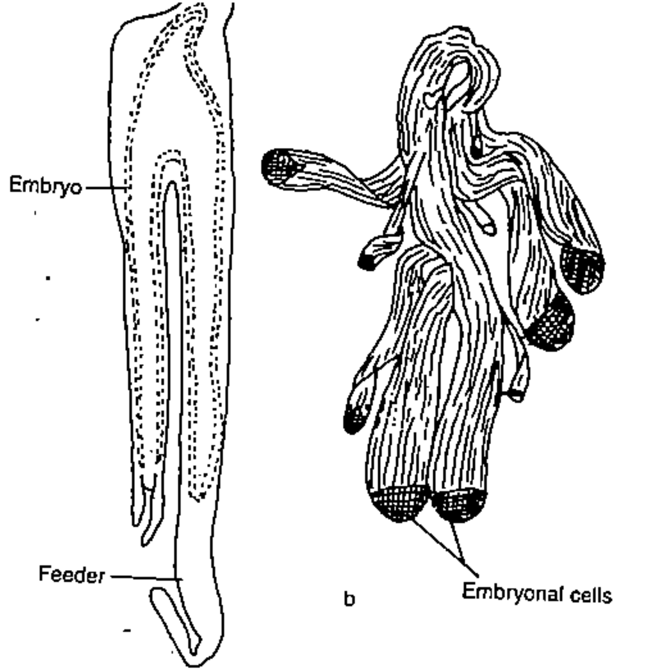

Fig. 4B.11 : *Gnetum gnemon* **a) L.S. mature embryo showing a well developed feeder which is much longer than the embryonal axis. The dotted lines represent vasculature. b) Polyembryony; note the development of additional embryos from primary suspensor tube (after Sanwal, 1962).**

As the endosperm grows, its shape changes with the lower part becoming broader than the upper. It even overgrows chalazal part. These cells undergo transverse divisions producing a distinct area called axial tissue. The upper part is gradually consumed by downgrowing suspensors, and later becomes compressed and crushed. The endosperm is rich in starch and oil droplets, and provides nutrition to the undifferentiated embryo which continues to grow even after the seed has fallen to the ground.

The life cycle of *Gentum ula* growing wild in the Western Ghats takes nearly 18 months from the time of initiation of strobilus to seed germination. Seeds take about 1 year to germinate after being shed. In N.E. India (Assam) seeds of *G. gnemon* are shed in June/ July and they germinate in September next year.

Seed : The seed in most species of *Gnetum* is oval, its colour ranging from green to red. The

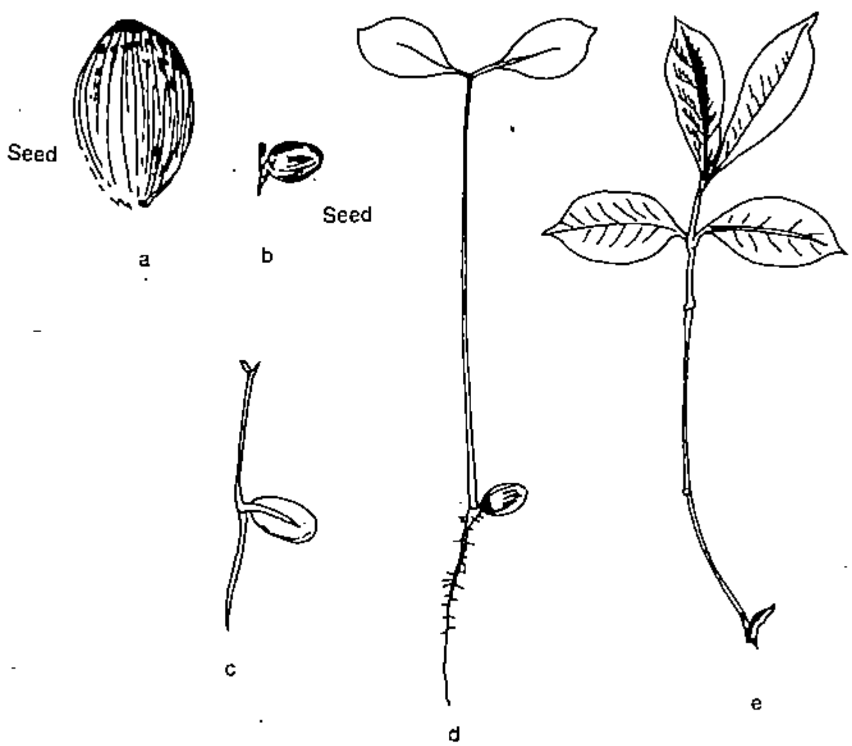

Fig. 4B.12: a-e) Germination of seed and seedling formation in *Gnetum* **(after Maheshwari & Vasil, 1961).**

seeds are shed at a stage when the embryo is not fully formed. The nucellus represents a thin strip at the apex; the endosperm is massive, surrounded by a three-layered seed coat.

There is always a time lag between seed shedding and seed germination. In *G. gnemon* seeds are shed in April and germinate in September, whereas in *G. ula* they take one year to germinate. The germination is epigeal (Fig. 4B.12).

SAQ 5

State whether the following statements are true or false. Write T for true and F for false in the given bracket.

1. In *Gnetum* a coiled secondary suspensor is formed which pushes the developing embryo deep into the endosperm. [ ]
2. In *Gnetum* 'feeder' is very prominent in mature embryo and is generally longer than the hypocotyl. [ ]
3. Polyembryony is not very frequent in *Gnetum*. [ ]
4. In *Gnetum* the seed consists of a three-layered seed coat. [ ]
5. In all the species of *Gnetum*, the seed germinates after one year of shedding. [ ]

SAQ 6

1. What is unique about fertilization in *Gnetum*?

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2. What types of polyembryony are recorded in *Gnetum*?

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3. Is the embryo fully mature when the seed is shed? Comment.

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4. How is the endosperm of gymnosperms different from that in angiosperms?

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Economic Importance

Gnetum gnemon is cultivated in Malaysia and Indonesia and some other southeast Asian Islands for its edible seeds. Young leaves and inflorescence are also eaten as vegetable. The bark yields a fibre from which ropes are made. Kernels of *G. ula* yield an oil which is used in Kerala for massage in rheumatism. *G. montanum* is reported to posses piscicidal properties.

4B.7 RELATIONSHIPS

4B.7.1 Relationships with *Ephedra* and *Welwitschia*

For a long time, the order Gnetales used to include, besides *Gnetum, Ephedra* and *Welwitschia* also. Some of the characters which these three genera share are a) the presence of tracheids and vessels in the wood, b) the male and the female reproductive parts borne on fertile shoots resembling flowers, arranged in compound strobili, c) better protection of the ovules as compared to other gymnosperms, and d) formation of a micropylar tube by the prolongation of the integument.

The group Gnetopsida was considered to be the most evolved amongst gymnosperms approaching towards angiospermous stock. However, two basic characters, which the three genera share with other gymnosperms are a) naked ovules borne in strobili and b) absence of style and stigma, and c) pollination being totally an ovular activity.

The present day botanists, agree to split the order into three separate orders viz. Ephedrales, Gnetales and Welwitschiales, each having a monotypic family namely Ephedraceae, Gnetaceae and Welwitschiaceae. The differences between *Gnetum* and *Ephedra* are well marked. Since the genus *Welwitschia* is not fully studied, it offers only few points. Some of the major differences between *Gnetum* and *Ephedra* are:

Gnetum is restricted to humid tropics or subtropics, whereas *Ephedra* grows in dry regions and even at high altitudes. The plants of *Ephedra* are bushy with minute leaves showing parallel venation, whereas those of *Gnetum* are trees or lianas possessing broad "angiospermous" leaves having reticulate venation. The stem of *Ephedra* shows typical xerophytic characters and is assimilatory in nature. It is green due to the presence of palisade tissue in the cortical region. The stele is simple. The stem of some species of *Gnetum*, on the other hand, shows anomalous secondary growth.

Though both *Ephedra* and *Gnetum* possess vessels, there is a marked difference in the basic nature of vessels. The vessel in *Gnetum* has a single large perforation in the end wall, whereas in *Ephedra*, it has a large number of bordered pits in which middle lamella is lacking. The ovule in *Ephedra* originates as a terminal organ on a lateral appendage of a fertile shoot, whereas in *Gnetum* it is cauline (at the tip of the shoot axis) in nature. This morphological difference is very significant and indicates a great phyletic gap between Ephedraceae on one hand, and Gnetaceae and Welwitschiaceae on the other.

The division of cells in the pollen grains of *Ephedra* follows the gymnospermous plan. The pollen grains are shed at five-celled stage consisting of two prothallial cells, stalk and spermatogenous cells and a tube nucleus. In *Gnetum* the pollen grains are shed at the three-celled stage, comprising a prothallial cell, a tube nucleus and the spermatogenous cell.

The development of the female gametophyte is monosporic in *Ephedra*, whereas it is tetrasporic in *Gnetum*.

The female gametophyte in *Ephedra* becomes cellular before fertilization takes place, whereas it is partly free nuclear in *Gnetum* at that stage.

A "tent pole" is present in many species of *Ephedra* but is absent in *Gnetum*, except for a rudimentary structure in *G. africanum*.

Archegonia are formed in *Ephedra,* whereas they are absent in *Gnetum.*

4B.7.2 Relationships with Angiosperms

Gnetum resembles angiosperms in many respects

i) *Gnetum* plant in its external appearance resembles a typical dicotyledonous plant. The reticulate venation in the leaves of *Gnetum* is similar to that seen in a dicot.

ii) Both the groups exhibit vessels in their xylem. The origin of vessels is, however, different in the two groups. In *Gnetum,* the vessels have evolved from tracheids having a number of bordered pits on the end wall, whereas, the angiospermous vessels have evolved from tracheids with narrow scalariform perforations.

iii) The tunica and corpus arrangement of shoot apex of *Gnetum* is angiospermous. However, the presence of central mother cells is a typical gymnospermous character.

iv) The integument of the ovule in *Gnetum* elongates to form a well developed micropylar tube. Germinating pollen grains have also been found at times in the tube. The situation strongly reminds of a style of an angiosperm carpel.

v) The megasporogenesis in *Gnetum* is tetrasporic which is not found in gymnosperms (except *Welwitschia*) and is common in many angiosperms. The formation of archegonium is completely suppressed in both groups. Some free nuclei of female gametophyte act as eggs in *Gnetum.*

vi) The storage tissue or endosperm in angiosperms develops after fertilization and is triploid (result of triple fusion). In *Gnetum,* though the cellularization starts prior to fertilization, it is complete only after fertilization and is haploid.

vii) The zygote does not undergo any free nuclear division.

Based on the above apparent resemblances it is regarded that angiosperms passed through some stage during the evolution which is now presently shown by *Gnetum.* It is thought that *Gnetum* has closest phylogenetic affinities to angiosperms than any other group of plants.

SAQ 7

1. Give two resemblances between *Ephedra* and *Gnetum.*

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2. Why is it said that *Gnetum* approaches angiosperms in some respects? Give two salient features.

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4B.8 SUMMARY

The genus *Gnetum* is widely distributed in the tropical and subtropical parts of the world. Five species occur in India chiefly in Western Ghats and Assam. *Gnetum* resembles more an angiosperm than a gymnosperm. *Gnetum* is dioecious and the inflorescence is either solitary or a fascicled panicle. Both male and female strobili look alike when young, but as the strobili grow the distinction becomes clear. The pollen grains are shed at the 3-celled stage (prothallial, tube and spermatogonous). During megasporogenesis tetranucleate coenomegaspores are produced. The female gametophyte is tetrasporic. Several gametophytes start growing but only 2 or 3 grow beyond 16-nucleate stage. An interesting feature is the absence of archegonia. Usually two free nuclei develop into eggs. In *G. gnemon* two sperm nuclei are released in the surrounding female cytoplasm, each fusing with a separate female nucleus thus causing double fertilization, resulting in two zygotes. After fertilization, only one of the zygotes develops into embryo. Only one or two embryos reach maturity, whereas the rest degenerate. Both simple and cleavage polyembryony are recorded. The seeds are shed at a stage when the embryo is not fully formed. *Gnetum* shares some characters with *Ephedra* and *Welwitschia,* and some characters with angiosperms.

4B.9 TERMINAL QUESTIONS

1. On what basis is *Gnetum* classified as a gymnosperm and not an angiosperm.

2. Is the origin of *Gnetum* well understood or is it still a puzzle? Comment.

3. Describe the megasporangium of *Gnetum* with diagrams.

4. Describe the female gametophyte of *Gnetum*.

5. How does pollination occur in *Gnetum*?

4B.10 ANSWERS

Self Assessment Questions

1) 1. Kerala
   2. moist
   3. reticulate
   4. vessels
   5. laticifers.

2) 1. Please refer to section 4B.3 – Subsection – Shoot apex
   2. Please refer to section 4B.3 – Subsection – Stem
   3. The wood of *Gnetum* is characterised by the presence of vessels and a single pore on their walls.

3) 1. In *Gnetum* archegonia are absent but when pollen tube makes contact with the female gametophyte, one or more nuclei in the equatorial region of the dialated part become large in size and dense staining. These are the egg nuclei whose usual number is two but, rarely, one or three nuclei may also develop into eggs.
   2. Please see section 4B.5 Pollination and fertilization.

4) 1. True
   2. True
   3. True
   4. False

5) 1. True
   2. True
   3. False
   4. True
   5. False

6) 1. In *Gnetum* double fertilization occurs resulting in two diploid zygotes. After fertilization each zygote develops into an embryo, but usually only one attains maturity in the seed.
   2. Refer to section 4B.6 – Embryogeny and seed development subsection Embryo development.
   3. See Subection – Embryo development.
   4. Refer to section 4B.6 – Embryogeny and seed development subsection endosperm.

7) 1. Both *Gnetum* and *Ephedra* have
      i) tracheids and vessels in the wood.
      ii) male and female reproductive parts borne on fertile shoots resembling flowers, arranged in compound strobili.
   2. See subsection 4B.8.2 – relationships with angiosperm.

Terminal Questions

1. The *Gnetum* plant externally resembles a typical dicotyledonous plant but there are several differences.
   i) The vessel is present in both angiosperms and *Gnetum* but their origin is different.
   ii) The Tunica Corpus arrangement of shoot apex of *Gnetum* is angiospermous. However, the presence of central mother cells is a typical gymnospermous character.
   iii) Endosperm is also found in *Gnetum* but it is haploid in nature and not triploid as in angiosperms.
   On the above given characters *Gnetum* is classified as a gymnosperm and not as an angiosperm.

2. See section 4B.11 – Relationships Points for reference.
   i) its affinities both with gymnosperms as well as with angiosperms make origin of *Gnetum* as puzzle.

3. See section 4B.4 – Reproductive structure and subsection 4B.4.2 Gametophyte.

4. See section 4B.4 – Reproductive structures and subsection 4B.4.2. Female strobilus and gametophyte.

5. See section 4B.5 – Pollination and Fertilization.

UNIT 5 ECONOMIC IMPORTANCE OF GYMNOSPERMS

Structure

5.1 Introduction
Objectives
5.2 Uses of Gymnosperms
5.3 Timber and its Products
5.4 Non-timber Products
5.5 Pulp and Paper
5.6 Food
5.7 Medicinal and Allied Uses
5.8 Aesthetic Value
5.9 Economically Important Indian Gymnosperms
5.10 Summary
5.11 Terminal Questions
5.12 Answers

5.1 INTRODUCTION

The gymnosperms are an important group of plants that inhabit mostly the temperate areas and the higher elevations in the tropics. The conifers comprise a major component of the forest flora in the northern and southern temperate belts. The timber or lumber industry plays a vital role in the economy of the countries situated in these geographical regions viz. USA, Canada and Northern Europe.

Gymnosperms are put to a variety of uses. Their wood is used in construction, building and furniture. They are also the source of paper and medicines, perfumes, varnishes, oils and edible nuts. Some gymnosperms are important in landscaping and horticulture.

Objectives

After studying this unit you will be able to:

- enumerate the uses of gymnosperms,
- list important species used as timber or for other non timber purposes,
- present a resume of the economically important Indian species and
- mention some of the recent developments regarding utilisation of gymnosperms for their therapeutic value.

5.2 USES OF GYMNOSPERMS

The gymnosperms in general and the conifers in particular are the source of numerous products used in our day-to-day lives. The trees are used to provide timber for building and construction work. They also are a source of numerous products such as resin, rosin, copal, sandarac, fatty oils and essential oils. The newsprint industry owes a lot to the paper obtained from coniferous wood. Seeds of some gymnosperms are edible and plant parts of some others may be eaten raw or cooked. Certain gymnosperms have been known to possess therapeutic properties and now these are being exploited commercially. Last but not the least, it is this very group of plants that is the source of the "Christmas Tree". Used by landscape architects, the gymnosperms are an excellent source of evergreen plants.

We will now present to you a detailed account of their economic importance.

5.3 TIMBER AND ITS PRODUCTS

The term 'timber' refers to trees or wood suitable for building purposes. 'Lumber' is another term that refers to timber but this word is used mainly in America. The gymnosperms, especially conifers, are an important source of timber all over the world. Large tracts of forests in the temperate belts of America, Europe and Australia are comprised of evergreen conifers.

The conifer wood lacks both vessels and xylem fibres, hence it is non-porous and soft. It consists of tracheids, xylem parenchyma and xylem rays. As it lacks fibres it has a higher content of cellulose compared to angiospermous woods and, therefore, it has a softer texture. The coniferous wood is generally straight-grained, light coloured and light-weighted. There is very little difference between heartwood and sapwood. It finds use where great strength and durability are not required. It is valued for furniture making and interior decoration. We shall now discuss some important timber sources in detail.

The common yew, *Taxus baccata*, offers the heaviest wood amongst softwoods. The wood of *Thuja plicata* is one of the most durable ones due to the presence of antibiotics. Hollowed out trunks have been used as canoes.

Taxodium is one gymnosperm that does well in swampy and wet areas. It is useful at places where resistance to decay is more important than strength.

Pine wood is a softwood which is put to a variety of uses all over the world. *Pinus sylvestris* (Scots pine), *P. caribaea, P. palustris, P. contorta* and *P. densiflora,* are some of the commercially important timber trees in America and Europe. The wood is used in construction and carpentary work. Other sources of pine wood are *P. halepensis* (Mediterranean); *P. nigra, P. pinaster* and *P. ponderosa* (N. Europe); and *P. monticola, P. strobus, P. lambertiana* and *P. radiata* (America). *Pinus roxburghii* ("chir"), is one of the most widely used commercial timber of India. It yields a resinous, non-durable and light wood which finds its use mainly in packing cases, construction work, low priced furniture, poles, railway sleepers, truck and bus chassis. *P. wallichiana* ("Kail" or blue pine) is comparatively hard and durable, and put to uses similar to that of "chir".

Box 5.1 : Conifer conservation

The conifers include the world's tallest, oldest and most massive living biological organisms. As a whole, they are, with few exceptions, large statured woody plants providing most of the timber to the world. Much of the world's timber from conifers is traditionally gathered by direct exploitation of entire wild stands of trees. The exploitation is to such a great extent that in Nature their populations have declined drastically, especially in many tropical and southern insular regions of the world. Many of the wild species are slow growing, providing the most valuable timber but little work has been done for replanting the same species and if any replacement is done that too is with a few, introduced fast growing species such as *Pinus* hence now wide spread conifer species are especially of pines. Thus many other localized conifer populations are highly vulnerable and aged specimens, once common, are now rare. A specialist conifer conservation group of the International Union for the Conservation of Nature has been established with its Secretariate at the Royal Botanic Gardens, Edinburgh. Some conservation backup, on an extremely modest scale, can be undertaken in conifers through seed banks and through the establishments of small selections of genetic material under cultivated conditions, sometimes far from the species and original homes. But the slow rates of growth and very great age of some taxa cannot be matched in brief periods of cultivation. Thus successful preservation of whole stands of unfelled wild trees is essential if the greater part of these immensely useful genetic resources are not to be wholly lost for the future.

The wood of spruce (*Picea* sp) is light weight, and straight grained but it is not very durable. The timber has a natural lustre which makes it attractive for plywood and indoor finishing. It is also used for making match boxes. At Christmas time this tree is sold for decoration. The maximum utilization of this wood is for making pulp and artificial fabric pulp. Some of the important species are *P. abies, P. engelmanni, P. glauca, P. mariana, P. rubens, P. sitchensis* and *P. smithiana.* Spruce wood shows spiral thickening on the inner wall of tracheids. These apparently are responsible for giving the wood a resonance that makes it ideal for use as soundboards for violins, pianos and organ pipes.

Larch trees (*Larix sp.*) yield moderately hard and durable wood that can be used even in contact with the ground such as pit props in mines and boat building. Posts of larches are known to last for 20 years or more and are a source of one of the toughest of all conifer woods.

The balsam fir (*A. balsamea*) produces on its bark blisters containing a clear resin which is known as Canada balsam.

There are about 40 species of fir (*Abies*) which are widely used in construction work, plastic and paper industries and as Christmas trees, *Abies alba. A. balsamea* and *A. concolor* form an important timber source in Europe and North America. *A. pindrow* occurs in India but its wood is not very strong or long lasting.

Douglas fir (*Pseudostuga menziesii*) is not a true fir. It grows into giant trees that are second only to the redwoods in size. It is probably the most desired timber tree in the world today. The wood, which is strong and relatively free of knots (because of rapid growth with less branching than most other conifers) is made into heavy plywoods and large beams. It takes paint and polish well.

Coast redwood (*Sequoia sempervirens*) is also prized for its wood, which has certain substances that inhibit the growth of fungi and bacteria. The wood is soft, light in weight, but strong and splits easily. It is a source of excellent timber, but as the species is facing extinction, it is protected in reserves and national parks. It is used for some type of construction, furniture, posts and several other purposes.

The common yew (*Taxus baccata*) yields one of the heaviest softwoods. The wood is used in making bows for archery, candle sticks and curios. As it is very durable, oily and decorative (because of irregular growth rings) it is used in furniture, flooring, panelling, etc.

The wood of *Taxus* has tertiary spiral thickenings on its tracheids which impart elasticity to the wood.

Cedrus deodara, the "deodar" (India) and *C. atlantica* (Algeria and Morocco) are valuable timber trees. The cedar wood is durable, oily and much in demand as the seasoned wood is resistant to insect attack due to the presence of oil. However, it is not suitable for ply wood because of large knots.

Red cedar wood (*Thuja plicata*) is used for pencils as well as for cedar chests, closet lining, fence posts and cigar boxes. The wood is durable due to the presence of certain ingredients that impart weather resistant properties, thus preventing decay. The wood of Eastern white cedar (*Thuja occidentalis*) is pliable, and several native American tribes used it for making canoes. The white cedar is an attractive tree and is grown as Christmas tree in Indian plains.

Agathis australis (Kauri pine) is the chief timber tree of New Zealand. It is the most important conifer of the Southern Hemisphere. *Araucaria* species are important sources of timber in Brazil and Australia.

The dammar tree is also the source of *dammar* and *amber*.

SAQ 1

Match the species given in column B with the uses given in column A.

	Column A	Column B
1.	Non-porous and soft wood	*Picea* sp.
2.	Widely used as commercial timber of India	*Abies* sp.
3.	Wood used in manufacture of sound boards of violins, pianos, etc.	*Pinus roxburghii*
4.	One of the toughtest of all conifer woods	Conifer wood
5.	Mostly used for paper industries or as ornamental plant	*Larix* sp.

5.4 NON-TIMBER PRODUCTS

Besides yielding timber, the wood of conifers is put to a variety of uses.

Resins:

Resins are plant exudates that make the wood resistant to decay. They are insoluble in water but dissolve in organic solvents.

The wood of a large number of conifers shows the presence of resin ducts which yield oleoresin on tapping. An **oleoresin** (pine gum, pine pitch or turpentine) is a mixture of rosin and essential oil. On distillation of turpentine (i.e. crude resin), a brittle resin is left behind called **rosin of gum rosin**. Rosin is also obtained by solvent extraction of old stumps. This is called **wood rosin**. Rosin is used in making varnishes, inks, etc.

Box 5.2 : Turpentine collection

> Turpentine oozes out from the resin canals after cambium layer has been exposed by a cut, and at the same time the development of new ducts above the cut is stimulated. In the species used commercially the ducts are exceedingly large, and there is a heavy production of the oleoresin. Chipping, and re-exposing of the cambium, has to be performed periodically; otherwise the oxidation and crystallisation of the resin would clog the old ducts.

Amber occurs as lumps of translucent material with a yellow tint. Some lumps weigh up to 45 kg.

Copal and **Sandarac** are hard resins which contain very little essential oil. Copal is obtained from living trees as well as fossil state. The most important is **Kauri gum** or **Kauri copal** from *Agathis australis*. It is used for the preparation of lacquers, varnishes and enamels. **Manila copal** is obtained from *A. alba Tetraclinis* and *Callitris* produces Sandarac.

Amber is also a fossil resin secreted by the extinct pine, *Pinus succinifera*. Fossil amber sometimes shows the presence of remains of plants and animals trapped in the resin. It has been reported that the human blood, when kept in an amber container, does not coagulate.

Canada Balsam is the resin obtained from *Abies balsamea*. Its refractive index is near that of glass and it does not crystallize. It is used as a mounting medium for microscopic histological preparations and a cement for lenses in optical work.

Box 5.3 : Resins

> The term resin is a generally used to describe the brittle, glassy, thickened exudate of certain plants. Resins are plant exudates which make the wood resistant to decay. Conifers are amongst the major resin sources of the world. Resins are water insoluble, but dissolve easily in organic solvents. Resins are put to a variety of uses; the superior grade is used in the sizing of paper, as a constituent of varnishes, enamels, plasters, medicines and ointments; the inferior grades go in the making of oil cloth, grease, insecticides, adhesives, plastics, disinfectants, shoe polish, etc. The huge kauri pines (*Agathis*) of New Zealand, which belong to a different family from that of true pines, are the source of a mixture of resin which are used in high-quality colourless varnishes. This was also the resin originally used in the manufacture of linoleum.
>
> In India the tapping of pine trees (*Pinus roxburghii* and *P. wallichiana*) is generally done from March to November. Tapping is done in two ways; (i) light continuous tapping and (ii) heavy tapping. A rectangular piece of galvanized iron is hammered in, to form a "lip" and a nail is driven about 2 cm. below the lip on which the collecting vessel is hung. A channel is made just above the lip and this facilitates collection of the exudate. Every year the channel is increased at its upper end. After 5 years a new face is made on the same tree trunk and the process continues till the complete girth is used. In heavy tapping numerous faces are tapped simultaneously. This is done on trees that are old and earmarked for felling in the future.

Tannins : Tannins are extracted from the bark of some of the tree species of gymnosperms (*Picea, Larix, Sequoia, Tsuga, Araucaria*). Tannins are used in the leather and petroleum industry for dyeing tanning purposes, and in medicine. However, tannins from these sources have as yet not been exploited commercially. The bark of larch and spruce are also used for tanning of leathers.

Miscellaneous Uses : The roots of white spruce are pliable and the split form were used for basket and canoe making by native Americans.

SAQ 2

Fill in the blanks :

1. An oleoresin is a mixture of .... and ....
2. Kauri copal is obtained from ....

3. .... and .... are hard resins which contain very little essential oil.

4. .... is a resin, which is used as a medium for mounting microscopic objects.

SAQ 2

What is resin? Discuss its uses.

....

....

....

....

....

5.5 PULP AND PAPER

Conifers are preferred throughout the world as a source of pulp because of greater average length of their tracheids and large percentage of long tracheids per given volume of wood. The best source is *Picea* which produces wood pulp that is light coloured with low resin content.

Pulp from conifer wood is used world-wide for the manufacture of paper. The newsprint industry is almost entirely dependent on this source. Superior quality writing and printing paper is manufactured from the wood of conifers such as *Picea, Abies, Tsuga, Larix* and *Pseudotsuga.* The chief source for pulp and paper making in North America is white spruce (*Picea glauca*).

Major portion of wood pulp is derived from coniferous wood especially *Picea, Abies* and *Pinus.* Several products such as rayon, transparent and photographic films etc. are also manufactured from wood pulp.

In India, *Picea smithiana, Abies pindrow* and *Pinus roxburghii* provide excellent quality pulp. The wood of *Cryptomeria japonica* yields kraft paper.

5.6 FOOD

The cycads are used as food in many parts of the world. They are eaten as a source of starch which is obtained either from the stem pith or the seed kernels.

Box 5.4 : Sago production

The *Cycas* plants which are nearly seven years old and have not fruited are best suited for stem starch purposes. The plants are cut just before the flush of new leaves and the outermost dry annularly furrowed stem alongwith the fronds are removed. Only the innermost cylindrical axis is used which after drying is made into flour. The starch is converted into spherical granules, called "sago". These granules are passed through sieves to obtain several grades such as 'bullet sago', 'pearl sago', etc.

The starch (popularly known as "sago") is obtained from the stem *Cycas circinalis, C. rumphii, C. revoluta, Zamia* and *Macrozamia.* The pith of *Encephalartos* stem is used for making "kaffir bread" in Africa. Cycads have a toxic principle (cycasin) which is inactivated by heating. Seeds of *Cycas* and *Macrozamia* are eaten in India and Australia, respectively by the tribals.

Roasted seeds of *Araucaria, Ginkgo* and *Torreya* are consumed in Australia, Chile and Japan. Pine seeds have been used for a long time as a food item. In India, too, *Pinus gerardiana* (Chilgoza pine seeds) have been marketed by traders who obtain most of the supply from Afghanistan. The tree grows in the higher altitudes of the Western Himalayas (Himachal Pradesh). In Europe and North America also, edible seeds of pines (*P. pinea, P. cembra, P. pumila, P. edulis, P. parryana, P. monophylla*) are sold as nuts for use in soups, desserts and in the manufacture of candies and confectionary.

Inner soft parts such as phloem and cambium of many conifers have been used as emergency food since time immemorial. The phloem contains sugar that makes it taste sweet. Some N. American tribes ate the material raw. Others dried it and ground it into flour, while others boiled it and stored it as dried strips for use in winter.

The fleshy red aril surrounding the seeds of *Taxus* is sweet and consumed by animals. But the seeds themselves and other parts of the plant are poisonous.

The *Ginkgo* seeds possess fleshy seed coat which has a foul odour but the kernels (starchy endosperm in seeds) are edible. In China and Japan these are widely used either boiled or roasted.

SAQ 4

State whether the following statements are true or false; write T for true and F for false in the given brackets.

1. Pearl sago is obtained from the fruits of *Cycas revoluta.* [ ]
2. The seeds of nearly all the pines are edible. [ ]
3. Aril, seeds and other parts of the *Taxus* plant are sweet and edible. [ ]
4. In India chilgoza seeds are obtained from *Pinus gerardiana.* [ ]
5. The stem starch commonly known as sago is obtained from *Cycas circinalis, C. rumphii* and *C. revoluta.* [ ]

5.7 MEDICINAL AND ALLIED USES

One of the best known medicinally important gymnosperms is *Ephedra.* The alkaloid ephedrine is extracted from the green branches of *Ephedra gerardiana, E. equisetina* and *E. sinica.* Ephedrine is an important ingredient of cough mixtures and nasal drops. It dilates the bronchial tube and also contracts the mucous membrane. Presently all pharmaceutical industry requirements of ephedrine are met from the commercially synthesized alkaloid. Local requirements in indigenous medicine are still fulfilled by using plant extracts.

Taxus (Yew) is used for curing a number of ailments. Leaves of T. *baccata* are used in asthma, bronchitis, epilepsy and indigestion. The plant contains a toxic principle taxine which is an active heart poison. Another important drug presently being marketed is taxol which is obtained from *Taxus brevifolia.* It has been effectively used as an anti-cancer drug (especially against ovarian, breast and colon cancer). As a large number of yew trees are being felled to obtain this drug, efforts are now on to produce the chemical taxol through tissue culture. The alternative possibility of chemical synthesis is also being investigated.

Box 5.5 : Cancer and Taxol

In 1989, at Johns Hopkins Oncology Centre, N.Y. Washington, researchers have reported that ovarian cancers that had not responded to traditional therapies (including, in some case, surgery) had a decrease of 50% or more in the size of their tumors, and one women's tumor disappeared altogether after treatment with taxol – a drug obtained from the bark of the Pacific yew tree (*Taxus* spp.). Pacific yew trees are small and do not occur in extensive stands. They grow very slowly and take nearly 70 years to attain their full size.

Seeds of *Ginkgo biloba* are used in the cosmetics industry in China and Japan. Unripe seeds are collected and the pulp of the seed coat is utilized.

The leaf extract of *Ginkgo biloba* is useful in the treatment of cerebral insufficiency and vertigo. Ginkgolide compounds also antagonise platelet activating factor (PAF) in vertebrate systems.

Cycas seeds are used as an emetic and a cure for boils, and sores. *C. rumphii* pollen is believed to be narcotic. The powdered stem of *C. pectinata* is used as hair wash for diseased hair roots. *Zamia* seeds yield a poisonous substance that acts as a cure for gout and pains. The peculiar odour of *Cycas* male cones drives away bugs and sometimes even rats from fields or stored grains.

Essential oils extracted from conifers are used to some extent in perfumery, or in the preparation of insect repellents, deodorants and certain medicines for skin ailments. The oil from female cones of *Juniperus communis* is used to flavour liquors (gin and other alcoholic beverages). In India, *Cedrus deodara* oil is used in perfumery and soaps. It also serves as an immersion oil for microscopic work.

SAQ 5

Fill in the blanks:

1. The alkaloid .... is extracted from ....
2. The drugs .... is obtained from *Taxus brevifolia.*
3. .... compounds also antagonise platelet deactivating factor (PAF) in vertebrates.
4. .... oil is used in perfumery and soaps.

SAQ 6

Write a short note on Taxol.

....

....

....

....

5.8 AESTHETIC VALUE

The scenic beauty of hill stations can be attributed in large measure to the presence of conifers on the mountain slopes. Their evergreen habit, symmetric growth and tall appearance are a treat to the eyes. Planted as garden or as avenue trees or even as green belts to screen off the sunshine, they are the pride of horticulturists and garden lovers. Pines, cedars, firs, spruces, junipers and hemlock are common planting material where the climate is of the temperate type. Gymnosperms also offer a good source of planting material for developing "Bonsai" plants. This art of dwarfing plants and maintaining them as showpieces originated in Japan; junipers and pines are favourites for this purpose.

As stated earlier in Unit 1, *Ginkgo biloba* (maiden hair tree) is a gift and relic of the past. The plants are extensively cultivated in numerous gardens and arboreta of the world as botanical curios.

Cupressus funebris is generally planted around tombs and religious buildings; *Taxus* is an ornamental and an excellent plant for topiary work. Other conifers commonly grown in gardens are *Biota, Thuja, Juniperus, Araucaria* and *Pinus.*

At the time of Christmas, saplings and branches of *Picea abies* are commonly used in Europe for decoration. In India, it is *Cedrus* and *Thuja* which fulfil this role. In warmer areas (i.e. tropical and sub-tropical) cycads are used as outdoor plants. Their captivating graceful appearance adds to the beauty of gardens in these areas; they are also grown in green houses in the temperate regions.

Miscellaneous Uses – The fossil resin amber is used for beads, ornaments or for carving, making figurines and cigar holders. Portions of amber containing remains of plants and insects are artistically modelled into pendants and show pieces.

5.9 ECONOMICALLY IMPORTANT INDIAN GYMNOSPERMS

One of the most important amongst timber trees of North India is *Cedrus deodara* (deodar or cedar wood). It is the strongest Indian coniferous wood and, when seasoned, it is almost as strong as teak. It is used for making furniture, doors and windows, flooring and also for carving. It is resistant to insect attack due to the presence of oil. The oil extracted from it is used in perfumery and scenting soaps.

Other timber yielding conifers of India are *Cupressus torulosa* (growing in the Western Himalayas) and *Picea smithiana* (the west Himalayan spruce). *Pinus roxburghii* (chir) and *P. wallichiana* (kail) also find extensive use both in cheap quality furniture, construction work and packing cases. The former is also the source of turpentine oil, tar and pitch. The wood of *Abies* is used as timber to some extent.

The seeds of *Pinus gerardiana* yield the edible chilgoza which is sold as a dry fruit.

Extraction of taxol on commercial scale from *Taxus* trees has been taken up on a large scale (See box 5.6) and India is one of the suppliers of raw material.

5.10 SUMMARY

- The gymnosperms are put to a variety of uses. They provide timber, resins, paper and board, edible seeds and some are even the source of medicines.
- The Coniferales are an important source of timber all over the world, yielding wood that is put to a variety of uses all over the world.
- In India *Pinus roxburghii* (Chir) is most widely used as a commercial timber.
- The spruce (*Picea*) is used for making sound boards of musical instruments.
- Coast redwood is also prized because its wood is resistant to bacteria and fungi.
- Resin from pines is the source of turpentine and rosin. Turpentine oil is used as a solvent and rosin is used for making varnishes, ink, etc.
- The major portion of wood pulp for paper production comes from conifers such as *Picea, Abies* and *Larix.*
- The stem starch known as "sago" is obtained from *Cycas.*
- Some species of gymnosperms are medicinally important such as *Ephedra* from which ephedrine is extracted. Another important drug taxol is obtained from *Taxus brevifolia* which is effective against ovarian cancer.
- The evergreen habit, symmetric growth, and tall appearance make gymnosperms aesthetically important. *Cupressus, Juniperus, Pinus, Taxus, Ginkgo, Thuja* and *Araucaria* are commonly grown in gardens.
- Conifers are widely used for commercial purpose and exploitation to such a great scale that several species are becoming endangered. A specialist conifer conservation group has been formed to protect wild conifer forests.

5.11 TERMINAL QUESTIONS

1. Enumerate the uses of gymnosperms.

....

....

....

....

2. What is resin and what are its sources ?

....

....

....

....

....

3. Write a short note on cancer taxol.

....

....

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....

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4. Give the names of the major conifers that are a source of timber in India.

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....

5. Why is the newsprint industry largely dependent on the conifer wood?

....

....

....

....

....

6. Write a short note on the aesthetic value of gymnosperms.

....

....

....

....

7. If money is not a constraint and you wish to make a dream landscape, what type of gymnosperms you would choose and why?

....

....

....

....

5.12 ANSWERS

Self-assessment Questions

1) 1. c
   2. c
   3. d
   4. a
   5. f
   6 g
   7 e

2) 1. rosin, essential oil
   2. *Agathis australis*
   3. Copal and Sandarac
   4. Canada Balsam

3) See section 5.4.

4) 1. T
   2. T
   3. F
   4. T
   5. T

5) 1. *Ephedrine; E. gerardiana*
   2. Taxol
   3. Ginkolide
   4. *Cedrus deodara*

6) refer to section 5.7

Terminal Questions

1) Make a list of uses of gymnosperm and write few lines on each.

2) Please refer to section 5.4 and Box 3.

3) Please refer to the section medicine and allied use and Box 4.

4) See section 5.3. Timber and its products.

5) See section 5.5 pulp and paper.

6) See section 5.8. Aesthetic value.

7) You should make a list of the gymnosperms you will like to plant, and then make a rough sketch keeping in mind the following points (1) climate (2) arrangement the gymnosperms according to their (a) height, (b) leaf structure (c) branching.

   The answer will differ from person to person.

GLOSSARY

Albuminous Cell : Parenchyma cells associated with sieve cells in gymnosperms.

Bulbil : A fleshy, axillary bulb-like structure that develops above ground, and functions in asexual reproduction.

Dichasial cyme : A cymose inflorescence in which two lateral branches occur about at the same level.

Dioecious : Having male and female reproductive organs on different plants.

Ectomycorrhizae : In the ectomycorrhizae the fungus produces mycelium on the root surface. The hyphal strands penetrate the root between the cortical cells and form there a net.

Endoscopic embryogeny : In plants, the condition when the apex of the developing embryo points towards the base of the archegonium.

Exoscopic embryogeny : In plants, the condition when the apex of the embryo gets turned towards the neck of the archegonium.

Extinct : The worldwide disappearence of a specific organism or a group of organisms.

Manoxylic : Stems with scanty amount of xylem.

Megasporophyll : Leaf-like structures bearing megasporangia.

Mesozoic : A geological era beginning 225 million years ago and ending 65 million years ago.

Micropyle : A pore leading from the outer surface of the ovule between the edges of the integuments down to the surface of the nucellus.

Microsporangium : A sporangium that bears microspores.

Microsporophyll : Leaf - like structures bearing microsporangia.

Monoxylic : Having one ring of vasculature.

Nucellus : Tissue composing the chief part of the young ovule in which the embryo sac develops.

Polyarch : Stele having many protoxylem steles.

Polyxylic : Having several rings of xylem formed as a result of accessory rings of cambia.

Rachis : The central petiole of a compound leaf.

Xeric : A plant that normally grows in dry habitats.

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Uttar Pradesh
Rajarshi Tandon Open University

UGBY -02
PLANT DIVERSITY-II

Block

2

FLOWERING PLANTS

UNIT 6

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UNIT 7

Tissues 23

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Root, Stem and Leaf 57

UNIT 9

Flowers, Fruits and Seeds 117

UNIT 10

Pollination Biology 155

BLOCK 2 FLOWERING PLANTS

Unit 6, entitled 'Introduction to Angiosperms' deals with the flowering plants which are today the dominant plants on earth. These plants are distributed all over the earth and meet much of the ecological and economic needs of mankind. The unit gives you a glance at the general characters of angiosperms that include features such as presence of flowers, evolution of vessels and sieve tubes, seeds enclosed in fruit and double fertilization. The angiosperms are adapted to grow in diverse habitats such as deserts, mountains, wetlands and mangroves. They possess effective methods of pollination and seed dispersal with the help of wind, water, insects, birds and other animals. The angiosperms originated in the cretaceous, probably from some now-extinct gymnosperms. They evolved rapidly thereafter. The unit tells you about the major groups of angiosperms and their basic characteristics.

Unit 7, entitled 'Tissues' deals with the fundamentals in plant anatomical studies. In this unit, three basic categories of tissue types composing the body of the angiospermous plants are discussed. These are – the meristems, mature tissues, and the epidermal tissue system. Each of these categories is further subdivided into subcategories, for instance, meristems is divided into apical, lateral and intercalary meristems and so on. Diagnostic features of each of these tissue types, along with their common variant forms, and their functions are dealt with in detail. While some of these tissues, e.g., parenchyma and its variants, may be found throughout the plant body, but some tissues such as the ones comprising the apical meristems, are located at restricted sites only. This aspect needs to be marked, and clearly comprehended – as this is the underlying theme of this unit.

Unit 8 deals with the morphological and anatomical details of root, stem and leaf. The stem and leaf constitute the shoot and they both develop from shoot apex. The connection and mutual dependence between these two organs exist throughout the life of the plant. The root usually develops below the soil surface; some times roots grow in air too and stem below the ground but the basic difference in the development and arrangement of primary tissue in root and shoot are always distinguishable.

Unit also deals with various specialized forms of root, stem and leaf which are due to their various functions or environmental conditions. The anatomical details of root, stem and leaf and also the difference between monocot and dicot stem are also given in the unit.

Unit 9 deals with the formation of flower, fruits and seeds. Flower or inflorescence is a modified shoot apex which shows considerable diversity in relation to the mechanism of pollination. The reproductive apex is surrounded by meristematic cells which develop into various floral parts. This unit also deals with the genesis of floral parts (sepal, petal, stamen and pistil) in detail. Fruits their classification, types, development and abscission is discussed in light of morphogenesis.

Apomixis, parthenocarpy and pathenogenes can be exploited for human needs. Diversity in seed forms, seed appendages are also given in detail.

Pollination constitutes a very intricate, highly specific, and dynamic phase of the sexual reproduction in flowering plants. Different plant species have developed and perfected as many pollination strategies over their evolutionary histories. Each of these ways of pollination is not only important to the species involved, but it also constitutes a very interesting and intriguing area for academic pursuit. In Unit-10, 'Pollination Biology' we have taken up for discussion, few such ways of pollination practiced by different groups of plants, that are fairly well known to us. Our intention here is to make you aware of the lots of 'give and take' between the pollinator and the plant, as well as other interesting biological facts relating to this very essential process in the reproductive cycle of the flowering plants.

UNIT 6 INTRODUCTION TO ANGIOSPERMS

Structure

6.1 Introduction
    Objectives
6.2 General Characters of Angiosperms
6.3 Distribution and Diversity of Flowering Plants
6.4 Plant Habit
    6.4.1 Adaptation to diverse habitat
    6.4.2 Adaptation in leaves
    6.4.3 Adaptation in stems
    6.4.4 Modifications of stem, root and leaf
6.5 Vascular Tissues in Angiosperms
6.6 Reproduction in Angiosperm
6.7 Dispersal of Fruit and Seed
6.8 Plant Defence
6.9 Origin of Angiosperms
6.10 Classification of Angiosperms
6.11 Autotrophic and Heterotrophic Plants
6.12 Insectivorous Plants
6.13 Ecological Value of Plant Diversity
6.14 Economic Importance
6.15 Focus of Research in India in Angiosperms
6.16 Summary
6.17 Terminal Questions
6.18 Answers

6.1 Introduction

In Block I you have studied about gymnosperms in detail. You will recall that the gymnosperms have seeds borne naked on megasporophylls that are mostly arranged in cones. This block and coming blocks are wholly devoted to angiosperms. In this Unit of Block II you will be studying about angiosperms, which have flowers and in which seeds are enclosed in a carpel or fruit. The angiospermae (angio = a box or case; sperma = semen or seed) are also known as Anthopsida (antho = a flower or a bright colour) or Magnoliopsida.

The angiosperms are the youngest of the major plant groups, having evolved or diversified 141-65 million years ago. Yet, now they are the largest class of plants with 13,000 genera and 2,40,000 species (Takhtajan, 1980). Flowering plants dominate the earth and are the most significant organisms in maintaining the life support system on earth. They also fulfill most of the economic needs of mankind.

Angiosperms vary in size from tiny duckweeds such as *Lemna* and *Wolffia* (2mm across) that float on water to huge trees like banyan, *Ficus benghalensis* and eucalyptus (almost 100 m tall). They grow in warm tropics and temperate mountain tops, deserts and in water. In fact, they occupy every nook and corner of earth except the arctic zone. They are most easily recognised by their flowers which consist of sepals, petals, stamens and carpels. Flowers which are pollinated by insects or birds are large, ornamental and sometime even fragrant. On the other hand, flowers pollinated by wind or water are small with inconspicuous sepals and petals. Angiosperms can also be recognised by their net-veined leaves and by their characteristic fruits which enclose the seeds. The fruit, which may be dry or fleshy, is adapted to protection and effective dispersal of seeds at the appropriate time.

As compared to gymnosperms, the flowering plants are endowed with more efficient systems of conducting water and food. While in gymnosperms the xylem generally has only tracheids for conduction of water, in angiosperms vessels are also present which form perforated tubes capable of faster conduction. In gymnosperms the phloem has sieve cells which are interconnected laterally by sieve areas with narrow apertures. Phloem in angiosperms has, in contrast, sieve tubes having sieve elements arranged end-to-end, separated by sieve plates having wide pores through which food can get translocated much faster. These factors have helped angiosperms in becoming the dominant plants on earth.

The angiosperms are not only the most widespread, varied and spectacular group of plants, but these are also economically and ecologically the most important. Most of the food, fibres, drugs, medicines, essential oils, tannins and dyes, timber and firewood, and a variety of other products used by man are derived from angiosperms. The flowering plants clothe the earth and help in sustaining and building up the soil, water and air resources. The rich diversity of animal life, particularly the insects, birds and mammals, has co-evolved and is dependent on angiosperms for its survival. According to famous plant taxonomist Arman Takhtajan "in the final reckoning the dominance of flowering plants made possible the appearance of man".

In this Unit we shall give you an overview of angiosperms. Later in Block III A, III B and IV, you will study more about these plants.

Objectives

After studying this unit, you should be able to:

- describe the general characters of angiosperms,
- explain their distribution and diversity,
- describe their anatomical and reproductive features,
- distinguish their structural modifications,
- enumerate the economic and ecological significance of angiosperms.

6.2 GENERAL CHARACTERS OF ANGIOSPERMS

The angiosperms are a large and varied group, with its members occupying diverse habitats and differing in details of their morphololgy, internal structure, metabolism and life cycle. However, they share certain characters in which they are different from other plants. These peculiar features not only define the group, but also explain its extraordinary success.

The presence of vessels, with perforated water conducting elements arranged end to end to form long tubes, in xylem of angiosperms helps in efficient conduction of water. The phloem, having sieve tubes consisting of interconnected sieve elements arranged in straight rows, provides an efficient mechanism for conduction of food. More efficient xylem and phloem have helped angiosperms in attaining greater dimensions through faster growth. Because of these features angiosperms were able to develop broad leaves which can photosynthesis, more efficiently while keeping themselves cool through evapotranspiration.

The flower is the most distinct characteristic of the angiosperms. The gymnosperms usually have distinct male and female strobili or cones. The male strobilus has microsporophylls, each with a variable number of microsporangia on its abaxial surface. Megasporophylls, which may or may not be in cones, bear one to many naked ovules. In contrast, a flower has accessory whorl(s) of perianth (sepals and petals) surrounding the stamens, each with 2 or 4 microsporangia, and carpel(s) enclosing one to many ovules.

In gymnosperms pollination, transfer of pollen grains from microsporangia to megasporophylls, occurs by wind. In angiosperms, on the other hand, transfer of pollen grains from the stamens to the carpels is carried out by wind, water, insects, birds or bats. In wind-pollinated flowers, like those of mulberry, the flowers are small with inconspicuous perianth. However, in animal-pollinated flowers the perianth is ornamental and often even fragrant. Flowers of rose, for example, are both beautiful and fragrant. Flowers of mustard, salvia or of the orchids have distinct symmetry, texture and colour which attract insects such as bees and butterflies. These flowers offer nectar as a reward to the animal pollinators. Differentiation of the carpel to form a stigma for receiving the pollen grains, an extended style and an ovary which encloses the ovules help in protection of the seeds from damage by pollinating organisms.

In angiosperms the pollen tube brings two male gametes to the female gametophyte or embryo sac. One gamete fuses with the egg to form the zygote, which give rise to the embryo. The other gamete fuses with the polar or central cell nuclei of the embryo sac to form the nutritive tissue endosperm. The process is known as double fertilization. Thus, unlike in gymnosperms, endosperm is formed only if the embryo sac is successfully fertilised to form the embryo. Double fertilisation has contributed to efficiency and economy of the reproductive process in angiosperms.

In angiosperms, the fruit, which encloses the seeds, has diverse mechanisms for effective dispersal of the seeds. Fruits of balsam, *Impatiens balsamina* and spurges, *Euphorbia* spp. open violently and throw away the seeds some distance away. Some fruits or seeds are carried to distances by wind, water or animals. For example, fruit of coconut, *Cocos nucifera* can travel in sea water hundreds of kilometers with the seed inside intact. Fruits of mistletoe, *Viscum album* are carried by birds. Tiny seeds of orchids are blown by wind. Many seeds have hairs, as in milkweed *Calotropis procera*, or wings as in drumstick, *Moringa oleifera*, with the help of which they fly some distance in the air. Seeds of litchi, *Litchi chinensis* have a sweet white aril surrounding the hard, brown seed. The hard seed of castor, *Ricinus communis* has a soft, collar-like food-ladden outgrowth called caruncle. Such seed appendages help in dispersal by animals which consume the soft portion and discard the hard seed. Dispersal of fruit or seed far away from the parent plant provides better and less competitive conditions of germination of seed.

Takhtajan (1969) has pointed out great uniformity among angiosperms in at least seven characteristics – (1) staminal structure, (2) **carpels with style and stigma,** (3) constancy of relative position of **gynoecium** and **androecium** in the flower, (4) three-nucleate pollen tubes, (5) characteristic female gametophyte with egg flanked by **synergids** and lacking an archegonium, (6) **the double fertilization** process, and (7) presence of sieve tubes. To Takhtajan's list may be added the following unique characteristics of angionsperms: (8) development of the embryo within a closed carpel well protected from the effects of drought, low humidity, and small herbivorous animals; (9) leaves having three or more orders of branching of the veins; (10) pollen grains (microspores) characterized by well-developed, usually reticulate, **exine sculpturing** and presence of columnar structure; (11) well-developed phloem with sieve tubes; and (12) the replacement of tracheids in the xylem by vessels and fibers. These features are almost completely limited to the angiosperms, and all are consistently observed throughout the class.

SAQ 1

Give any five differences between Angiosperms and Gymnosperms.

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6.3 DISTRIBUTION AND DIVERSITY OF FLOWERING PLANTS

The angiosperms are cosmopolitan in distribution. They occur on beds of sea, rivers and lakes, high mountains and even deserts. Extreme xerophytes such as *Opuntia*, cacti and *Euphorbia* spp. are tolerant of dry conditions and can grow where rainfall is scanty. Species of *Sedum* and *Crassula* grow on exposed rocks. Among hydrophytes are plants like *Hydrilla verticillata* and ribbon-weed *Vallisneria spiralis* which are submerged in water, and horned water chestnut, *Trapa bispinosa* and water hyacinth, *Eichhornia crassipes* which are free floating. Members of family Podostemaceae grow on rocky substrata under rapidly flowing water. Mangrove plants such as *Rhizophora* and *Avicennia* grow in saline water of estuaries along the sea coast. A large number of angiosperms are epiphytic, i.e. they grow or trunks of other trees as support. Among these are orchids such as *Vanda.*

In a forest one can see several strata of trees of different heights, a number of climbers and epiphytes, and a rich diversity of shrubs and herbs on the forest floor. The streams and wetlands have hydrophytes, while the banks and shaded areas have mesophytes such as species of *Polygonum, Ranunculus* and *Oxalis*. Thus, every corner of land or water is occupied by angiosperms.

6.4 PLANT HABIT

The angiosperms display a wide variety in their size, form and morphology. Many of them are annual plants which complete their life cycle within a year. These include the grasses, among which are important crops like wheat and rice, and horticultural species such as nasturtium, *Tropaeolum majus* and candytuft, *Iberis amara.* Carrot (*Raphanus sativus*) is an example of a biennial plant which flowers and completes its life cycle in two years. Shrubs such as milkweed, *Calotropis procera* and oleander, *Nerium indica*, and all trees are perennial. These grow continuously and flower once or more every year. Indian silk cotton tree, *Bombax ceiba* and laburnum, *Cassia fistula* flower once every year. Mexican cotton, *Chorisia speciosa* flowers twice a year. Perennials include plants such as ginger, *Zingiber officinale* and saffron, *Crocus sativus* which perennate through underground rhizomes or corms.

Banana should be described as a perennial herb because its underground rhizome sends out many pseudo-trunks (made up by folded leaf bases) each of which flowers and fruits only once. The bamboos spread vegetatively through the rootstock and flower once in several years.

6.4.1 Adaptation to Diverse Habitat

You would have noticed that many gymnosperms, specially the conifers, occur on mountain slopes and cool climates. In contrast, angiosperms are common in a wide range of habitats. The plant body shows various adaptations to the habitat, but it has the same basic features. Buried in the ground is the root system which descends vertically downward because of the positively geotropic nature. The main root which is formed by extension of the radicle of the embryo is termed primary root or tap root, while the branches are designated as secondary or tertiary roots. Root hairs on the fine branches are mainly responsible for absorption of water. Most of the trees have a deep tap root system, but many plants in the dry region have a network of branches in the superficial soil too. While the main root absorbs water from the deep soil, the superficial roots rapidly absorb water when it is available following rainfall. Monocots such as the grasses lack a well-developed primary root system. New roots arise near the base of the radicle and are termed seminal roots. Later more roots arise from the base of the plumule or from the lower nodes. These are termed fibrous roots. The adventitious roots, which arise from places other than the radicle, are also active in absorption of water.

Xerophytic plants, which are adapted to grow in dry places such as deserts (e.g., cactus and *Opuntia*), generally have well-developed root system. However, hydrophytes or the plants growing in water (e.g., *Hydrilla*) possess a poor root system or the roots are altogether absent as the plant can absorb water all over the surface.

6.4.2 Adaptation in Leaves

Angiosperms usually have prominent leaves. The size of the leaves varies from a few millimeters (e.g., *Euphorbia prostrata*) or centimeters (as in sacred basil, *Ocimum sanctum*) to a few metres (as observed in banana, *Musa paradisica* and oil palm, *Elaeis guineensis*). Leaves are so arranged on the branches that maximum light can be trapped for photosynthesis. The leaves may be simple, with a single lamina (as in banyan, *Ficus benghalensis*), but many angiosperms such as rose, neem and wattle have compound leaves in which the lamina is segmented into small leaflets. The arrangement of leaves is also variable in each species. It can be whorled (many leaves on each node), spiral (leaf at each node at an angle of 90° on successive nodes), opposite (two leaves at each node at an angle of 180°) or alternate (one leaf at each node at an angle of 180° at successive nodes). The leaves are sessile or with a petiole whose size varies in different species.

In xerophytes the leaves are reduced to scales (as in *Casuarina equisetifolia*) or sometime modified to spines (as in *Opuntia*). The leaf surface often has a thick cuticle, luxuriant growth of hairs and wax to cut down on loss of moisture. In the plants of dry habitat stomata are confined to lower surface of leaves and are modified in various ways so that minimal water is transpired while the gaseous exchange goes on. Many xerophytes have ability to store water in thin-walled tissues of the succulent leaves (as in *Kalanchoe* spp.) or stem (as in *Opuntia*).

The hydrophytes which are only partly submerged in water have narrow lobed or arrow-shaped leaves (e.g., arrowhead, *Sagittaria*). Those which are anchored on the lake or river bed and remain submerged in water have small, narrow and ribbon-like leaves (e.g., *Hydrilla* and *Vallisneria*). Many hydrophytes are anchored but their broad leaves float on surface of water (e.g., *Trapa bispinosa* and water hyacinth, *Eichhornia crassipes*). Tiny leaves of *Lemna paucicosata* can be seen forming a mat on water surface. The floating leaves are broad to gain buoyancy. An important characteristic of the hydrophytes is that they have air cavities in their root, stem and leaves which make them light enough to float and carry out gaseous exchange even inside water. Since light is cut off as it traverses down water, submerged aquatic plants have their chloroplasts concentrated in superficial cell layers for more efficient photosynthésis.

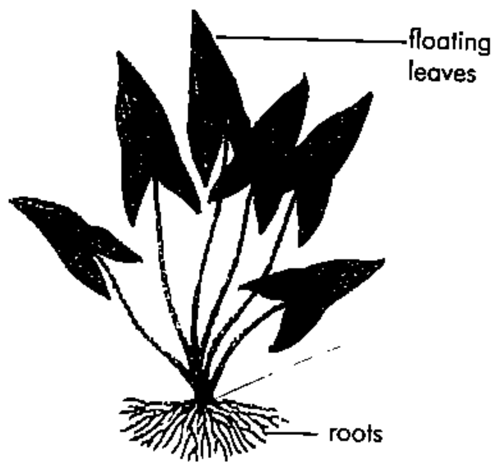

Fig 6.1: Arrowhead (*Sagittaria*) a primitive monocot class Liliopsida in the Subclass Alismatidae.

6.4.3 Adaptation in Stems

In most angiosperms the stem is erect, growing with a short meristem which is more complex than in gymnosperms. The tip of the shoot apical meristem has the ability to form an inflorescence or flower after a certain period of vegetative growth and in response to certain environmental conditions. The axillary buds cut off from the meristem form lateral branches which spread out for maximum exposure of leaves to sunlight. In a forest many plants climb around shrubs and trees and expose their own leaves over the canopy of the host. Palay rubber, *Cryptostegia grandiflora* and *Tinospora cordifolia* are good examples of such biomes. On the other hand, cucurbits such as bitter gourd and pumpkin have weak stem which can trail or climb on support with the help of tendrils.

In the xerophytes which have reduced leaves, the stem is itself green and photosynthetic as in *Capparis* and *Casuarina*. In *Opuntia* and many species of *Euphorbia* too much of the photosynthesis is carried out by stem, which is succulent due to presence of water-storage cells. Submerged hydrophytes too have narrow leaves and their green stems supplement the photosynthesis carried out by the leaves.

There are several small, soft annual plants such as green gram, *Cicer arietinum* and buttercup, *Ranunculus scleratus* which are designated as herbs. Several others belong to the category of shrubs, which are medium sized, with a hard trunk but soft branches. These include 'curry-patta', *Murraya koenegii* and *Salvadora persica*. Trees are tall, with hard trunk and branches. Some species of *Eucalyptus* extend up to a 100 meter. The tree of banyan, *Ficus benghalensis* spread very wide, sending down aerial roots from the lateral branches which provide additional support to the tree.

In a forest herbs, shrubs and trees of various height form foliage at various levels so that several species can grow in an area and maximize photosynthetic productivity.

6.4.4 Modifications of Stem, Root and Leaf

Usually the stem is erect and its branches bear the leaves. The stem supports the aerial system and transports food and water through its phloem and xylem. However, in many angiosperms the stem is variously modified for perennation, propagation and storage of food material. Whatever the modification, the stem is recognizable by its distinct nodes and internodes, anatomy and presence of scale leaves and adventitious roots at the nodes.

Many creeping plants such as *Oxalis corniculata* and *Hydrocotyle asiatica* have special branches called runners which carry the buds in all directions from the mother plant. Thus, a single plant soon extends over a large area. In *Mentha* spp ordinary branches arch down and enter the soil where daughter plants are formed. These are termed stolons. When an underground runner, or an axillary bud arising from its node, turns upward and forms a daughter plant it is called a sucker. Suckers are observed in *Chrysanthemum*.

In many angiosperms the stem is modified for storage of food material. In ginger, *Zingiber officinale* and turmeric, *Curcuma domestica* the edible part is the fleshy, much-branched stem which serves as an organ of perennation. Adventitious branches from underground part of the stem in potato, *Solanum tuberosum* swell at their tips to form tubers that store food, mostly in the form of starch. In saffron, *Crocus sativus* and gladiolus the perennation occurs with the help of corms, which are solid lower parts of the stem, each with a large apical bud. The corm is covered with small scale leaves and from its lower end arise adventitious roots. Another modification of stem is observed in onion, *Allium cepa* and tuberose, *Polyanthes tuberosa*. These plants have a bulb in which the stem is reduced to a disc-like structure with fleshy scale leaves growing from it. At the apex there is a bud from which a flowering scape develops in the appropriate season. Daughter bulbs or cloves develop from the mother bulb which serve as very effective means of vegetative propagation.

In many angiosperms the leaf shows modifications which are primarily meant to reduce the loss of moisture or for storage of water. In *Opuntia* and *Berberis* the leaves are modified into spines for protection and reduction in loss of water. In many xerophytes and halophytes, such as the species of *Kalanchoe* and *Sedum*, the leaves are fleshy because of storage of water. In climbing plants such as *Lathyrus odoratus* the leaf lamina is modified to form tendril which helps the plant climb over support.

Roots of angiosperms are often modified for diverse functions. Banyan tree, *Ficus benghalensis* has prop roots which hang down from horizontal branches of the stem and eventually provide support to these branches like pillars. Maize, *Zea maize*, screwpine *Pandanus foetidus* and many mangroves such as *Rhizophora* have stilt roots arising from the lower nodes which grow obliquely downward into the soil and firmly anchor the stem. Mangrove plants that grow in waterlogged soil have respiratory roots or pneumatophores, which grow vertically upward and carry out gaseous exchange. Roots in many plants store food material. Such storage roots are observed in raddish, carrot and beetroot. The reserve food is usually utilized by the plant during flowering and fruiting. The details of modification you will study in unit 8.

SAQ 2

Match the words given in column B with names given in column A.

	A		B
a)	*Cassia* sp.	(i)	Perennate through underground rhizomes or corms
b)	*Crocus sativus*	(ii)	Flowers twice a year
c)	*Chorisia speciosa*	(iii)	Perennial
d)	*Raphanus sativus*	(iv)	Biennial
e)	*Nerium indica*	(v)	Flowers once a year

SAQ 3

List the modifications that take place in the leaves of hydrophytes.

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SAQ 4

Fill in the blank with proper word/words

i) In a modified stem we can recognize the stem by presence of .... and ....
ii) In...................spp. where ordinary branches arch down and enter the soil to form the daughter plants are called...................
iii) Chrysanthemum is a good example of ....
iv) In.................. ....food is stored in form of ....
v) In.................. ....the leaf lamina is modified to form............... .
vi) Mangrove plants that grow in water logged soil have..............or...............

6.5 VASCULAR TISSUES IN ANGIOSPERMS

A major factor responsible for success of angiosperms on earth is considered to be their more efficient mechanisms for transport of water and food. In gymnosperms, barring the more advanced Gnetales and Welwitschiales, water is mainly conducted by tracheids which are perforate xylem elements connected to each other laterally by pits. On the other hands, angiosperms have vessels in which several vessel members are arranged in vertical rows connected with wide perforations. Because of the more efficient conduction of water by vessels, angiosperms grow faster and taller in diverse habitats.

The phloem, which conducts food from the leaves to other organs where it is utilized or stored, is also more evolved in angiosperms. Gymnosperms have sieve cells which are connected to each other by lateral sieve areas having minute pores through which food can be transported only at a slow pace. Angiosperms, on the other hand, have sieve tubes in which the sieve tube members are arranged end to end in long files separated by sieve plates with wide pores. The sieve tubes have live companion cells which assist in more efficient conduction of food material. This will be dealt in detail in unit 7 of this block.

The gymnosperm wood has tracheids which not only conduct water but also provide strength to the organ. In angiosperms the composition of xylem is more complex. The tracheids have given rise to vessels for conduction of water, and to fibers for support and strength. Fibers have thicker walls, narrow lumen and pits are reduced or absent. Because of fibers, wood of angiospermous trees has a hard texture and greater tensile strength.

SAQ 5

Differentiate between vascular tissues of Angiosperms and gymnosperms.

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6.6 REPRODUCTION IN ANGIOSPERM

Angiosperms owe their dominance on earth to a considerable part to their mechanism of reproduction. The detail of reproduction in angiosperm is given in Unit 9 – Flower, Fruit and Seed. Unlike gymnosperms, which have cones, the angiosperms have flowers that display far more diversity and adaptations. A flower has accessory outer whorls called sepals and petals. These enclose the fertile parts, the stamens and carpels. The number, arrangement, size and shape of sepals, petals, stamens and carpels are variable. The sepals and petals may be small or inconspicuous as in the grasses, amaranths and mulberry. In *Euphorbia* spp. the male flower has only one stamen and the female flower has only one pistil; the sepals and petals are absent. However majority of angiosperms have large and conspicuous petals as in *Petunia*, rose and cotton. The flowers are essentially modified in relation to the mode of pollination.

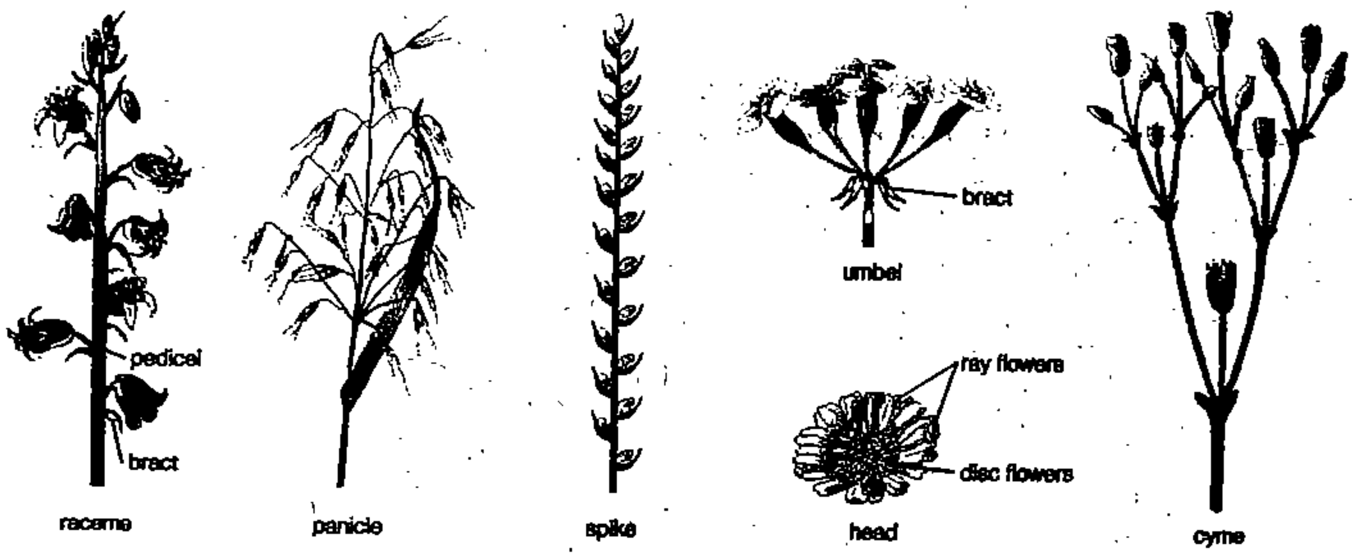

Fig 6.2: Types of inflorescences.

The stamens bear anthers which produce the microspores or pollen grains. The pollen grains in angiosperms represent the much reduced male gametophyte, having a vegetative cell and a generative cell. The latter divides to produce two sperms or male gametes.

In the primitive angiosperms, such as the members of Magnoliaceae and Ranunculaceae, the stamens and carpels have a leaf-like appearance. However, in all other angiosperms the stamen is differentiated into filament and anther. A flower has one or many, but usually 3-5, free or fused stamens. The carpels are also one to many, but usually up to five and fused to form a single multicarpellary pistil. The pistil is differentiated into an ovary, style and stigma. The ovary encloses one or more ovules. The structure of the ovule is similar to that of gymnosperms except that in angiosperms the integuments may be one or two. Meiosis occurs in the megaspore mother cell in the nucellus of the ovule to form a haploid embryo sac. The embryo sac represents the highly reduced female gametophyte. It has an egg, two synergids, a central cell with two polar nuclei and three antipodal cells.

Flowers pollinated by abiotic agencies such as wind and water have inconspicuous sepals and petals, but they produce a huge quantity of small and smooth-walled pollen grains. The stigma is prominent, sometime feathery as in the grasses, in order to trap pollen grains. Flowers pollinated by day insects such as bees and butterflies have bright and showy flowers, often with fragrance (as in rose) or with bisymmetrical shapes similar to insects (as in legumes and orchids). Flowers pollinated by nocturnal insects like moths have a strong scent as in the queen-of-the night, *Cestrum nocturnum*. Bird-pollinated flowers, such as those of Indian silk cotton, *Bombax ceiba* and 'dhak', *Butea monosperma* are large, cup-shaped and brightly coloured. Flowers pollinated by biotic agencies such as birds and insects offer nectar as reward to their pollinators. Usually animal-pollinated flowers have a large number of ovules and seeds in each ovary (as in tomato, pumpkin and poppy) as the same crawling or flying individual can bring in a large number of pollen grains, which are large, sticky and variously sculptured.

Pollen grains germinate on the stigma to form pollen tubes which grow through the styles to reach the ovule(s) in the ovary. Receiving the pollen grains on the stigma separated by the style not only protects the ovary, but it has enabled the angiosperms to develop a mechanism for recognition of the desired pollen, so that only pollen grains of the same species can germinate on the stigma of a flower. A pollen tube enters the ovule through the micropyle and finds its way into one of the two synergids that flank egg in the embryo sac. The pollen tube discharges both the male gametes or sperms in the penetrated synergid. From the synergid one gamete enters the egg and fertilizes its nucleus to form the diploid zygote, while the other fuses with the central cell nuclei to form the triploid primary endosperm nucleus. This process of double fertilization is unique to angiosperms. The zygote divides mitotically in a particular pattern to form the embryo, which forms the next generation of sporophyte. The primary endosperm nucleus divides repeatedly to form endosperm which stores food for nutrition of the embryo in the seed. In gymnosperms endosperm with stored food develops even when no embryo is successfully formed in a seed. In angiosperms endosperm is formed only if the egg is fertilized and an embryo is formed in the seed. Because of the resulting economy, many angiosperms produce seeds in far more profusion than gymnosperms.

Pollination of stigma activates the ovary to form a fruit, while double fertilization leads to development of the ovules into seeds. The fruits and seeds in angiosperms are variously adapted to fulfill the two major requirements of protection and effective dispersal of the embryo. In many plants, such as almond, coconut and groundnut, the fruit wall is hard but the seed coat is thin and soft. In the fleshy fruits like tomato, sapodilla and guava the fruit is soft and pulpy but the seeds inside are hard. The embryo is, therefore, well protected and insulated against the vagaries of nature till such time when the seed can germinate and embryo can grow to form a new plant.

SAQ 6

Describe the features of wind pollinated flower.

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SAQ 7

List the features of the flowers which help in attracting the pollinators.

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6.7 DISPERSAL OF FRUIT AND SEED

You will recall that in gymnosperms the seed dispersal occurs by wind. In some gymnosperms the seed has wings with the help of which the seed gets carried away to some distances. In angiosperms the fruits and seeds have diverse mechanisms for dispersal over large areas.

The capsule of poppy has a long stalk on which the fruit swings with the wind discharging tiny seeds in all directions. In balsam, *Impatiens* spp. the five carpels of the cylindrical capsule separate and curl inward with a jerk throwing the seed two metres away. Many fruits and seeds are dispersed by wind. Orchids produce seeds in millions which are dispersed by wind. Many fruits (e.g., *Acer* spp) and seeds (drumstick, *Moringa oleifera*) have wings. Seeds of Indian silk cotton, *Bombax ceiba* and of the milkweed *Calotropis procera* have hairs with which the seeds are blown far away. Plants growing in or near water bodies often utilize water as an agency for dispersal of seeds and fruits. Coconut, *Cocos nucifera* is an excellent example of a fruit which has spread to coastal areas of different continents because of its ability to float over hundreds of kilometers. Many fruits and seeds are carried by animals. Plums, grapes, figs and guava are examples of fruits eaten by birds. The seeds ready for germination are expelled with the droppings at places suitable for growth. Many composites such as *Bidens* spp and cocklebur, *Xanthium strumarium* have hooks or prickles with which the fruits stick to furred animals and get distributed over a large area. The fleshy aril which cover the seeds litchi, *Litchi chinensis* and the leguminous tree *Pithecellobium dulce* is consumed by birds which discard the hard seed. The seeds of castor, *Ricinus communis* have a collar-like caruncle at one end. Ants consume the food-rich caruncle and in the process disperse the seed.

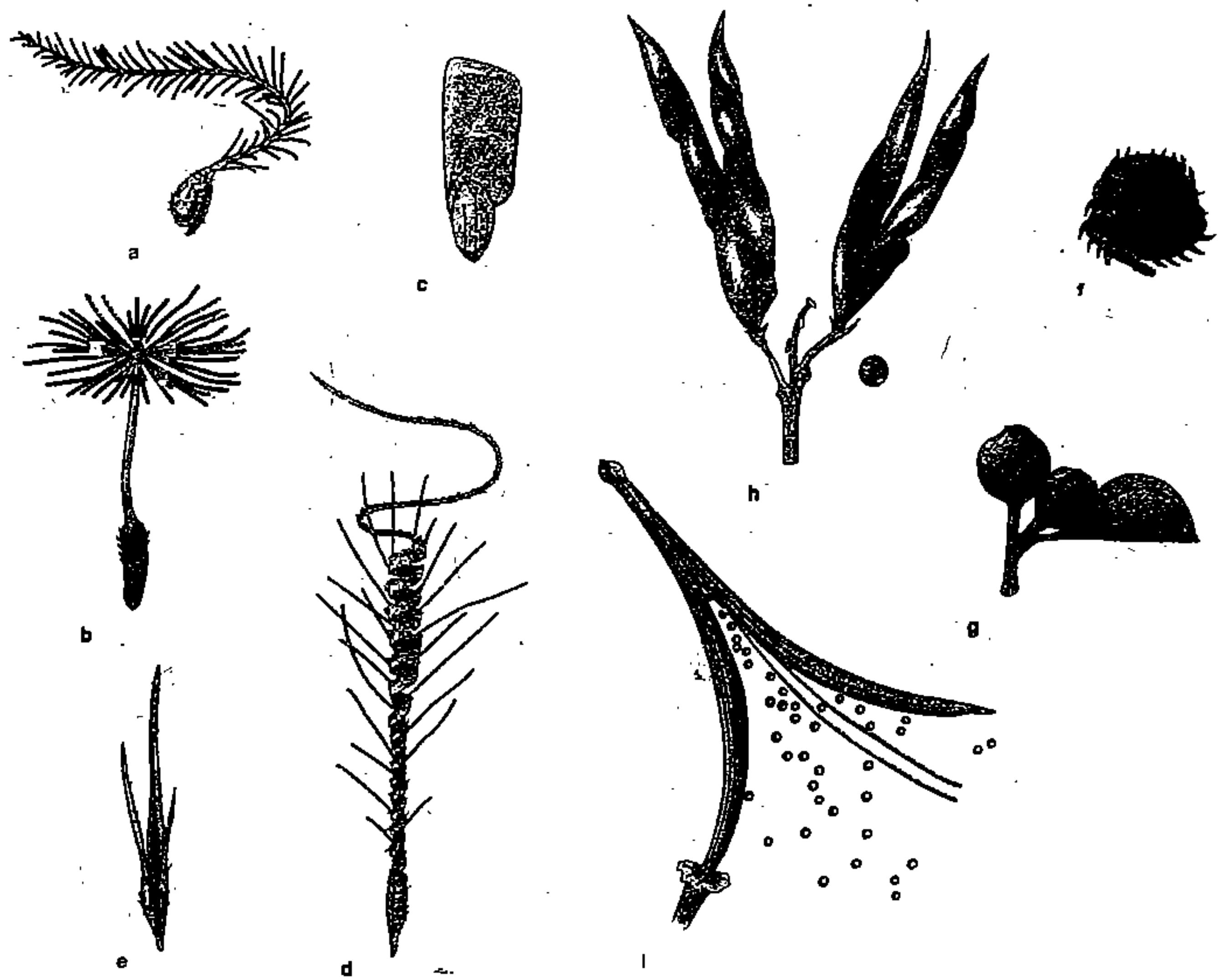

Fig 6.3: Fruits and seeds showing various mechanism in dispersal by wind. a) *Clematis* b) Dandelion (*Taraxacum vulgare*), c) Seed of Coulter's big-cone pine (*Pinus coulteri*). d) Cranesbill (*Geranium*), e) Foxtail (*Hordeum hispida*), f) Bur clover (*Medicago denticulata*), g) Fleshy edible fruit of *Cotoneaster*, h) Vetch (*Vicia sativa*), i) California poppy (*Eschscholtzia californica*).

The seeds of most of the flowering plants contain starch, lipids and/or proteins in their endosperm (e.g. castor and wheat) or embryonal tissues (groundnut and mustard). The stored food helps the young sporophyte in early growth following initiation of seed germination. The food stored in grain of angiosperms is also the main source of nutrition for man and his livestock.

6.8 PLANT DEFENCE

Flowering plants have evolved a variety of means to defend themselves against pests, pathogens and herbivores. Many are armed with epidermal appendages called trichomes. Non-glandular trichomes, such as those present in sorghum and soybean, pierce the bodies of insects or merely entangle their limbs. Glandular trichomes release a variety of essential oils, mucilage, gums and resins, organic acids, alkaloids and even toxic substances which repel or kill the predators. Gram *Cicer arietinum*, tobacco *Nicotiana tabaccum* and mint *Mentha spicata* are examples of plants having glandular trichomes. Many angiosperms have tannins, resins and other bitter substances (e.g., acacias and prosopis) because of which animals shirk them. Spurges *Euphorbia* spp, milkweed *Calotropis procera* and poppy, *Papaver somniferum* are examples of plants that contain a milky fluid called latex which is effective against herbivory. Incidentally, the secondary compounds which many angiosperms contain as a safeguard against their own enemies are the bases of numerous medicines, spices, narcotics, insecticides and a variety of other products used by man.

6.9 ORIGIN OF ANGIOSPERMS

Most of the evolutionary botanists consider angiosperms to be a monophyletic group. Presence of flowers, sieve tubes with companion cells, vessels, 8-nucleate embryo sac, and occurrence of double fertilization are characters exclusive to angiosperms. The chances of these features arising independently in more than one group of ancestral plants are insignificant (Takhtajan, 1969; Sporne, 1974). The angiosperms are most likely to have arisen from a primitive group of gymnosperms, which probably does not exist now. Fossil record indicates that the earliest angiosperms probably originated in early cretaceous (about 141-65 million years ago) and by the mid-cretaceous they had already become dominant and diversified into the major groups represented now.

The most primitive surviving angiosperms are grouped in the Magnoliales, which are trees having primitive type of vascular tissues (some lack vessels) and flowers with many free, spirally-arranged sepals, petals, stamens and carpels. The stamens and carpels are flat, leaf-like with minimal differentiation.

6.10 CLASSIFICATION OF ANGIOSPERMS

The present day angiosperms are classified into two major groups – the Dicotyledonae (Magnoliopsida) and Monocotyledonae (Liliopsida). The dicotyledons or dicots number about 2,00,000 and the monocotyledons or monocots about 50,000 species. These two groups differ in many respects. As the names suggest, dicots have embryos with two cotyledons (like the gymnosperms), and monocots have embryos with only one cotyledon. In general appearance the dicots usually have broad leaves with reticulate (net-like) venation, whereas monocots have narrow leaves with parallel venation. The flowers in dicots have five, or less often four, sepals and petals. In monocots there are three (or in multiples of three). In dicots the stem and root show secondary growth which involves a cambium whose meristematic activity results in a solid cylinder of xylem surrounded by a cylinder of phloem. Because of secondary growth the trunk of dicots undergoes increase in girth with age and many of them grow into large trees. Monocots lack secondary growth. New vascular bundles are differentiated toward the periphery and lie scattered in the ground parenchyma. The stem and roots in monocots remain relatively thin.

Takhtajan (1969) regards the Magnolidae to be the evolutionary base from which all Magnoliopsida (dicots) and Liliopsida (monocots) have evolved. He classified the Magnoliopsida into seven subclasses, and Liliopsida into three subclasses. The Hamamelidae is a relatively small subclass of temperate woody plants such as hazel (*Hamamelis* spp), alder (*Alnus* spp), oak (*Quercus* spp) and birch (*Betula* spp). The members reverted to wind pollination and, therefore, most of them have flowers in catkin which look superficially like cones. Another line which evolved from the Magnolidae is the Ranunculidae, which retain the primitive floral characters but evolved a herbaceous habit, as in buttercup *Ranunculus sceleratus*. From Ranunculidae arose the Caryophyllidae which have herbaceous habit but specialized floral characters as seen in cacti, sugarbeet and amaranths. The Dilleniidae subclass has large herbaceous as well as woody families such as those of mustard, mulberry and dipterocarps. The group also includes cotton, jute, cannabis and tea. The subclass Rosidae is the most diverse group which includes the legumes, spurges (*Euphrobia* spp), eucalyptus, rose and the carrot. The most advanced subclass of dicots is the Asteridae, which has families that include tomato, mint and sunflower. These plants are herbaceous with specialized inflorescences, flowers and fruits.

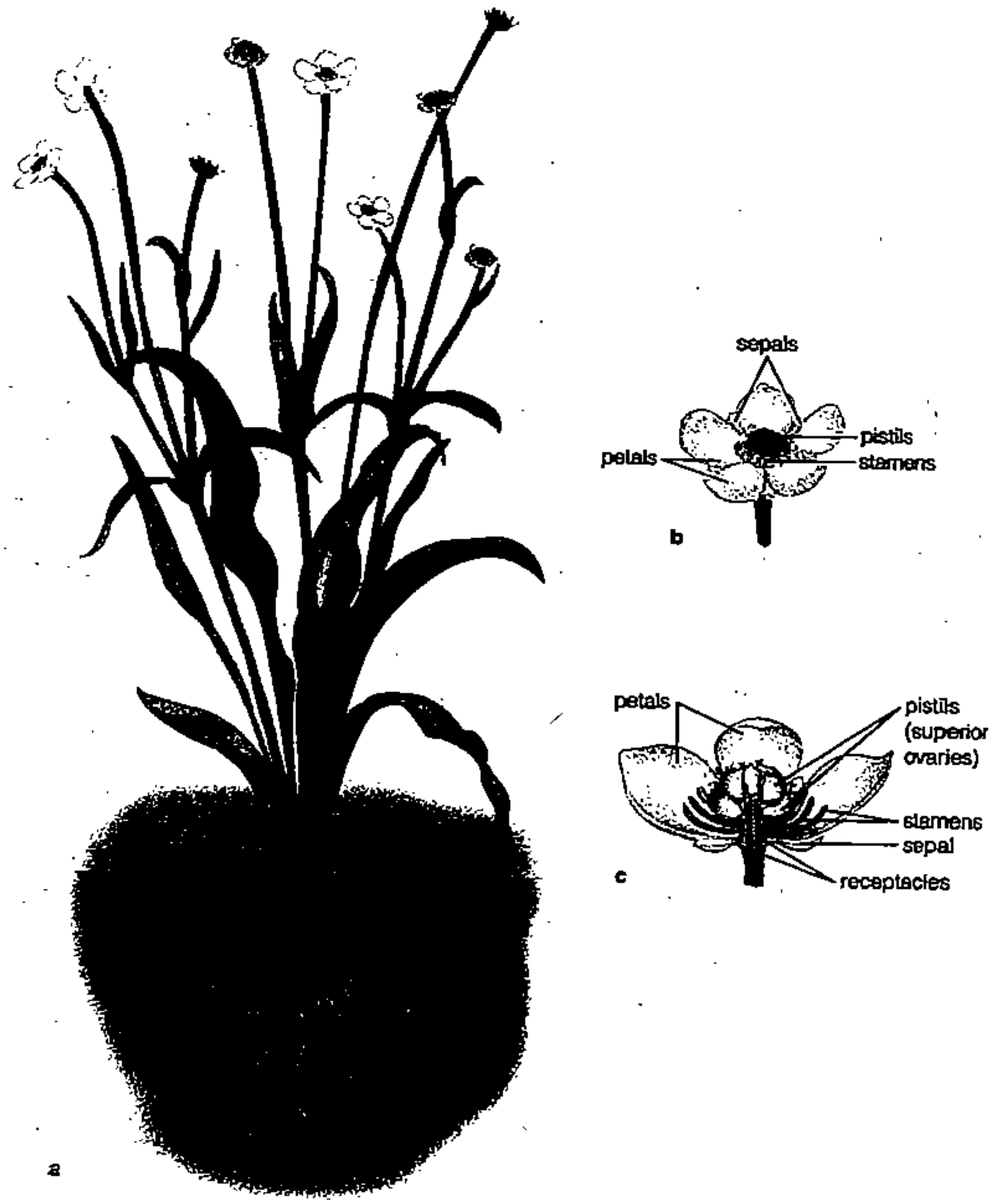

Fig. 6.4: Ranunculidae – the primitive class represented by *Ranunculus alismaefolius*. a) Entire plant. b) Single flower. c) Section of flower.

The Liliopsida (monocots) diverged early from the Magnolidae (dicots). The most primitive Liliopsida are in the Alismatidae, which can be scarcely distinguished from the dicots. They are herbaceous, aquatic plants with vessels only in the roots (e.g., arrowhead, *Sagittaria* spp). A more advanced subclass is the Arecidae, which includes the palms such as coconut, oil palm and date palm. The subclass also has the smallest flowering plants, the duckweeds (*Lemna* and *Wolffia*). The most advanced subclass of monocots is the Lilidae which too is very diverse. One of its lines includes highly specialized orchids, lilies and bromeliads which have colourful flowers pollinated by insects. The other line has small, reduced and wind-pollinated flowers as seen in grasses, bamboos and sedges.

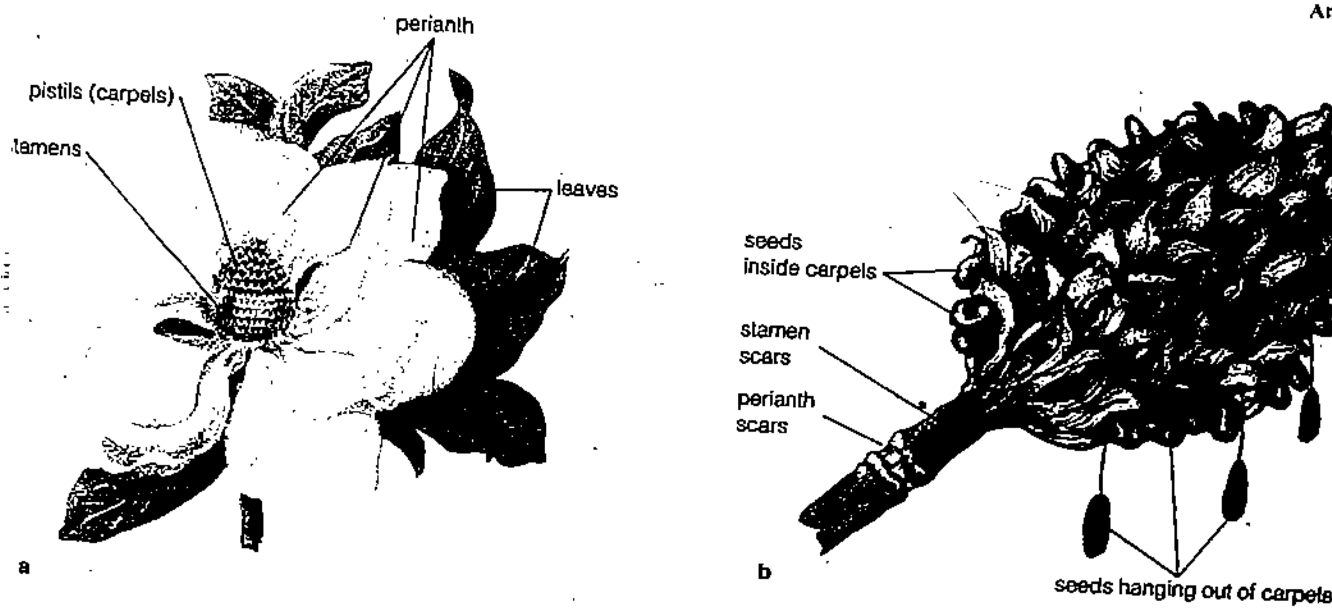

Fig 6.5: ***Magnolia grandiflora.*** **a) Flower. b) Fruit. Novel structures of plant in the division are shown here: the flower, the pistil (carpel) with enclosed ovules, and the fruit.**

6.11 AUTOTROPHIC AND HETEROTROPHIC PLANTS

Most angiosperms are autotrophic. They manufacture their own food through photosynthesis, drawing only inorganic raw materials from the environment. There are special adaptations even in autotrophs, specially those growing in specialized habitats such as water, desert or mangrove swamps. Some xerophytes for example are succulent – their fleshy stem (*Opuntia*) or leaf (*Kalanchoe*), have water storage tissue. The epiphytes grow on other plants without drawing water or food from their host. The orchids, a majority of which are epiphytes, have clinging roots to fix them to the support and aerial roots which help in absorbing moisture from the atmosphere. Sandalwood, *Santalum album* is a root parasite. It drains only water from the host during early stages of development. The heterotrophic plants derive their organic nutrients from other living or dead organisms. When an organism grows on another organism and sucks the nutriment from the living host, it is called parasite. If a parasite is green and makes a part of its nutritional requirement through photosynthesis, drawing the remaining food and wate from the host, it is called partial parasite or semiparasite (e.g., mistletoe V*isum album*). Some parasites like dodder, *Cuscuta reflexa* have no chlorophyll. They absorb their nutrition completely from the host stem with the help of special haustoria. Such parasites are called total parasites. *Orobanche* spp. and *Rafflesia arnoldi* are examples of root parasites which draw their food and water from roots of the host.

Plants which grow on dead bodies of other organisms or on their decaying products like humus and dung are called saprophytes. *Monotropa*, which lacks chlorophyll, is a total saprophyte because it draws its nutrition from decayed leaves on the forest floor. The details of plant parasites are given in Unit 24.

Many angiosperms have symbiotic relationship with other organisms. The roots of most of the plants are inhabited with fungi which help in synthesis and absorption of inorganic nutrients like phosphorus. Many orchids fail to grow unless infected by specific mycorrhiza. Leguminous plants have root nodules inhabited by bacteria *Rhizobium*, which help in fixing atmospheric nitrogen into nitrates which can be absorbed by the plant.

6.12 INSECTIVOROUS PLANTS

Some angiosperms have mechanisms to trap insects and digest their protein matter with the help of enzymes. In sundew, *Drosera* spp, which are small plants growing in grasslands, the upper surface of leaves is covered with glandular trichomes which trap and digest insects. Bladderwort or *Utricularia* spp are free-floating aquatic plants having finely dissected submerged leaves. Many leaf segments are modified into bladders or utricles in which the small aquatic organisms are trapped and digested. In *Nepenthes khasiana* the lower part of the leaf has a flat lamina but the upper part is modified to form a pitcher with a lid. The edge of the pitcher is slippery and curved so that insects slip inward and are prevented from coming out by downwardly directed hairs. The drowned insects are digested by the enzymes secreted by glandular trichomes lining the inner surface of the pitcher. The details of these plants you will study in unit 24 of this course.

6.13 Ecological value of plant diversity

Flowering plants occupy each and every nook and corner of earth. In doing so they not only enhance the primary productivity of the ecosystems where they grow, but they also provide valuable ecological services. The plants help in formation and maintenance of soil structure and retention of nutrients and moisture in the soil. Shorn of the protective vegetation cover, the soil particles become loose and are easily eroded by water or blown by wind. Natural plant cover also helps to maintain hydrological cycles. It helps in regulating and stabilizing water run off so that floods and drought are avoided. Loss of vegetation cover results in siltation of waterways, loss of water yield and quality and degradation of aquatic habitats. Plant diversity also forms the basis of numerous food chains. Incidentally, much of the food consumed by man also comes, directly or indirectly, from plant sources.

Flowering plants also play an important role in breakdown and absorption of many pollutants created by men. Vegetation is also essential for maintenance of the oxygen/carbon dioxide balance in air.

6.14 Economic importance

The existence of human being (and most of the other organisms) is heavily dependent on angiosperms. Five thousand plant species have been used by man, however only twenty plant species are used as food. The angiosperms now feed much of the world's population. Wheat, *Triticum aestivum*, rice, *Oryza sativum* and maize, *Zea mays* are three carbohydrate crops that are staple for a vast majority of people. Millets such as sorghum, *Sorghum bicolor* and pearl millet, *Pennisetum americanum* are staple food for the poor in Asia and Africa.

Wood is important to man as fuel, for construction purposes and as raw material for industrial products like paper. Tropical trees such as sal, *Shorea robusta*, teak, *Tectona grandis* and sisoo, *Dalbergia sisoo* are important sources of timber. Several species of bamboo are important raw material for fibre pulp for making paper. Fibre for making clothes comes from cotton, *Gossypium* spp, hemp, *Crotalaria juncea* and linen, *Linum usitatissimum*. Fibre extracted from jute *Corchorus* spp has been traditionally used for making gunny bags. Fibre from the mesocarp of coconut fruit gives the coir fibre which finds maximum use in making mattresses.

Many plants store oil in their seed endosperm (e.g., coconut) or embryo (mustard, soybean and groundnut). These are the sources of edible oil. Among plants with delicious fruits are mango, *Mangifera indica*, litchi, *Litchi chinensis*, plum, *Prunus* spp, apple, *Malus* sp. and guava, *Psidium guajava*. Many species of cucurbits such as bottle gourd and pumpkin and varieties of *Brassica oleracea* such as cabbage, cauliflower and knol khol provide important vegetables for human food.

Through trial and error man learnt the use of hundreds of plants for care of common diseases. For example, *Rauwolfia serpentina* has been used against snakebite and *Aconitum napellus* against fever. Almost all the medicines used in Ayurvedic system of medicine and a majority of medicines used in Allopathic and Homeopathic systems of medicine have their source in plants.

Plants also provide man numerous other products such as essential oils, gum and resins, narcotics, beverages and rubber. Blocks III A and III B are fully devoted to the Economic botany of of Angiosperms which you will study later in the course.

SAQ 8

Match the words given in column B with names given column A

	Column A		Column B
a)	*Cuscuta reflexa*	1)	succulent stem
b)	*Rafflesia arnoldi*	2)	draws nutrition from decaying leaves
c)	*Opuntia* sp.	3)	Rhizobium
d)	*Monotropa*	4)	drain only water
e)	Leguminous plants	5)	no chlorophyll
f)	*Santalum album*	6)	root parasites

6.15 Focus of research in India in Angiosperms

Since angiosperms meet much of the ecological and economic needs of mankind, these plants are subject of intense research all over the world. In India a large number of research institutes and universities are engaged in research on flowering plants. National Botanical Research Institute at Lucknow has its focus on horticultural and energy plants. Central Institute of Medicinal and Aromatic Plants, Lucknow, Central Drug Research Institute, Lucknow, and Regional Research Laboratory at Jammu and Jorhat carry out intense research on medicinal plants. Botanical Survey of India, with its headquarters in Howrah, West Bengal and five regional stations, is responsible for study, monitoring and conservation of wild plants of the country. National Bureau of Plant Genetic Resources has its headquarter, in New Delhi and Regional Stations at several places in India. The Bureau has the mandate to conserve wild forms, landraces and relatives of agricultural crops. A National Gene Bank has been set up in New Delhi. G.B. Pant Institute of Himalayan Environment and Development, Kosi-Katarmal, Almora in Uttranchal, Institute of Himalayan Bioresource Technology, Palampur, Himachal Pradesh and Tropical Botanical Garden, Thiruvananthapuram are also engaged in development and utilization of plant resources. In addition to these institutes, a large number of research laboratories of Indian Council of Agricultural Research are engaged in research on agricultural crops. Almost every university in India has a Botany Department. These departments have their focus on cytogenetics, taxonomy, ecology, anatomy, embryology and physiology of flowering plants. Significant advancements have been achieved in biochemistry and tissue culture. In recent years plant scientists in India have focused their attention on genome analysis and molecular characteristics and on utilization of tissue culture technique for conservation and improvement of plant resources.

6.16 SUMMARY

- About 250,000 species of flowering plant exist on earth today. Flowering plants dominated world vegetation throughout the Cenozoic era despite major geographic, climatic and vegetational changes.
- Angiosperms are seed plants. The ovule and the seed that develops from the ovule are enclosed within an ovary rather than borne naked as in gymnosperms. The ovary is a part of carpel or pistil and carpel is the part of new complex structure called flower. Synonymous names for angiosperms are Anthophyta and Magnoliophyta.
- The Magnoliophyta contains two classes Liliopsida (monocots) and Magnoliopsida (dicots). The presumed most primitive subclass in the Liliopsida is the Alismatidae, which includes water plantains. The presumed most primitive subclass in the Magnoliopsida is the Magnoliidae. The most advanced subclasses are the Liliidae among monocots and the Asteridae among dicots.
- Novel aspects of the angiosperm life cycle include: i) reduction in size and complexity of gametophytic generation. ii) enclosure of ovule within ovary. iii) double fertilization. iv) dispersal of seed and fruit by wind, water or animals. These adaptations have ecological consequences and may explain why angiosperm supplanted gymnosperms as the dominant terrestrial plant life-forms.
- In angiosperms, there are several types of root, stem, leaves and inflorescences which explains its adaptations to the variety of climates and cosmopolitan distribution.

6.17 TERMINAL QUESTIONS

1. Write all the differences between Angiosperms and Gymnosperms which you have read.

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2. What is double fertilization?

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3. Describe various means of dispersal of the seed in Angiosperms.

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4. Write short notes on the following:

   i) Origin of Angiosperms

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   ii) Classification of Angiosperms

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iii) Economic importance of Angiosperms

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5. Write a short note on the focus of research in India on Angiosperms.

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6.18 ANSWER

1.	Angiosperms	Gymnosperms
1)	The abundance and prominence of the xylem vessels	Most of the gymnosperms have only tracheids
2)	The formation of flower with sepals petals, or both in addition to the sporophylls are found in Angiosperm	The gymnosperms have distinct male and female strobili or cones
3)	The seeds are enclosed in fruits	The seeds are naked
4)	Endosperm is formed only if the Embryo sac is fertilized	Endosperm is formed without fertilization
5)	Double fertilization is found in angiosperms	single fertilzation is found in Gymnosperm

2. a-v, b-i, c-ii, d-iv, e-iii

3. (i) In submerged hydrophytes leaves become small, narrow and ribbon like.

(ii) In plant which are anchored, their leaves float on the surface. The leaves are broad to gain buoyancy.
(iii) Leaves have air cavities which make them light to float easily and can carry out gaseous exchange even inside water
(iv) In submerged aquatic plants the chloroplasts are concentrated in superficial cell layer for more efficient photosynthesis

4. i) nodes, internodes
   ii) *Mentha*, Stolons
   iii) suckers
   iv) *Solanum tuberosum*, starch
   v) *Lathyrus odoratus*, tendril
   vi) Respiratory root, pneumatophore

5. Read section 5.5 and give any three points which are different in angiosperms and gymnosperms.

6. The wind pollinated flowers have following features:
   i) The flowers are large in numbers and produce large amount of pollen grains.
   ii) The flowers do not have showy petals.
   iii) The pollen grains are small, dry and smooth.
   iv) The female flowers have large or feathery stigma to trap pollen from air.

7. Most of the angiosperms depend on birds, insects and bats for their pollination. To attract these pollinators following features are found in flowers.
   i) The flowers are big and bright, they have nectar and odour to attract pollinators.
   ii) Pollen grains are big, moist and in clusters.
   iii) Many flowers mimic butterflies or moths.

8. a-5, b-6, c-1, d-2, e-3, f-4

Terminal Questions

1. See answer of SAQ 1 and Unit 1 of Block 1 – Gymnosperms.
2. The fertilization of one male gamete with egg cell to form the diploid zygote, while the other fuses with the central cell nuclei to form the diploid primary endosperm nucleus is known as double fertilization, which is unique in Angiosperms.
3. See Section 6.7.
4. See Section 6.9, 6.10 and 6.14.
5. See Section 6.15 and go through the daily papers and write about present day status of research in Angiosperms in India.

UNIT 7 TISSUES

Structure

7.1 Introduction
Objectives
7.2 Meristems
7.2.1 Apical Meristems
7.2.2 Lateral Meristems
7.2.3 Intercalary Meristems
7.3 Mature Tissues
7.3.1 Simple Tissues
7.3.2 Complex Tissues
7.4 Epidermal Tissue System
7.5 Summary
7.6 Terminal Questions
7.7 Answers

7.1 INTRODUCTION

Our planet is inhabited by an amazing diversity of plants, and some 260000 species of flowering plants form a major chunk of it. Remember! this figure refers to only the species known to us, and one does not have any idea yet, of the species occurring on this planet that are still unknown to us. Further, the above figure would swell many-fold if we consider the varieties and local variants of each species. Have you ever thought - what causes this diversity? In other words, what makes one species different from the other, for each plant has the same overall basic plan - the root and the shoot system. The answer lies in the diversity of the tissues composing the plant body.

In this unit you would study about the basic tissues that constitute a plant body. A range of structural variations in each tissue is taken up for discussion to give you an idea as to how the cell types of a tissue assume various forms in different plants. Keep a note of these variations in your mind to enjoy the amazing creations of nature. Before you begin to study the tissues, it is important to understand and form a clear picture of the basic terms related to this topic. Since this unit is about tissues, you should first know what is meant by this term? **Tissue refers to a group of cells performing common function(s).** Any plant organ may be composed of a number of different tissues, each of which is classified according to its position, structure, origin and function. Tissues composed entirely of one cell type are said to be **simple** or **homogenous**, whereas those made up of two or more cell types are known as **compound** or **heterogeneous**. Tissues can also be classified as **meristematic** if they undergo active division, or **permanent/mature** in which growth and differentiation have been completed.

Objectives

After studying this unit you should be able to:

- identify the meristematic tissues occurring in the different regions of the plant;
- mention the diagnostic features of simple mature tissues;
- distinguish between the meristematic and mature tissues;
- enumerate the structural peculiarities of the complex tissues;
- differentiate between the simple and complex tissues; and
- enumerate the identifying features of the tissues composing the epidermal tissue system.

7.2 MERISTEMS

When a seed germinates, all the cells of the embryo undergo divisions repeatedly up to a certain stage, hereafter further cell divisions become restricted to some definite sites of the plant which are referred to as the **merstematic zones**. Depending on the location in the plant body, three kinds of meristems have been identified: **apical**, **lateral** and **intercalary** (Fig. 7.1).

What are meristems? These are the tissues whose cells are capable of repeated divisions. The newly produced cells by the meristems are small, hexagonal, box-like structures, each with a proportionately large nucleus in the centre and tiny vacuoles or no vacuole at all. As these cells mature they assume different shapes and sizes, related to the cell's ultimate function.

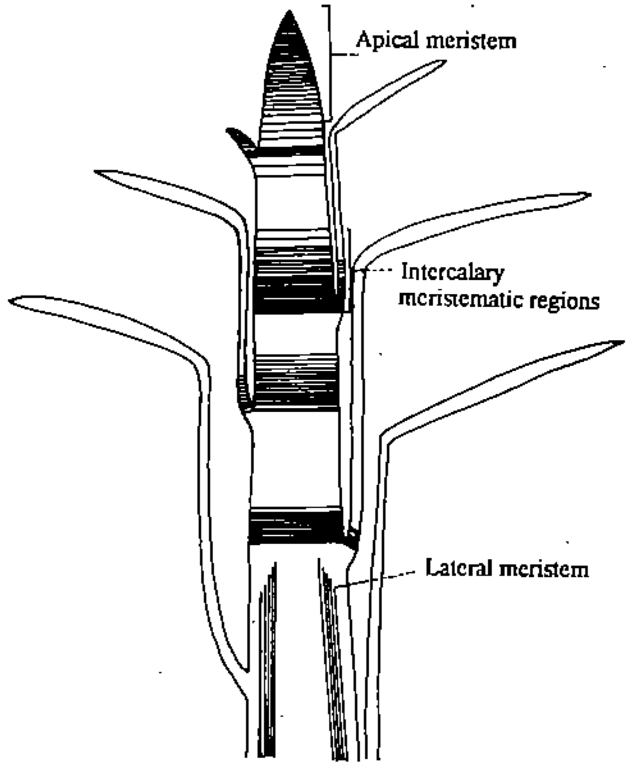
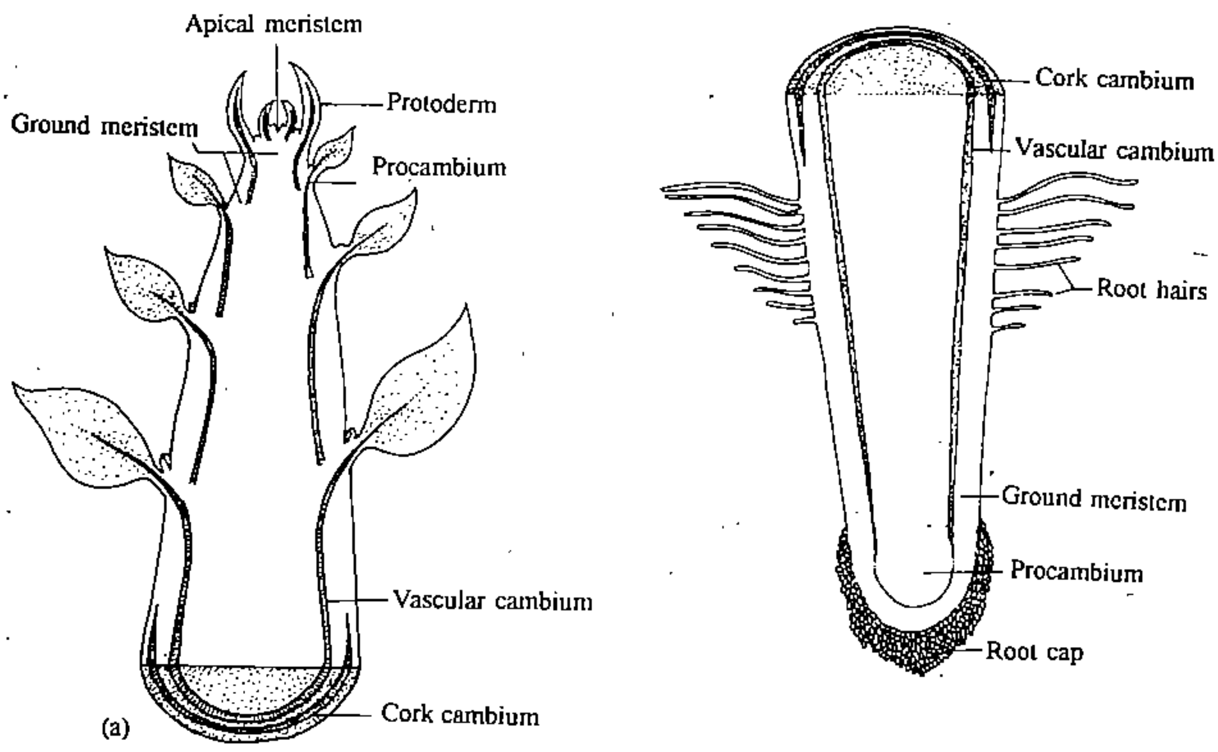


Fig. 7.1: Schematic outline diagram of a portion of stem cut longitudinally to show the position of the meristems. The areas marked dense are youngest, whereas the clear areas represent mature or slowly growing regions of the plant (from Eames & MacDaniels, 1987).

Meristems have been classified as primary or secondary based on their origin. Primary meristems are those whose cells develop directly from the embryonic cells and so constitute a direct continuation of embryo. The secondary meristems are the ones that develop from mature tissues which have already undergone differentiation.

7.2.1 Apical Meristems

You have already studied in Unit-7 of LSE-06 course that the apical or the primary meristems are located at the apices of the main and the lateral shoots and the roots (also see Fig. 7.2). These produce cells which result in the longitudinal, or the primary growth of the plant.



(1) Shoot Apex

You may recall that growth in many lower plants occurs due to the activity of the apical cell whereas in angiosperms the growth of the shoot system occurs by a well organized apical meristem. These meristems contain several zones the details of which you would study in Unit-8. The shoot meristem remains an important component both in the vegetative and the reproductive phases of the plant. However, in both these phases, the respective meristems are characterised by certain peculiar features. These are discussed below.

The Vegetative and Floral Shoot Apex: Among angiosperms, the size and shape of the shoot apical meristem is highly variable. It ranges from 80 μm to 1500 μm in diameter. This range can be seen even within a single family, e.g., Cactaceae. Further, in a large number of plants the size of the meristem also varies with the developmental stage . A difference of up to three thousand times has been recorded between the apex of a seedling and mature plants of *Homalocephala* and *Echinocactus*! Talking about the variation in shape, it varies from hemispherical to elongate, or it may be like a parabola, or flat, and even concave. You may recall the structure of shoot apex you have studied in Unit-7 of the LSE-06 course. Do you remember that a number of leaf initials are present near the shoot apex and the youngest initial is nearest to the apex. The time between the initiation of one leaf and the initiation of the next is called a **plastochron**. And the height of the shoot apex refers to the vertical distance from the apex down up to the axil of the youngest leaf primordium. So, as the apex cuts a number of leaf initials, the reference point for measuring the apical height and diameter also changes. The shoot apices in different species take varying time for cutting the next primordium. The shape of the meristem also changes, as it goes through the cycle of leaf production. As an initial is cut, the apex becomes short and narrow. In other words, the shoot apex goes through a 'minimal' and 'maximal' phase during each plastochron (Fig. 7.3).

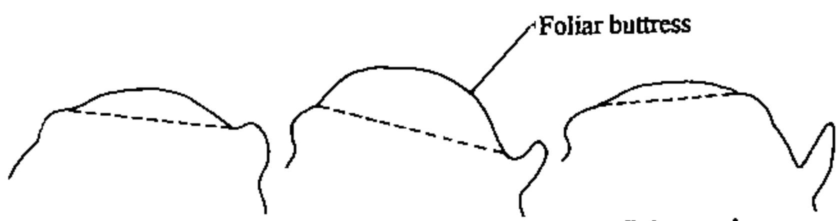


Fig. 7.3: An outline sketch of an apical meristem at the minimum and maximum phases during the plastochron (Redrawn from Mauseth, 1988).

Due to the activity of the shoot apex, the plant accomplishes its vegetative growth. The shoot apex may be active throughout the year or during certain parts of the year only. The plant after accomplishing certain degree of vegetative growth, enters the reproductive phase and starts bearing flowers or inflorescences. The apex at this stage is known as the reproductive apex or the floral apex. The floral apex remains the prime site of activity while generating the floral organs. How does the floral apex differ from the vegetative apex - you may ask. Several physiological and cytohistological studies on plants belonging to different species, during the transformation of vegetative apex to floral apex, have brought out marked differences in the two stages. The details, however, differ from species to species but, by and large, it has been found that the reproductive apex produces its primordia much more rapidly than leaf primordia produced by the vegetative apex. In addition, there is a rise in the mitotic index, a related increase in DNA synthesis, an increase in nucleolar diameter, presumably as new ribosomes are prepared that will be necessary for the increased rate of protein synthesis in such cells that are metabolically active. Another feature heralding the reproductive stage is the sudden increase in the elongation of the internodes also known as **bolting**. This change is particularly striking in plants that have no elongated axis during the vegetative stage, as in many grasses and the rosette types of plants.

One important point that you should remember is that, *not all the floral apices are transformed out of the vegetative apices but some are initiated as floral apices only*. This may become clear to you from the example of sunflower and other similar plants that produce flowers in their leaf axils. The floral apex, just like the vegetative shoot apex, also exhibits plastochronic size fluctuations during successive stages of development of bracts, perianth (sepals and petals), stamens and carpels. The appearance of floral apex also signifies the end of growth at the given apical meristem because of the determinate nature of flower. As in annual plants it clearly marks the end of growth and the approach of death of the entire plant. But in several perennial plants, *the floral meristem occasionally resumes vegetative growth again after the floral parts are formed.*

(2) Root Apex

You are already familiar with the concepts related to the root apex structure from your study of the course LSE-06. Can you now bring out the gross similarities as well as the differences between the shoot and the root apex? Let us begin first with the similarities between the two. Both are large, multicellular structures with distinct zonation. You may recall their structures from Sections 7.2 and 7.3 of Unit-7, LSE-06.

In contrast to the apical meristem of the shoot, the root apical meristem becomes subterminal in position because of the presence of root cap. This is in the sense that it is located beneath the root cap. Another difference is that there is absence of lateral appendages comparable to the leaves or the branches. You may recall that the root branches arise endogenously beyond the region of most active growth. *Unlike the shoot apex that shows periodic changes in its shape and structure while initiating leaves, the root apex lacks such changes.* Since roots lack nodes and internodes, the root apex grows more uniformly in length than the shoot.

7.2.2 Lateral Meristems

Lateral meristems are located along the periphery of an organ. They are composed of initials that divide largely in one plane, i.e., periclinally (Fig. 7.4). This results in an increase in the diameter of an organ. As a result of their activity, cells get added to the existing tissues. The two main lateral meristems are the **vascular cambium** and the **cork cambium**.

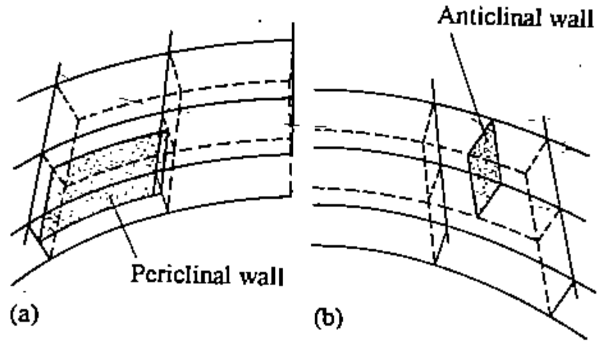


Fig. 7.4: a) Diagrammatic representation of periclinal division in a cell, shown here by the periclinal wall. The periclinal walls are parallel to the surface and these contribute in increasing a tissue's thickness. It is pertinent here to know about anticlinal division too, represented in b). Observe that the anticlinal wall is perpendicular to the surface of the tissue or the organ.

(1) Vascular Cambium

This lateral meristem forms the secondary vascular tissues, and is found both in stems as well as in roots. It develops either as longitudinal strands or as hollow cylinders. In certain plants including the monocotyledons, all the cells of the procambium undergo differentiation to form primary vascular tissues. But in most of the dicotyledons, a portion of procambium remains meristematic even after the primary growth is complete. These meristematic cells develop as the cambium of the secondary body. Such a cambium lies between the phloem and the xylem, and is known as the **fascicular cambium** (Fig. 7.5), owing to its proximity to the vascular tissues. The strips of the fascicular cambium usually become joined by **interfascicular cambium** strips and appear as a ring in transectional view, or as a hollow cylinder in a three-dimenisional view. Is it now clear to you that the interfascicular cambium is not a continuation of the procambium but it develops from parenchyma? Hence, these cambial strips that arise later are referred to as **secondary meristems**.

Coming back to the hollow cylinder of cambium that is formed throughout the length of the main plant axis. In most dicotyledons the cambial cylinder develops between the primary xylem and phloem and this position is retained by the plant throughout its life. The cells of vascular cambium undergo periclinal divisions and cut off xylem mother cells on its inner side and phloem mother cells on the outer side (Fig. 7.6 a-g) that eventually differentiate into their respective secondary elements.

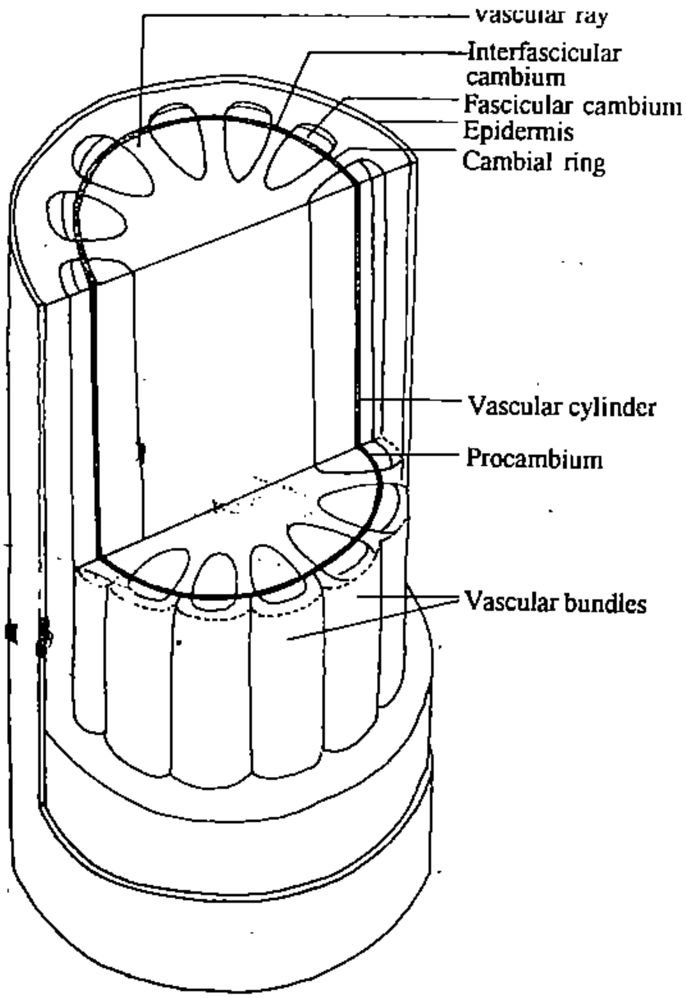


Fig. 7.5: A three dimensional view of a dicot stem depicting cambial ring in the portion cut in the transverse plane, and the longitudinally cut portion shows only a partial view of the hollow vascular cambium cylinder (After Hartman et al., 1988).

The cells of vascular cambium are classified as lateral meristem and they too are meristematic yet different from the apical meristems. Let us see how? The thin-walled cells of vascular cambium are highly vacuolate unlike most other meristematic cells. These cells show an abundance of organelles like, such as ribosomes, dictyosomes and smooth endoplasmic reticulum (ER). These cells, during their resting phase, also contain

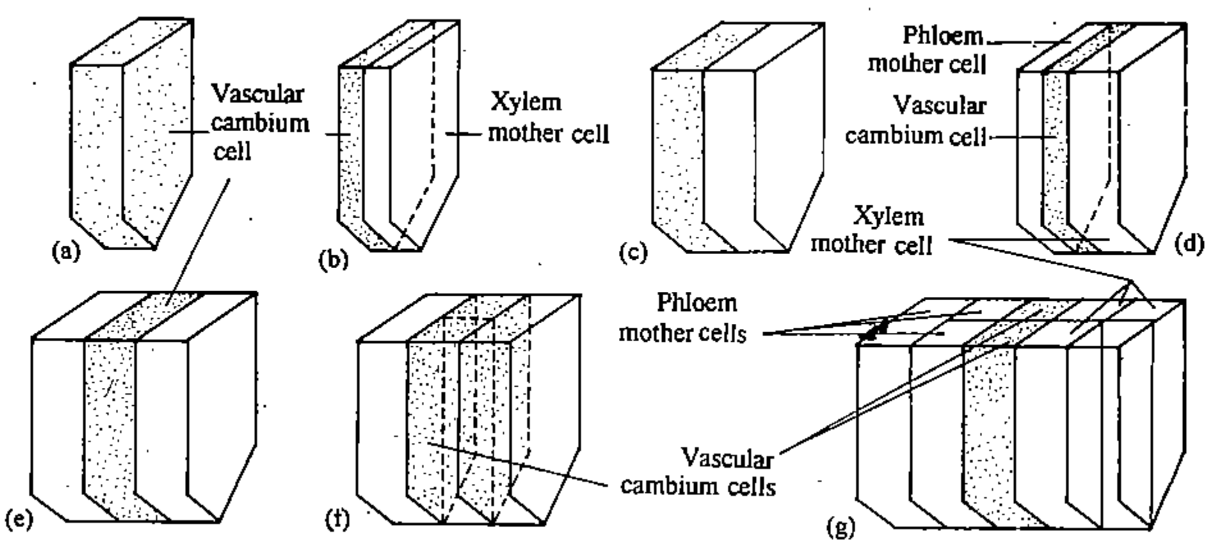


Fig. 7.6: Diagrammatic representation of formation of derivatives of vascular cambial cell. a) A cambial cell, note it is a diamond-shaped cell. The face cutting xylem mother cell in b faces the interior of the plant. Figures b-g) depict formation of xylem and phloem mother cells due to the activity of the cambium. (Redrawn from Mauseth, 1988).

lipids and protein bodies. On resumption of activity the vascular cambium cells exhibit dissolution of lipids and proteins that results in the formation of vacuoles. This accounts for their highly vacuolate nature. Their one unique feature is the 'beaded' cell walls (Fig. 7.7). This is due to the presence of pit fields with plasmodesmata on their cell walls. They have another distinguishing feature, that is, their radial walls especially of the xylem and phloem mother cells are thicker than the tangential ones. This is due to the periclinal divisions in the cambial cells, during which the thickening of the radial wall is continuous.

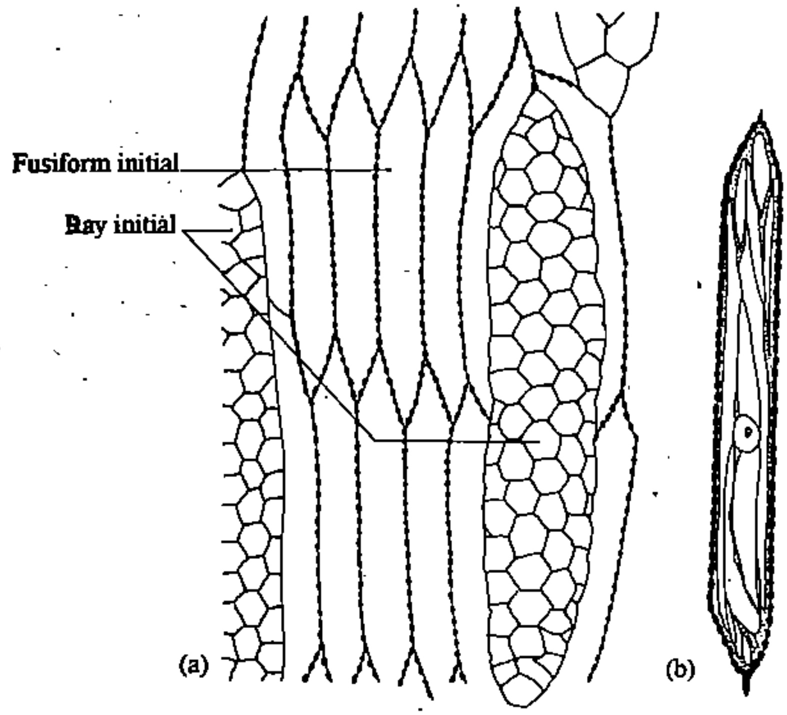


Fig. 7.7: ***Robinia pseudoacacia.*** **a) Tangential longitudinal section through cambial region. Note the beaded walls of the fusiform initial. b) A diagrammatic representation of a fusiform initial showing highly vacuolate protoplast and numerous primary pit fields due to which the cell walls appear beaded [Redrawn from: a) Cutter, 1978; b) Fahn, 1977].**

The vascular cambium is composed of two types of cells - the elongate **fusiform initials** and the more isodiametric **ray initials** (Fig. 7.8). While the fusiform initials produce the axially elongated or oriented elements of the wood and the inner bark (tracheary elements, fibres, xylem and phloem parenchyma) the ray initials produce radially-oriented rays known as the vascular rays.

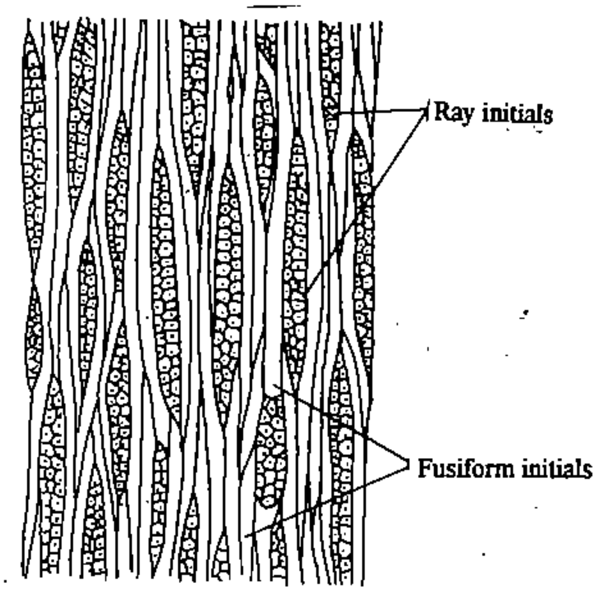


Fig. 7.8: A tangential section through the vascular cambial zone showing the fusiform and ray initials (Redrawn from Mauseth, 1988).

Fusiform initials are long cells, that range in length from 140- 462 μm in dicots, from 700-4500 μm in *Pinus* and even up to 8700 μm in *Sequoia sempervirens.*

There is variation in this length even within different species of a genus, e.g., in *Dalbergia melanoxylon* it is 154 μm and it is 203 μm in *D. sissoo*. The length also varies according to the factors like environmental conditions, age, nutrition conditions, and general vigour of the plant. In cross section they appear rectangular or slightly flattened, whereas in tangential section their tapering ends are clearly visible. The length of fusiform initials has been of much interest, because it affects the length of the derivatives especially the secondary xylem that constitutes the wood.

The **vascular cambia** are of **two types** based on the arrangement of the fusiform initials. In the **storied or stratified cambium** (Fig. 7.9), the fusiform initials are aligned with

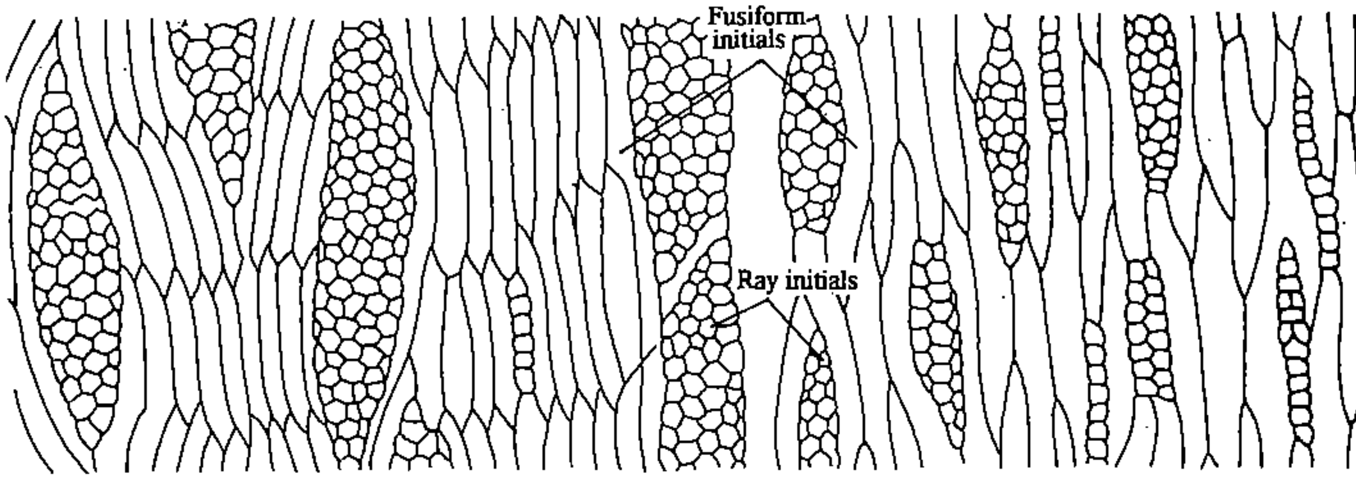


Fig. 7.9: Diagrammatic representation of the storied type of cambium in *Robinia* (a); and non-storied cambium in *Fraxinus* (b) (Redrawn from Fahn, 1977).

each other laterally and form stories or tiers. The length of these initials varies from 140 μm to 520 μm. It is quite a rare feature in plants and occurs in some advanced dicots, e.g., *Aeschynomene*, *Hoheria*, *Robinia* and *Tamarix*. The more primitive and the more common type of vascular cambium is **non-storied or non-stratified cambium** (Fig. 7.9). The length of initials of this type of cambium varies between 320-2300 μm in many dicots. In many vassel-less dicots, the fusiform initials may reach a maximum length of 6200 μm. One example of this is *Fraxinus*.

The storied and non-storied cambia also exhibit different behaviour while in division. In storied forms, the multiplicative divisions are by true anticlinal, longitudinal divisions in which the cell plate is formed from tip to tip. The two daughter cells thus formed are of equal length, and also the cells are aligned with the position of their mother cell wall and their neighbouring cells (Fig. 7.10a). In non-storied cambia, the multiplicative divisions are of the pseudotransverse type (Fig. 7.10b). That is, the division appears to be longitudinal to begin with, but the phragmoplast and the ends of the cell plate do not reach the far ends of the cell. Instead the cell plate turns towards the side walls and fuses with them. The new wall is thus shorter than the original side walls. The resultant daughter cells too are shorter than their mother cell and also their ends do not lie at the same level.

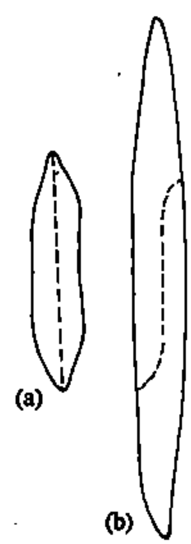


Fig. 7.10: Diagrammatic representation of division in fusiform initials. a) A fusiform initial with radial multiplicative division. The two daugther cells are equal in length to each other as well as to the mother cell. b) Pseudotransverse division in a fusiform initial. Note the new cell wall does not extend to the either end and the neither daughter cell is equal to the mother cell (from Mauseth, 1988).

The activity of vascular cambium leads to secondary growth in the plant body. Annual or biennial plants commonly have a regular sequence of vegetative stage, reproductive stage, somatic death and seed dispersal. Between the vegetative and the reproductive stage, usually, the plant body undergoes secondary growth, and in this phase the vascular cambium becomes active. The perennial plants undergo a number of secondary growth cycles. That is to say, the vascular cambium becomes active for specific periods and then reverts to a dormant stage. Dormancy is linked to stress conditions like heat, cold or lack of water. The cambia of all the plants do not undergo dormancy. There are plants whose cambium remains active through their entire life span and continues to add xylem and phloem elements of almost same size. This type of a cambial activity is usually found in plants growing in tropical regions. Such trees therefore do not show formation of **growth or annual rings**. Growth rings are formed mainly in temperate plants in response to seasonal fluctuations that govern the cambial activity. In such plants, vascular elements of larger dimensions are produced during the favourable season, and elements of narrower dimensions in the less favourable one.

Secondary growth is an important function of vascular cambium, but is not the only one. It has another function, just as important - to survive! As the apical meristems of roots and shoots must remain intact and function normally, the vascular cambium too must live and operate successfully for the entire life time of the plant - up to 11,000 years in some instances and not just for one or two seasons. Still another important point is that unlike apical meristem, vascular cambium is irreplaceable. If apical meristems are damaged the axillary buds take over the meristematic function.

(2) Cork Cambium

The cork cambium, like the vascular cambium, forms a thin cylinder that runs the length of roots and stems of woody plants and is located to the exterior of the vascular cambium. In a transverse section, the vascular cambium appears as a tube of smaller diameter lying within the tube of the cork cambium. The product of cork cambium is **bark** or the **periderm**. Like the vascular cambium, the bark is laid down after the primary tissues have matured and thus it is secondary in origin.

Commercial cork is made up from the bark of trees, particularly *Quercus suber*. Phellogen growth of about 10 years is just sufficient to yield commercial grade cork. The features that govern the commercial value in cork are its imperviousness to gases and liquids, its strength, elasticity and lightness.

The periderm is actually a mixture of tissues. It is formed by the cork cambium or the **phellogen**. The cells of phellogen are meristematic, but unlike the vascular cambium, all the cells are of one type. The cells of phellogen divide periclinally to give rise to radial files of cells. The cells cut toward the outside of the phellogen differentiate as cork or **phellem**, and those toward the inside form **phelloderm** or secondary cortex (Fig. 7.11). The phellogen is a secondary meristematic tissue. It originates from cells of epidermis or hypodermis, i.e., from the cells that have undergone differentiation. The cork cells are dead at maturity and have suberized cell wall, that make them water proof and tough. On the other hand, the cells of the phelloderm are living. Certain regions of the periderm are differentiated as lenticels. Some parts of the phellogen, usually below stomata function rather differently, and produce lenticels (also see Unit-8). These consist of mass of loosely arranged cells - the complementary tissue which facilitate gaseous exchange with the external environment. Surely you might have seen lenticels in a large number of instances. These are present on potato tubers; fruits such as apples, pears; stems of *Vitis*; and on roots such as *Daucus*.

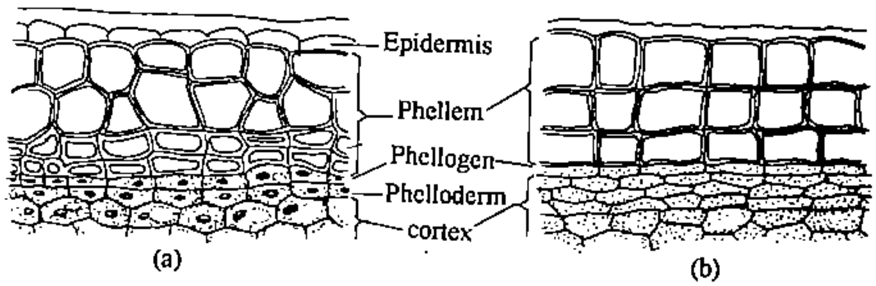


Fig. 7.11: A part of the cross section of a branch of *Populus deltoides* (a), and *Solanum dulcamara* (b), showing the periderm and its components. Also figure (a) shows development of phellogen from the outermost layer of the cortex, whereas figure (b) shows a phellogen differentiated from the epidermis (After Eames & MacDaniels, 1987).

Fig. 7.12: Schematic diagram showing regions of occurrence of intercalary meristem. The regions where the intercalary meristem and young tissue occur are represented by black areas, slightly older areas are represented by shaded areas and regions containing mature cells are left white (Redrawn from Prat, 1935).

7.2.3 Intercalary Meristems

Grasses and related plants have neither a vascular cambium nor a cork cambium, but they do have apical meristems, and the other meristematic tissue called intercalary meristem. It is situated in the vicinity of nodes and occurs at intervals along the stem (Fig. 7.12), that is, many such meristems are separated by zones of fully matured cells. The intercalary meristems, in due course of time, too undergo differentiation into mature tissues. They are, therefore, not present throughout the entire life of the plant. Intercalary meristems, like the apical meristems, add to the length of stems. In addition to the stems of grasses and many monocots, some species of Caryophyllaceae and Polygonaceae possess intercalary meristems. Peduncles of inflorescences of certain plants, leaves of Poaceae, and the gynophore of *Arachis hypogaea* elongate as a result of the activity of the intercalary meristem.

SAQ 1

State whether the following statements are true or false.

(i) Increase in diameter of an organ is by periclinal division of apical meristem.

(ii) The gynophore of *Arachis* elongates as a result of activity of the intercalary meristem.
(iii) The hollow cylinder of cambium in the old stem of plants is formed by fascicular cambium only.
(iv) The cork cambium is primary in origin.
(v) Intercalary meristems are present between the mature tissues.

SAQ 2

Fill in the blank spaces with appropriate words.

(i) The time between the cutting off of one leaf and the initiation of the next is known as ....
(ii) The vascular cambium is made up of .... and ....
(iii) Increase in girth of stems takes place by the activity of ....
(iv) The vascular cambium is both .... and .... in origin.
(v) The phellogen gives rise to .... on outside and .... on inner side.

7.3 MATURE TISSUES

Mature tissues are composed of cells that after being produced by the meristems assume various shapes and sizes related to their functions as they develop and mature. It is important to know that cells forming the tissue are continuous and furnish some portion of the structural or functional basis of the plant. Included in various plant tissues are collection of cells specialized for growth, storage of food, protection from dehydration, support, conduction of water, synthesis of food, and absorption of water and mineral elements. Tissues composed entirely of one cell type are said to be **simple** and are homogeneous; whereas those made up of two or more cell types are heterogeneous or **complex** tissues. We have first taken up the simple type of mature tissues for discussion followed by complex tissues.

7.3.1 Simple Tissues

There are very few simple tissues in plants. The common ones are **parenchyma, collenchyma** and **sclerenchyma**. These three terms denoting different kinds of tissues are also applied to individual cells, for example, a cell of the tissue sclerenchyma is also called a sclerenchyma cell. Another point you should note is, the adjectives such as 'parenchymatous', or 'collenchymatous' refer to the cells that possess some characters of the tissue in question, which in this case refers to the cells of parenchyma and collenchyma respectively. Now we shall resume our discussion on the above mentioned basic three kinds of simple tissues.

(I) Parenchyma

Parenchyma cells are the most abundant of the cell types found in almost all major parts of higher plants. They may be primary or secondary in origin, that is, they may originate from the apical meristems of stems and roots; from the intercalary meristems of leaves; from the vascular cambium or even the phellogen in mature organs that have undergone secondary growth. The parenchyma cells are the least altered during the process of differentiation which is limited to vacuolation and the addition of a certain amount of primary wall material to their rather thin and plastic walls. Several features of parenchyma are listed below.

- They are living cells (Fig. 7.13) even at maturity.
- The parenchyma tissue occur in all the areas of plant such as the pith; cortex of stems and roots; epidermis and vascular tissue of roots, stems and leaves; mesophyll of leaves; floral parts; endosperm of seeds; and flesh of fruits. The epidermis is also composed of modified parenchyma, details of which you would study later in this unit.

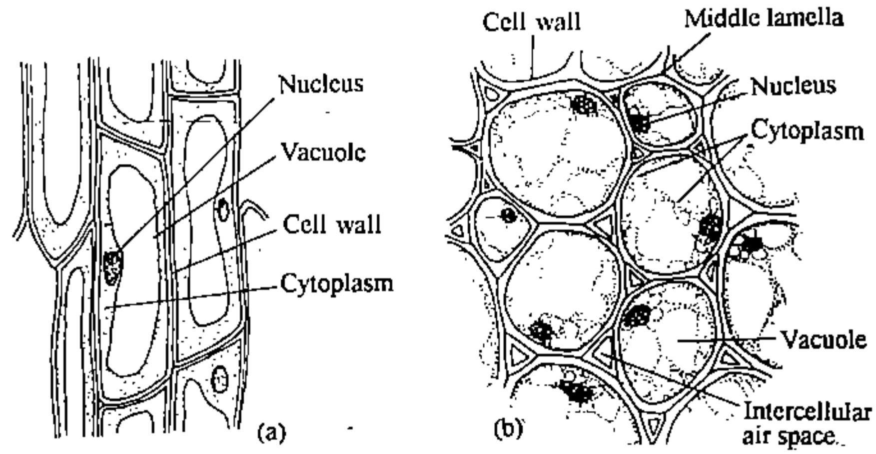


Fig. 7.13: Diagrammatic representation of parenchyma cells in longitudinal section (a), and transverse section (b). Note the cells have protoplasm and prominent nuclei in them.

- Usually they are not much elongated. The newly formed cells are more or less spherical, and subsequently they assume various sizes and shapes (Fig. 7.14). They commonly acquire a polygonal shape (Fig. 7.15) due to the pressing of cells against each other, whereby their pliable walls get flattened at the points of contact. Majority of them are fourteen-sided.

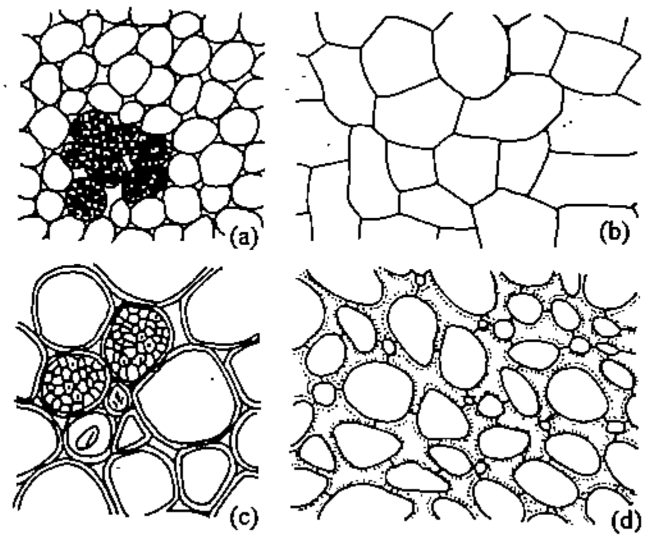


Fig. 7.14: Diversity in parenchyma cell shape as seen in transverse sections. Cells from: (a) cortex of root of *Asclepias incarnata*, a few cells are filled with starch grains; (b) the pith of *Zea*; (c) thick-walled, lignified cells from the pith of a twig of *Castanea dentata*; (d) thick-walled cells from the pith of *Clematis virginiana*. (Redrawn from Eames & MacDaniels 1987)

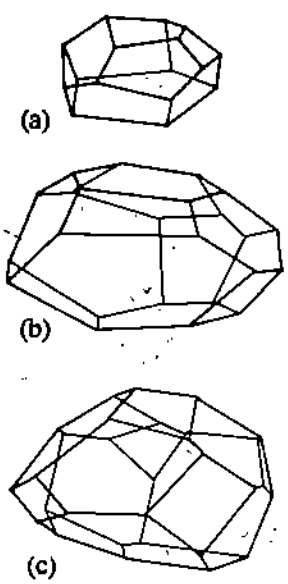


Fig. 7.15: Diagrammatic depiction of a few parenchyma cells from the pith of *Ailanthus* in a three dimensional view. Cells with 10 faces (a); 14 faces (b); and 17 faces (c). (Redrawn from Hulbary, 1944).

- They have a thin and cellulosic primary cell wall and lack a secondary wall (Fig. 7.13).
- Their cells are vacuolate and contain living protoplasts (Fig. 7.13). Some cells contain small and simple pits (Fig. 7.16).
- The presence of air spaces is a common feature of parenchyma cells (Figs 7.13 and 7.14).
- The parenchyma cells can be reprogrammed to differentiate into different cell types.
- The parenchyma cells may live for a long time; in some cacti, for example, they may live over 100 years.
- Parenchyma cells exhibit tremendous functional diversity. On the one hand, they may be generalists, that is, simple cells with no specialisation. On the other, some of them are highly specialized. Based on the functional diversity, parenchyma are grouped into five classes; **synthetic parenchyma, structural parenchyma, boundary parenchyma, transport parenchyma,** and **storage parenchyma.** A few examples of each of the categories are given below.

(i) Synthetic parenchyma - This includes all those parenchyma that either synthesize new cells or some products. Photosynthetic parenchyma or chlorenchyma (Fig. 7.17, see palisade tissue), *meristematic* cells, and *secretory parenchyma* largely constitute this category. The main function of chlorenchyma is to store the light energy as chemical energy in organic compounds. To do this the light must be intercepted and carbon dioxide must be absorbed into the cell. To enable the cells to perform the above tasks optimally these cells have large surface areas and are cylindrical; large air spaces around them provide maximum amount of surface for the absorption of carbon dioxide; and a large central vacuole pressing chloroplasts into a uniform layer next to the wall not only prevents self shading within the cell but also places chloroplasts exactly at the site of carbon dioxide absorption. The large surface area of chlorenchyma allows water to evaporate out of the cells into the intercellular spaces and be lost through stomata. In desert plants, where water conservation is required, the chlorenchyma cells are closely packed, thereby reducing the area for water loss. This can be seen in Crassulaceae and Mesembryanthemaceae.

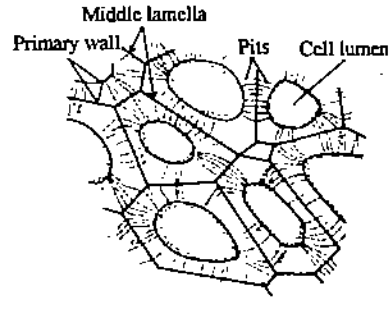


Fig. 7.16: Diagrammatic representation of parenchyma cells from the endosperm of *Diospyros*. The cells are connected to each other through a number of pits. (From Esau, 1985).

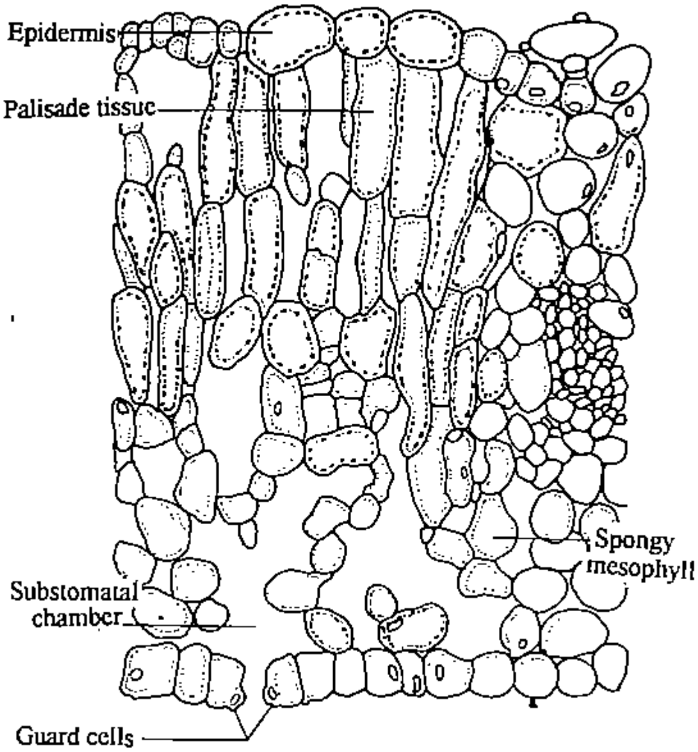


Fig. 7.17: *Syringa* sp. vertical section of a portion of the leaf. Note the features of the photosynthetic palisade tissue. (Redrawn from Cutter, 1978).

Meristematic parenchyma, these cells are characterised by being small-sized with a small number of organelles. They are able to absorb sugars, water and inorganic nutrients and use them to synthesize whole cells.

Secretory parenchyma, these cells secrete a variety of substances either on the exterior of plant, e.g., cutin; or restricted to certain cavities and ducts inside the plant, e.g., latex and resin.

(ii) Structural Parenchyma - As their name suggests they exhibit a form of structural specialization. Its common form is aerenchyma (Fig. 7.18). In such a tissue, the intercellular spaces are the main features of interest. These spaces arise either by splitting apart of the middle lamella region between the cells or by the breakdown of cells. In aquatic plants, the intercellular spaces are very well developed that together form connected system throughout the plant body. In this way a continuous gas phase that ramifies throughout the tissue is formed. This enables the submerged stems, petioles, and roots of the aquatic angiosperms, e.g., water lilies and plants from mangroves to fulfill their oxygen requirement. In addition, the large vertical air spaces in many aquatic plants often contain stellate cells or astrosclereids (Fig. 7.18 d) that are often transversely intersected at regular intervals by diaphragms. This can be commonly seen in the petioles of *Nymphaea*. These astrosclereids often branch into the columnar air spaces and lend support to the petiole.

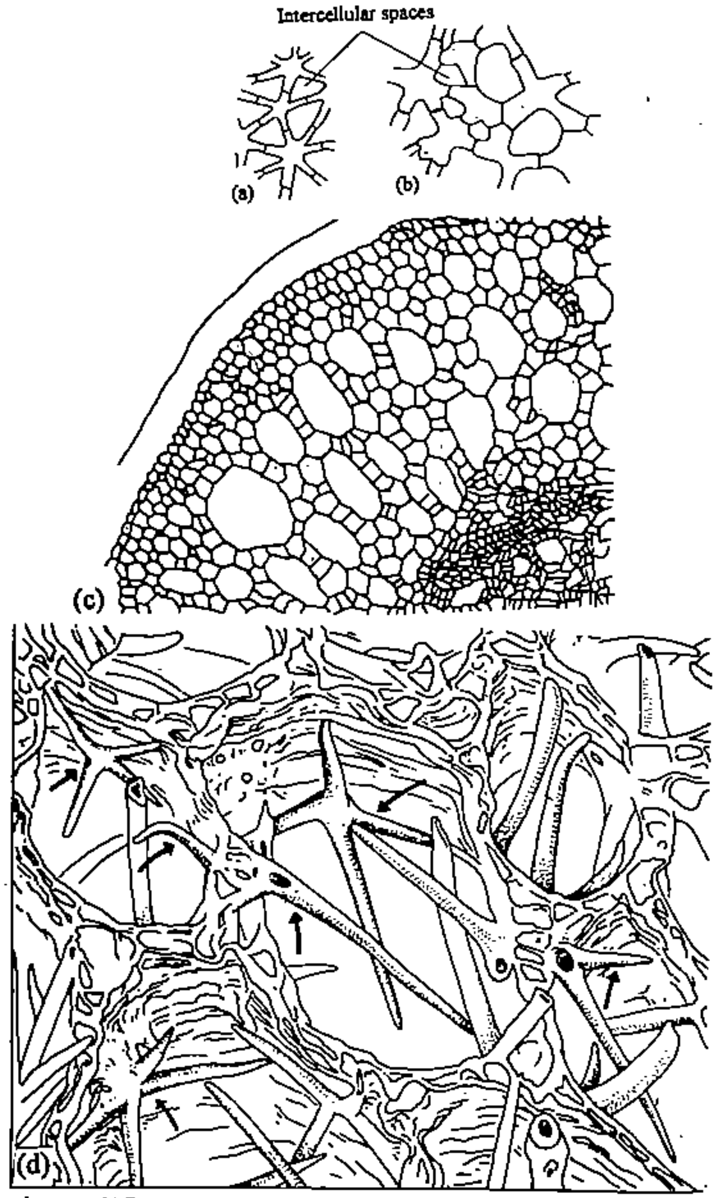


Fig. 7.18: Aerenchyma. a,b) Parenchyma cells with many arms joined enclosing large intercellular spaces. A few cells from the pith of *Juncus* (a) and the leaf mid rib of *Canna* (b). c) A portion of the stem of *Ludwigia terrestre*, whose cortex is largely composed of aerenchyma. d) Diagrammatic depiction of the astrosclereids (arrows) in the aerenchyma from the petiole of *Nuphar variegatum*. [Adapted from Cutter, 1978 (a,b and d); Mauseth, 1988 (c)].

The aerenchyma tissue not only provides aeration and buoyancy to aquatic plants, but is also relatively strong despite its light weight. One interesting aspect of the aerenchyma is that the air spaces occupy an area that is about half the volume of the tissue. In such instances the cells invariably develop lobes or arms, and become star-shaped as in *Juncus*, *Musa* and *Scirpus*. And if the air spaces are even larger than this they often have tissue sheets traversing through their spaces. This devise lends extra support.

(iii) Boundary Parenchyma - If you can recall the anatomical structure of root, stem or leaf, you may remember that the interfaces between many of their regions, or between the plant structure and environment are composed of parenchyma cells. Examples of interfaces between the various plant tissues include endodermis in roots that isolates the conducting tissue from the cortex; similarly the bundle sheath in monocot leaf is an interface between the vascular bundle and the mesophyll cells. The epidermal cells of roots, stems and leaves are mostly parenchymatous and they form an interface between the plant structure and the environment. You would learn more details about the epidermis at the end of this unit.

(iv) Transport Parenchyma - These are exemplified largely by the transfer cells (Fig. 7.19). In many areas in a plant, materials are required to be transferred rapidly and in large quantities over short distances - into a gland, into and out of sieve elements, and into a developing embryo. This task is accomplished by transfer cells. These are specialized parenchyma cells whose walls have extensive wall ingrowths extending into the cell cavity (Fig. 7.19). The increased wall area facilitates efficient transfer of materials.

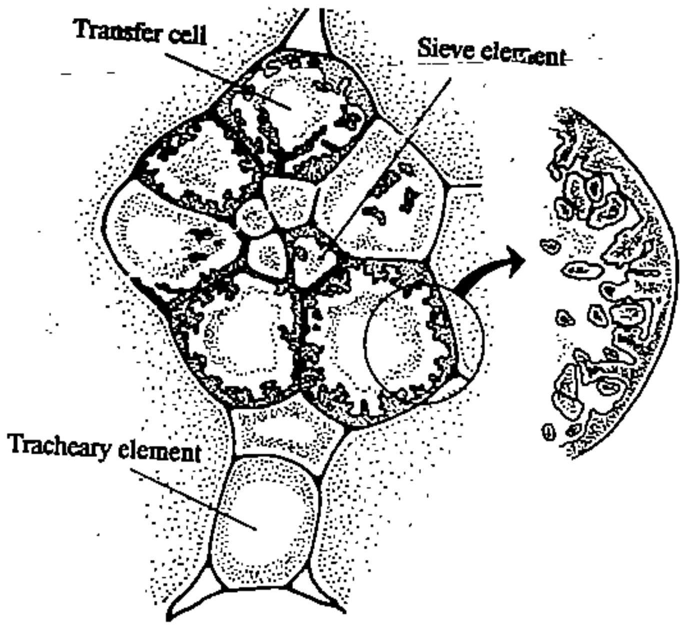


Fig. 7.19: *Sherardia arvensis*. A portion of leaf vasculature enlarged to show transfer cells surrounding the phloem elements. (Redrawn from Pate & Gunning, 1969).

(v) Storage Parenchyma - Plant parts that store some products such as starch grains (Fig. 7.14), oils, proteins and so on, are mostly parenchymatous. Based on their exclusive function they are termed as storage parenchyma. Most plant parts such as fruits, seeds and tubers with storage products are used as food. The starch storing cells are commonly seen in cereal grains and potatoes; proteins in beans and pears; and oil in avocado and safflower. Cells of this type are often gorged with the storage product so that the vacuole and other organelles are completely obscured. In succulent plants such as cacti and euphorbias their parenchyma cells store water. Such cells are large and bulk of their volume consists of a greatly expanded vacuole surrounded by a thin layer of cytoplasm (Fig. 7.20).

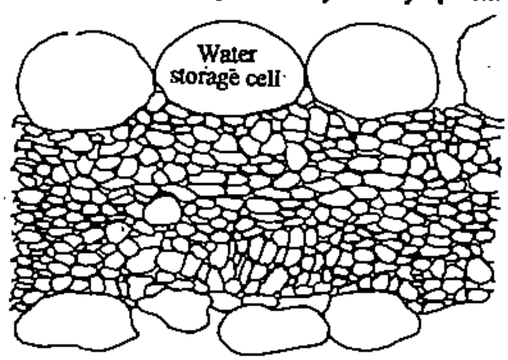


Fig. 7.20: A portion of the leaf of *Carpobrotus* cut in transverse section. Many of the epidermal cells are many-fold enlarged and serve as water storage cells. (Redrawn from Mauseth, 1988)

Box 7.1: The Versatile Parenchyma.

The parenchyma cells owing to living protoplasts and the ability to resume meristematic activity are a versatile tissue that is favourite of horticulturists. In horticultural practices, if an organ is excised from a plant and used as a cutting, new roots or bud primordia develop from its parenchyma cells only. Besides, this tissue also plays an important role in wound recovery and regeneration. Mature parenchyma cells quite often resume meristematic activity when their environment is artificially changed. In culture media, even a small number of such cells are able to produce whole plants that bear viable seeds. These cells are so versatile that their protoplasts, when grown under suitable culture conditions, are able to develop into complete plants.

In recent years, the isolated protoplasts from leaf mesophyll cells have been successfully regenerated into whole plants under controlled conditions. One potentiality of this work is the formation of somatic hybrids produced by first fusing the isolated protoplasts of two different species and then generating plants from them. Such methods enable one to overcome genetic incompatibility.

(2) Collenchyma

This is another form of simple tissue as it consists of only one type of cells. They resemble parenchyma closely and often one interprets them as thick-walled parenchyma. Collenchyma are little more altered in the process of their differentiation than the parenchyma cells and are described as a living flexible tissue with considerable tensile strength. The main characteristics of collenchyma are as follows:

- These are living when mature. They have living protoplasts often containing chloroplasts and large, central vacuole (Fig. 7.21). Tannins are also commonly seen.

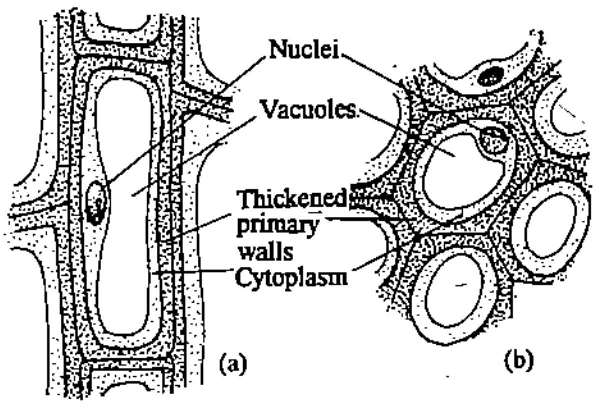


Fig. 7.21: a,&b) A diagrammatic representation of collenchyma cells. These are characterised by having non-lignin thickening on the inner side of the primary layer of the cell wall. These cells contain living cytoplasm.

- Simple pits are present in them.
- Air spaces too are sometimes present.
- Ontogenetically, collenchyma develops from elongated cells which resemble procambium and which appear in the very early stages of differentiation of the meristem, or from more or less isodiametric cells of the ground meristem.
- They function as supporting tissue in young growing organs and even in mature organs in herbaceous plants.
- They are found in stems, leaves, floral parts, fruits, petioles, and peduncles. They usually occupy a peripheral position in organs. In stems these are often seen immediately beneath the epidermis or below a few outer layers of parenchyma. They often form a complete cylinder near the periphery of the stem or occur in the form of discrete strands.
- These are often elongated along the axis of the organ in which they are situated.
- In addition to the cellulose wall, they have an extra layer of primary wall that is composed of hemicelluloses, or pectic substances either evenly distributed within the cellulose wall or concentrated in the **angles of the cell.**

Box 7.2: Test for Cellulose.

Treat the tissue with a solution of Iodine Potassium iodide, followed by 60% sulphuric acid. The walls stain for cellulose.

- These cells have a considerable degree of plasticity and they stretch irreversibly with the growth of the organ.
- Like parenchyma cells they are capable of reverting into a meristematic state.
- Based on the type of wall thickening, three main types of collenchyma (Fig. 7.22) have been recognised.

(i) Angular - the commonest type, wall thickening deposited predominantly at the corners or angles of cells, e.g., in celery potiole, stem of *Datura, Vitis, Begonia, Coleus, Morus* and *Cucurbita*.

(ii) Lamellar - In this type, the wall thickening is deposited more heavily on the tangential than on the radial walls of the cells, e.g., in stems of *Sambucus nigrum, Rhamnus*.

(iii) Lacunar - In such cells, thickening is deposited mainly around the intercellular spaces between the cells. Such cells can be seen in the aerial roots of *Monstera*; and petioles of *Salvia, Malva, Althaea, Asclepias, Dahlia, Helianthus*.

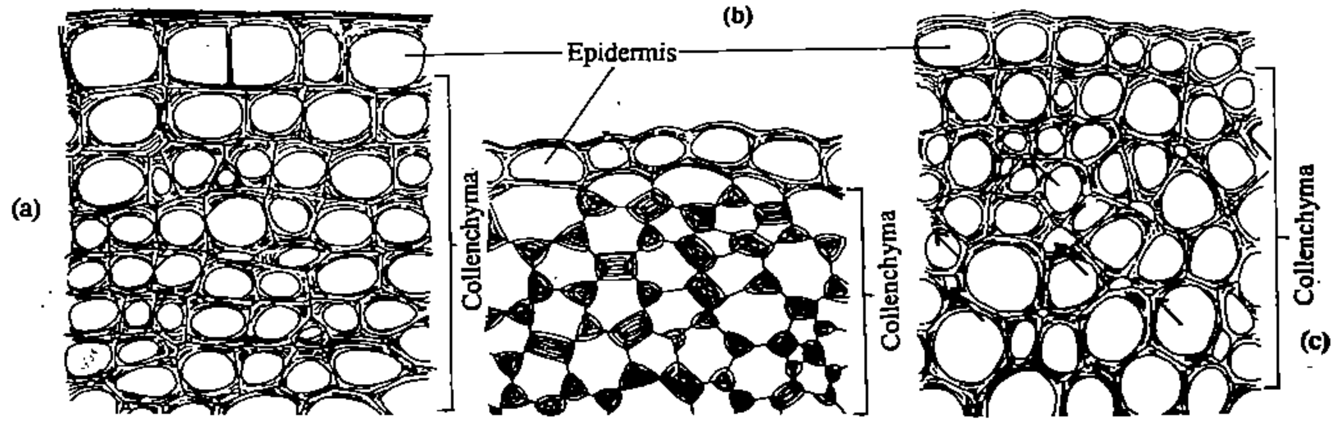


Fig. 7.22: Types of collenchyma. a) Lamellar collenchyma from *Sambucus*. Thickenings mainly on tangential walls. b) Angular collenchym from *Cucurbita*. Thickenings in the angles. c) Lacunar collenchyma from *Lactuca*. Note a large number of intercellular spaces (see arrows) and the prominent thickenings located next to these spaces. (Redrawn from Esau, 1985).

(3) Sclerenchyma

Sclerenchyma comprises a complex of thick-walled cells, whose principal function is to provide mechanical strength. They have the following cellular peculiarities.

- At maturity they generally lack protoplast and are mostly dead cells.
- They develop in any or all parts of the primary or the secondary plant body. They may be formed directly from the meristematic cells or by the modification of the parenchyma or collenchyma cells.
- Their thickened secondary walls that are often lignified are considered as the identifying feature of this tissue. Their walls usually possess simple pits (Fig. 7.23).

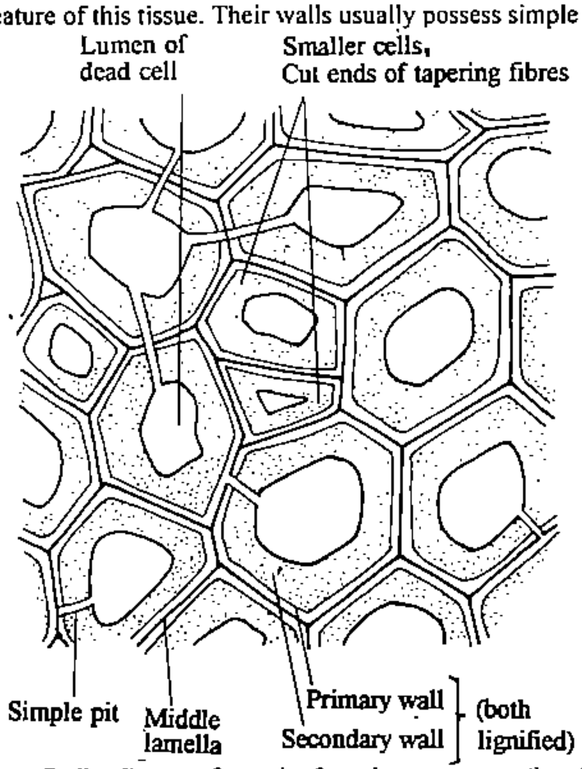


Fig. 7.23: *Sansevieria* sp. Outline diagram of a portion from the transverse section of leaf showing details of the cells. Note the cells are connected by means of simple pits. (Redrawn from Berrie et. al., 1987).

- These cells enable the plant organs to withstand various strains like the ones resulting from stretching, bending, weight and pressure, and minimising damage to the thin-walled softer cells.
- Two types of sclerenchyma occur: sclereids and fibres (Fig. 7.24).

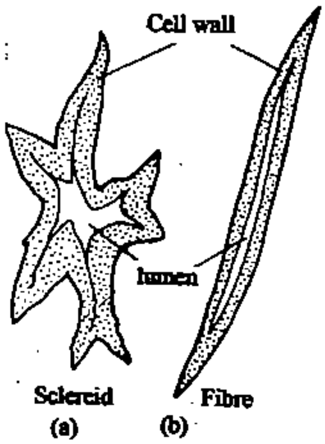


Fig. 7.24: Types of sclerenchyma (a) sclereid; and (b) fibre.

Sclereids

Sclereids are highly variable in shape (Fig. 7.25). Their various forms are described a little later. The term stone cell is often used for a sclereid that is almost isodiametric, unbranched and without uniform shape. The hardest parts of the seeds, nuts and hard fruits are usually composed of sclereids of various types. Together they impart hardness and mechanical protection as in a walnut shell. They may also be found randomly distributed in various tissues of the plant. They may occur singly or in groups (Fig. 7.25), sometimes associated with the xylem or phloem as in the bark of *Cinnamomum*; or in the parenchymatous tissues, e.g., pith and cortex of stems and petioles of *Hoya*; in the roots of *Nymphaea*; leaf mesophyll of *Nymphaea*; flesh of fruit of *Pyrus*; seed coats of *Pisum* and *Phaseolus*. In the seed coat they usually occur as a complete layer (Fig. 7.26 a, b) whereas in other tissues they are distributed randomly (Fig. 7.26 c). In addition, they also occupy specific positions, e.g., at the ends of veinlets as in the leaves of *Mouriria* (Fig. 7.26 d, e). Such sclereids are known as terminal sclereids. Sclereids also occur near the margins of leaves as in the leaves of *Camellia*. Gritty texture of pears is due to the presence of groups of sclereids in the fruit flesh. Sclereids are extremely variable in shape (Fig. 7.26) and distribution. They are very interesting cells. They may occur singly or in groups (Fig. 7.26).

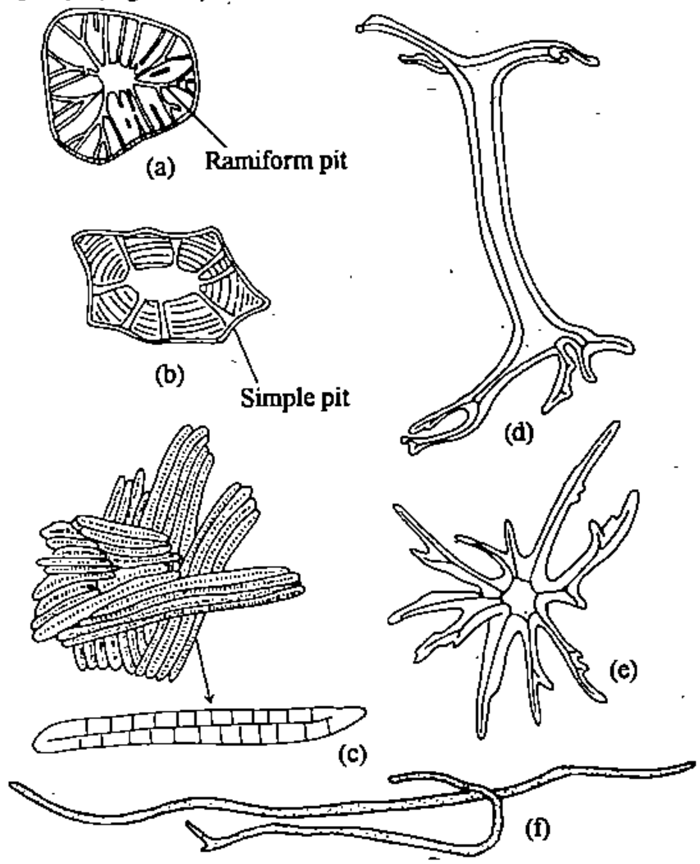


Fig. 7.25: Various kinds of sclereids. a) Stone cell from the flesh of pear (*Pyrus*) fruit; b) sclereid from stem cortex of wax plant (*Hoya*); c) sclereids from endocarp of fruit of apple (*Malus*); d) a columnar sclereid with ramified ends, from leaf mesophyll of *Hakea*; e) astrosclereid from stem cortex of *Trochodendron*; f) filiform sclereids from mesophyll of olive (*Olea*). (Redrawn from Esau, 1979).

Sclereids exhibit variation in their forms. Some of the commonly recognised forms are discussed, below:

(i) Brachysclereids - These are commonly known as the stone cells, and are isodiametric in shape. These occur in the flesh of the fruit of *Pyrus* and in the parenchymatous tissues or phloem of stems, e.g., *Cinnamomum* and *Hoya* (also see Fig. 7.25 a, b).

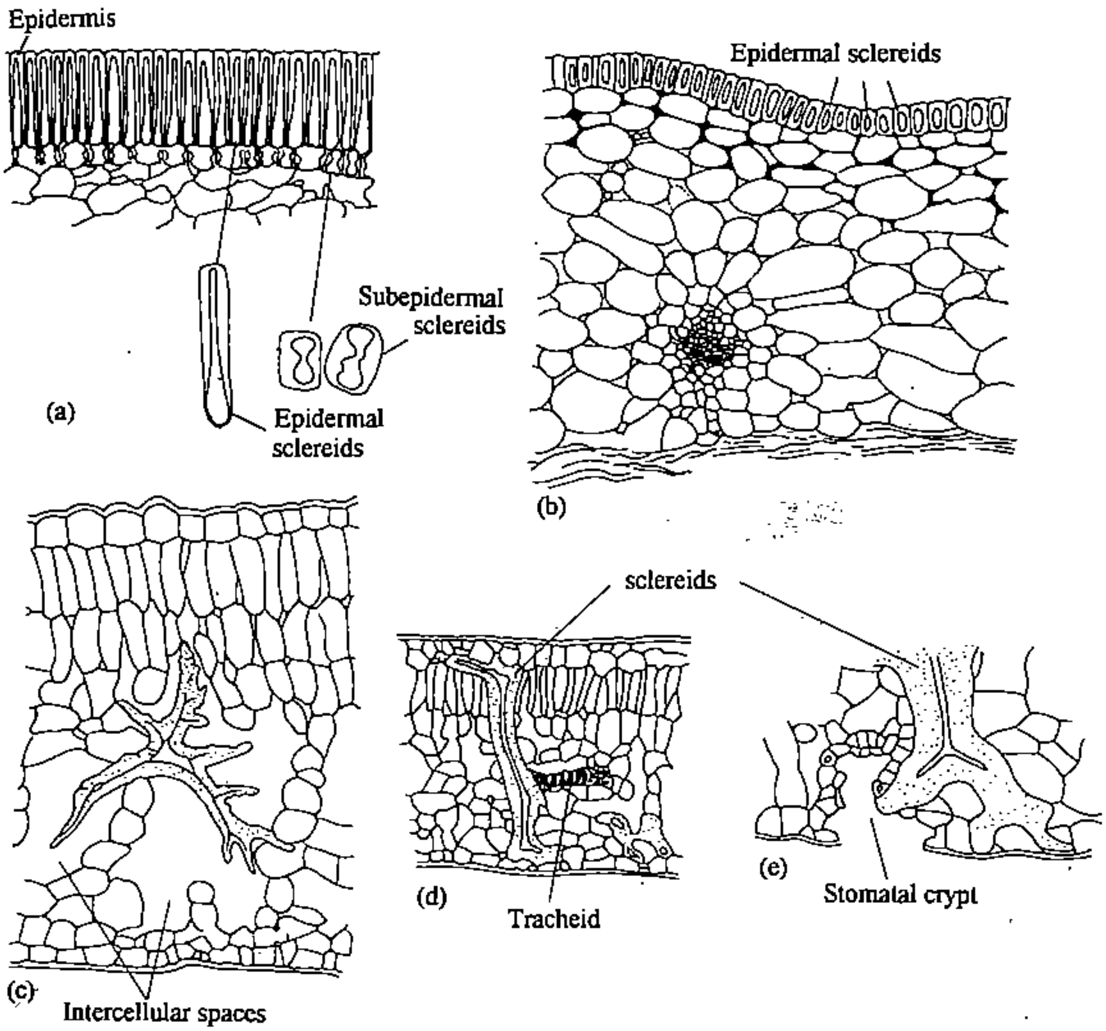


Fig.7.26: Distribution of sclereids. a) A portion of transverse section of seed coat of *Phaseolus*, showing two continuous layers of sclereids. Note the characteristics of sclereids (in enlarged view) from the epidermal and the subepidermal layers: b) *Allium sativum* (garlic), a part of the transverse section of the scale. The sclereids comprise most of the epidermal layer. c) A branched sclereid as seen in the transverse section of the *Trochodendron* leaf blade; d) A columnar sclereid with horizontal branches at its ends from the leaf of *Mouriria* (shown here in trans-section). Note the sclereid is in contact with the tracheid. e) A terminal portion of sclereid as in d enlarged to show its extent. One of its branches has extended to the cuticle and the other one has penetrated between the two guard cells into stomatal crypt. [Redrawn from: a) Esau, 1985; b) Mann, 1952; c-e) Foster, 1947].

(ii) Macrosclereids - These are rod-shaped, often forming a continuous layer in the testa of the seeds, e.g., in the seeds of Fabaceae (Fig. 7.26 a); and the endocarp of apple (Fig. 7.25 c).

(iii) Osteosclereids - These are bone-shaped and their ends are often enlarged or lobed. These forms exist in the seed coats and leaves of *Hakea* (Fig. 7.25 d).

(iv) Astrosclereids - These are variously branched and are often star-shaped, and are found in the petioles and leaves, e.g., *Thea*, *Trochodendron*, and *Nymphaea* (Fig. 7.25 e).

(v) Trichosclereids or filiform sclereids are elongated, hair-like forms that may also be branched. These are commonly found in the aerial roots of *Monstera* and in the leaves of *Olea* (Fig. 7.25 f).

Fibres

Human beings have been using plant fibers for atleast 10,000 years. Even now more than 40 different families of plants are in commercial use in the manufacture of textile goods, ropes, strings, canvas and many other products.

The fibres vary considerably in length but they are typically many times longer than broad. Mostly they are elongated elements with tapering ends (Fig. 7.27) which overlap and are often fused with each other. Their value as strengthening tissue is largely due to their arrangement in these long masses and to the overlapping and interlocking of the cells.

Their secondary walls are usually lignified leaving a narrow cavity or lumen. These cells mostly lack protoplasts. Recent findings have revealed that xylem fibres in many plants retain living contents for several years.

Fibres occur in roots, stems, leaves and fruits in association with different tissues. Along the xylem and phloem you can see them as a sheath or cap associated with the vascular bundles especially in the leaves. They are also present in the parenchymatous tissue of the pith or the cortex.

Fibres occur singly or more commonly in bundles. They can be classified into two types depending on their occurrence. (i) Xylem fibres which are associated with xylem and (ii) extraxylary fibres occur in tissues other than xylem as in phloem, cortex, pericycle and pith. The fibres of cortex, pericycle and phloem are referred to as the **bast fibers**. In monocotyledonous leaves, fibres are present not only as sheaths around the vascular bundles but they also extend between the bundles and the upper and the lower epidermises. The whole strand of this kind is known as the 'hard'. The leaf fibres on commercial scale are obtained from sisal (*Agave sisalana*).

Fibres may originate from the procambium or vascular cambium if they are associated with the primary or secondary system of phloem or from the ground meristem. Primary fibres grow in length with the organ in which they occur. The fibres of *Cannabis* (hemp) and *Corchorus* (jute) extend as the internodes of the stem elongate, and may continue to increase in length much after the period of internodal extension. This is also true in the fruit of *Luffa* whose network of fibres is used commercially as sponge. In *Boehmeria*, fibres elongate faster than the surrounding cells. Individual fibres may attain considerable length, e.g., 1-10 cm in hemp, and up to 55 cm in ramie. Deposition of secondary wall takes place after elongation of the fibres has ceased. As a result, the basal end of a fibre has a thick secondary wall while the apical end still has living contents and thin wall, as seen in *Boehmeria*.

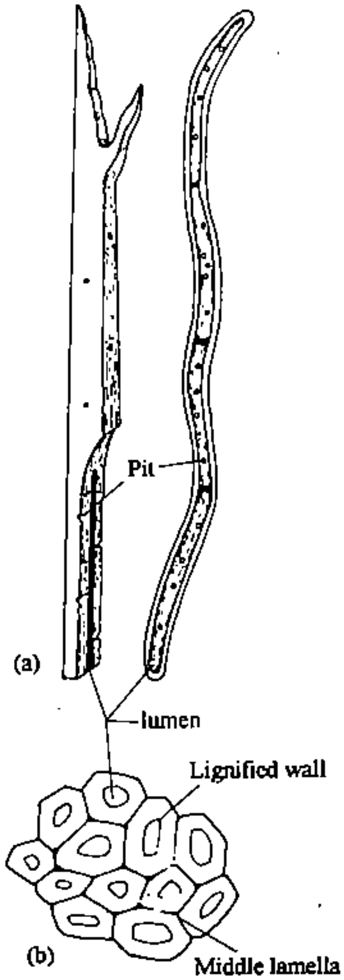


Fig. 7.27: Outline sketch of fibres in longitudinal view (a), and in cross section (b). (After Weier et al., 1982).

Box 7.3: Fibre Identification Parameters.

Plant fibres find wide applications such as in the making of ropes, paper and other substances. Many times one needs to verify the quality and identify the pulp used in the making of a product. The fibres of many plants have been studied carefully to identify characters that are of taxonomic importance. Among these are the length, width, the ratio of the wall thickness to the diameter of the lumen, cross markings left by the surrounding cells and the presence of crystals or silica deposits.

SAQ 3

Fill in the blank spaces with appropriate words.

(i) Stellate parenchyma is seen in the mid-rib region of .... leaf.

(ii) The .... tissue provides aeration and buoyancy to the aquatic plants.

(iii) .... cells play a role in wound recovery.

(iv) .... are the sclereid types present in the leaves of *Hakae*.

(v) The gritty texture in the fruit of *Pyrus* is because of the presence of .... in the flesh.

(vi) Collenchyma and sclerenchyma perform similar function, that is, of .... in the plant.

(vii) The leaves of .... constitute commercial source of fibre.

(viii) In many aquatic plants the branches of .... are seen in the spaces of the aerenchyma tissue.

7.3.2 Complex Tissues

A complex tissue is the one which is made up of more than one type of cells working together as a unit. The two most important complex tissues in plants - **xylem** and **phloem** function primarily in the transport of water, ions and soluble food substances throughout the plant. Both of these together form the vascular system of the plant.

(I) Xylem

Xylem which is an important component of the complex 'plumbing' system of plant conducts water and dissolved substances from the root to the various parts of the shoot system. In addition, it also aids in providing mechanical support to the whole plant and acts in storage of nutrients. It consists of a combination of parenchyma cells, fibres, vessels and tracheids (Fig. 7.28). Tracheids and vessel elements have several features in common and are often referred to jointly as tracheary elements. Their common characters are:

- They are dead when mature;
- They are usually elongated along the axis of an organ;
- They have lignified cell walls. The lignin is deposited in a number of patterns leaving areas of primary wall uncovered.

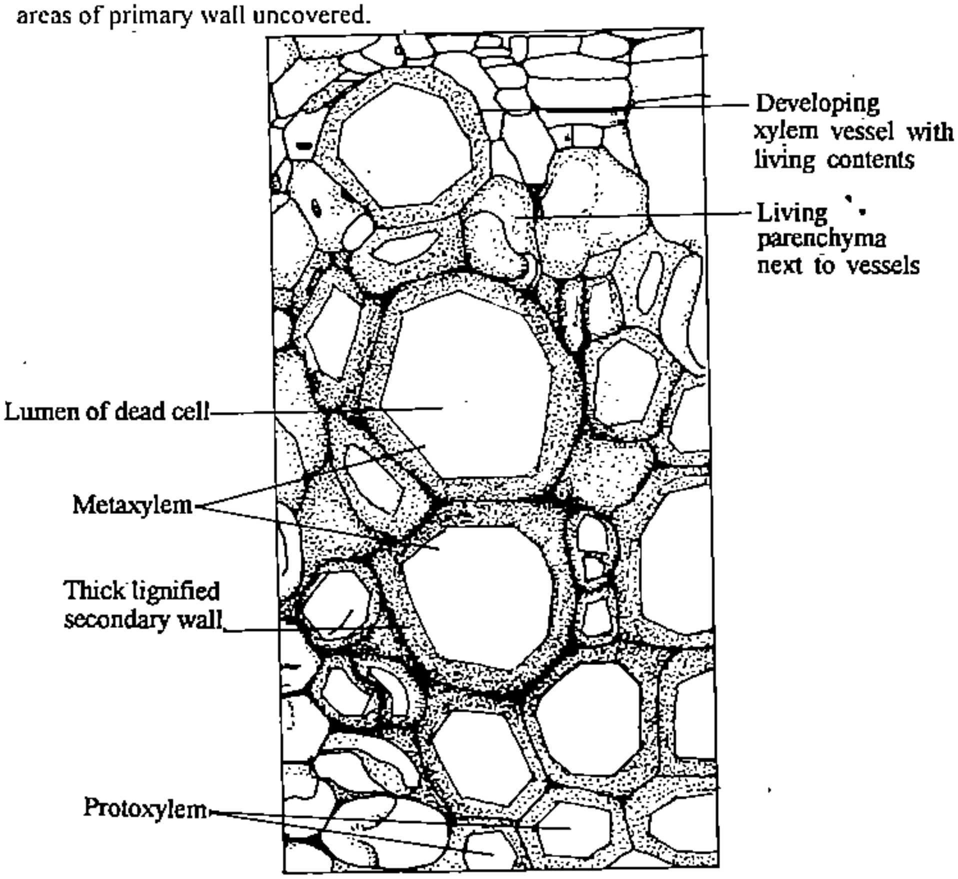


Fig. 7.28: *Tridax* sp. A portion of xylem cut in transverse section showing the various components. (Redrawn from Berrie et al, 1987).

Xylem differentiates from the procambium during the primary growth of the plant. The procambium is situated below the growing root (if seen in inverted form) or shoot apex or associated with the leaf primordium. The procambium consists of meristematic, densely cytoplasmic cells, elongated in the longitudinal plane of the organ in which it occurs. The xylem produced by the procambium in the primary body is called the **primary xylem**. The first elements of the primary xylem to differentiate and become mature are known as **protoxylem**, and those that mature later are called **metaxylem** (Fig. 7.28). In many plants, after the completion of formation of primary body, secondary growth takes place as seen in gymnosperms and dicotyledons. Here the vascular cambium gives rise to **secondary xylem**.

As you know xylem is composed of vessels, tracheids, parenchyma and fibres. Vessels are long tubes made up of individual cells called vessel elements (Fig. 7.29) that are arranged end to end along the axis of the organ forming tubes. The vessel elements are open at each end and have oblique, pointed or transverse ends. The cross walls between successive vessel elements are perforated giving free passage for water from cell to cell. Perforation involves the dissolution of cross wall in a characteristic pattern. Tracheids, which like vessel elements are thick-walled and are dead at maturity, are elongated structures with tapered ends (Fig. 7.30). Their nonperforate ends overlap with each other and wherever two tracheids are in contact with one another, pairs of pits are usually present. The pit pairs permit water to pass from cell to cell. The pattern of the secondary wall laid down in the tracheary elements varies according to the stage of elongation of the organ in which they are situated at the time of differentiation. Tracheary elements which differentiate in the growing or elongating organ have patterns of thickening which allows stretching. These include **annular** thickenings in the form of separate rings, **spiral** thickenings in a continuous spiral, and **scalariform** thickenings like the rings of a ladder (Fig. 7.31 a-c). Tracheary elements in which secondary wall is laid down after elongation is over, have **reticulate**, that is, net-like thickenings (Fig. 7.31 d) or thickenings with bordered pits (Fig. 7.31 e). The bordered pits are so called because the edge of the secondary wall overhangs the edge of the pit so that the pit field is wider than the pit aperture and the pit is seen as two concentric circles when seen in surface view.

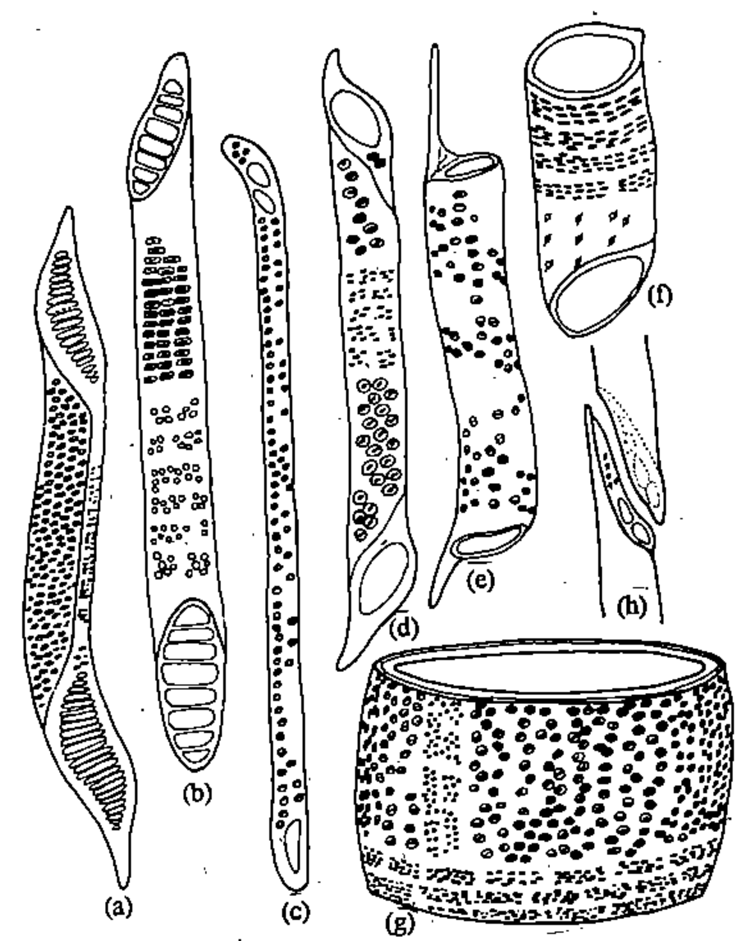


Fig. 7.29: Vessel elements from different species: a) ***Betula alba*****, b)** ***Liriodendron*****, c)** ***Lobelia cordinalis*****, d)** ***Quercus alba*****, e)** ***Malus pumila*****, f)** ***Acer negundo*****, g)** ***Quercus alba*****. h) End portion of two vessel elements from** ***Lobelia*****, note the juxtaposed areas of the two elements. (Redrawn from Eames & McDaniels, 1987).**

Xylem fibres (Fig. 7.32 a-c) are like the typical sclerenchymatous fibres as mentioned earlier. These are elongated, strengthening cells with thickened walls. Their ends are pointed at the time of maturity and they lack protoplasts. They differ from tracheids chiefly in their walls and reduced number of pits.

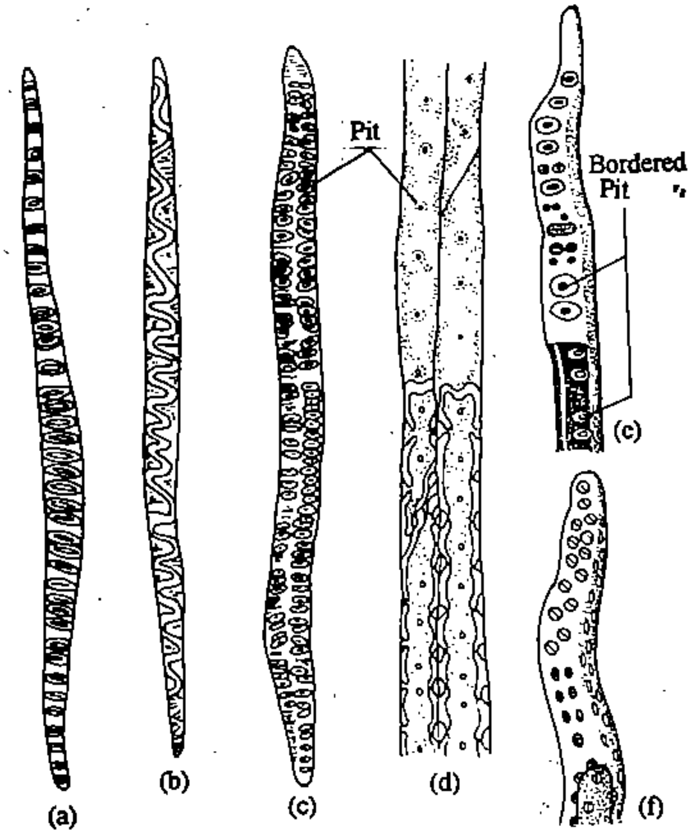


Fig. 7.30: a-d) Diverse forms of tracheids in longitudinal view. e, f) End portion of two tracheids, compare these to the end portions of the vessels as shown in Fig. 7.29. (Redrawn from Barden et al., 1987).

Xylem parenchyma cells (one such cell shown in Fig. 7.32 d) are scattered amongst the xylem elements. They are often little more elongated than the typical parenchyma of ground tissue and their primary walls sometimes get slightly lignified. Their chief function is food storage and lateral transport.

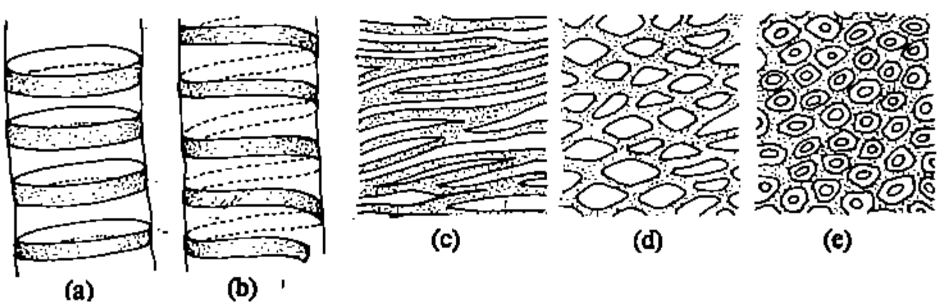


Fig. 7.31: Patterns of wall thickening in tracheary elements. a) annular; b) spiral; c) scalariform; d) reticulate without pits; and e) with bordered pits. (Redrawn from Berrie et al., 1987).

(2) Phloem

Phloem is a tissue responsible for the transport of dissolved organic substances like sucrose and amino acids from places in which they are formed to places where they are used or stored. Like xylem, phloem too is a complex tissue that is made up of several elements in angiosperms such as sieve elements, companion cells, parenchyma, fibres and sclereids. Certain secretory cells like laticifers and oil cells are also found associated with the phloem.

The primary phloem develops from the procambium, and can be categorised as protophloem and metaphloem. Protophloem develops from procambium during an early ontogenetic stage, whereas metaphloem develops at a later stage of development.

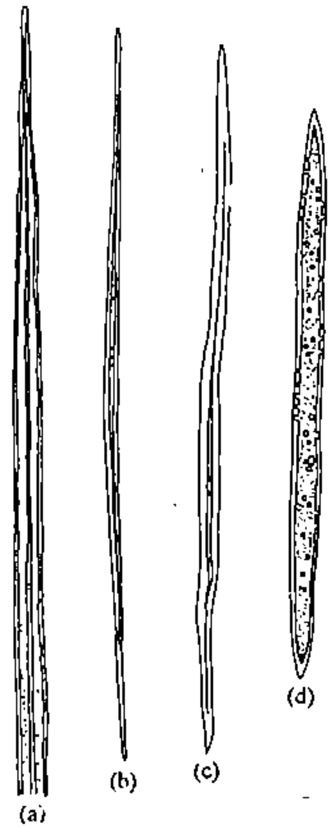


Fig. 7.32: a-d) Some forms of xylary fibers. a) From *Quercus rubra*, b) from *Carya ovata*, and c) from *Guaiacum sanctum*. d) A parenchyma cell from the wood of *Sassafras variifolium* (Redrawn from Eames & MacDaniels, 1987).

The conducting elements of phloem are the **sieve elements** which are of two types: sieve cells (Fig. 7.33 a) in almost all non-angiosperms and some primitive angiosperms, e.g., *Austrobaileya scandens*, and sieve tube members (Fig. 7.33 b) in the majority of flowering plants. Mark out the differences between the two in the Figure 7.33. The sieve elements being parenchyma cells have a primary wall and no secondary wall. Among angiosperms the sieve tube members and companion cells originate at the same time, and that too by the division of the same procambial cell. That's why the proximity of the two is well marked (Figs 7.34 and 7.35). Young sieve tube members have the usual complement of organelles: nucleus, plastids, mitochondria and dictyosomes. As the sieve

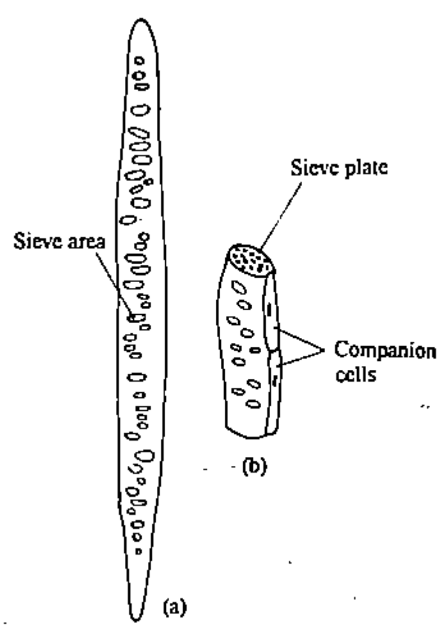


Fig. 7.33: Sieve elements. a) Sieve cell with tapering ends and several sieve areas on the surface of the cell. b) A sieve tube member. Note it differs from the former in being more wide and having distinct transverse end walls with prominent sieve areas.

tube member matures, its protoplast becomes greatly modified. Its nucleus disintegrates, the plastids lose most of their internal membranes but usually retain starch. The plasmalemma remains intact. The mitochondria become small, cytoplasm is much reduced in amount and exists chiefly as a thin peripheral layer. The vacuole membrane or tonoplast also disintegrates and the endoplasmic reticulum sometimes aggregates in parallel arrays along the cell wall. The central part of the sieve tube member cell is occupied by a mass of tubules or strands. This mass known as **slime**, is usually visible with the light microscope. It is made up of proteins so it is referred to as P-protein. Closely associated with the sieve elements are the albuminous cells in non-angiosperms and the companion cells in the angiosperms.

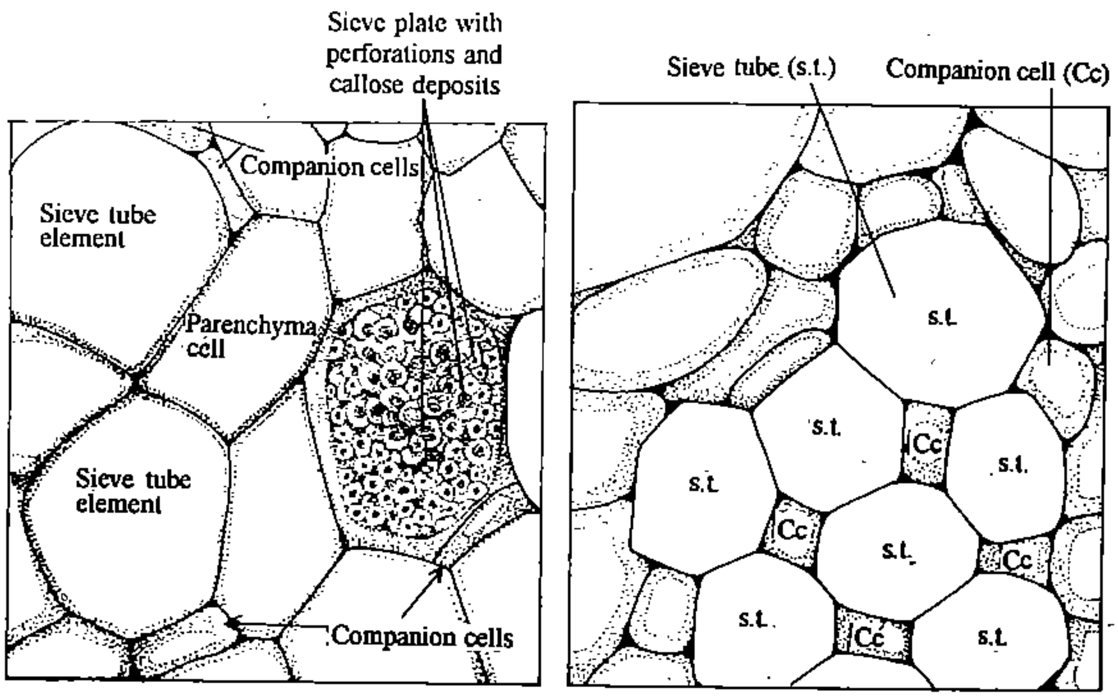


Fig. 7.34: Phloem in transection in a dicot (a) and a monocot (b) plant. Note the proximity of the sieve elements and the companion cells in both the cases. (Redrawn from Berrie, et al, 1987).

The companion cells have normal protoplast (Fig. 7.35) with all the organelles. It is believed that these cells control the metabolic activity of the sieve tube members that have no nucleus. Several plasmodesmata connect the protoplasts of companion cells and sieve tube members (Fig. 7.35). A characteristic structural feature of mature sieve tube members is the **sieve plate** (Fig. 7.35). This may occur on the end or side walls. If a sieve plate has only a single sieve area it is **simple**, with more than one it is **compound** sieve plate (Fig. 7.36). The pore size or its diameter varies considerably, average being 1.18 µm and up to 10 µm in *Cucurbita* or even 14 µm in *Ailanthus altissima*. The sieve tube members unite end to end and form a column or a sieve tube.

Phloem parenchyma (Fig. 7.35) are living cells that are scattered among other cells of the phloem. These are similar to the parenchyma of the ground tissue, but the cells are narrow and relatively more elongated. These cells enable substances to move laterally and often act as storage tissue too.

Phloem fibres are elongated sclerenchymatous cells occurring in groups in the phloem.

Monocots and dicots exhibit some differences in the composition of the phloem tissue. In monocots, phloem contains only sieve tube elements and companion cells. In most dicots, phloem parenchyma and, sometimes, phloem fibres also occur.

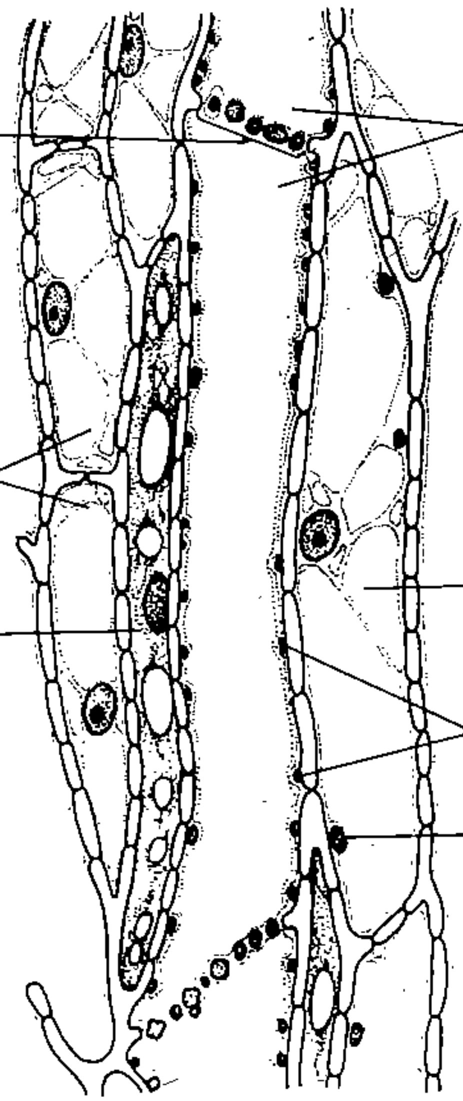


Fig. 7.35: Phloem tissue from the stem of tobacco. Mark cellular details of the various phloem components. (Redrawn from Wierer et al. 1987).

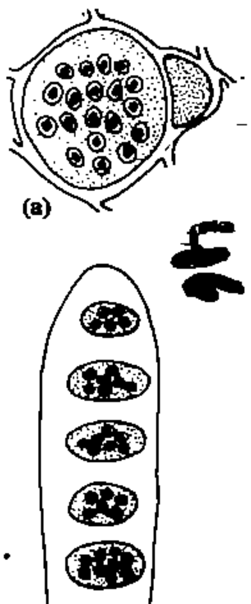


Fig. 7.36: Two types of sieve plates - simple (a), and compound (b).

SAQ 4

Label the following statements True with T and False with F.

(i) The first elements of primary xylem to differentiate and mature are known as metaxylem.

(ii) The progenitor of secondary xylem is vascular cambium.

(iii) Vessels, tracheids, fibres and parenchyma cells are the main components of xylem.

(iv) The vessel elements differ from the tracheids mainly in the perforations of the end and the cross walls.

(v) The chief constituents of phloem in the angiosperms are sieve elements, companion cells, parenchyma, fibres and sclereids.

(vi) The protophloem develops from interfascicular cambium during early ontogeny.

(vii) The sieve tube members and companion cells in angiosperms originate one after the other.

(viii) P-protein is found both in the sieve tube members and the companion cells.

7.4 EPIDERMAL TISSUE SYSTEM

The root and shoot systems of herbaceous plants are covered by outermost layer of cells called the epidermis. This constitutes the epidermal tissue system. This also represents the interface between the plant and the environment that includes a large number of factors - both biotic and abiotic. Epidermal tissues in different plant species growing in diverse conditions have evolved certain very special features to suit their respective environmental conditions.

The epidermis of the stem, leaves and floral parts originates from the surface layer of shoot apical meristem, and that of root from the layers of root apical meristem. In some species, the root epidermis may have a common origin with the cortex or with the root cap. The epidermis may be single- or multi-layered. In the roots of epiphytes, epidermis is multilayered and is known as **velamen**, e.g., in orchids such as *Vanda*.

The epidermal tissue system performs many important functions.

(i) Regulation of movement of substances - One of the primary functions of the epidermis is to regulate movement of substances into and out of the plant body. The epidermal cells of both the root and the shoot systems have appropriate features to achieve this. The protoplasts of root cells is 'drier' than the soil, therefore they can readily absorb water from the soil. On the other hand the shoot system, which is exposed to the dry atmosphere, needs a protective devise to prevent water loss from the plant. This clearly marks the contrasting roles played by the epidermises of the root and the shoot systems. Another example citing the contrasting roles of epidermis is as follows. Uproot a healthy mesophytic, and a xerophytic plant. Keep them as such. After some hours the mesophytic plant would show signs of wilting whereas the xerophytes may take much more time to show such symptoms. Why is it so? It is basically due to the differences in their epidermal layers. The wilting in a xerophyte say a cactus gets enhanced if its epidermis is peeled off. Does this clarify the point to you? Another functional attribute of epidermis is specialized epidermal system that enables epiphytes to attach to the surface of trees to fulfil their requirements for water and nutrients from the rainwater and the dust.

(ii) Protection from sunlight - The epidermises of the plants occurring in deserts, seashores and alpine regions protect them from the damages caused by direct sunlight. Some of the damaging effects of direct sunlight are overheating of the protoplasm and bleaching of chlorophyll.

(iii) Protection against other organisms - Most plants are parasitized by a variety of pests and pathogens. These range from viruses and bacteria to higher plants. The epidermis of any plant is in fact its first line of defense against the wide range of biological enemies. A resistant epidermis easily wards off the diverse biological agents thereby ensuring the health of the plant. Have you ever observed that some parasitic angiosperms such as mistletoes and dodders attack only certain plants whereas others remain unaffected. The resistant epidermis of the latter, can be one reason. Similarly, insects are a constant menace to plants. Many plants such as stinging nettles develop epidermal glands containing toxic or noxious substances that prevent parasitisation by insects or damage by large animals.

(iv) Protection against nonbiological agents - Nonbiological agents like wind, salinity and moisture stresses have lead to the development of certain adaptive features to tide over the adverse situations. Many of these would be elaborated a little later. One interesting example to tide over high wind velocity is that of banana. Its newly formed leaves have entire lamina, but it is common to see old leaves torn at several places, so much so that they look like compound leaves. Actually certain weak areas exist on the lamina of the leaf and at these regions only the lamina splits. This is one form of adaptation to prevent damage due to high speed wind. Similarly young shoots and leaves of several plant species have flexible, tear-resistant coverings especially at the edges of the leaves that enable these structures to withstand gentle breeze and minimise any damage due to high speed winds.

(v) Epidermal function in reproduction - A number of mechanisms have evolved that encourage or ensure cross pollination. One example is the anther epidermis that opens early, releasing pollen grains, while the stigma epidermis is still nonreceptive. The second instance is the epidermis of the stigma that tests any pollen landing on its surface, and rejects the ones not suitable for the plant. This is what is known as the compatibility reaction. Remember you have learnt about it in LSE-06.

Besides these, the epidermises that develop various colours, textures and scents help to attract pollinators to bring pollen to the stigma. Similarly secretion of nectar by the floral or extrafloral nectaries is done either by secretory epidermis or epidermis that accumulates and releases nectar to the pollinators.

(vi) Secretions - In the secretion of certain exudates that attract and trap insects in insectivorous plants and the removal of excess moisture through hydathodes, the epidermis plays important roles. These would be taken up in detail subsequently in the course.

Structural Variations and Specialities

After having viewed epidermis from the point of view of its functional diversity, we shall now look at the structural features that enable the plants to perform these diverse functions.

In flowering plants the mature epidermis (of root and shoot system in total) is composed of four kinds of cells; the ordinary epidermal cells, guard cells, trichomes and root hairs. The ordinary epidermal cells are the ones that lie between the more specialized cells of the epidermis. They are more in number and cover the greater part of the plant body. They exhibit a wide range of variations in shape, size as well as contents. For example, in seed coats and bud scales elongated cells are common where there is need of extra protection. They are variously modified in relation to the organ where they occur. For instance, they are elongated parallel to the organ. In surface view they may be rhomboidal- sinuous and of different forms.

A universal feature of ordinary epidermal cells is that they are firmly attached to each other along their sides but less firmly to the tissue beneath. Therefore, in many plants the epidermis could be easily peeled away as a sheet from the underlying cells.

Ordinary epidermal cells usually live as long as the lifetime of annual or biennial plants, but are often replaced by bark in perennial plants.

Epidermal cells besides including living protoplasts, also contain leucoplasts, chloroplasts and anthocyanins. These cells may elongate or enlarge, and undergo secondary thickenings as the organ matures. The thickening is often more on the periclinal walls and minimal on the anticlinal walls.

One of the main function of the epidermis is to control the amount of water loss. For this purpose there is deposition of hydrophobic materials - the cutin and the cuticle on the outer wall of the epidermal cells (Fig. 7.37). Cutin is a high molecular weight lipid polyester that results from the polymerisation of certain fatty acids. In addition to water retention, it reflects some of the excess solar radiation because of its shiny nature. Mostly cuticle is deposited as a smooth layer; however, in some species it has complex patterns of striations, bumps and even wrinkles.

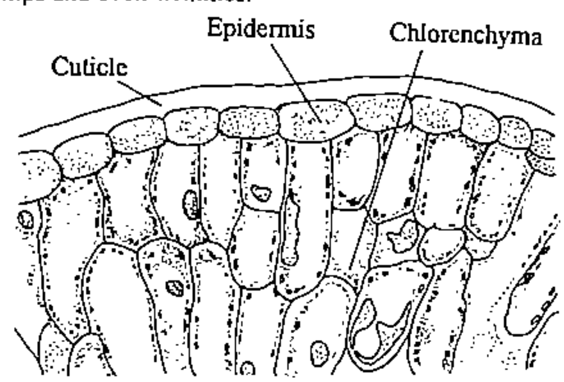


Fig. 7.37: A portion of the leaf of *Taxus* in cross-section. Mark the prominent layer of cuticle on the outer side of the epidermal cell layer (Redrawn from Mauseth, 1988).

Besides cutin, the epidermises of many species are coated with waxy depositions that make the surface look greyish in colour and extremely hydrophobic and nonwettable. This becomes an important factor in the application of exogenous substances such as herbicides and growth regulators. These depositions no doubt are important for the plant as they act as effective sunscreens. For example, the wax layer of *Echeveria bracteosa* reflects about 25% of the incident light. Waxes also provide protection from the insect attack.

(1) Stomata

Despite the cutins and waxes, the epidermises of the aerial parts of the plant do not become absolutely impermeable, and they are interrupted by minute openings or the **stomatal pores**. Each pore is surrounded by two **guard cells** (Fig. 7.38) forming stoma. The guard cells are different from the ordinary cells in their size and arrangement. Sometimes the cells adjacent to the guard cells are also different in size, shape and cell content from the ordinary epidermal cell. Such cells are termed as the **subsidiary cells** (Fig. 7.38). The guard cells including the pores and the surrounding subsidiary cells, all together form a stomatal complex. Based on the number and arrangement of the cells of stomatal complexes, five kinds have been recognised (Fig. 7.39).

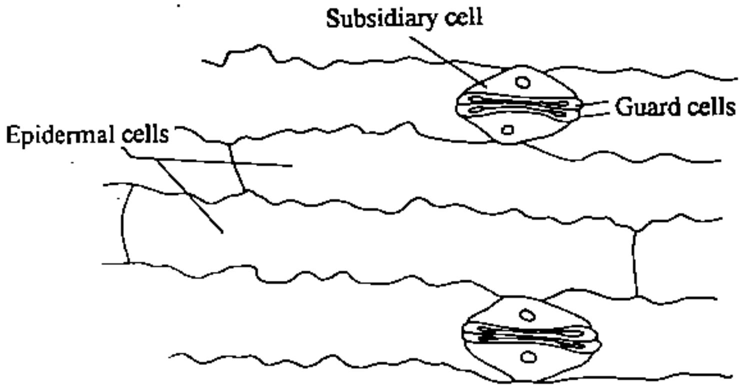


Fig. 7.38: A portion of paradermal section of *Zea mays* leaf showing guard cells, subsidiary cells and other epidermal cells.

Stomata occur on almost all green parts of a plant especially leaves and stems. On the leaves, they are typically more abundant on the lower or the abaxial surface, with very few or no stomata on the upper or the adaxial surface. The dicot leaves have haphazardly arranged stomata, whereas in monocots these are arranged in rows. Stomata are also found on some non-green portions of the plant such as petals, stamens, fruits and seeds, but they are invariably non-functional. All roots, with the exception of pea root lack stomata.

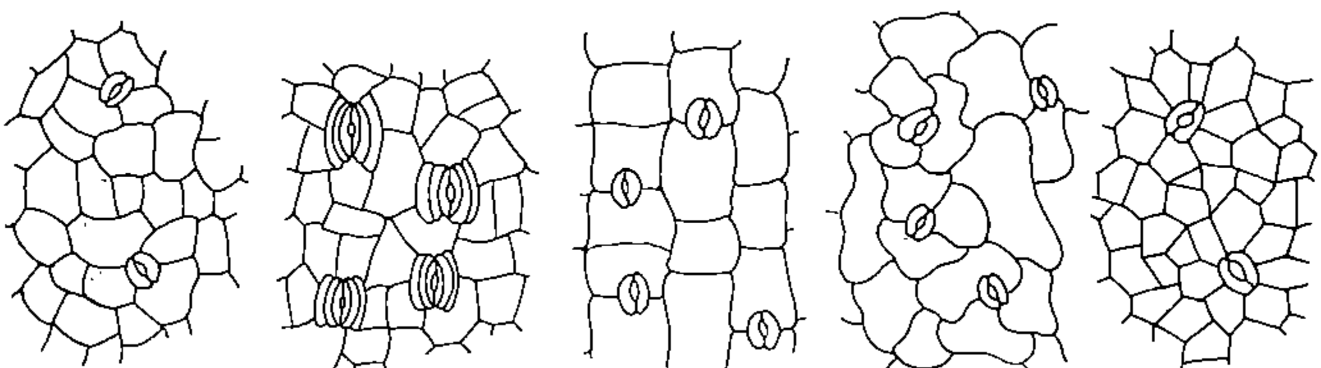


Fig. 7.39: Five kinds of stomatal complex: (a) anomocytic types lack subsidiary cells; (b) paracytic type - each guard cell is accompanied by one or more subsidiary cells aligned parallel to it; (c) diacytic type - two subsidiary cells are aligned perpendicular to the guard cells; (d) anisocytic type - three unequally sized subsidiary cells are arranged around the guard cells, and (e) actinocytic type - many guard cells surround subsidiary cells.

(2) Trichomes

A trichome is referred to any cell that projects markedly out of the plane of the epidermis. They perform a wide range of functions from secretion to protection. These have been categorised as and nonglandular and glandular trichomes.

(i) Nonglandular Trichomes: These exhibit a wide range of variations from unicelled ones to multicelled structures. Some of these forms are depicted in Fig. 7.40. Observe each figure carefully and note how many cells constitute each form, what is their arrangement, and compare one form with the other.

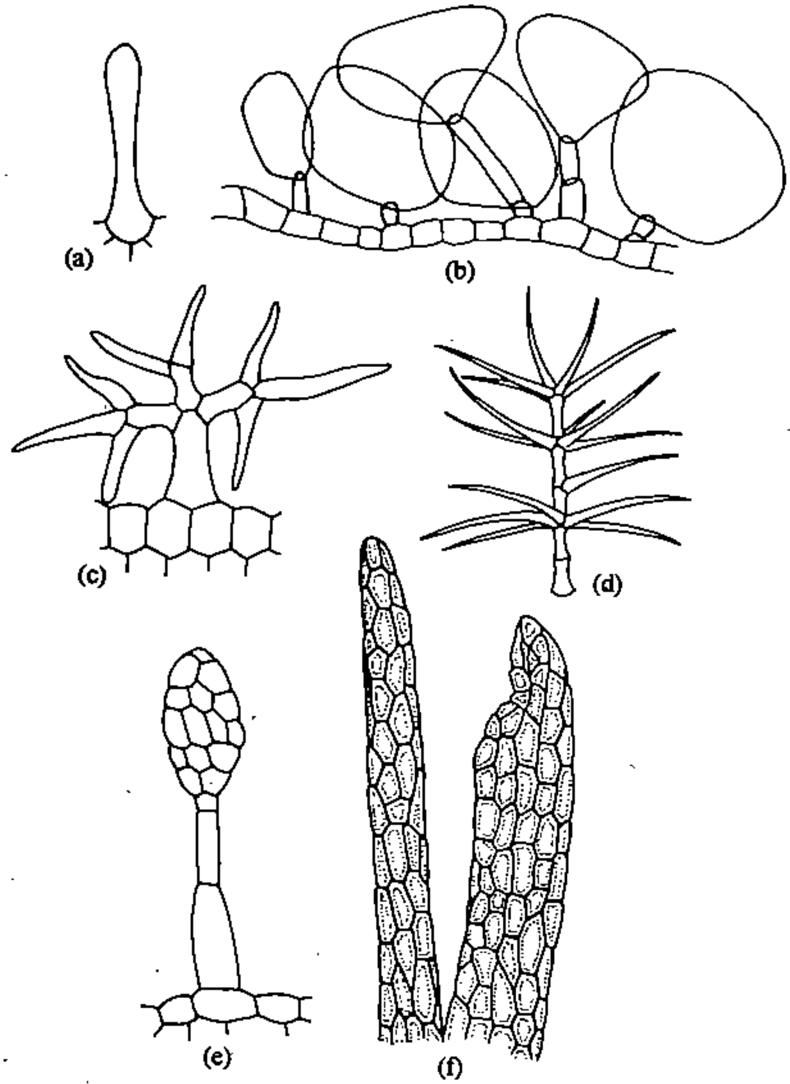


Fig. 7.40: Diverse forms of non-glandular trichomes. a) Single-celled trichome; b-f) Multicelled trichomes.

The main function of these trichomes is to provide a covering to protect from the various environmental disturbances. Since the structure of trichomes is highly specific in different species, this is used as an invaluable tool by the taxonomists. Trichomes or hairs of many species are also economically important. The cotton fabrics which are known from 900 to 200 BC, are actually derived from its trichomes. Another example is *Ceiba kapok*, the source of 'Kapok'.

(ii) Glandular Trichomes: Their characteristic feature is that they have a secretory role. Oils, resins and camphors are secreted by such hairs. Glandular trichomes too exhibit considerable diversity and may be either unicellular or multicellular (Fig. 7.41).

In such trichomes there is a stalk and a head (Fig. 7.42), and the latter is the secretory region. A cuticle-like layer covers the single-celled or multi-celled head of the trichome, and the secretions collect between the cells and the cuticle which is lifted away from the cellulosic portion of the wall. The cuticle then gets torn and the secretions are liberated. The stalks of large glandular trichomes are invariably connected to vascular tissues (Fig. 7.41 f, arrow) with prominent tracheary elements. In addition the transverse walls of the stalk cells have been found to contain a large number of plasmodesmata to facilitate flow of materials to the head. Similarly the foot cell and the collecting cells have labyrinthine walls and become transfer cells. Rarely the surrounding epidermal cells are modified into collecting cells.

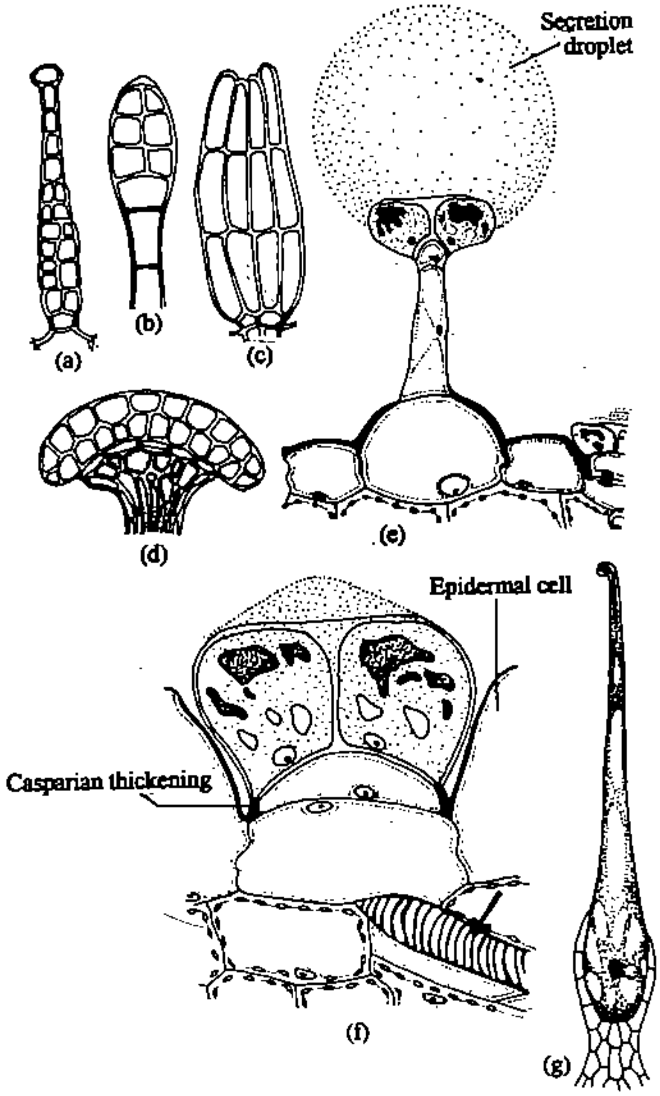


Fig. 7.41: a-g) A few forms of secretory trichomes. In a-d) and f) note the casparian thickenings. g) This glandular trichome is also known as stinging hair and is found in *Urtica*. The single-celled needle-like trichome is surrounded by epidermal cells arranged in a cup-like manner. The tip of the gland readily breaks even on slight touch. The broken portion is very sharp and penetrates the skin and injects its poisonous irritating cell contents containing largely histamines and acetyl choline. (Redrawn from Fahn, 1977).

A feature of the glandular trichomes that you should notice is the presence of casparian strips in the region isolating the secretory region (Fig. 7.42). Because of them the secretory products cannot flow back into the plant apoplastically.

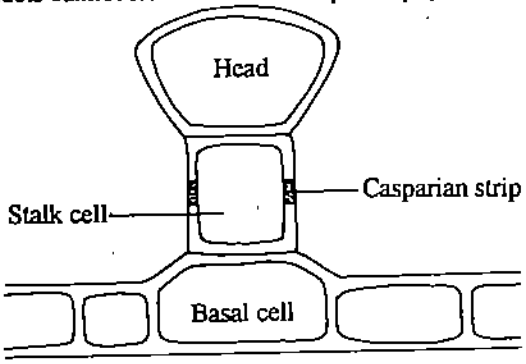


Fig. 7.42: Diagrammatic representation of a glandular trichome showing its various parts. This is the basic plan of most glandular trichomes and the variations are due to different number and arrangement of their constituent cells.

(3) Some special epidermal cells

Certain forms of the epidermal cells such as **silica**, **cork**, **crystal-containing**, and **bulliform** cells are some special cells found in the epidermises of different plants.

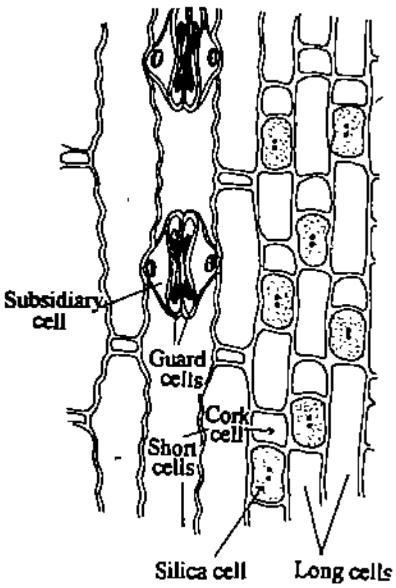


Fig. 7.43: A portion of the epidermis of *Pennisetum clandestinum* showing silica and cork cells arranged in longitudinal rows. (Redrawn from Fahn, 1977).

Silica cells (Fig. 7.43) differ from the adjacent epidermal cells in size and shape, and contain silica bodies which may be round, elliptic, dumb-bell or saddle-shaped. They occur solitary or scattered randomly over the leaf surface or arranged in longitudinal rows above the veins.

Cork cells are small, highly vacuolate with suberized walls, and their lumens are filled with ergastic substances. They are often found associated with the silica cells as in *Pennisetum clandestinum* (Fig. 7.43) and impart mechanical strength to the plant. In cereals, silica has been found to prevent accumulation of other elements such as potassium and calcium on the leaf surface.

Crystals of calcium carbonate known as the cystoliths occur in specialized epidermal cells or the lithocysts (Fig. 7.44). Such cells are invariably larger than the adjacent epidermal cells and unlike the trichomes project inside the cell cavity. Lithocysts are characteristic of families Acanthaceae, Cucurbitaceae and Moraceae. In the families Opiliaceae and Boraginaceae such crystal containing cells are found in groups.

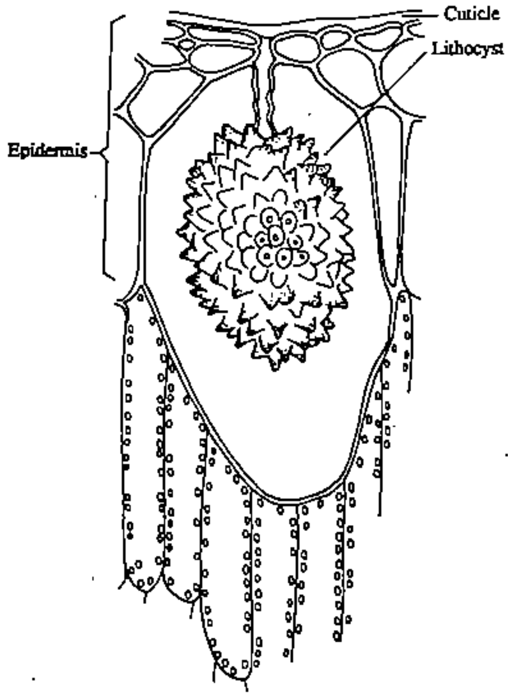


Fig. 7.44: A portion of leaf of *Ficus elastica* showing a multiseriate epidermis and a lithocyst. (Redrawn from Fahn, 1977).

There is yet another special type of cells found in the epidermises of monocots especially the grasses and sedges. These cells are the bulliform cells (Fig. 7.45). These are large, thin-walled cells arranged in long bands parallel to the length of the leaf. They act as points of flexure, i.e., when they are swollen and turgid the leaf opens, but when they loose water and become flaccid the leaf folds, thus minimising exposed surface. The activity of these cells thus helps in controlling water loss from the leaf.

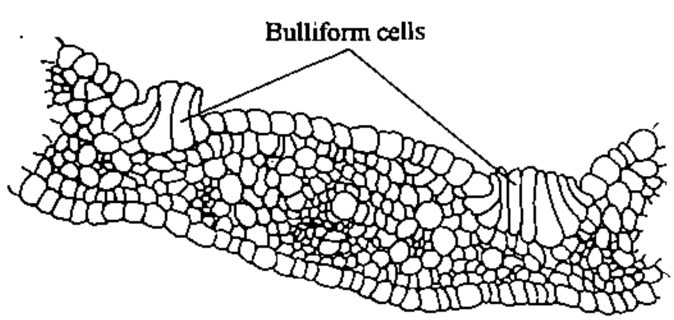


Fig. 7.45: A portion of leaf of *Tripsacum dactyloides* in cross section showing the prominent bulliform cells. (Adapted from Mauseth, 1988).

Root hairs represent another kind of special dermal structures that are of universal occurrence with the specific function of water and nutrient absorption. Most root hairs are unicellular (Fig. 7.46), with one exception of multicellular root hairs that is of

Kalanchoe fedtschenkoi. The root hairs vary in length from 80 to 1500 μm, and their diameter varies from 5 to 17 μm. In some plants, almost every epidermal cell grows out as a root hair, but in others the cells undergo an unequal division, and the short cell known as the *trichoblast* or *piliferous cell* grows out as the root hair. The root hairs provide an extended area for efficient absorption. In a single rye plant there are about 14 billion root hairs with a surface area of about 400 sq. m! Like other trichomes, the root hairs too have a short life span and they die within a few days of their formation. They are sloughed off the root. But sometimes some of the root hairs persist and their walls become thickend due to lignification or suberization.

Fig. 7.46: A diagrammetic sketch of a portion of root in longisection, showing a unicelled root hair.

SAQ 5

Choose the correct word(s) from those given in the parenthesis.

(i) The epidermises of the shoot and root systems develop from the (shoot and root apical meristems respectively/shoot apical meristem only).
(ii) The continuity of epidermis in the aerial regions is interrupted by the (organs/stomata).
(iii) The attachment of epidermal cells is more firm (on their sides/to the tissues beneath them).
(iv) The type of stomata in which the guard cells are surrounded by three unequal subsidiary cells is (cyclocytic/anisocytic).
(v) (Cotton/Maize) is a good example of fibres developing from the trichomes.
(vi) The (crystal/bulliform) cells aid in controlling water loss from the leaves of grasses and sedges.

7.5 SUMMARY

In this unit you have learnt that:

- The plant body is made up of basically two types of tissues - meristematic and mature tissues.
- Meristematic tissues retain the capability of division throughout the life of the plant and can be divided into three types depending upon their position - apical, lateral or intercalary.
- The apical meristems are present at the apices of stems and roots. Lateral meristems are present parallel to the surface of organs, and intercalary meristems are present in between the mature tissues.
- Mature tissues are of two types - simple and complex.
- Simple tissues are those that are composed of only one type of cells. Three types of commonly occurring simple tissues in plants are: parenchyma, collenchyma and sclerenchyma.
- Parenchyma tissues mainly perform the functions of photosynthesis and storage, whereas collenchyma and sclerenchyma provide mechanical support to the organ and the whole plant.
- Complex tissues are made up of more than one type of cells. They are of two types: xylem and phloem. Xylem performs the function of conduction of water and phloem

transports food materials. Xylem and phloem remain in close association in a plant organ and they together form vascular tissue.

- Epidermis is the outermost layer of the plant. It is protective in function. Several stomata interrupt the continuity of epidermis and perform the function of gaseous exchange and transpiration. Besides stomata, several kinds of trichomes are also present on the epidermis of aerial parts of the plant. The epidermis of the roots system is characterised by the presence of the root hairs.

7.6 TERMINAL QUESTIONS

1. Differentiate between the following pairs of words:
   (i) Storied and nonstoried cambium

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   ....

   (ii) Lamellar and lacunar collenchyma

   ....

   ....

   (iii) Brachysclereid and macrosclereid

   ....

   ....

   (iv) Tracheids and vessel elements

   ....

   ....

   (v) Simple and compound sieve areas

   ....

   ....

2. Match the items given in **Column I** with those given in **Column II**.

	Column I		**Column II**
(i)	*Arachis hypogaea*	(a)	epidermal hairs
(ii)	*Nymphaea* petiole	(b)	sponge
(iii)	*Agave sisalana*	(c)	jute
(iv)	*Cannabis*	(d)	lignin
(v)	*Corchorus*	(e)	astrosclereids
(vi)	Sclerenchyma	(f)	hemp
(vii)	Luffa fruit	(g)	intercalary meristem
(viii)	Brachysclereids	(h)	hard fiber
(ix)	Cotton	(i)	*Urtica*
(x)	Stinging hairs	(j)	*Pyrus*

3. Classify parenchyma tissue on the basis of their functional diversity.

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4. What are the various forms of sclereids? Give diagnostic features of each along with their one example.

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7.7 ANSWERS

Self-assessment Questions

1. (i) False
   (ii) True
   (iii) False
   (iv) False
   (v) True

2. (i) plastochron
   (ii) fusiform, ray initials
   (iii) lateral meristems
   (iv) primary, secondary
   (v) phellem, phelloderm

3. (i) canna
   (ii) aerenchyma
   (iii) Parenchyma
   (iv) Osteosclereids
   (v) brachysclereids
   (vi) support
   (vii) Sisal (*Agave sisalana*)
   (viii) astrosclereids

4. (i) F
   (ii) T
   (iii) T
   (iv) T
   (v) T
   (vi) F
   (vii) F
   (viii) F

5. (i) shoot and root apical meristems respectively
   (ii) stomata
   (iii) on their sides
   (iv) anisocytic
   (v) Cotton
   (vi) bulliform

Terminal Questions

1. (i) See Subsection 7.2.2
   (ii) See Subsection 7.3.1
   (iii) See Subsection 7.3.1
   (iv) See Subsection 7.3.2
   (v) See Subsection 7.3.2

2.

I	II
(i)	g
(ii)	e
(iii)	h
(iv)	f
(v)	c
(vi)	d
(vii)	b
(viii)	j
(ix)	a
(x)	i

3. See Subsection 7.3.1

4. See Subsection 7.3.1.

UNIT 8 ROOT, STEM AND LEAF

Structure

8.1 Introduction
  Objectives
8.2 Root
  8.2.1 Root Apex
  8.2.2 Root Structure
  8.2.3 Specialized Root
8.3 Stem
  8.3.1 Shoot Apex
  8.3.2 Primary Structure
  8.3.3 Secondary Structure
  8.3.4 Comparison between Dicotyledon and Monocotyledon stem
  8.3.5 Specialized Stem
8.4 Leaf
  8.4.1 Internal Structure
  8.4.2 Comparison between a Monocotyledon vs Dicotyledon Leaf
  8.4.3 Specialized Leaves
  8.4.4 Abscission
8.5 Summary
8.6 Terminal Questions
8.7 Answers

8.1 INTRODUCTION

The primary vegetative vascular plant body develops from an embryo. The embryo has at its opposite poles two growing points: root and shoot apical meristems. When a seed germinates, these meristems contribute to the establishment of root and shoot systems. The meristems produce new cells which grow, differentiate and mature into a variety of primary tissues. The root system comprises of roots which anchor the plant to the soil and take up water and mineral salts from it. The shoot consists of an axis, the stem and the laterals, the leaves and shoot buds. The leaves produce food and lose water by transpiration. The stem supports leaves, conducts and transports water and mineral salts from roots to leaves. It also translocates the photosynthetic products from leaves to other parts of the plant. The different organs -the roots, stems, and leaves are made up of various kinds of tissues placed and organized into a specific pattern. There is a distinct correlation between such a pattern and the function the organ performs. Later in the life of an organism, especially with a longer life span, these organs (root and stem) produce secondary tissue as a result of secondary growth. The secondary activity takes place because of lateral meristems known as vascular cambium and cork-cambium. In this unit, you would study the development and structural organization of root, stem and leaf. You would also study how an organ modifies its structure to carry out specific function and/or to adjust to the environmental needs.

Objectives

After studying this unit you will be able to:

- identify various organs present in a vegetative plant body;
- understand the concept of tissue system in relation to organs;
- describe the internal make-up (anatomy) of root, stem and leaf;
- differentiate and compare the internal organization of various organs;
- correlate the pattern of placement of various tissues in an organ to the functional ability of the organ concerned;
- know about the origin and function of secondary meristems;
- differentiate between primary and secondary tissues;
- recognize and identify the difference between the structures of organs in dicotyledonous and monocotyledonous plants;
- appreciate the close relationship between structure and function, and adaptability.

You are advised to dig up young plant from the soil and compare its organization to one shown in figure 8.1.

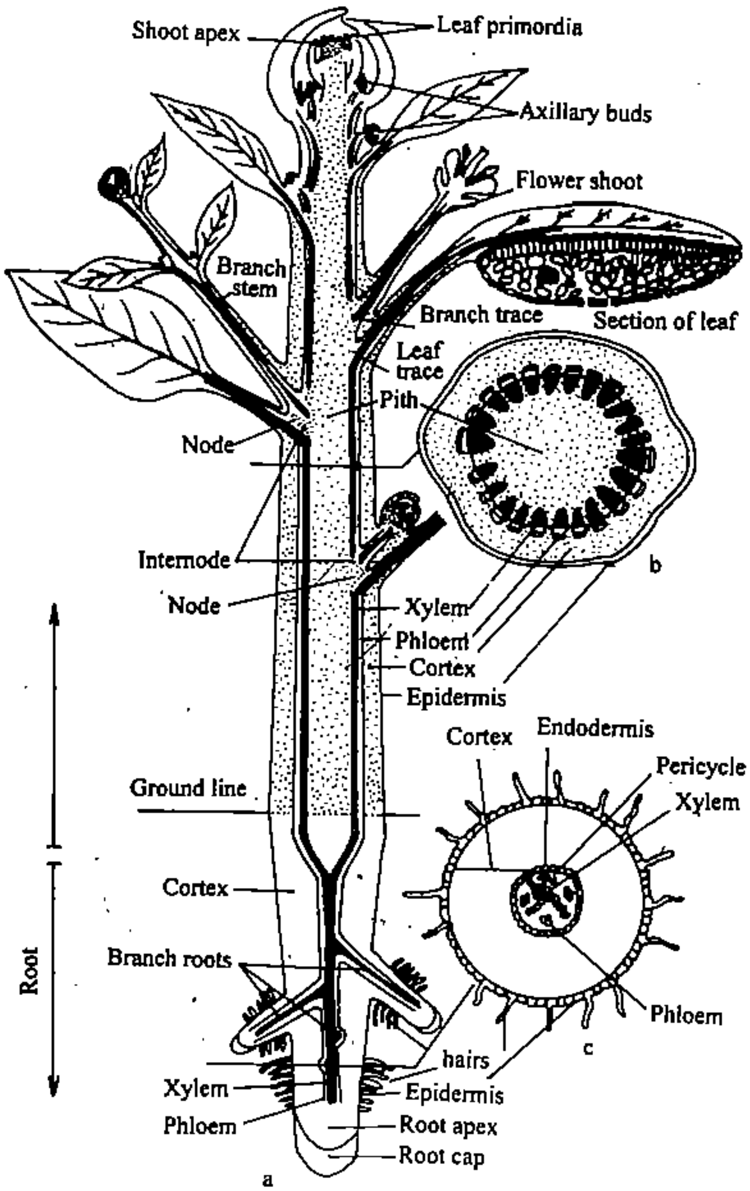

Fig. 8.1: A young plant.

Study Guide

Before you start studying this unit, you must read unit 7 on tissues. You must acquaint yourself with the concept of meristem, differentiation, cell division, permanent tissues, etc. You should be able to recall the organization of a plant cell and the roles of various cell organelles. You should look at the various diagrams very carefully.

Prior Reading

Unit - 17 of Cell Biology,
LSE - 01Unit - 7 of this Block
Unit - 4 of Development Biology LSE-06.

8.2 ROOT

The root is usually located in the lower portion of the plant axis. It generally grows and develops under the surface of soil. The roots are involved in the uptake of water and mineral nutrients, food storage and anchorage. They are present in all vascular plants except the group *Psilotales* (Pteridophyta, the non-seed bearing vascular plants), the plants of which are root less, they are also absent in members of the family podostemaceae. The first root of a plant develops from the radicular portion of the embryo. This constitutes the **primary root**. The mature portion of this root produces **lateral roots**. This process is repeated a number of times to produce a **root system**. The primary root is also referred to as **tap root** (Fig. 8.2a), and is characteristic of **gymnosperms** and **angiosperms**. In monocotyledonous plants, the primary root stops growing soon after it is formed and additional roots develop from the hypocotyl and the stem. Such roots and any other roots which develop from regions other than the radicle of the embryo are called **adventitious roots**. Such a root system forms a **fibrous root system** (Fig. 8.2b). All kinds of roots whether primary, lateral, or adventitious, however, possess a similar structural plan. This structure is basic, primary and prior to any secondary growth, if any, taking place in a root. Let us study more about it.

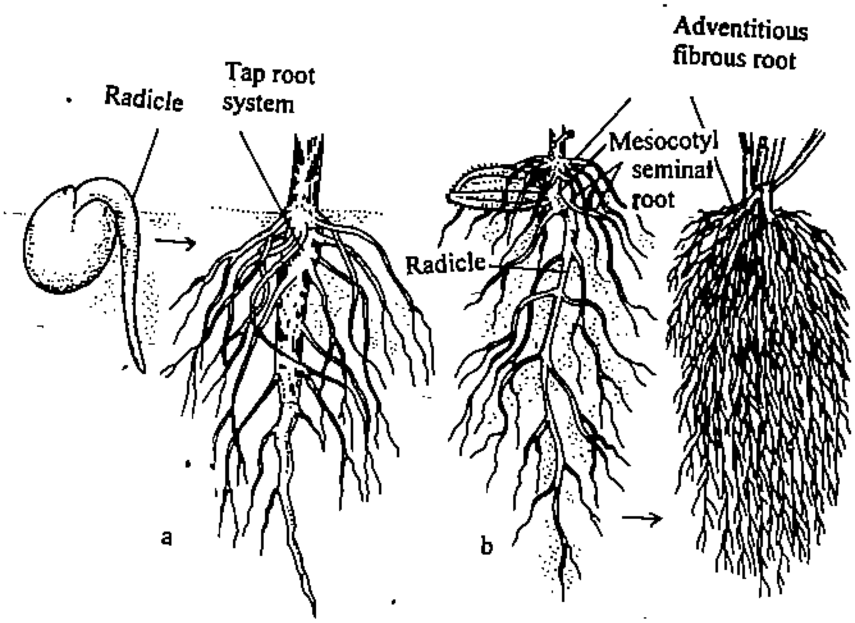

Fig. 8.2: Development of root systems. a) Germinating dicot seed with growing radicle which develops into a tap root system (see arrow). b) A rice seedling develops extensive fibrous adventitious root system (see arrow).

8.2.1 Root Apex

Theories of Root Apical Organization

During the course of embryogeny, certain cell(s) take up on themselves, the task of contributing more cells by mitotic cell divisions. These cells possess dense cytoplasm, large and conspicuous diploid nucleus, and many tiny vacuoles. These vacuoles are distinctly visible only under electron microscope. All the cells in a given primary root owe their origin to these cells which constitute the so called **root apical meristem**. The cell(s) present in the meristem are termed as initial(s). Since they are localized in root apices, they are referred to as **root-apical initials**. Though, all roots are characterized by the presence of such initials, yet their number, location, placement and mode of function are not fully understood. All plant species do not necessarily possess exactly similar root apical structure. A large diversity is recorded in this context. Many attempts have been made in the past to provide an insight into the organization of root apex. We will now discuss a few of such works.

Apical Cell Theory: In roots of certain vascular cryptogams (eg., *Equisetum*, *Ophioglossum*, *Dryopteris*) only a single tetrahedral apical cell is present (see fig. 8.3a). It is suggested that all the cells in a root are derived from it. This forms the basis of apical cell theory proposed by Nägeli (1844).

However, two or more initials are reported in family, Marattiaceae (a fern family). In higher vascular plants often many apical initials are observed. Hence, this theory is not applicable to most vascular plants.

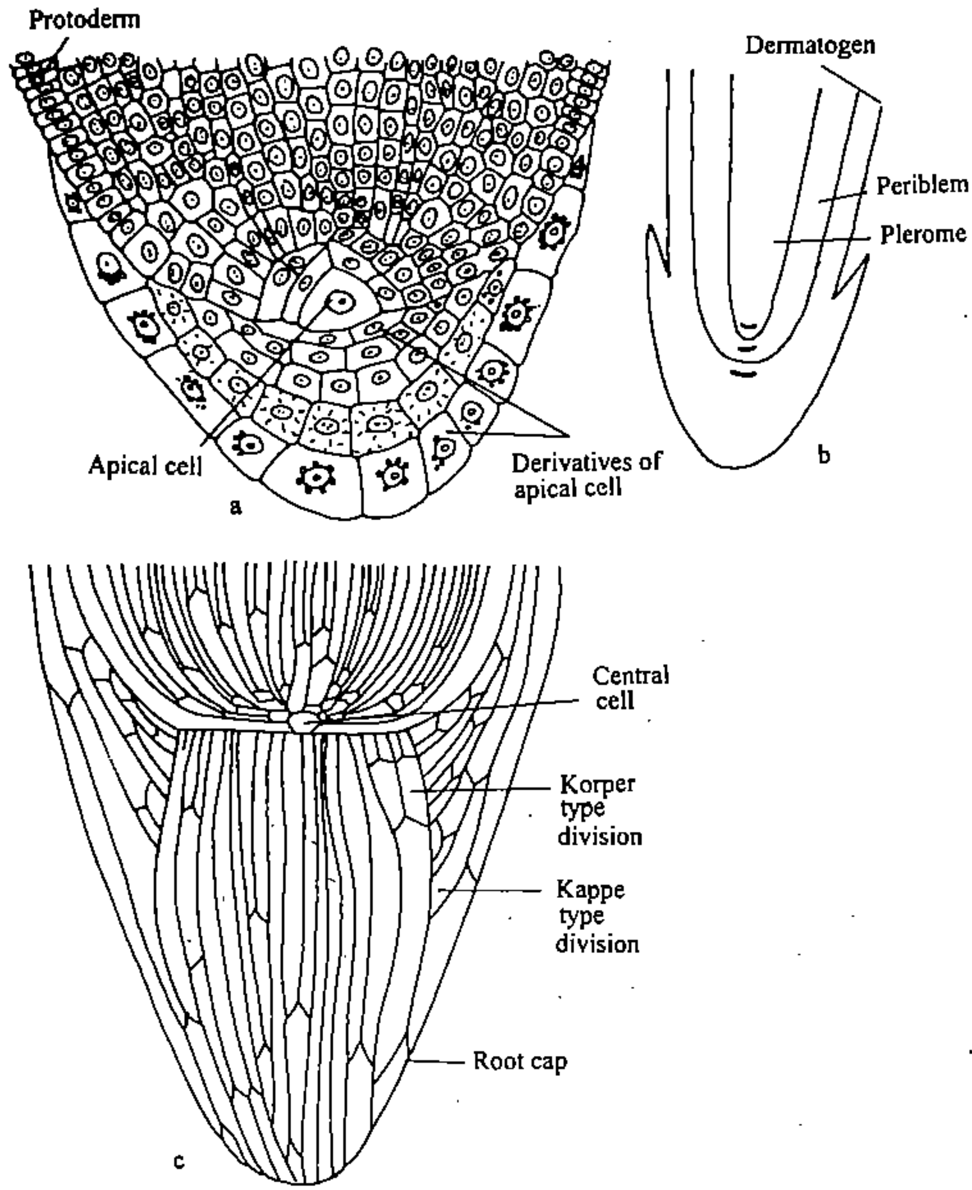

Fig. 8.3: Diagrammatic representation of root apical meristems a) Median longitudinal section of a root tip of *Pteris*, showing a single apical cell with four cutting faces (one not in plane of section). (Modified from A.J. Eames and L.H. MacDaniels, *An Introduction to Plant Anatomy* McGraw-Hill Book Co., Inc., New York). b) Schematic representation of the growth of root apex of a dicotyledon interpreted in terms of Hanstein's histogen concept. c) Root apex of *Zea mays* in longitudinal section showing pattern of cell lineages, interpreting its organization on Körper-Kappe concept. (Adapted from F.A.L. Clowes, Endeavour, 24, 1965).

Histogen theory: J. Hanstein (1868) proposed histogen theory and postulated the existence of three cell-initiating centres or regions which he termed as **histogens.** These are **dermatogen, periblem** and **plerome** (see fig. 8.3 b) which form epidermis, cortex and vascular tissue, respectively in a mature root.

Figure 8.4 shows different kinds of root apices. Look at the arrow. In *a*, all the cells of root are derived from a single apical cell. In *b*, one layer of cells gives rise to the vascular cylinder and the other produces cortex, epidermis and root cap. Most gymnosperms possess such root apex. The pattern *c*, which is characteristic of many dicotyledons, one layer gives rise to vascular cylinder, another to cortex and the third is the joint originator of epidermis and root cap. Type *d* root apex differs from c in having an independent origin of root cap, but epidermis and cortex have common initials. Such root apices are present in most monocotyledons.

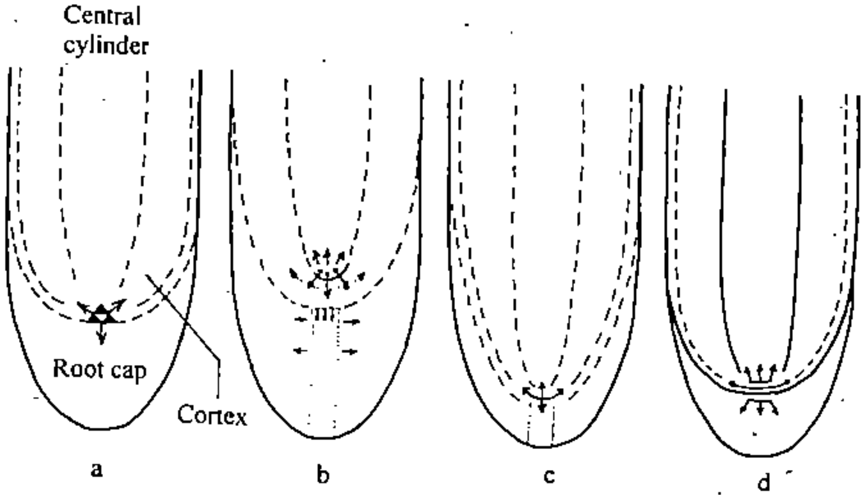

Fig. 8.4: Organisation of root apical meristem. a) A single apical cell is source of all parts of root and root cap. b) Two groups of initials, giving rise to the vascular cylinder and to the cortex, epidermis and root cap. c) Distal region with poorly individualized initials is the source of central cylinder, cortex, and column. d) Three groups of initials, giving rise to vascular cylinder, cortex, epidermis and root cap. (Adapted from K. Esau, Plant Anatomy, John Wiley & Sons. Inc., New York. 1965).

Körper-Kappe Theory: According to this theory, the cells divide in a pattern which was termed as **T**- division. In the outer region of the root apex [kappe (cap) region] the daughter cells divide longitudinally and at right angles to the plane of first cell division. Thus the plane of two cell divisions form a T in a median longitudinal section of a root. In the körper (body) region (**root body zone**) these divisions result in an inverted **T** pattern (see fig. 8.3c). Körper-kappe theory was proposed by Schüepp in 1917. According to him the origin of various root tissues can be pointed by tracing these cell division patterns.

Promeristem: The term promeristem refers to that part of the apex which is capable of giving rise to all the tissues of the root. It could be one or many celled. It was initially believed that promeristem is rather a small region. However, on the basis of detailed experimental studies carried out by F.A.L. Clowes (in 1950's) in root apices of *Vicia faba* and *Fagus sylvatica*, it is suggested that the promeristem is somewhat cup-shaped group of cells on the periphery a central inactive region (Fig. 8.5).

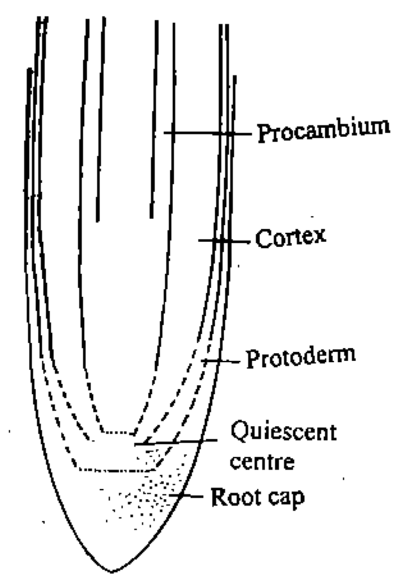

Fig. 8.5: Median longitudinal view of a root tip showing the primary meristem and primary tissues and regions that develop from them.

Quiescent centre: The central inactive region beneath the active cup-shaped group of initials as mentioned above was named by Clowes as quiescent centre or **quiescent zone**. This region is supposed to be hemispherical and multicellular. The cells within this zone have smaller nuclei, fewer mitochondria and little network of endoplasmic reticulum.

They stain poorly for RNA and when the roots were grown in medium containing labelled phosphorus and thymidine, this zone incorporated very little of these substances. These observations suggest that the cells within quiescent zone show very low activity. Incidentally the cells in this region have a very prolonged G-Phase of mitosis and therefore are able to withstand damage when exposed/subjected to low temperature condition and then restored to high temperatures, or to radiations.

Various suggestions have been put forward to explain the functions and reasons for quiescence. Some of these are summarized below: (1) they represent the site of synthesis of plant growth substances; the cells with higher concentration of these substances are quiescent while those with lower concentrations are capable of cell division; (2) root cap cells control quiescence in these cells; (3) pressure exerted by the rapidly dividing neighbouring cells cause inactivity in this zone; (4) they are reservoir of typical diploid genome of the spp., since dividing cells are more susceptible to change., etc.

It must be mentioned here that roots of not all species show the existence of quiescent centre. Such a centre is often absent in younger roots. In *Euphorbia escula* which has dimorphic root system, the quiescent centre is present in long roots but dwarf roots are devoid of it. All that we can summarise is that root apices have one or more apical cells which give rise to all the mature tissues in a primary root.

8.2.2. Root Structure

The root structure, especially the zonations can best be understood by looking at a longitudinal section passing through apical region (see fig. 8.6). The various zones that one can demarcate are **root cap, region of cell division, region of elongation and region of maturation.**

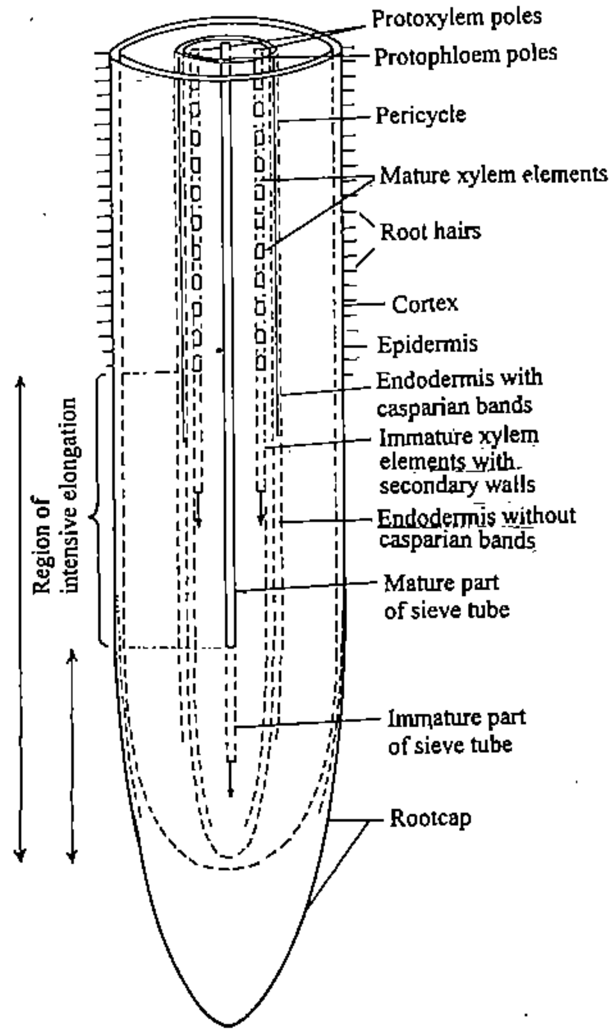

Fig. 8.6: Diagrammatic representation of various zones and tissue in a developing root (Adapted from Esau, Plant Anatomy, 1964)

Root Cap

The root apex is enclosed partly within a fully differentiated, mature and multicellular structure called root cap. It occupies most distal position of any root. The cells of root cap are living parenchyma cells which often contain starch grains, and exhibit irregular placement. Whenever the central cells of root cap form distinct and constant structure, they are termed as **columella**.

Root cap protects the root promeristem and aids in the penetration of growing roots into the soil. The root cap cells of certain plants can be removed. Such roots, without their caps, show erratic geotropic responses. It is, therefore, inferred that the root cap controls the geotropic growth of the root.

The cells of root cap are rich in certain solid cell-inclusions, termed **statoliths** (see fig. 8.7). These are principally starch grains enclosed in amyloplast envelopes. Such cells are called **statocytes or statocysts**. It is suggested that statoliths transmit gravitational stimuli to the plasmalemma of the statocytes.

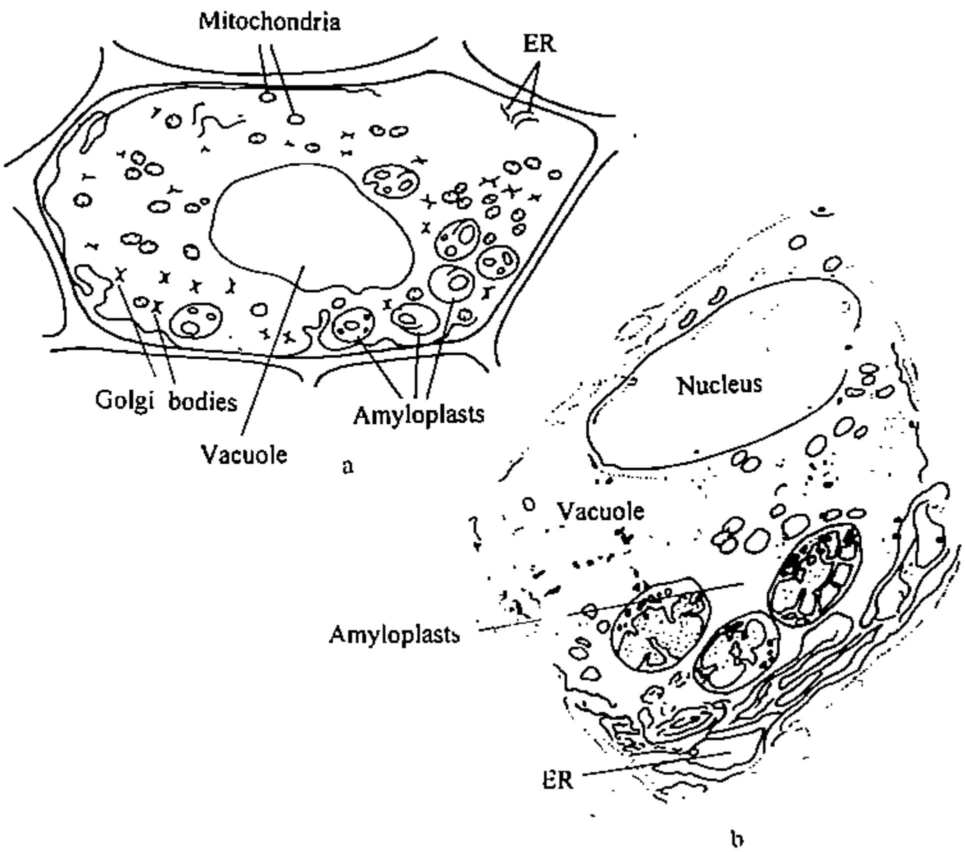

Fig. 8.7: Drawings of statocytes of root tips showing sedimentation of the amyloplast statoliths to the lower side of the cell due to gravitational stimuli. a)*Vicia faba*, the amyloplasts sedimented to the lower side of the cell and the ER is displaced to its upper side. (Adapted from Griffiths and Audus, 1964. b) *Lepidium sativum*, amyloplasts on top of static ER complex (Drawing based on electron micrograph. Sievers and Volkmann. 1972).

The life span of root cap cells is very short. The outer most cells die, separate disintegrate and are replaced by new cells almost continuously New cells are produced by root apical initials. In maize (*Zea mays*), roots kept in water at 23°C 3000-7000 cells are produced and sloughed off in 24 hrs.

The root cap though characteristic of most root is absent in roots of some parasitic **and some mycorrhizal roots. In water plants root cap cells degenerate early.**

Region of Cell Division

The cells in the different regions of the root apex divide at different rates. In many roots, the maximum mitotic activity occurs some distance behind the promeristem. Roots may show diurnal periodicity in mitotic activity. In *Melilotus*, mitoses were most frequent at noon and at midnight.

Since root tips show extensive and maximum cell division activity, our understanding of mitosis in plants is based on the study of root tips.

Region of Elongation

Activity in the cells proximal to promeristem and in the region of cell division results in the elongation of root. The cells of this region show distinct vacuolation and,decreased mitotic activity. This region is active in absorption of water and minerals from the soil and, hence, is also termed as region of absorption.

Region of Maturation

This region lies proximal to the region of elongation, and its cells lose their divisional capacity. The various tissues with which one associates a root are present in this and beyond this zone.

SAQ 1

1. Fill in the blank space(s) with appropriate word(s).

   a) The first root of a plant that develops from the radicular portion of the embryo is known as ....

   b) A root that originates from any place other than the radicle of an embryo is called ....

   c) Apical cell theory of root apex organization was proposed by ....

   d) The histogen layer which is postulated as vascular tissue initiating centre is termed as ....

   e) The part of the root apex which is capable of giving rise to all the tissues of the root is called ....

   f) F.A.L. Clowes has proposed the concept of .... in the root apex organization.

Primary Structure:

In the root three primary tissue zones can be recognized. They are: **epidermis, ground tissue, and vascular tissue** (see Fig. 8.8).

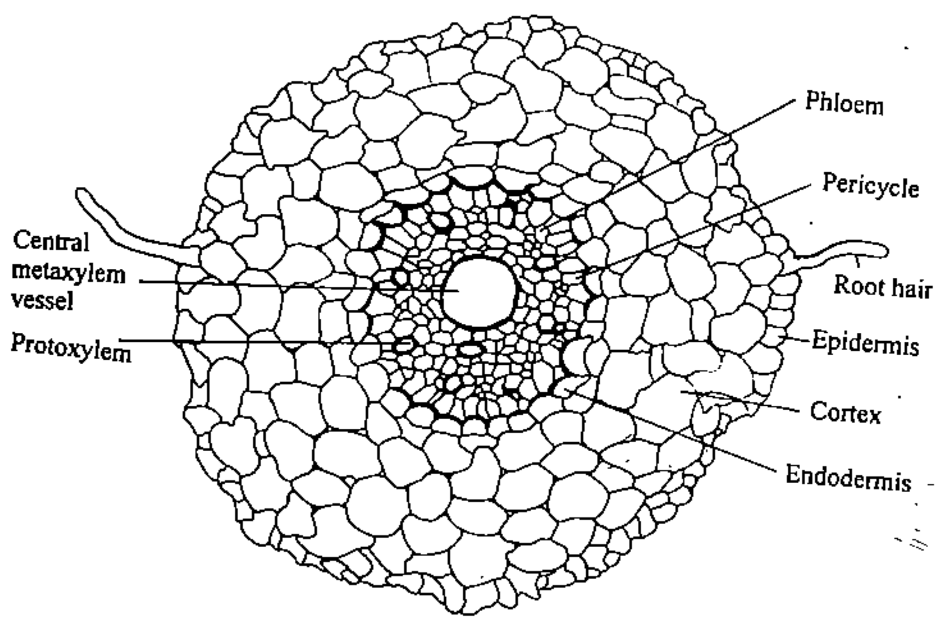

Fig. 8.8: Cross-section of a root of a seedling of *Triticum* (adapted from Avery, 1930).

Epidermis: Epidermis is the outermost layer of the primary root. Its cells in the short-lived roots are generally thin-walled. They become thick or even lignified if the epidermis persists for long or when the roots get exposed to the air. The epidermis is usually single-layered but in certain aerial roots(eg. in Orchidaceae and some epiphytes) it could be multilayered and is referred to as **velamen** (see Fig. 8.9).

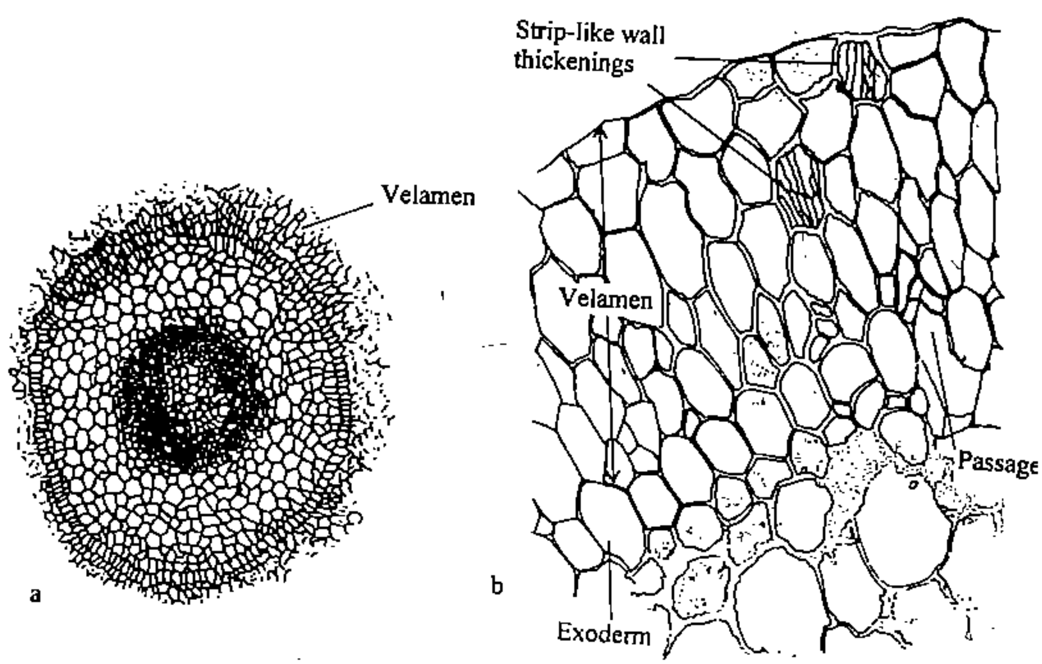

Fig. 8.9: a) C.S. of the aerial root of an epiphytic orchid showing the presence of velamen. b) A portion of velamen, enlarged.

Root Hair: The epidermis of the root is characterized by the development of single-celled outgrowths, the **root-hair**. They are never formed close to the apical initials. The root-hair rich zone of epidermis is some distance away from the apical initials. Root hair initial is small and as it begins to bulge outward, (Fig. 8.13) its nucleus and almost all the cytoplasm migrates into it. The root hair grows by depositing wall material at the tip and the region closer to the root does not elongate. There is a giant central vacoule, and majority of the cyloplsm forms an extremely thin layer next to wall. If the hair runs into a small soil particle, it may grow in two directions around it, becoming forked. Some desert plants produce more hairs when the soil is dry than when it is moist.

Dittmer (1937) estimated 10,000,000,000 root-hair on a single mature rye plant in moist soil or even in humid air.

Older portions of roots have never been found to produce root hair.

The function of root hair is not to absorb material directly but rather facilitate absorption by the regular epidermal cells; that is, the presence of root hair greatly alters the environment immediately adjacent to the root-the rhizosphere.

In older parts of the root they die and dry out. The root epidermis of water plants generally lacks root hair. The root hairs are short-lived except in roots which lack secondary-thickening/or in those roots which do not develop periderm.

All the cells of root epidermis do not develop into hair. It is not always possible to distinguish the initials which are destined to differentiate as root hair from the ones which do not do so. However, in *Phleum*, *Hydrocharis*, and *Raphanus*, it is very easy to recognise root-hair initials. Such cells are termed as **trichoblasts**.

Ground Tissue: The portion of the root inner to epidermis and outer to the vascular cylinder constitutes the cortex which is multilayered. In dicotyledons and gymnosperms the cortex is mainly parenchymatous. In many monocotyledons, however, where the roots are long-lived, much sclerenchyma develops. Such sclerenchyma occupies peripheral layers.

The cortex in root is usually wider than in the stem and plays a major role in storage. Conspicuous **schizogenous** intercellular spaces are very common in root cortical cells. In grass family, additional **lysigenous** spaces are also formed. Large air canals are common in the root cortex of Araceae (Palmae).

The cells of cortex are generally achlorophyllous, however, chloroplasts are reported in roots of water plants and many epiphytes.

In certain plants such as *Phoenix*, *Smilax*, *Iris* and *Citrus*, the outermost cell layer(s) of cortex, just below the epidermis, is (are) specialized and is termed as **exodermis**. Its cells are suberized and are protective in function.

Endodermis: The endodermis is the innermost layer of the cortex that separates the vascular cylinder from the rest of the cortex. The radial and cross cell walls of endodermal cell develop specialized thickenings. Such thickenings are integral parts of the primary cell wall and the middle lamella is impregnated with suberin and lignin. This band of thickening is called **casparian strips** (see Fig. 8.10). Under the electron microscope, these strips appear as slightly thickened, homogenous electron opaque wall region. Like most of the other living cells, plasmodesmata are present all over the endodermal cell walls except at the portion where casparian strips are deposited. At this junction, the strips adhere to cell membrane. Certain cells of endodermis, especially opposite to protoxylem, as seen in cross section of the root do not develop casparian strips. Such cells are called **passage cells**. They allow passage to substances between cortex and vascular tissue.

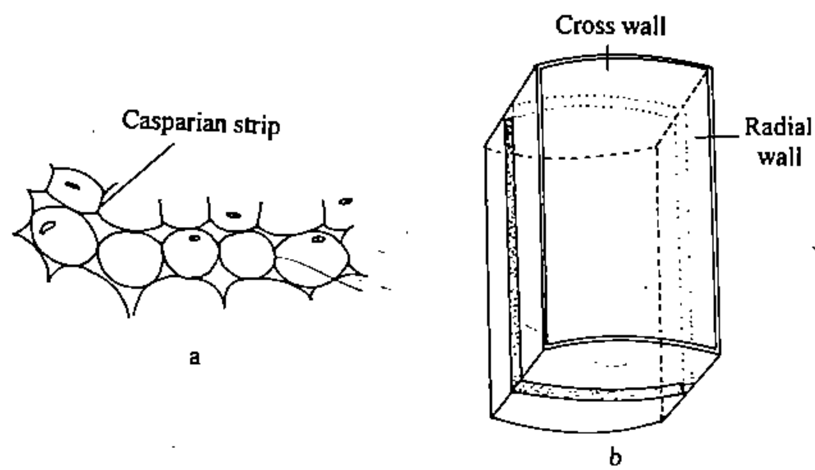

Fig. 8.10: Casparian strips in endodermis. a) Portion of a C.S. of a root showing part of the endodermis and a row of parenchyma cells. b) Three-dimensional diagram of a single endodermal cell with casparian strip (adapted from Esau, 1953).

The Vascular Tissue: The development of vascular tissue in root is both diverse and interesting. The direction of differentiation of procambium is from older mature region towards the apex, i.e., acropetal. All the cells of vascular tissue arise from the central procambial strand. The procambium consists of densely staining meristematic cells placed in a plane parallel to the long axis of the organ.

The first elements of xylem and phloem that mature are at the periphery of procambium. These are termed as **protoxylem** and **protophloem**, respectively. The differentiation and maturation of xylem and phloem progresses towards the centre of the procambium. The later developed elements of xylem and phloem are called **metaxylem** and **metaphloem** respectively. Moreover, both xylem and phloem may start developing simultaneously but alternately across the circumference of procambium. In a mature primary root, the xylem and phloem may have originated at two, three, four, five or many points. Such roots are consequently referred to as **diarch, triarch, tetrarch, pentarch** or **polyarch** (see Fig. 8.11).

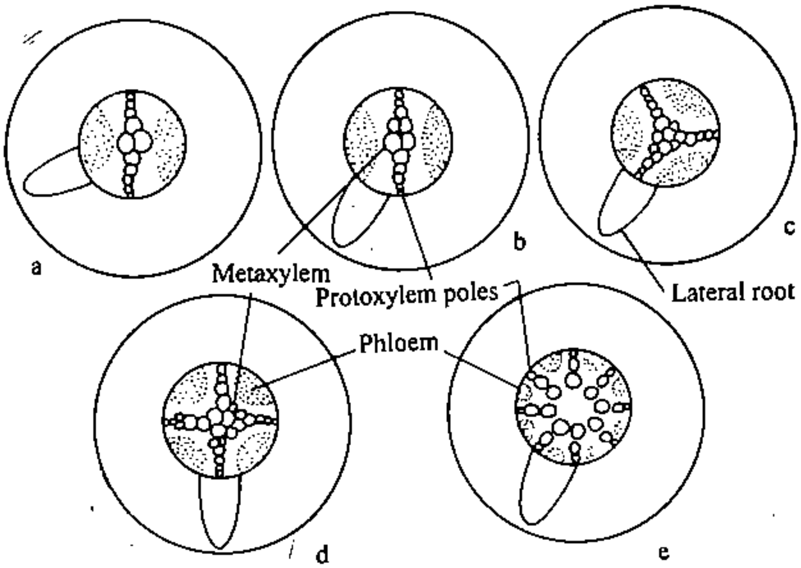

Fig. 8.11: Radial arrangment of vascular tissue in roots as seen in C.S. a-b) Diarch. c) Triarch. d) Tetrarch and e) Polyarch roots. Also note the specific region of root from where the lateral roots originate. (From Esau, 1985)

The central portion of the procambium which does not differentiate as xylem and phloem develops as parenchymatous **pith**. The pith may be highly inconspicuous as in the diarch roots or very large as in polyarch roots (in most monocots). The cells of the procambium that lie outer to the protoxylem and protophloem but inner to endodermis differentiate as one to few layered **pericycle**. Pericycle is a very interesting tissue. It is parenchymatous and possesses potential to regain the ability to divide once again. It can associate itself in the formation of vascular cambium, cork cambium and lateral roots. The cells of pericycle are normally diploid and are sometimes, referred to as **pericambium.**

Origin of Lateral Roots

The primordia of lateral roots are generally formed in the pericycle. The endodermis may also participate in the formation of such primordium e.g., in ferns and other pteridophytes. The origin of lateral roots is thus endogenous i.e. from deeper tissues.

The cells of the pericycle initially divide periclinally (i.e. new cell walls are formed parallel to the surface of the root). Further cell divisions are both periclinal and anticlinal. Subsequently, the cells of the endodermis also divide to keep pace with emerging lateral root primordium. The group of cells thus produced develop and organize a new root apical meristematic zone. This zone resembles the apical meristem/root apex of the parent root. Such a new root now formed pushes through endodermis, cortex and epidermis of the parent root in lateral direction and ultimately emerges out. During this emergence, the lateral root displaces and/or destroys the cortical cells.

The position at which the prospective lateral root is initiated is very much distinct in relation to xylem and phloem of the parent root. In diarch roots, they usually occur between xylem and phloem, in triarch and tetrarch roots they develop opposite to protoxylem and in polyarch roots they originate from cells opposite to protophloem (see fig. 8.11). In aquatic plants, the lateral roots are formed close to the root apex. One of the essential factors for the development of lateral roots is probably auxin. It specifically stimulates cell division in certain regions of the pericycle.

Secondary Structure:

Usually the taproot and the main lateral roots of gymnosperms and woody dicotyledons and, rarely, the smallest root branches develop secondary thickenings. In herbaceous dicotyledons, however, the secondary growth may be absent or is negligible, eg. *Ranunculus*, or well developed as in *Pisum* and *Cicer*. Monocot roots do not develop secondary structures.

The process which leads to the development of secondary structures and formation of secondary tissues is called **secondary growth**. The initiation of secondary growth in the roots is quite distinct from the one encountered in stems which you have already studied in LSE-06 in Unit 10.

Let us now look at the events which lead to the initiation of secondary growth in a typical dicotyledonous root. As mentioned earlier in this chapter, the primary root does not possess any vascular cambium. However, certain procambial cells lying below the metaphloem (as seen in **C.S.**) or parallel or inner to metaphloem (as seen in **L.S.**) remain undifferentiated. Initiation of secondary growth starts from these cells which differentiate into **vascular cambium** (see 8.12 a,b). The number of such isolated vascular cambial strands is two, three, and four in diarch, triarch and tetrarch roots, respectively. Polyarch roots, characteristic of monocotyledons only, do not undergo secondary activity. Once formed these vascular cambium meristems divide periclinally to cut off cells on its either side. Thus at this stage the secondary tissues are being formed albeit in patches.

In next event, the pericycle elements lying opposite to protoxylem differentiate into vascular cambium (Fig. 8.12 c). The number of such patches (vascular cambium of pericyclic origin) again corresponds to the number of protoxylem points.

Very soon thereafter, the vascular cambia produced beneath metaphloem and above protoxylem join at several points to form an undulating cambial ring (Fig. 8.12 d,e). Later, this ring assumes a circular outline (see Fig. 8.12 f).

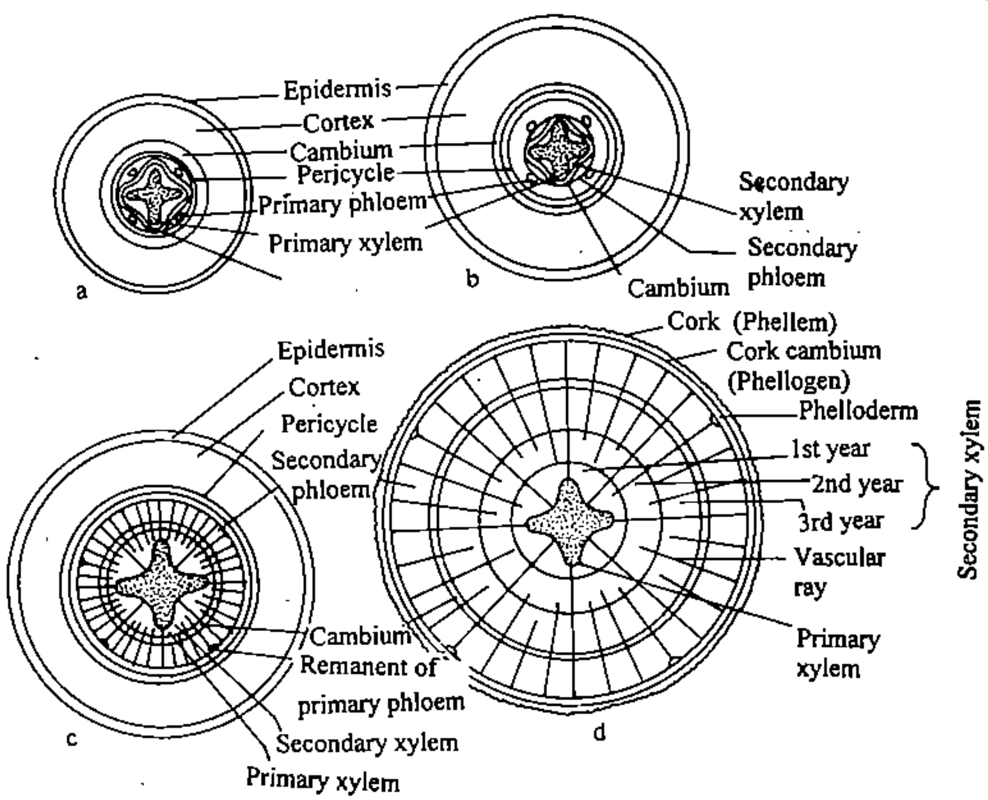

Fig. 8.12: Diagrammatic representation of secondary growth in a typical dicotyledonous root. a) Primary root. b) Beginning of secondary activity. c and d) Old roots showing development of secondary tissue.

The tissue cut off by the vascular cambium towards outside is called **secondary phloem** and the one cut off towards inside is **secondary xylem**. The general pattern of the composition, development and structure of these secondary tissues is similar to the one observed in stem which you have studied in quite detail in Unit 10 of LSE-06. Interestingly, in root even after secondary growth, the primary xylary elements are not lost (Fig. 8.13).

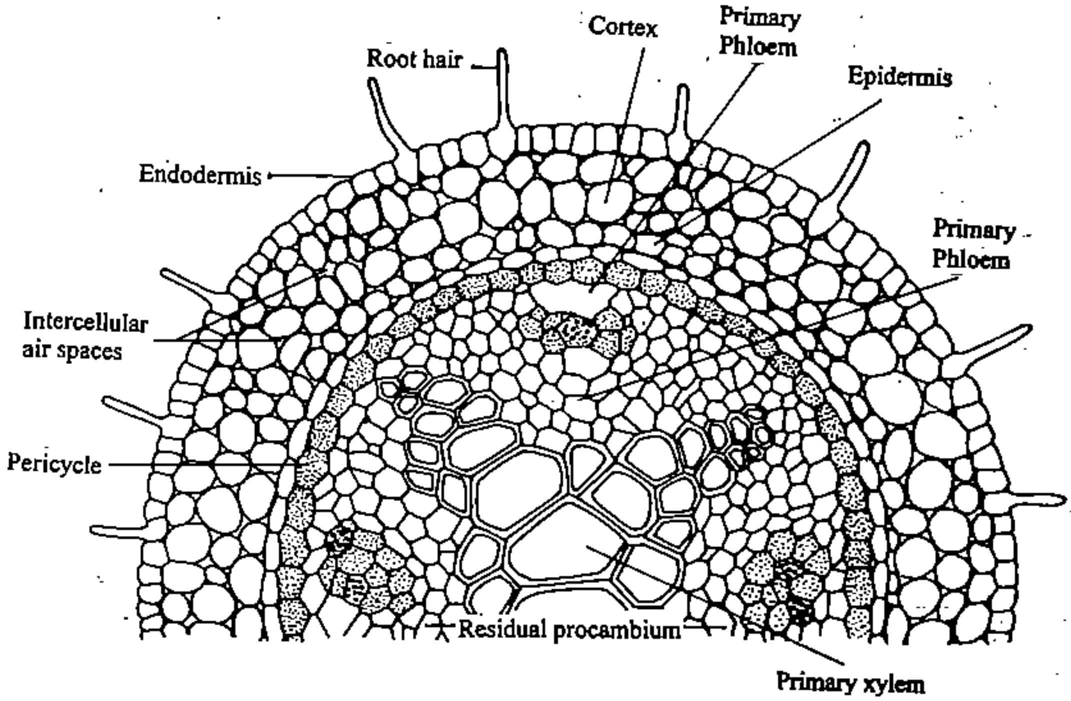

Fig. 8.13: Cross section of the secondary root showing primary xylary tissues.

Periderm

In herbaceous dicotyledons where secondary growth is very little or meagre, the tissues outside the stele remain intact, and an exodermis may develop beneath the epidermis that provides mechanical strength.

However, in woody dicotyledons the prolonged and sustained activity of vascular cambium results in enormous amounts of secondary tissue, especially secondary xylem. This addition of tissues increases the girth of the root. This increased volume puts pressure on the outer primary tissues such as cortex and epidermis. Before these tissues are sloughed off, they are replaced by a more efficient, protective covering tissue, the **periderm**. The details of periderm structure and development, you have already studied in Block II, Unit 10 of LSE-06. Periderm in root mostly originates in pericycle. However, the origin of periderm from cells outside the stele has also been reported. The root periderm may form, at places, **lenticels** for good aeration. Once a periderm is formed, the primary tissue beyond it is sloughed off.

In roots of certain families of angiosperms such as Hypericaceae, Myrtaceae, Onagraceae and Rosaceae, the periderm is made up of two types of cells, suberized and non-suberized. Single-layered suberized cells are sandwiched between multilayered non-suberized cells. Such a periderm is called **polyderm**.

SAQ 2

Choose the correct alternative from the ones provided within parentheses.

a) Aerial roots of orchids possess (single/multi-layered) epidermis.

b) The cells which differentiate into root hairs are known as (protoderm/trichoblast).

c) The cortex in a root is (single/multi) layered.

d) Conspicuous (schizogenous/lysigenous)intercellular spaces are very common in root cortical cells.

e) Specialized, suberized and protective layer just below the epidermis in *Phoneix*, and *Citrus* is termed (endodermis/exodermis).

f) Casparian strips are characteristic of (epidermis/endodermis).

g) The first elements of xylem that mature in a root are known as (metaxylem/ protoxylem).

h) Pith is most conspicuous in a (diarch/polyarch) root.

i) The lateral roots have (exogenous/ endogenous) origin.

j) Statoliths are present in (root cap/phloem) cells.

Comparison of Primary and Secondary Structures:

In the preceding section you have studied the general outline of angiosperm root structure and organization. However, within this common framework we find that the roots of dicotyledons and monocotyledons on one hand and the primary and secondary roots on the other have certain features characteristics of themselves only. Given below are two tables highlighting the comparative features of the same:

Table 8.1: Comparison of structure of a primary dicotyledonous and a monocotyledonous root.

Dicot root	Monocot root
Epidermis Thin/thick walled	Relatively thick walled
Cortex Mostly parenchymatous, sometimes outer cells sclerenchymatous	Peripheral cells generally thick walled; often sclerenchymatous
Vascular bundles Diarch to hexarch	Often polyarch
Pericycle Gives rise to lateral roots, vascular cambium and cork cambium	Produce only lateral roots
Cambium Develops later to produce secondary tissue	Absent, even in those whose stems show abnormal secondary activity
Pith Small or absent	Large and well developed

Table 8.2: Comparison of structure of a primary and a secondary root.

Primary root	Secondary root
Epidermis Cuticle thin/absent. Hair unicellular and simple.	Epidermis may be completely sloughed off.
Cortex Generally parenchymatous, not much differentiated but with prominent intercellular spaces; may perform storage function.	May get completely sloughed off.
Endodermis A complete ring with casparian bands and with passage cells.	Usually not discernible.
Pericycle Single/few layered, parenchymatous	Differentiate into vascular cambium, loses its identity.
Vascular bundles Radial stele, 1-6 xylem/phloem strands, protoxylem and protophloem exarch, (centripetal development)	Radial arrangement lost; Primary phloem obliterated; primary xylem retained even after extemsive secondary growth. Secondary tissue cut off both centripetally and centrifugally.
Pith Small or absent	Absent
Vascular cambium Absent	Originates in patches; forms complete ring; functions prominently
Secondary xylem Absent	Cut off by vascular cambium towards inside centripetally; once formed retained for ever; has axial and ray system: conducts water, minerals, provides strength, very large.
Secondary Phloem Absent	Cut off by vascular cambium towards outside centrifugally; fragile, accumulates marginally, older part degenerates; has axial and ray systems; conducts organic metabolites.
Periderm Absent	Formed after the activity of vascular cambium, replaces epidermis.
Lenticels Absent	Protective in function. May be formed by phellogen. Helps in gaseous exchange.

Specialized Roots

unit you have so far read about the structure and organization of a typical root performs the basic function of anchorage and uptake and translocation of water and als from the soil. However, in nature, we come across roots that perform a wide of functions. Consequently, their structure and organization are modified. The basic however, remains the same. We shall now look at some such modified roots and r adaptive features.

e roots that we will discuss are: **food-storage** roots; **water-storage** roots; **propagative** ots; **pneumatophores**; **aerial** roots; **contractile** roots; **buttress** roots; **mycorrhiza**, and oot nodules.

Food Storage Roots

In primary roots the food, mainly in the form of starch, is stored in thick cortex. After secondary growth, the food is generally found stored in secondary xylem and secondary phloem parenchyma. Usually, roots contain much more parenchyma than the stems.

In plants such as *Raphanus sativus* (radish), *Brassica rapa* (rape), *Daucus carota* (carrot), *Beta vulgaris* (suger beet), and *Ipomoea batatas* (Sweet potato), roots develop into a thick food storing fleshy organ. In such roots hypocotyl and tap root become thickened following secondary growth. Tracheary elements are produced in small amount and secondary xylem axial parenchyma is produced in large quantity (to store food) thus making the organ fleshy (see fig. 8.14 and 8.15).

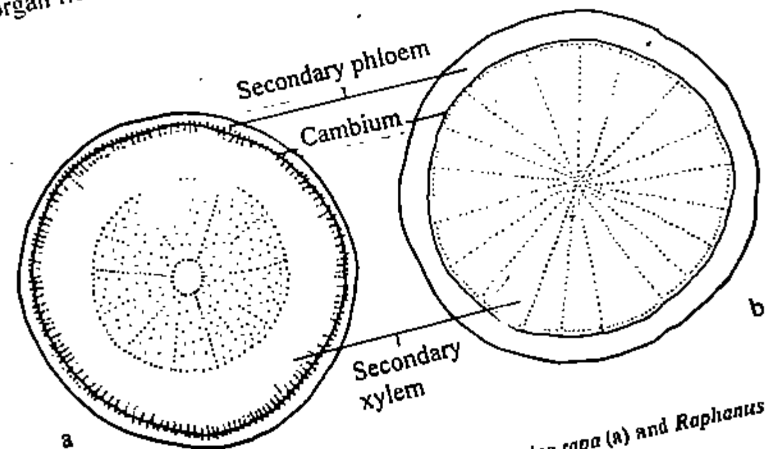

Fig. 8.14: Transverse sections of storage roots of *Brassica rapa* (a) and *Raphanus sativus* (b).

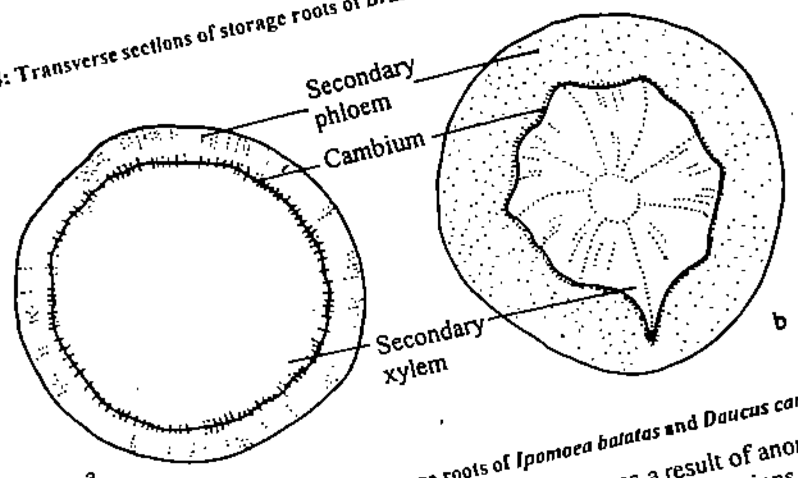

Fig. 8.15: Transverse sections of the storage roots of *Ipomoea batatas* and *Daucus carota*.

eet root *Beta vulgaris* hypocotyl and root become fleshy as a result of anomalous ening (see fig. 8.16). The vascular cambium formed originally functions only for a duration. Thereafter, numerous, successive cambia are initiated exterior to the latest d secondary phloem. All these cambia function normally but produce more of ymatous than any other kind of cells. Sugar is the main food stored. You have studied in detail about beet root in Unit 10 in LSE-06 course.

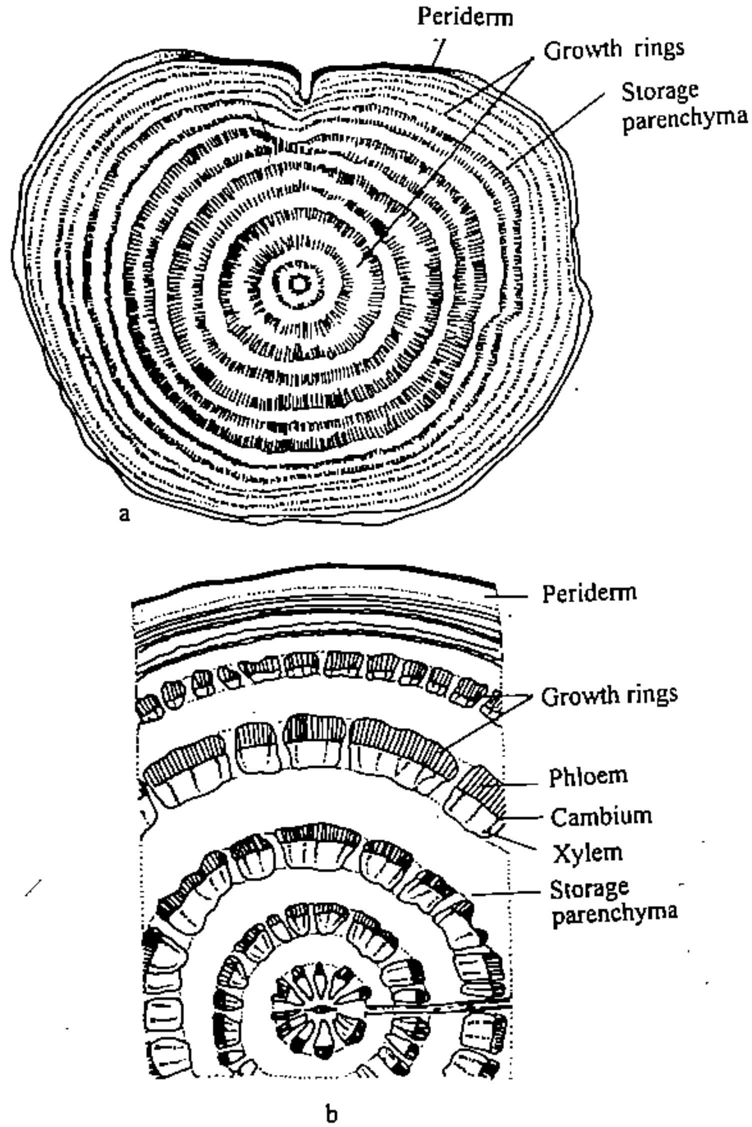

Fig. 8.16: Transverse sections of storage root of *Beta vulgaris* showing growth rings. In b a portion of a is magnified.

In sweet potato (*Ipomoea batatas*) an irregular shaped fleshy food storing root is formed. To begin with normal secondary growth takes place. Then the cells around any vessel or vessel group form a ring of vascular cambium. Such a cambium produces more and more of secondary xylem parenchyma. This process is repeated many a times resulting in an irregular outline.

Water Storage Roots

Such roots are adapted to xeric conditions. The modifications are the development of succulence. The parenchyma cells become large and store water. A thick bark develops to prevent loss of water from inside. Sclerification of cortical cells provides strength to the root.

Aerial Roots

Roots produced from stem or a branch that remain free in the air are called aerial roots. They are reported mostly from a diverse group of tropical plants viz: *Ficus* spp., epiphytic tropical Araceae and Orchidaceae. When these roots touch soil, they serve as **prop** roots. If they attach to some solid substratum, they are called **climbing** or **adhesive** roots. The adaptive features of such roots include photosynthetic ability. In orchids the roots possess multilayered epidermis, the **velamen** (see fig. 8.17). The cells comprising velamen are dead, possess band-like thickened wall and are filled with air when the air is dry. The innermost cell layer of velamen is termed exodermis. The smaller, thin-walled cells of this layer are called passage cells.

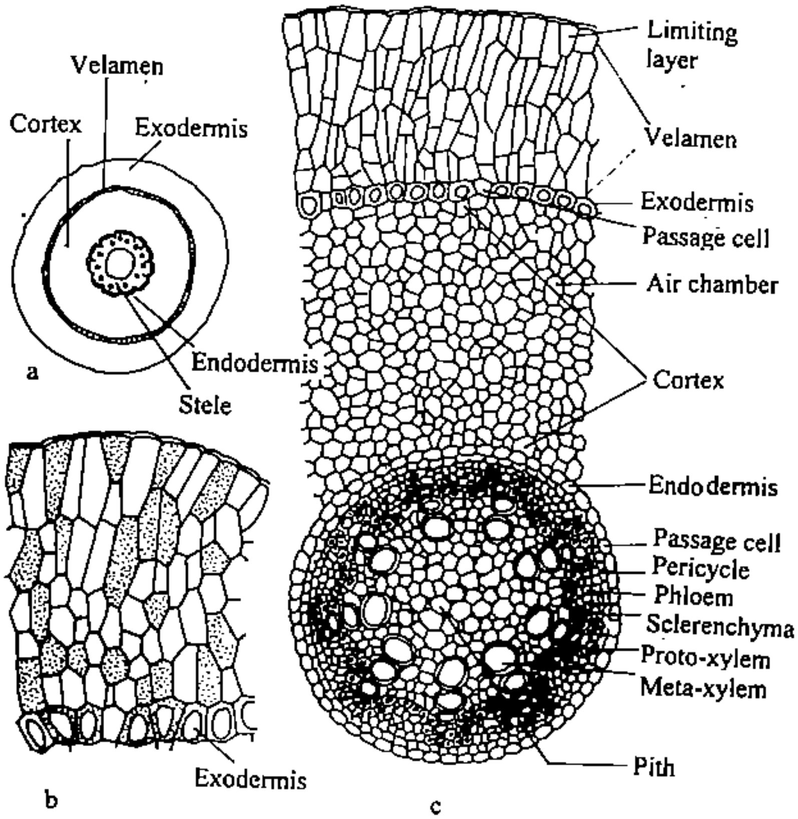

Fig. 8.17: Root of an orchid. a) Transverse section of root (diagrammatic). b) Velamen with exodermis (enlarged). c) A portion of the root in transverse section.

Pneumatophores

They are also known as breathing roots (see fig. 8.18 and 8.19). They are found in plants growing in marshy places with scant oxygen eg. mangroves. Unlike normal roots, they grow vertically upward thus becoming negatively geotropic. They absorb oxygen from the atmosphere through specifically located lenticels at the tips (e.g. *Avicennia*). The peripheral cells develop as cork. The cortex shows well developed intercellular spaces. In a cross section (Fig. 8.18) you can see that the narrow stele is surrounded by a very wide aerenchyma produced by phellogen (e.g. *Rhizophora*).

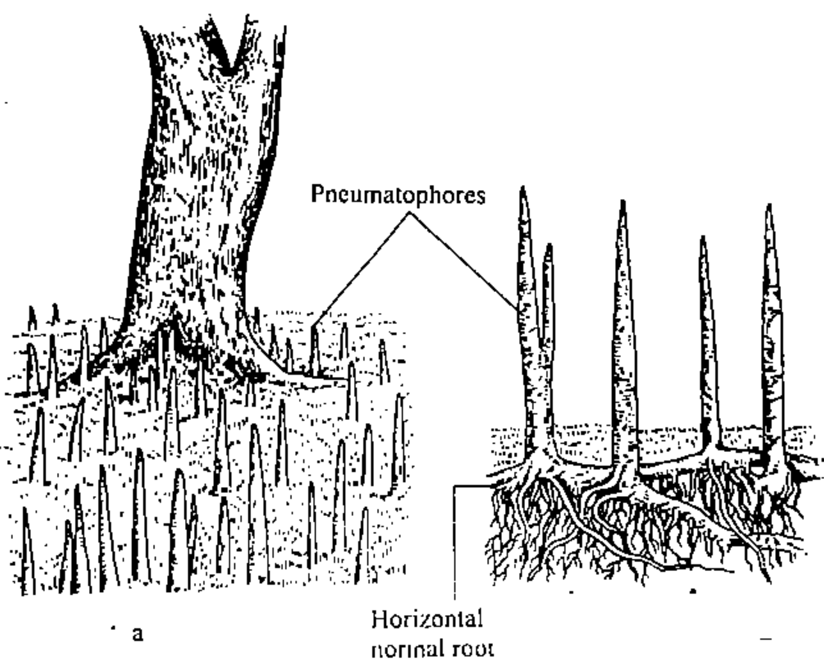

Fig. 8.18 : Pneumatophores. a) Pneumatophores at the base of a mangrove tree. b) Section through soil showing origin of pneumatophores.

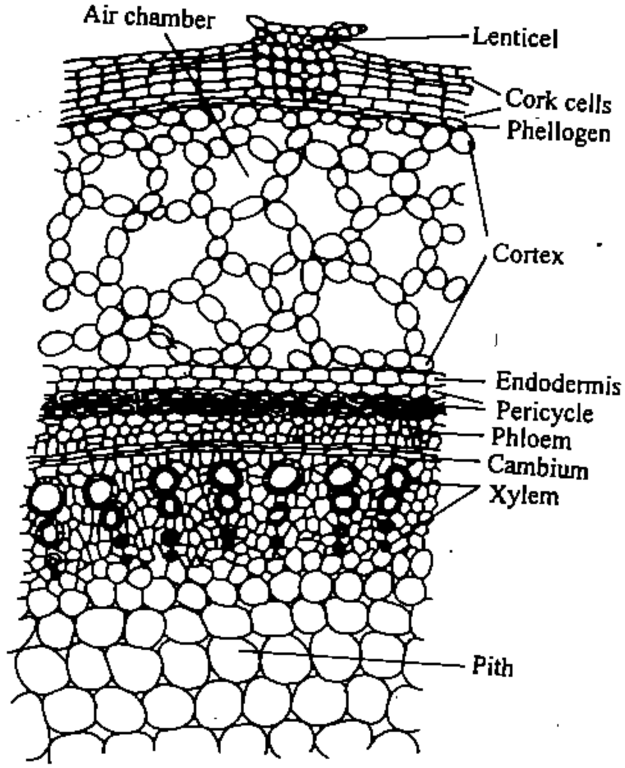

Fig. 8.19: A portion of a breathing root in transverse section.

Contractile Roots

The cortex of the root is usually sloughed off soon after secondary growth. However, in certain herbaceous dicotyledons and many monocolytendons, the cortex has a prolonged life and undergoes many changes at maturity. One such change is the wrinkling of root surface. Roots with such wrinkles are called **contractile roots**. Such roots occur in *Daucus*, *Medicago*, *Oxalis*, *Trifolium*, *Allium*, *Gladiolus*, *Crinum*, and *Narcissus*.

The contraction of root occurs in various steps and by different methods. It could be by vertical shortening and radial extension of cortical parenchyma cells (starting with outer cortex and extending radially towards interior of cortex). *Gladiolus*, *Crinum* and *Narcissus* follow such pattern.

In the roots of *Oxalis* and orchids, transverse discs of cells collapse and get crushed longitudinally by the layer of turgid cells placed above and below. Repeated collapses like this result in wrinkling (Fig. 8.20).

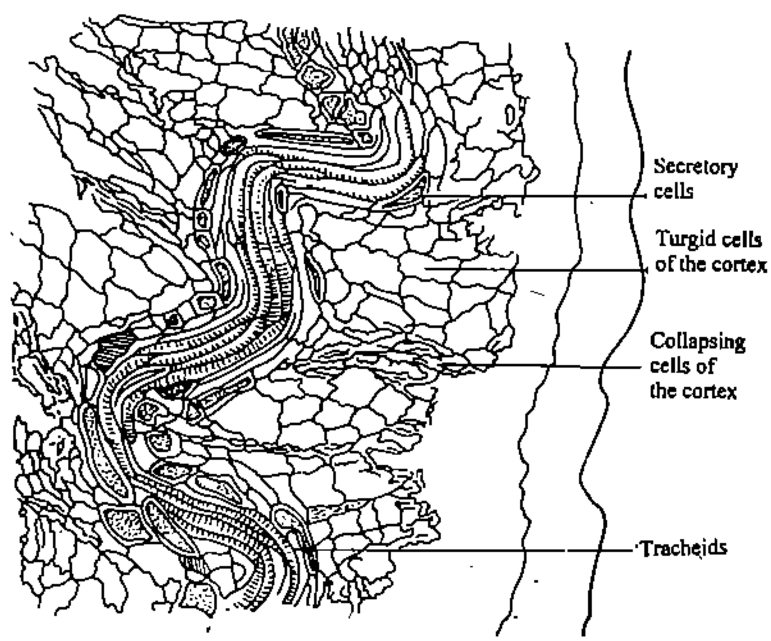

Fig. 8.20: A portion of longitudinal section of contractile root of *Oxalis hirta* showing turgid and collapsing cells of the cortex (Adapted from A.J. Davey. Ann. Bot. (N.S) 10, 1946).

Buttress Root

Buttress roots (Fig. 8.21) are common in many tropical trees. They are found at the base of trunk. They are produced by the bases of main roots in which secondary thickenings are assymmetric (more thickenings on upper side) resulting in board or plank-like structures. Internally, the wood is found better suited for support rather than for the conduction of water.

Haustoria Roots

Parasitic angiosperms develop special structures called **haustoria**. They connect the parasite to the host forming a channel for nutrient flow. There are two kinds of haustoria: **primary** and **secondary**. The haustorium is termed primary when the root apex directly functions as the haustorium. When the haustoria arise laterally along the root they are termed secondary. Let us study the haustorium structure of *Cuscuta*.

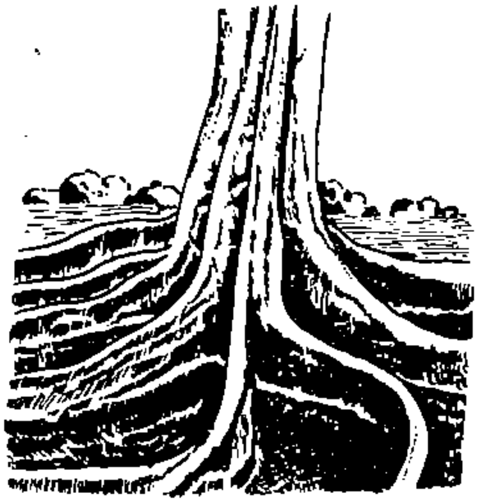

Fig. 8.21: Buttress roots of *Eriodendron aufractuosum* (Adapted from a photograph in Mclean and Inimey-Cook 1957).

Cuscuta has only a ephemeral root at seedling stage. The seedling has no leaves and the root soon withers. The thread like stem twines around the host and develops many haustoria.

The stem of *Cuscuta* (dodder) has four cortical layers. The outer two layers develop flat pads which attach firmly to host epidermis. There at the centre of pad a haustorium develops out of all the four cortical layers. Soon the haustorium penetrates the host cortex as elongated cells, called **hypha(e)**. Within the host cortex, these hyphae grow independently and spread throughout the host tissue. Ultimately, hyphae make contact with host vascular system. Then, the vascular strands of the host and the parasite make contact. The channel is finalized (Fig. 8.22).

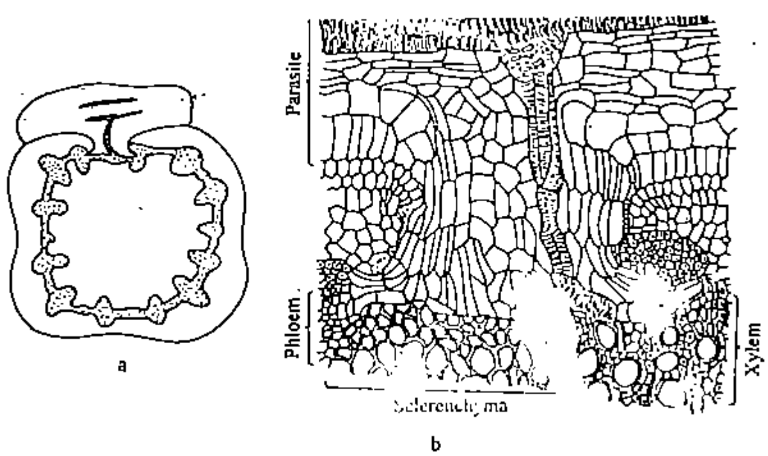

Fig.8.22: Hautorial connection of parasite with host - *Cuscuta* on *Bidens*. a) Cross section of stem of host, oblique section of stem of parasite, and longitudinal section of haustorium penetrating host as far as the vascular tissues. b) Detail of haustorium and surrounding tissues. The vascular tissues of parasite makes connection with those of host.

Mycorrhiza

The epidermis and cortex of the root of many plants are often associated with soil fungus. The association between the fungal hyphae and the roots of higher plants is called **mycorrhiza** (Fig. 8.23). Usually, this association is symbiotic. Both the higher plants and the fungus derive benefit from such association. There are two kinds of mycorrhiza: **ectomycorrhiza** and **endomycorrhiza**.

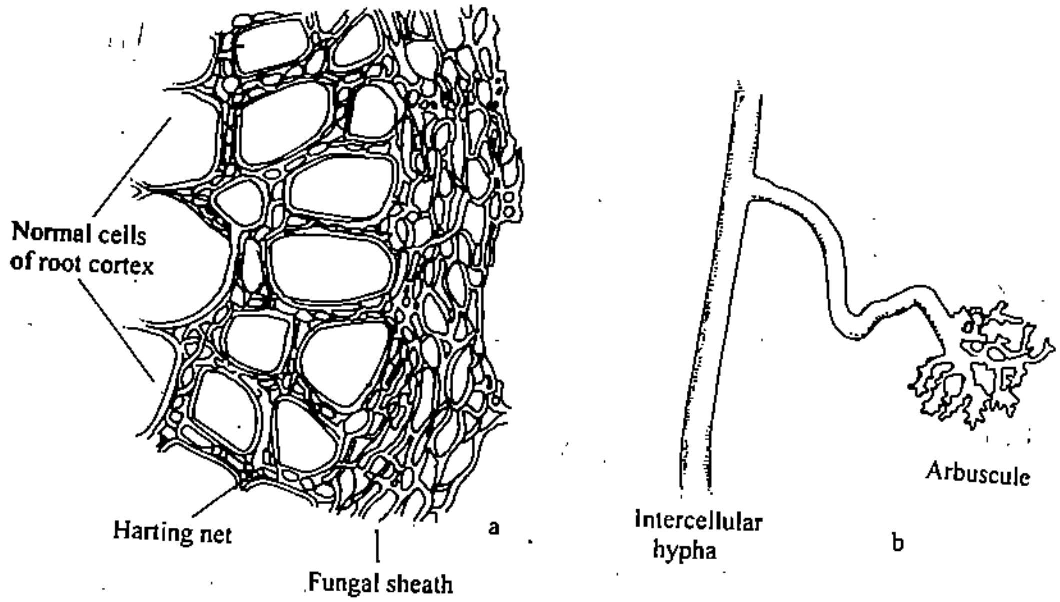

Fig. 8.23: Diagrams of mycorrhizae. a) Ectomycorrhiza based on a micrograph of Meyer (1973). b) Endomycorrhiza based on a micrograph of Cox and Sanders (1974).

Ectomycorrhiza: In this association, the fungus produces mycelium on the root surface. The hyphal strands penetrate the root between the cortical cells and form a net (Hartigs net). It is common in roots of several trees such as *Pinus*, *Abies*, *Cedrus*, *Quercus*, *Populus*, *Fagus*, *Salix*, *Eucalyptus* and *Betula*.

Endomycorrhiza: In this association, the fungus forms an inconspicuous mycorrhiza on the root surface but invades the interior of root cells. Roots of Orchidaceae, Ericaceae, *Acer* and *Liriodendron* have such an association.

Detailed observations with electron microscope show that in the endomycorrhiza the plasmalemma of the host cells surrounds the individual branches of the fungal hyphae, forming a structure called **arbuscule.**

The endomycorrihizae involving nonseptate fungi are preponderant type, and possibly upto eighty per cent of all terrestrial plants have such association. These are called vesicular - arbuscular mycorrhizae or V A mycorrhizae because once the fungus penetrates the host it produces characteristic vesicles and arbuscules.

The host root gets nutrients from soil through fungus and the host provides the fungus with carbohydrates, amino acids, vitamins and other substances. The host cortex cells do not consequently store any starch. It is found that because of mycorrhizal association the host is less susceptible to drought.

Root nodules

Association with bacteria occurs commonly in the roots of the family, Leguminosae and non- leguminous trees such as alder, sea buckthorn. The swellings on the roots caused by such an association are called **nodules**. The nodules are formed following the penetration of nitrogen fixing bacterium, *Rhizobium* sp. into the root cortex via the root-hair. After infection, the bacteria enter the epidermis and then cortex forming a bacterial thread. These bacterial threads then become enclosed in a sheath of gum-like material. When the thread penetrates deep inside the root, it causes proliferation and induces cell division in the cortical cells. This interior region is called **bacteroid zone.** At this stage, the bacteria are released from the thread and the nodules resemble the primordia of lateral roots. With enlarging nodular size, the epidermis of the host root is broken but the nodules do not emerge out of the root. The cortical cells, however, divide and stretch to provide enough space for the enlarging nodules.

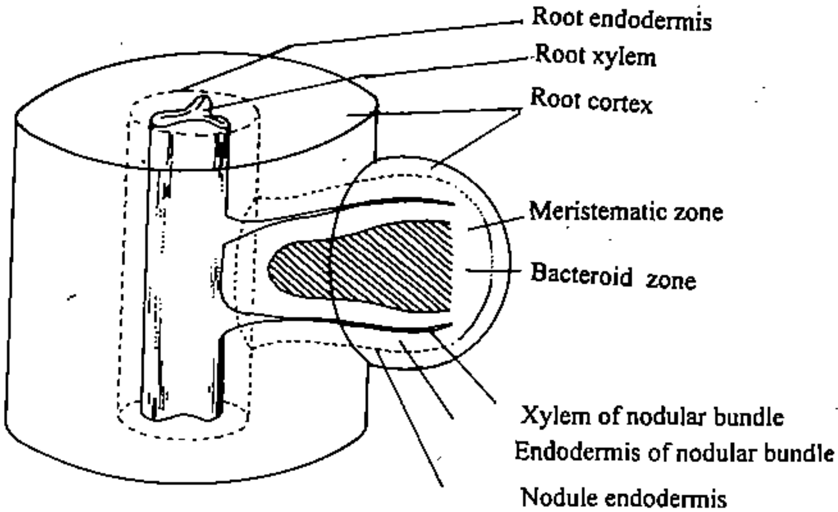

Fig. 8.24: Diagrammatic representation of leguminous root and nodule. (Adapted from Bond. 1948)

By the time the bacterioid zone is established, the branches of the root vascular tissue surround it. Each of these vascular bundles has a parenchyma sheath and a layer of endodermis. The parenchyma sheath cells may develop a few cell-wall proliferations (resembling those of transfer cells) (Fig. 8.24).

SAQ 3

Match the contents of columns A and B

	Column A	Column B
a)	Succulence	Nodule
b)	Velamen	Mangroves
c)	Pneumatophores	Aerial roots of orchids
d)	Thick fleshy roots	Mycorrhizal roots
e)	Parasitic angiosperm	Food storage roots
f)	Fungal association	Water storage roots
g)	Bacterial association	Haustarial roots.

8.3 STEM

The aerial parts of a vascular plant consists of an axis, the **stem**. It bears lateral organs. The erect stem usually is **orthotropic**. It could also be **decumbent** (growing or drooping downward), or **plagiotropic** (showing horizontal growth). The laterals are of two kinds: (i) the leaves with limited/determinate growth, and (ii) the bud with unlimited/ indeterminate growth. The leaves are usually dorsiventral; buds, however, possess radial symmetry. The stem together with laterals, the leaves and buds, constitute the **shoot** (see fig. 8.25). The portions of the stem at which leaves occur are called **nodes**. The leafless portion of the stem in between any two consecutive nodes is termed as **internode**.

8.3.1 Shoot Apex

Both the axis and the laterals in a shoot system owe their origin to one or a group of cells. Since these cells occupy the terminal/apical, most portion of the axis, they are called **shoot apical initial(s)**. Shoot apical initials along with their immediate derivatives constitute a **shoot apex**.

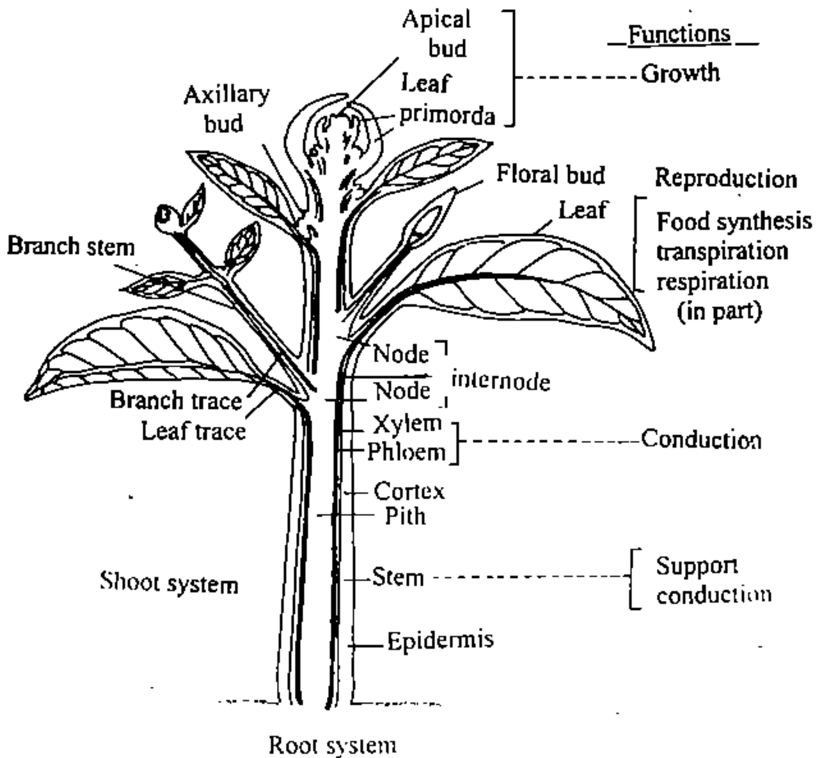

Fig. 8.25: Ground plan of the shoot system.

Shoot apical meristem organization

The shoot apical meristem is established in the developing embryo. It thereafter undergoes considerable change in size, shape and rate of growth.Such changes take place throughout the life of a plant. Shoot apical meristem, thus, is regarded as a vital, dynamic, ever-changing growing system. These changes are cyclic, and are more pronounced especially during the initiation and formation of a leaf by shoot apical meristem. During one cycle (also referred to as **plastochron**), the shoot apical meristem attains a minimum and a maximum area. These correspond to early and late stages of leaf initiation.

Shoot apical meristem thus contributes to the formation of shoot system. The region of a shoot apex, distal to the youngest leaf primordium, is regarded as the **shoot apical meristem.**

The width and shape of shoot apices may vary in different species. In general, cycads, cacti and some ferns have large shoot apices (see fig. 8.26).

Apart from forming stem and leaves, the shoot apical meristem may also give rise to a variety of other structures. We will discuss them in section 8.3.6.

Theories of shoot apical organization

Kaspar Friedrick Wolff in 1759 was first to recognise the importance of shoot apex. Since then a number of attempts have been made to describe and interpret the structure and mode of growth of shoot apical meristem. Some of the well known theories are: **apical cell theory**; **histogen theory**, and **tunica corpus theory** (see fig. 8.27).

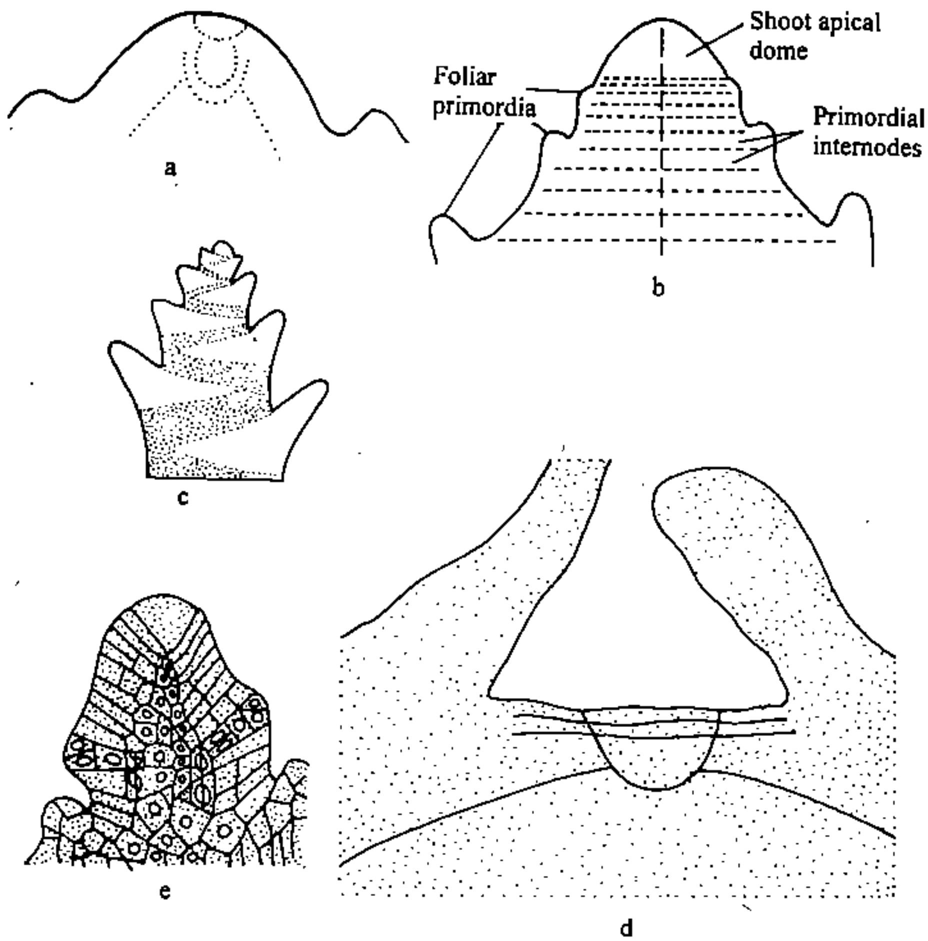

Fig. 8.26: Different shapes of shoot apices, a) Dome shape, b) Conical shape, c) Parabolic shape, d) Flat shape, e) Elongated shape.

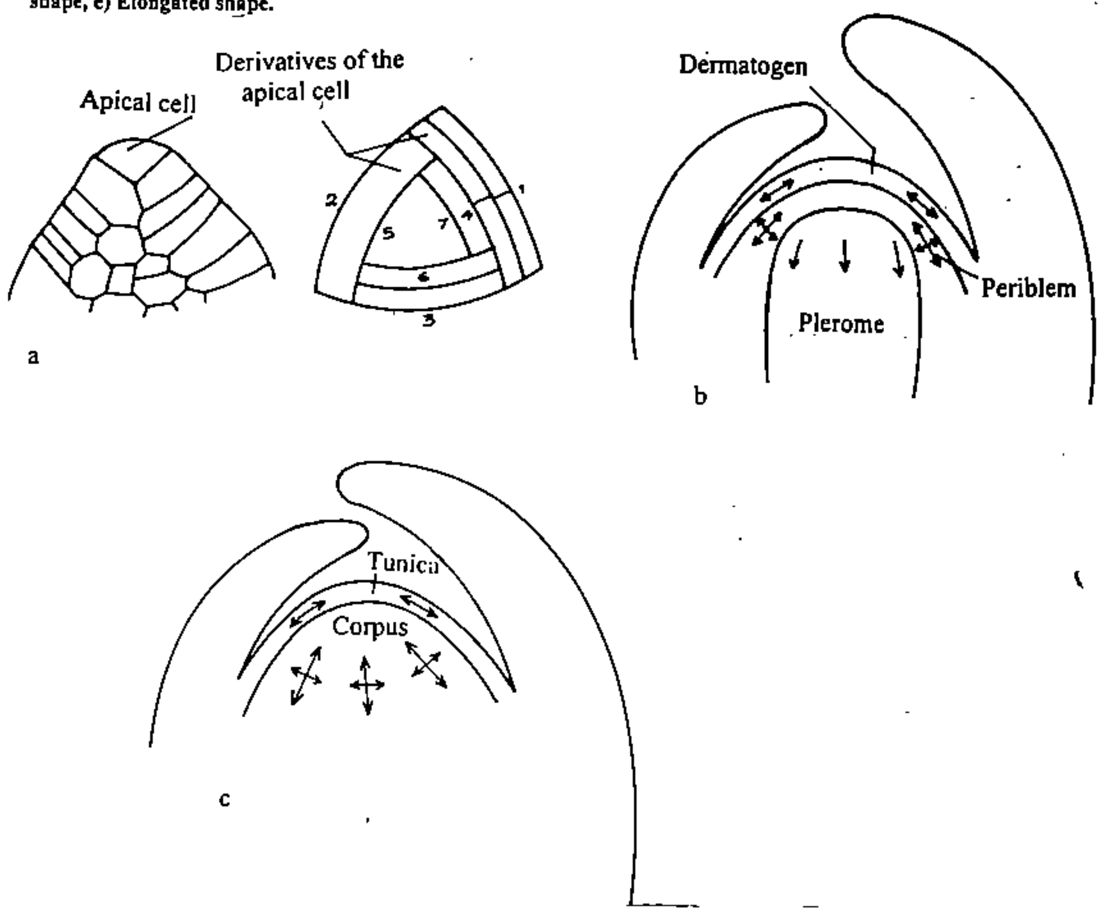

Fig. 8.27: Different theories of shoot apical meristem organisation, a) Apical cell theory, b) Histogen theory, c) Tunica corpus theory.

Apical cell theory

Apical cell theory was proposed in the mid-nineteenth century by C.W. Nägeli. Many cryptogamic vascular plants possess a single tetrahedral apical cell in the shoot apex. This single cell was suggested to be the originator of all the cells in the shoot system, hence the name, apical cell theory. This theory envisaged similar situation in all the vascular plants. When it was realized that such a situation does not exist in most higher plants, the theory lost its relevance.

Histogen theory

J. Hanstein in 1868 proposed this theory. According to him the shoot apex in higher vascu plants consists of a central core of irregularly arranged layers covered by a variable numb of mantle-like layers. A single or a group of initial gave rise to each of these layers. These layers are arranged in tiers in the apical meristem. He termed these layers or histogens as **dermatogen, periblem** and **plerome** (see section 8.2.1). The drawback of this theory is th attempt to assign specific destinies to the derivatives of the histogens.

Tunica-corpus theory

Proposed by A. Schmidt in 1924, the tunica-corpus theory has met with relative wider acceptance. It is primarily based on the plane of cell division in the cells of the shoot apex Accordingly the shoot apex comprised of two regions: the **tunica** and the **corpus**. The tunica consists of one to few layers of cells where walls are laid in an **anticlinal** plane. Th corpus, on the other hand, has a central core of cells in which cell divisions occur in all planes. At sites of leaf primordia formation, the tunica may divide periclinally.

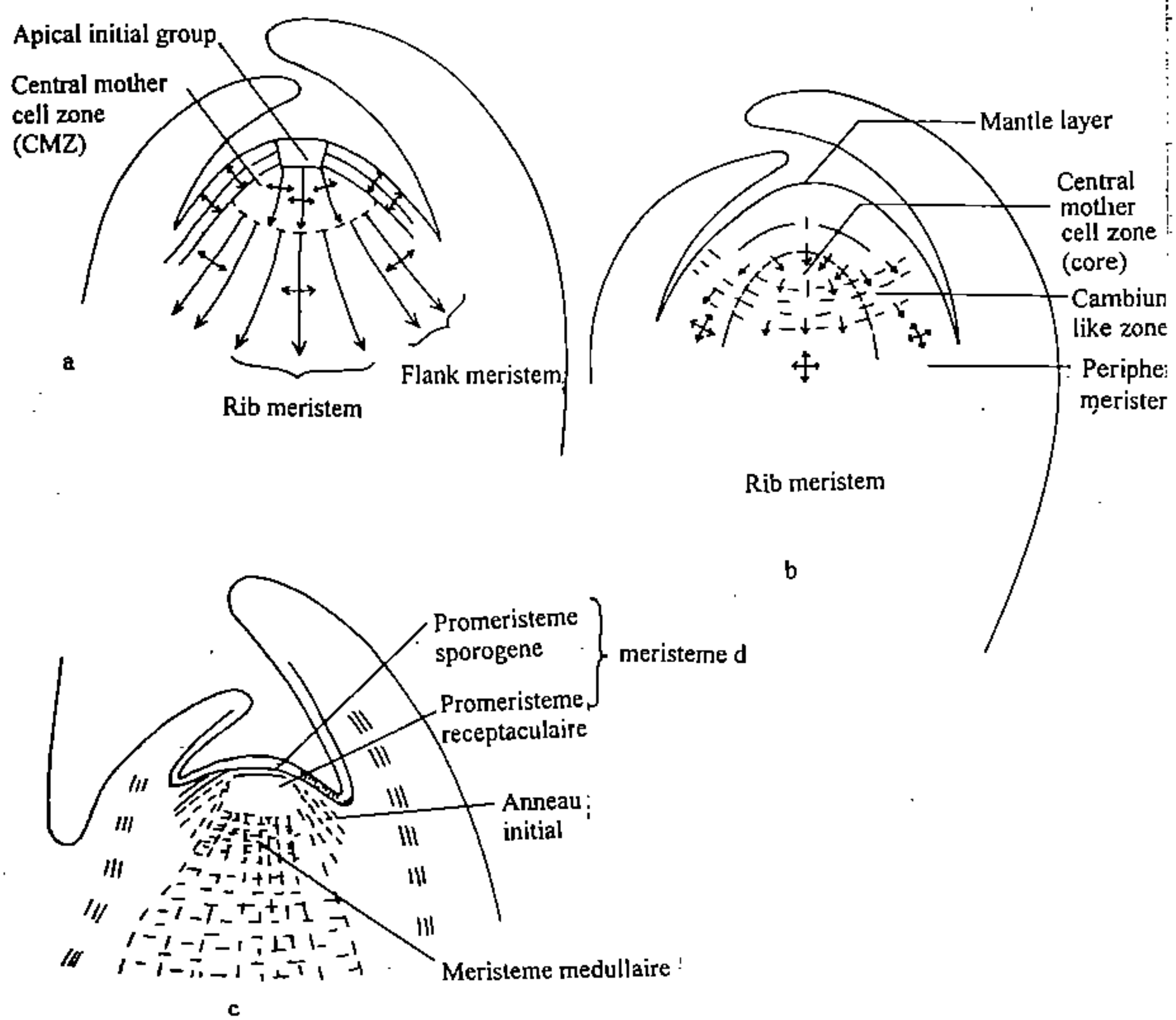

Fig. 8.28: Shoot apex and its growth centres. a) Schematic representation of the shoot apex of Ginkgo *biloba* to show cytohistological zonation. b) Schematic representation of growth of shoot apex of a dicotyledon interpreted in terms of the mantle-core concept. Arrows indicate direction of growth. c) Schematic representation of growth of shoot apex of a dicotyledon interpreted in terms of anneau initial and meristeme d'attente concept. (Apapted from R. Buvat. Annls. Sci., nat. (Bot.) 13, 1952).

Continuing meristematic residue

I.V. Newman (1965) suggested that perhaps no cell(s) in the shoot apex are permanent initials. Over a period of time a sequence of meristematic cells function as initials. These constitute '**continuing meristematic residue** (c.m.r.). The products of these temporary initials comprise general meristem.

A.S. Foster (1938), Plantefol (1948), Popham and Cham (1950), Buvat (1952), besides others have also proposed different shoot apical organizations. There is no unanimously acceptable theory shoot apex organization (see Fig. 8.28).

SAQ 4

Fill in the blanks with appropriate word(s):

a) A.Schmidt in 1924 proposed ....

b) The cells of tunica are characterized by the .... cell divisions.

c) The shoot apical meristem is often regarded as that zone of shoot apex which is .... to youngest leaf promordia.

d) The importance of shoot apex was first recognised by ....

e) The lateral of unlimited growth in a shoot system is known as ....

f) The site of shoot apex where a leaf primordium originates is called a ....

g) Cacti, cycads have largest .... apical meristems.

8.3.2 Primary Structure

The primary stem possesses three fundamental tissue systems: **dermal**, **vascular** and **ground** tissues. These are formed from **protoderm**, **procambium** and **ground** meristems, the three important derivatives of shoot apical meristem.

Dermal Tissue

The stem is bounded by an **epidermis** which is a layer of closely arranged, thin-walled achlorophyllous living cells. In plants, that occur in water or deeply shaded habitat, the epidermal cells may possess chloroplasts. The outer wall of epidermal cells is covered with cuticle. Photosynthetic stems bear stomata in their epidermis. Various kinds of trichomes may also be present. Details of epidermis have already been discussed in section 7.

Ground Tissue

All the cells of the organ other than those in epidermis and vascular tissue are regarded as ground tissue. In the stems of gymnosperms and dicotyledons, the ground tissue can be demarcated into **cortex** and **pith** (medulla). The former lies in between the epidermis and vascular tissue and the latter occupies the centre. In stems of monocotyledons, however, there is no real distinction between cortex and pith.

Cortex: Cortex comprises many layers of cells which are primarily parenchymatous. However, in many, especially younger, growing stems of dicotyledons the outer few layers (i.e., below the epidermis) are differentiated as collenchyma (you recall that collenchyma serve as tissue for mechanical strength in growing organs). This collenchyma can either form a continuous cylinder (eg. *Helianthus*, *Salvia*) or more commonly occur as bands in projecting ribs (eg. Umbelliferae, Cucurbitaceae). These peripheral layers may contain chloroplasts to carry out photosynthesis. Such tissue is termed chlorenchyma. Apart from collenchyma, the strengthening tissue or sclerenchyma (usually fibres) may occur near the periphery of stem, especially in the monocotyledons.

In many plants such as *Casuarina*, *Capparis*, *Cystisus*, and *Asparagus* which have much reduced leaves, the major photosynthetic function is taken over by the stem.

The cells of the cortex may contain starch (eg. most young stems), crystals (eg. *Ricinus*, *Colocasia*), sclereids (eg. *Trochodendron*), or these may be rich in oleoresins (eg. *Zingiber*) or may secrete oil (eg. *Helianthus*).

The innermost cell layer of cortex is termed **endodermis**. It may not be as conspicuous as in the roots. It is often not discernible in aerial stems; however, it is very conspicuous in *Piper* stem. In cortex of underground stems, endodermis is well developed.

In young stems of certain plants (eg. *Ricinus*, *Phaseolus*), the innermost cortical layer has abundant starch grains and is called **starch sheath** (see fig. 8.29).

Pith: The central portion of the stem, the pith is parenchymatous. Occasionally it may be lignified. It is very conspicuous in the primary stems of gymnosperms and dicotyledons.

Vascular Tissue

There is a lot of variation in the arrangement of vascular tissue in stem. In dicotyledons, the vascular tissue develops in the form of complete or broken cylinder between cortex and the pith. When broken, this cylinder has many individual discrete bodies called **vascular bundles**. In between vascular bundles is present interfascicular parenchyma.

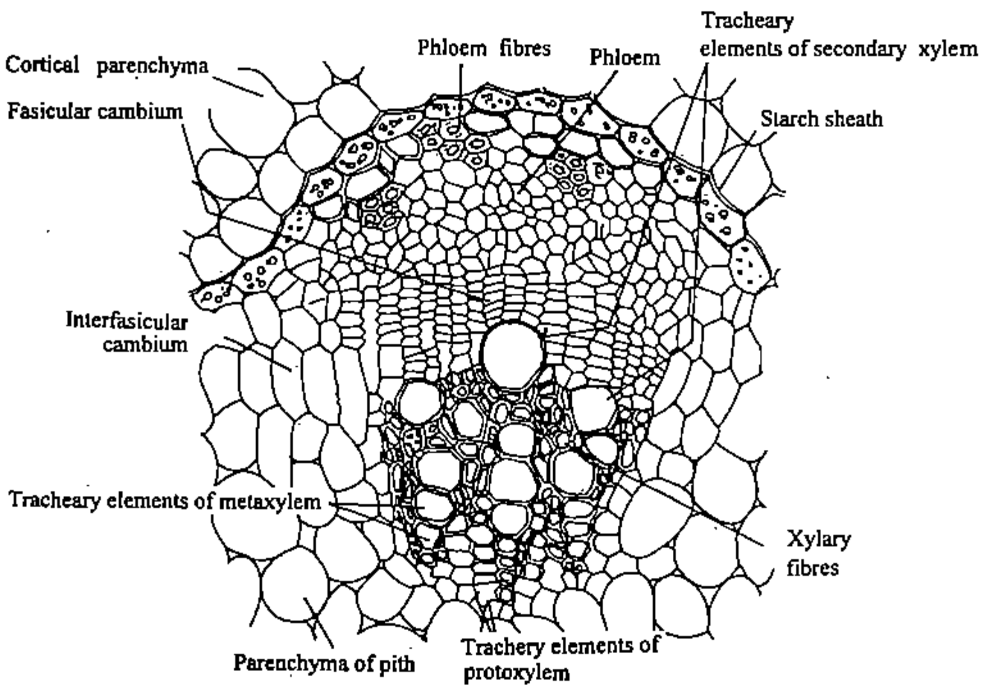

Fig. 8.29: Portion of a cross-section of a well-developed hypocotyl of *Ricinus* showing strach grains. (Adapted from Palladsin, 1914).

In contrast to root, where xylem and phloem alternate, in the stems, the xylem and phloem differentiate and lie on the same radius. The phloem differentiates outer side (epidermis) and the xylem towards inner (pith) side. Such vascular bundle is called **collateral** (eg. *Helianthus, Ranunculus*). When phloem differentiates on either side of the xylem, the vascular bundle is **bicollateral** (eg. *Cucurbita*). When in a vascular bundle xylem surrounds phloem completely, it is called **amphivasal** (eg. *Cordyline, Acorus, Dracaena*). **Amphicribral** vascular bundles are those in which phloem completely surrounds the xylem. They are common in many pteridophytes. (see fig. 8.30).

When in a vascular bundle cambium differentiates and occupies position in between xylem and phloem, the vascular bundle is termed **open** (Fig. 8.30 a, a'). A vascular bundle without a cambium is called **closed** (Fig. 8.30 b, b'). Amphivasal and amphicribral vascular bundles can be both open or closed. In bicollateral vascular bundles where both outer and inner cambia are present, it is only the outer cambium (between xylem and outer phloem) that is functional (Fig. 8.30 c, c').

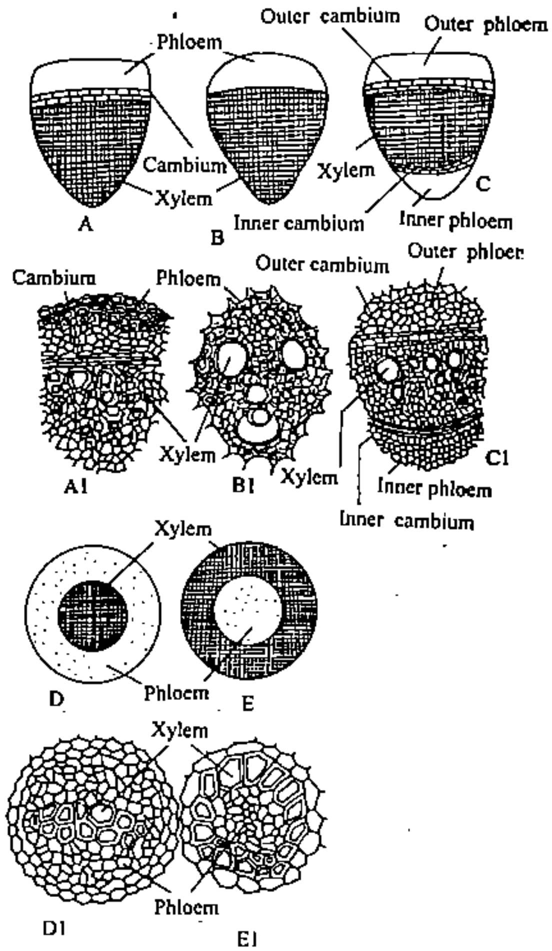

Fig. 8.30: Different types of vascular bundles. Collateral (a and b, a' and b'); Bicollateral (c and c'); amphivasal (e and e'); amphicribral (d and d').

In the stems of monocotyledons a large number of closed vascular bundles are seen scattered throughout the ground tissue. The xylem elements may form the letter Y,V or U (see Fig. 8.31). The protoxylem in many of these vascular bundles gets disintegrated as the organ matures. It leaves behind a protoxylem cavity/canal/lacuna.

In monocotyledons, the vascular bundles may be capped or encircled by a band of thick walled sclerenchyma fibres.

Only those stems which possess open vascular bundles can undergo secondary thickenings.

8.3.3 Secondary Structures

Most stems increase in their girth by secondary activity. Such activity is common in gymnosperms and dicotyledons, and is brought about by two kinds of lateral meristems; the **vascular cambium** and the **cork-cambium**. As a result of the secondary activity by the former the diameter of the stem increases considerably. Because of such increased girth, the primary tissues such as epidermis and cortex may be partially or completely sloughed off. It may also result in partial or complete obliteration of pith. Epidermis when sloughed off is often replaced by another protective cover, the **periderm** (formed due to the activity of cork-cambium). Since you have already read in detail about vascular cambium and cork-cambium and their activity in Unit 10 Block 2 of LSE-06, these are not being discussed here. Look at the diagram in figures 8.32 before reading this section.

Secondary xylem

The secondary xylem is charaterised by the presence of two systems; **axial** (vertical) and **ray** (horizontal). Together they constitute the wood of commerce. The secondary xylem has similar components as are present in primary xylem: xylem fibre, xylem parenchyma and tracheary elements. Comparison of two is available later in the section (8.3.4).

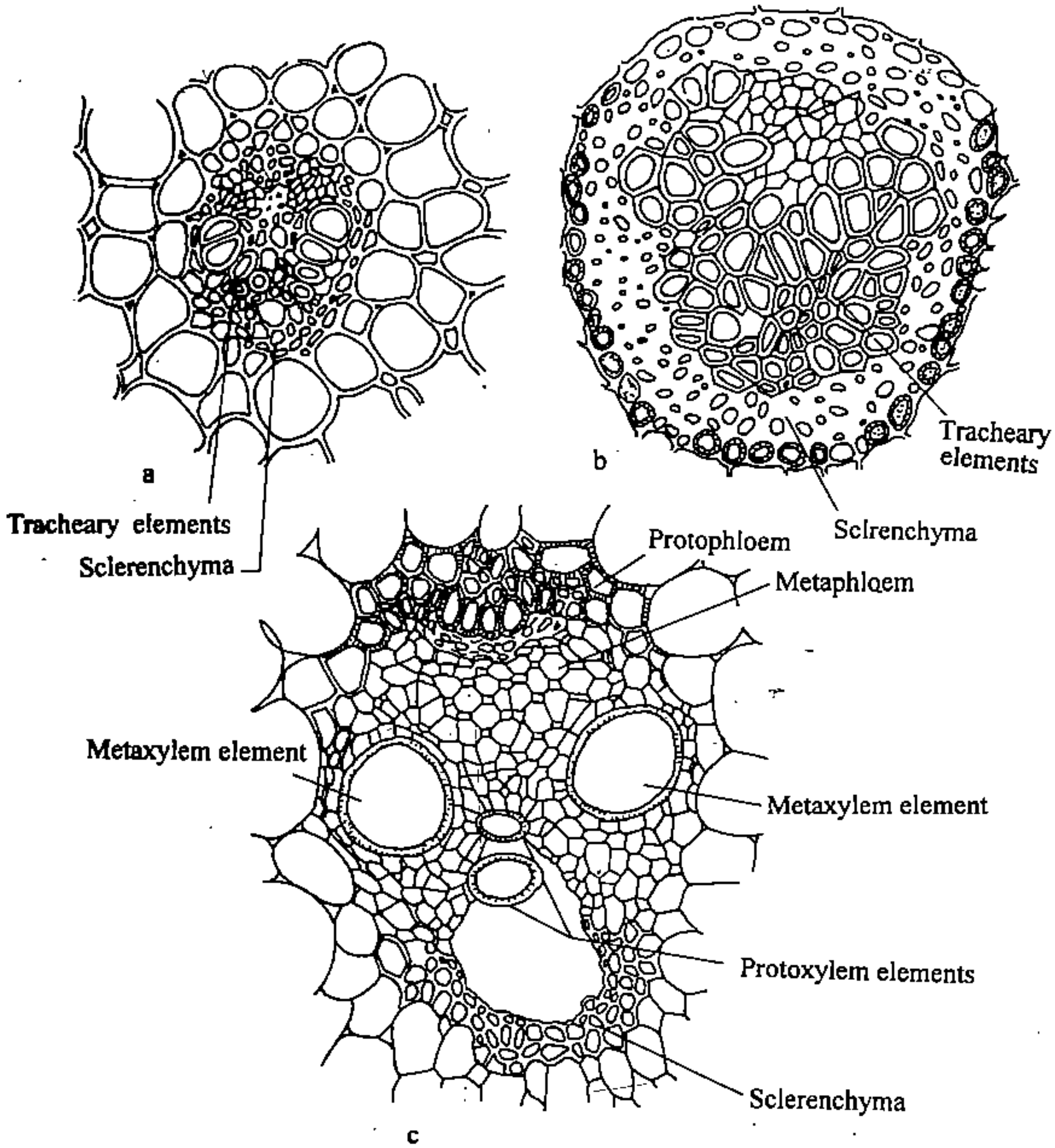

Fig. 8.31: Cross-sections through the vascular bundles of different types. a) *Xanthorrhoea* leaf showing V-shaped xylem. b) *Kingia* stem showing U-shaped xylem. c) Y shaped xylem in *Zea* stem.

Wood: It is the product of vascular cambium. It is classified as **softwood** (of gymnosperms, principally conifers), and **hardwood** (of dicotyledons). The chief difference is the absence of libriform fibres in softwood. The softwood consists largely of tracheids, but hardwood contains mostly vessels. They are also called **non-porous** and **porous wood** respectively. In hardwood, when the vessels are produced regularly and are distributed uniformly as in *Acer* and *Betula*, the wood is called **diffuse porous.** However, when the diameter of the vessels in certain part of the year/season is larger than at other time, the larger vessels appear arranged in distinct rings, as in *Quercus*, *Fraxinus* and in other temperate trees, the wood is known as ring porous. The region with larger vessels is termed **early or spring wood.** The portion where vessels are with smaller diameter, is called **late or autumn wood.** You have already read in detail about all the aspects related to secondary growth in Unit 10, Block 2 of Developmental Biology (LSE-06).

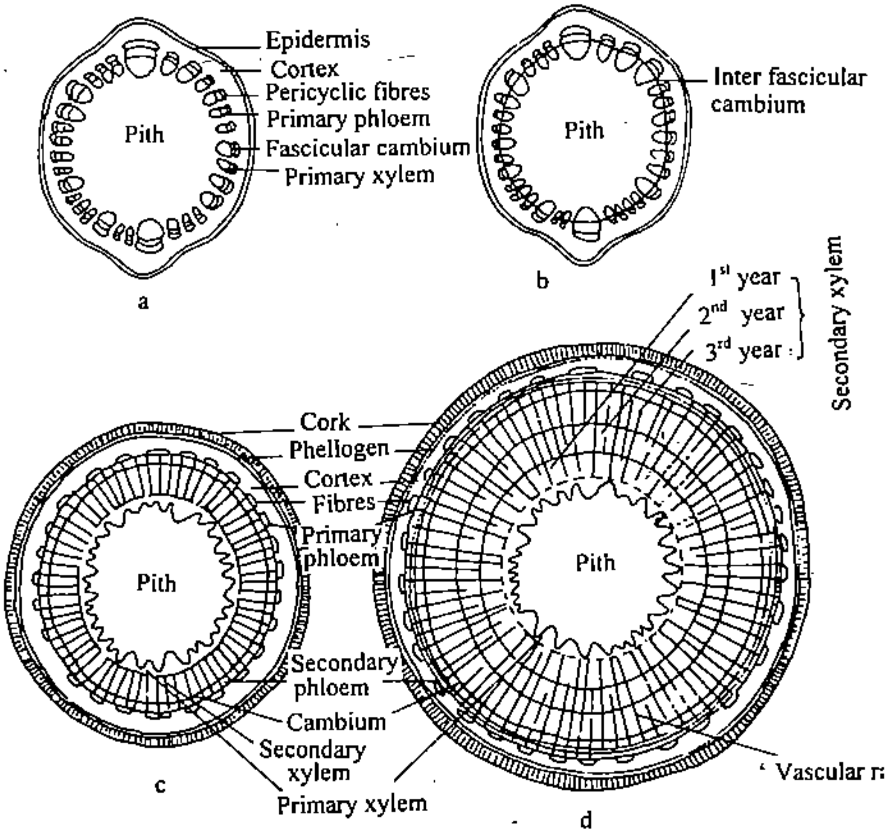

Fig. 8.32: Schematic representation of the stages of secondary growth in a typical dicotyledons stem, cross section of 3 years old stem is shown in d. (Adapted from R.M. Holman and W.W. Robbins. A Text-Book of General Botany, John Wiley & Sons, Inc., New York, 1934).

The wood parenchyma in the vertical system is classified on the basis of its position (see Fig. 8.33). **Paratracheal parenchyma** is associated with tracheary elements as seen in cross section. **Apotracheal parenchyma** is not associated with the tracheary element. When this parenchyma is produced at the beginning or at the end of the season, it occupies a distinct position and is termed **boundary parenchyma.**

In old stem, the wood seems to be demarcated into two postures. The peripheral, relatively smaller zone, lighter in shade is called sap wood and it comprises the portion that is still active. The older, central, massive and accumulative, darker and physiologically inactive wood is termed **heart-wood.**

In woods of *Quercus*, *Robinia* and teak (*Tectona grandis*) among others, the protoplasts of the parenchyma cells adjacent to vessels in the heart-wood penetrate and fill the cell-lumen. Such an intrusion is called **tylosis.** You should also read Unit 10 of Block 2 (LSE - 06) to get a better idea about formation of tyloses.

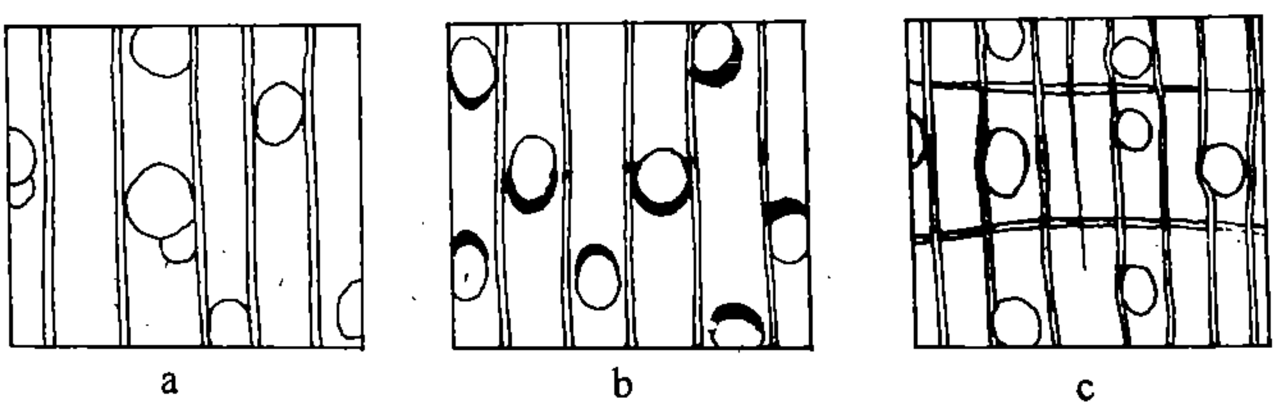

Fig. 8.33: Distribution of parenchyma in wood, a) Apotracheal, b) Paratracheal, c) Boundary. (Modified from K.R. Rao and K.B.S. Juneja. A hand book for field identification of fifty important timbers of India, The manager of Publications, Govt. of India, Delhi 1971)

The horizontal system of the wood comprises **rays** (vascular or xylem rays). They can be best studied by cutting T.S. (Transverse section), T.L.S. (Transverse longitudinal section and R.L.S. (Radial longitudinal section) of the wood (see fig. 8.34 and 8.35).

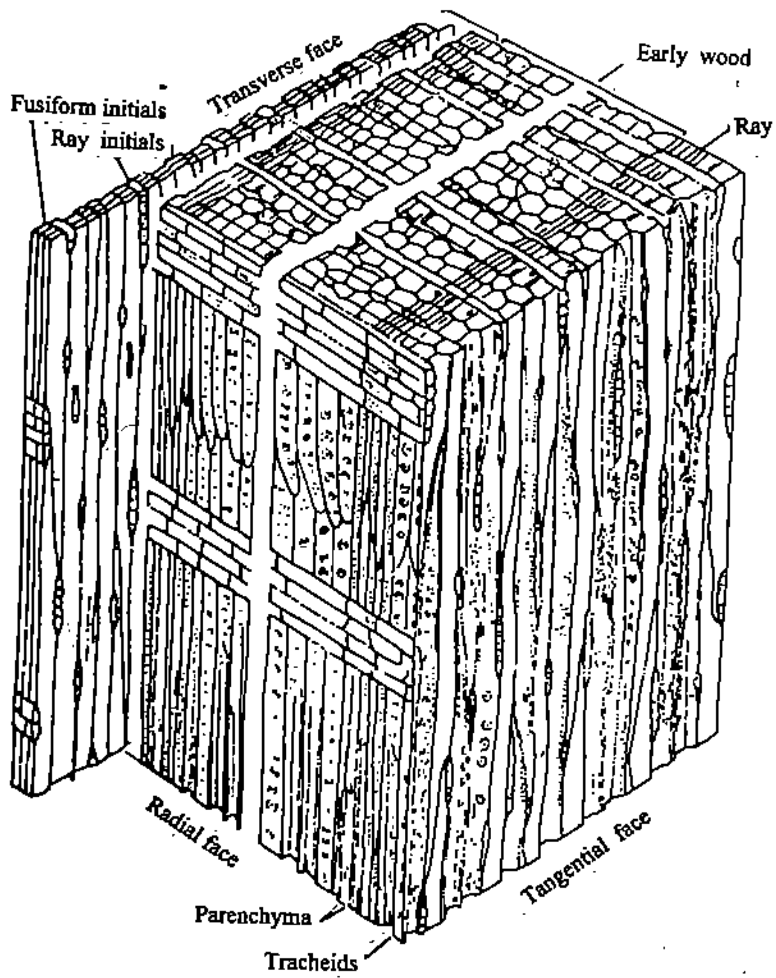

Fig. 8.34: Block diagram of the cambium and secondary xylem of *Thuja occidentalis* L. (White Cedar). Example of gymnosperm (conifer) wood. The vertical system is composed of tracheids and a small amount of parenchyma. The horizontal system consists of low, uniseriate rays composed of parenchyma cells.

The rays may be **uniseriate** (one-cell wide) or **multisereate** (several cells wide). This feature is best observed in T.L.S. The rays may be **homocellular** (homogeneous) if they have all the cells similar in kind or **heterocellular** (heterogeneous) if they have more than one kind of cells. All the cells of homocellular and most of the cells of heterocellular rays are elongated in radial plane. They are called **procumbent** ray cells. Less common but vertically elongated ray cells are known as **upright cells**. They are present usually on the margins of the heterocellular rays. The function of the rays is horizontal transport.

Secondary Phloem

As mentioned earlier, the secondary phloem is produced on the outer side by the vascular cambium.

It also contains vertical and horizontal systems. The cell types present in it are similar to those in the primary phloem.

Secondary phloem may have significant proportion of fibres in many plants e.g. *Corchorus* and *Cannabis*.

In most plants as the secondary activity progresses, the older secondary phloem is replaced by new secondary phloem. Such older, peripheral secondary phloem is called non-functional phloem. Sometimes, this non-functional phloem may continue to live and store starch. A characteristic feature of sieve tubes of such a phloem is the formation of definitive callose.

In *Vitis* and *Bombax*, the non-functioning sieve tube elements become filled with tylosis-like proliferations from the neighbouring secondary phloem axial parenchyma. Such invasions are called **tylosoids**.

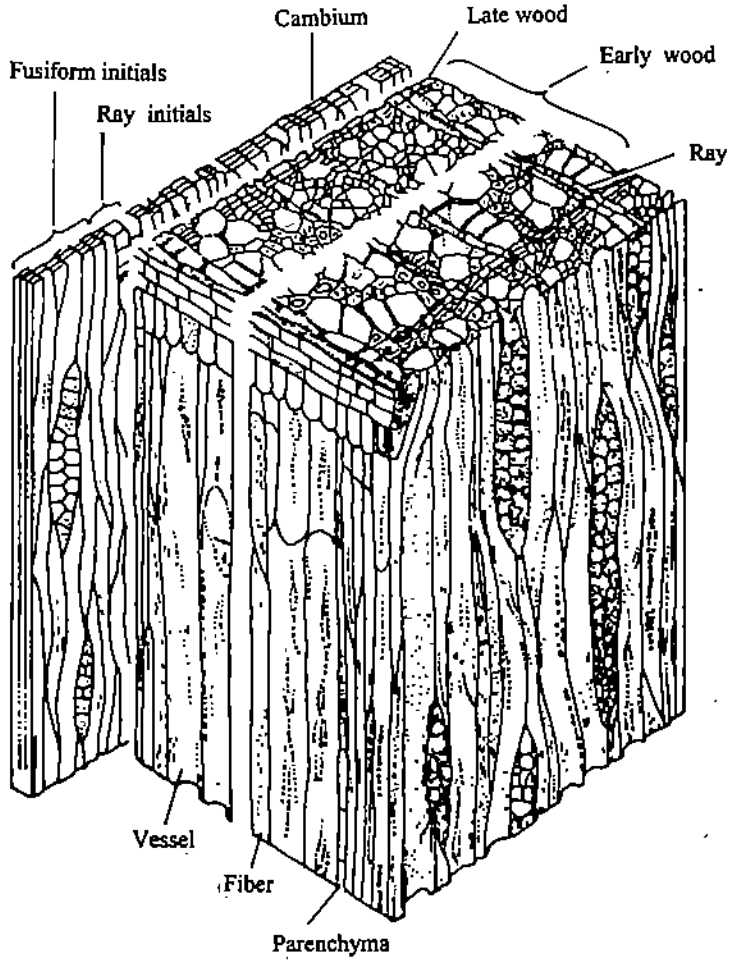

Fig. 8.35: Block diagram of the cambium and secondary xylem of *Liriodendron tulipifera* L. (Tulip Tree). An example of angiosperm (dicotyledon) wood. The vertical system consists of vessel members with bordered pits in opposite arrangement and inclined end walls bearing scalariform perforation plates; fibre tracheids with slightly bordered pits; and xylem parenchyma strands in terminal arrangement. The horizontal system contains heterogeneous rays (the marginal cells are upright, the others procumbent), uniseriate and biseriate, of various heights.

Bark

The first formed periderm may be replaced by newer periderm. When such replacement takes place, the latest periderm is always produced inner to the earlier (last formed) one.

This later produced periderm may have its origin in cortex, primary phloem or even in secondary phloem. Generally, two types of formation of subsequent periderms may be distinguished:

(i) Plants where first formed periderm is developed in inner tissue, the later formed periderms usually form an entire cylinder similar to the first formed periderm. Such plants produce **ring bark**.

(ii) Plants in which the first formed periderm originates in epidermis or outer layers of cortex, the later periderms develop in the form of scales or shells. The concave side of these scales is directed outwards. Such plants produce **scaly bark**.

Rhytidome: Whenever a new periderm is formed inner to the one already present, the tissues exterior to it become cut off from the inner tissues. The nutrition and water supply to them is cut off and such cells eventually die. A hard outer crust develops out of such tissues. This crust increase in thickness due to the additional cork tissue being produced from beneath. All such cork layers together with cortical/phloem tissues exterior to the inner most phellogen are termed as **rhytidome** (outer bark) (see Fig. 8.36).

All tissues exterior to the vascular cambium are included in the term **bark**. The living part of the bark inside the rhytidome is often referred to as **inner bark**.

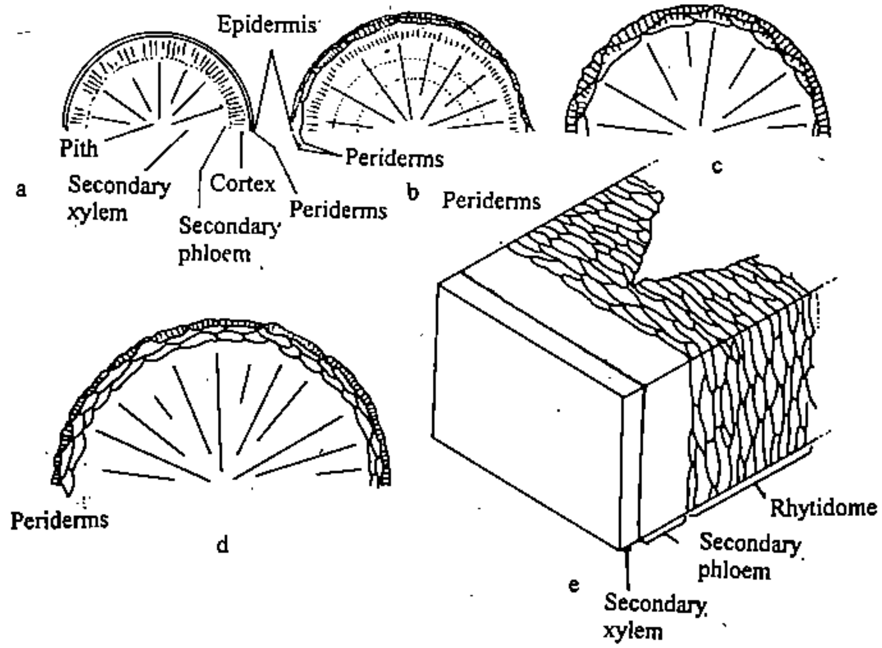

Fig. 8.36: Formation of periderm and rhytidome following the secondary activity in a stem.

Lenticels

Lenticels usually occur on stems, young branches, fruits and even roots and seeds. Lenticels are restricted areas usually below a stomata or a group of stomata. The phellogen in these regions cuts off loosely arranged parenchymatous non-suberized cells with intercellular spaces (termed as **complementary cells**) on the outer side instead of cork cells. The phelloderm is formed on the inner side. This structure constitutes a lenticel (see Fig. 8.37).

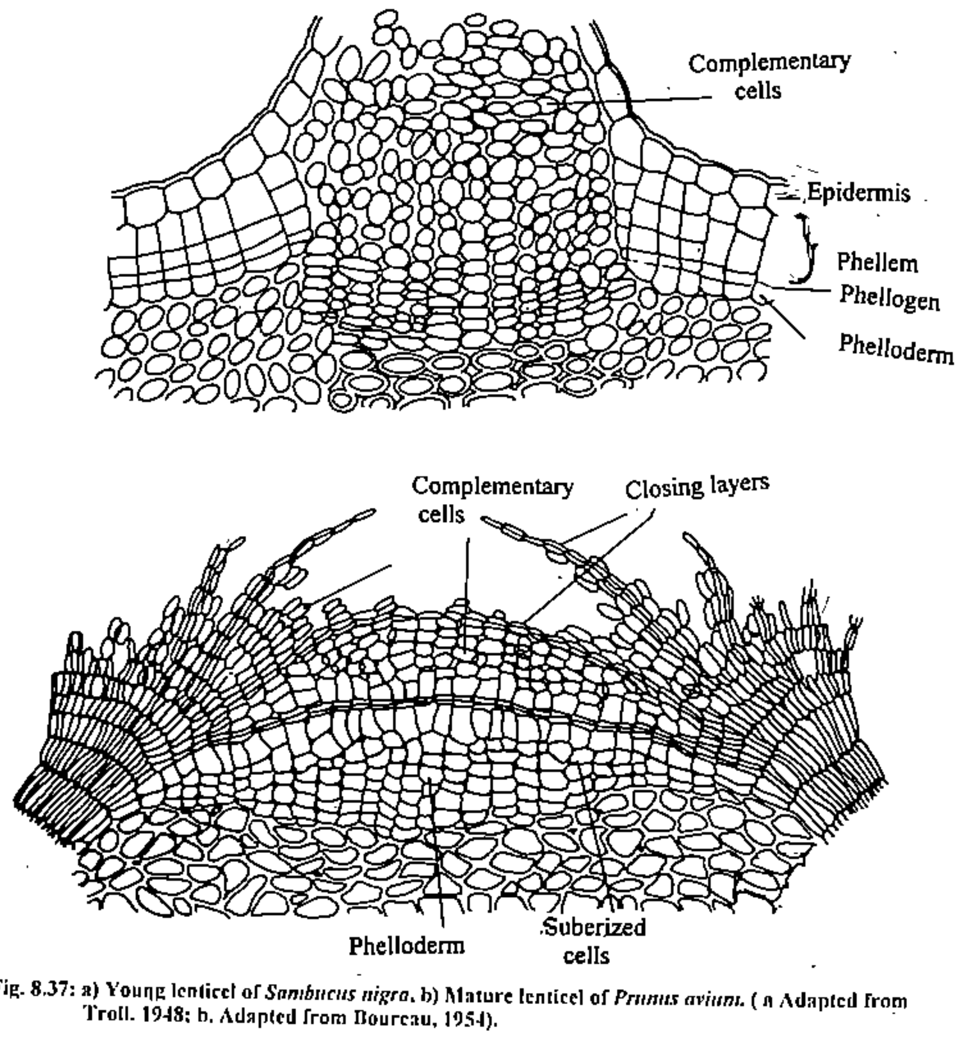

Fig. 8.37: a) Young lenticel of *Sambucus nigra*. b) Mature lenticel of *Prunus avium*. (a Adapted from Troll. 1948; b. Adapted from Bourcau, 1954).

Lenticels seem to protrude above the surrounding periderm/epidermis because of bigger size and loose arrangement of the cells. They are credited with the function of gaseous exchange.

SAQ 5

Answer the following questions:

a) Name three fundamental tissue systems in a primary stem.

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b) Name any three plants where photosynthetic activity is taken over by the stem.

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c) Name the tissue which provides the maximum strength to a monocot stem.

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d) List various kinds of vascular bundles that are encountered in stems.

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e) Give two groups of plants where one encounters closed vascular bundles in the stem.

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8.3.4 Comparison between a Dicotyledon and a Monocotyledon Stem

Plants differ from one another in their anatomical characters. These characters are not absolute. Many variations/exceptions do occur. A summary of some distinctive features is given below:

Table 8.3: Salient differences between dicot and monocot stem.

	Dicotyledon stem	Monocotyledon stem
Epidermis	Distinct with/ without trichome, stomata, rarely chlorophyllous	Generally thick walled, prominent
Hypodermis	May or may not be distinct, if present usually collenchymatous	Generally present, sclerenchymatous
Cortex	A few to many layered; parenchymatous, may have sclerenchyma	The cells following hypodermis are not differentiated and extended from hypodermis to the centre of the axis. It is known as ground tissue. (Parenchymatous/ sclerenchymatous)
Endodermis	Generally not distinct, mostly represented by cells, broken or complete ring	Not present
Pericycle	Present between the protophloem and endodermis, parenchymatous	Not present
Interfascicular Parenchyma	A strip of parenchyma between vascular bundles	Not present
Pith	A large, conspicuous, central cylinder, parenchymatous, may be idioblastic sclerenchyma	Not distinguished
Vascular bundles	(a) Conjoint collateral, open with endarch protoxylem.	(a) Conjoint collateral; closed with endarch protoxylem
	(b) Many, arranged usually in a ring.	(b) Many, scattered throughout the ground tissue;
	(c) Almost all of them are uniform in size.	(c) Larger towards centre and smaller towards periphery
	(d) Phloem parenchyma present	(d) Phloem parenchyma absent
	(e) Bundle sheath absent, poorly developed.	(e) Well developed bundle sheath present.

8.3.5 Specialized Stems

You have by now become familiar with the structure and organization of a stem which generally grows under normal environmental conditions. However, in a number of plants, the stem undergoes specialized modification so as to survive the specific unfavourable environmental conditions. We shall look at some such modifications in this section. In majority of these plants the modifications, in addition, make the organ a perennating one.

Rhizome: Rhizomes are underground dorsiventral stems or branches growing horizontally under the surface of the soil (Fig. 8.38). They possess nodes and internodes. Nodes bear brown scaly leaves. It has both axillary as well as apical buds. Adventitious roots develop at the nodes. Sometimes they may bear contractile roots. Rhizomes are generally fleshy due to storage of food materials. They grow by an apical meristem which gives rise to a shoot. This shoot apex dies very soon and the growth of rhizome is continued by axillary bud. Such growth is called sympodial.

Two very good examples of rhizome are ginger (*Zingiber officinale*) and turmeric (*Curcuma longa*).

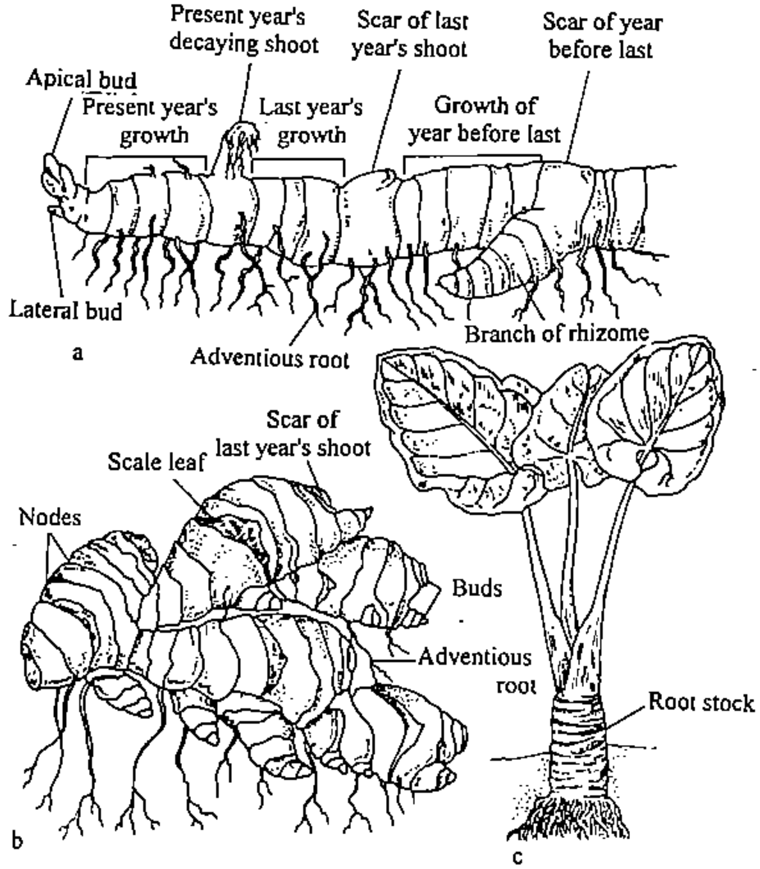

Fig. 8.38: Rhizome. a) A four-year old rhizome of a wild plant. The apical bud will develop next year's shoot while growth will be continued by the lateral bud in the direction of the arrow. The stem is, therefore, sympodial. b) Rhizome of ginger c) Rootstock (vertical rhizome) of *Alocasia indica.*

Tuber: Tuber is a general term applied to any fleshy part of the plant which may store food. They may be stem tubers or root tubers. The most common example of stem tuber is potato (*Solanum tuberosum*, Fig. 8.39 a). When a potato is grown from eye buds, the lower portion of its stem is covered by soil. Axillary or adventitious branches arise from this underground part of the stem. These branches swell into tubers due to accumulation of food substances (mostly starch), and arrest its growth. The tuber grows very slowly, and bears both nodes and internodes. The nodes are distinguished by the presence of scale leaves (at young stage) and eyes (rudimentary bud) in their axils. The eyes are arranged spirally and are more crowded towards the distal end (also called 'rose end'). The distal end is terminated by an apical bud. The tuber possesses a corky skin produced by phellogen. Some other examples of plants which form tubers are: *Cyperus rotundus* (Weed), vegetable, artichoke (*Helianthus tuberosus*, Fig. 8.39 b) stores inulin and Chinese artichoke (*Stachys tuberifera*) stores stachyose.

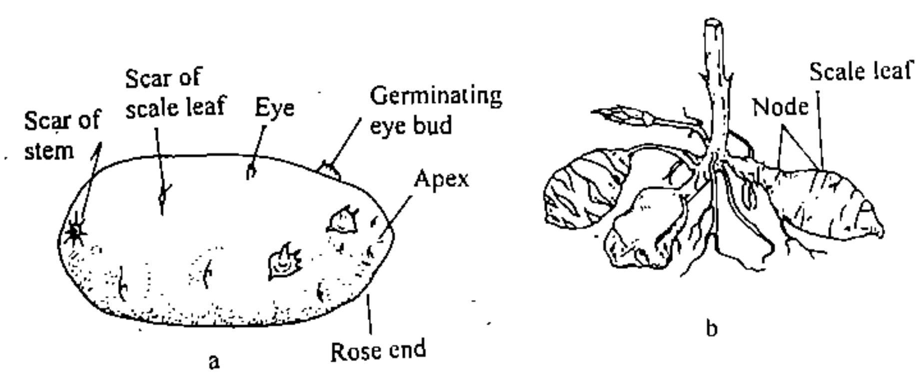

Fig. 8.39: Tuber : modified stem. a) *Solanum tuberosum*, b) *Helianthus tuberosus.*

Bulbs: A bulb is a modified axis with a much reduced stem (disc) and fleshy scale leaves growing from it. The disc has a convex or conical shape with extremely compressed internodes; the nodes produce fleshy scale leaves which store food. At the time of flowering the apical bud develops into a scape. Daughter bulbs may be formed from axillary buds. Adventious roots arise from the undersurface of the disc. Two types of bulbs are distinguished on the basis of arrangement of the fleshy leaves (see Fig. 8.40).

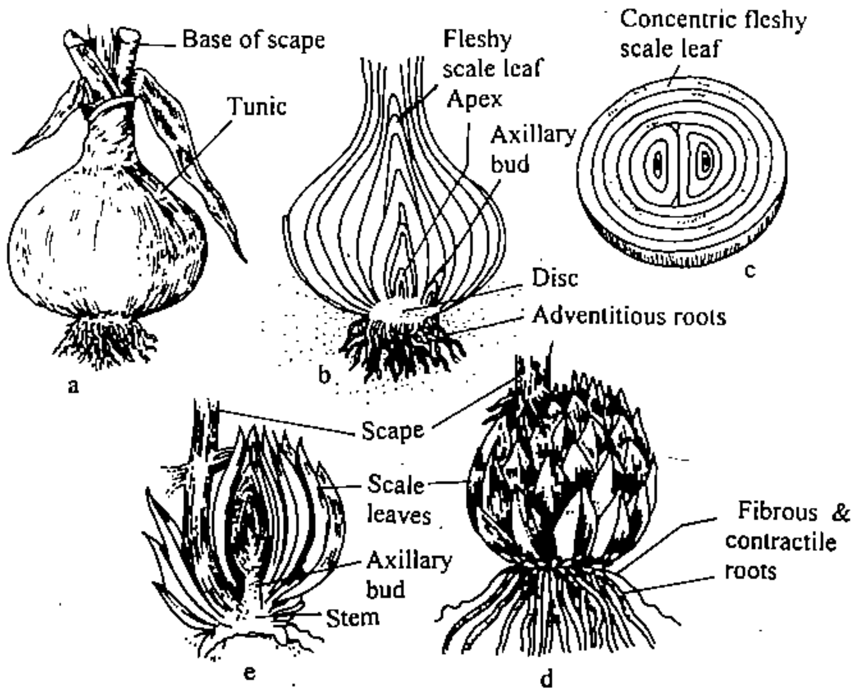

Fig. 8.40: Bulbs - modified stem, a) Tunicated bulb of onion, b) L.S. of bulb, c) T.S. of bulb, d) Scaly bulb of lily, e) L.S. of scaly bulb.

(i) **Tunicated bulbs:** Here, scale leaves are arranged in a concentric manner as seen in cross section. The whole bulb is covered with dry membranous scale leaves which form the tunic. Such bulbs are found in onion (*Allium cepa*);tulip (*Tulpia*); hyacinth (*Hyacinthus*) and tuberose (*Polyanthes*) (See Fig. 8.40 a, b,c).

(ii) **Scaly or imbricate bulbs:** The scale leaves are not concentric but are arranged loosely like a petal of a flower, overlapping each other at the margins. They are not compact but are covered by a common tunic. Garlic (*Allium sativum*) and lilies (*Lilium* spp) have such bulbs (See Fig. 8.40 d, e).

Corms: Corms are also called solid bulbs. They are much condensed vertical root stocks with a very large apical bud and some scale leaves. Adventitious roots grow either from the base or from all over the body of the corm.

Amorphophallus campanulatus corm is a huge condensed internode with numerous adventitious buds and roots all over its body. New daughter corms are produced by the accumulation of food at the base of the shoot forming a new internode. Saffron (*Crocus sativus*) also bears and grows by corms (see Fig. 8.41).

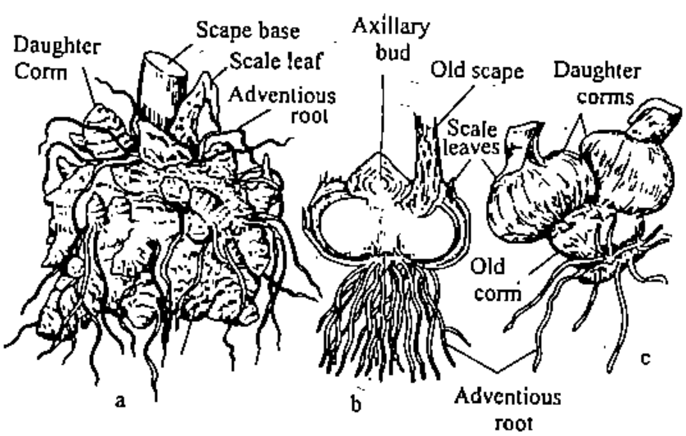

Fig. 8.41: Corm - modified stem. a) Corm of *Crocus* with daughter corms. b) L.S. of *Crocus* corm. c) Corm of *Amorphophallus*.

Runner, Offset, Stolon, Sucker

Plants with weak herbaceous habit propagate quickly by means of special branched stem which gives rise to new plants. Here, though the individual plant is short-lived, the colony is perennial. These modified branches either grow along the surface of the soil or water, or may be partially or wholly underground.

Runner: Creeping plants such as doob grass (*Cynodon dactylon*), *Oxalis* and *Fragaria*, form runners. Here, the axillary buds from the lowest leaves give rise to slightly modified branches. The basal internodes of the bud elongate and horizontally trail along the ground soil. In this way the bud is carried to distances away from the parent plant. The process continues (see Fig. 8.42 a).

Offset: Offset are found in aquatic plants. They are also a kind of runner, except that they are shorter and thicker. Water hyacinth (*Eichhornia crassipes*) grows by offset (Fig. 8.42 a).
Stolon: It is a special type of runner which does not grow horizontally from the beginning. At first it grows upward like ordinary branches and then arches down to meet the soil. After striking the soil daughter plants are formed. *Mentha* (Fig. 8.42 b) and some members of Rosaceae bear natural stolons.

Sucker: Sucker is an underground runner which soon grows up and forms a daughter plant after striking roots. Examples of sucker producing plants are *Chrysanthemum* and *Mentha arvensis* (Fig. 8.42 C).

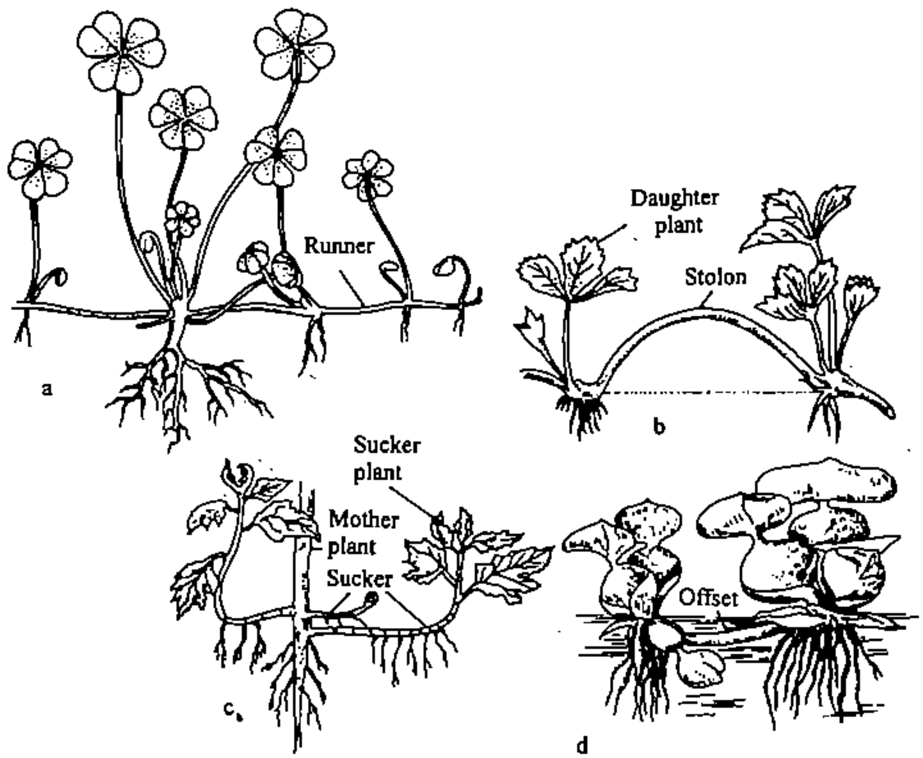

Fig. 8.42: Modifications of Stem: a) Runner of *Oxalis corniculata*. b) Stolon of *Mentha* sp. c) Sucker of *Chrysanthemum* sp. d) Offset of *Eicchornia* sp.

Cladophyll

They are also called **Phylloclade**. They are modifications encountered in xerophytic plants. The modifications help plant to minimise water loss. The growth of leaves is checked and this reduces transpiration. The stem becomes flattened or swollen. It is chlorophyllous and serves as a photosynthetic organ. Such flattened or swollen stem structures are called phylloclade or cladophyll (Fig. 8.43). The flat, fleshy portion is internode, and the leaves at the nodes are metamorphosed into spines or reduced to small scaly leaves.

Phylloclades commonly occur in the families Cactaceae, Euphorbiaceae, and in *Muehlenbeckia*, *Casuarina* and *Ruscus*. Phyllodade possessing only one internode is termed **cladode** (eg. *Asparagus*).

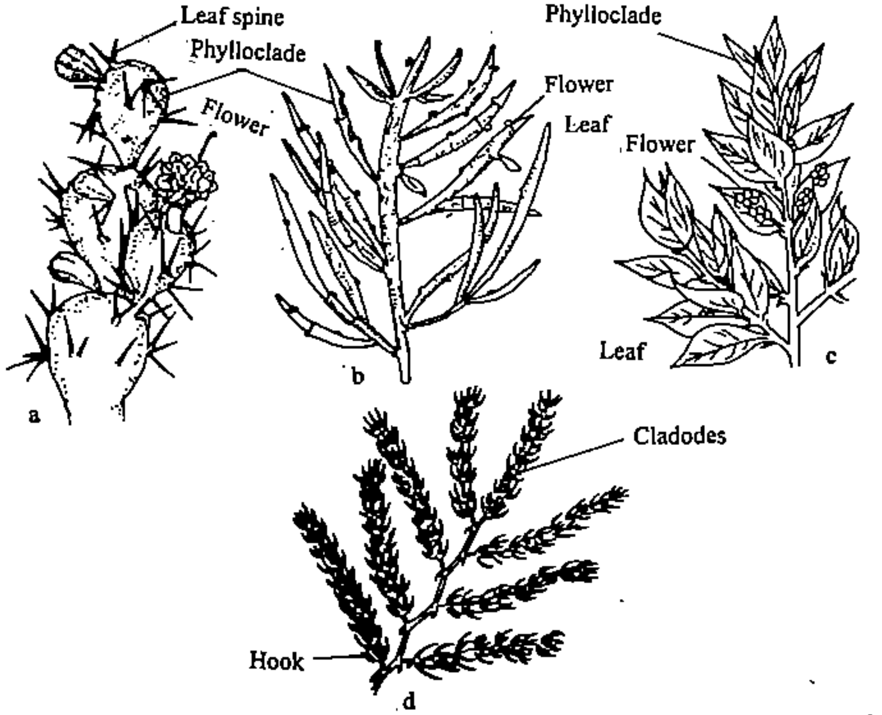

Fig. 8.43: Phylloclade a stem modification. a) Phylloclade of *Opuntia* b) Phylloclade of *Muehlenbeckia* c) Phylloclade of *Ruscus* d) Cladodes of *Asparagus*.

Thorns & Spines

Axillary buds are sometimes arrested and get transformed into very hard structures, called **thorns**. They are different from **spines** and **prickles**. Thorns are very deep seated structures with vascular connections and are a direct prolongation of stem (eg. *Carissa carandas*, *Prunus*, *Aegle marmelos*; Fig. 8.44). **Prickles** are mere superficial outgrowths on the epidermis whereas spines are intermediate forms (tips of date palm leaf segment, stipules of *Acacia*). Development of these structures is a xerophytic character.

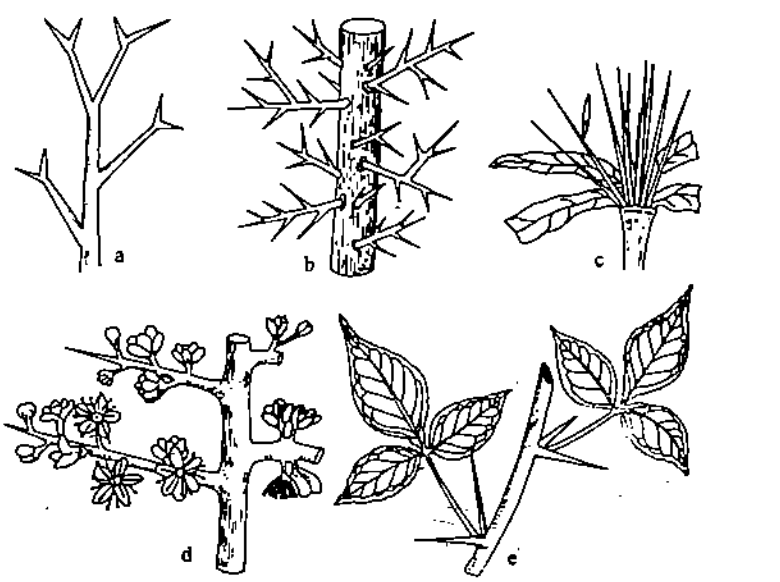

Fig. 8.44: Thorns. a) Branched thorn of *Carissa carandas* axillary in origin, b) Branched thorns of *Flacourtia cataphracta*. Some of these are not real thorns but mere subepidermal outgrowths. c) Axillary thorns of *Hygrophila spinos*. d) Thorns of prune (*Prunus*) bearing flowers. e) Paired thorns of *Aegle marmelos*.

Tendril

Tendrils are differently modified structures. They help in climbing. Some tendrils are modified stems, when they develop from axillary buds or the branched tips. In passion flower, the axillary branches are modified as tendrils. In *Vitis*, the tips of sympodial branches are modified as tendrils. In *Antigonon*, inflorescence axis gets modified into tendril (Fig. 8.45).

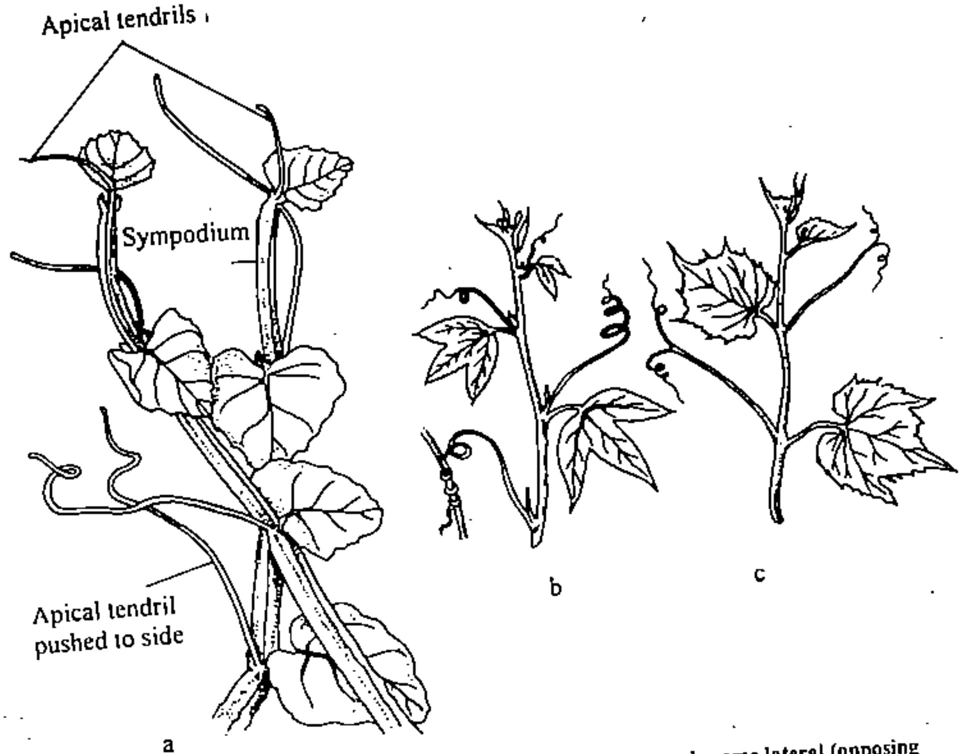

Fig. 8.45: a) Twigs of *Vitis quadrangularis* showing apical tendrils which later become lateral (opposing leaves) due to sympodial growth of stem. b) Axillary stem tendril of passion flower. c) Apical stem tendril of *Vitis*.

SAQ 6

(a) Give characteristics of:

(i) Rhizome ....

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(ii) Tuber ....

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(iii) Bulb ....

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(iv) Corm. ....

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(b) Give an example of each of the following:

(i) Runner ....

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(ii) Stolon ....

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(iii) Sucker

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(iv) Offset

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(v) Phylloclade.

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8.4 LEAF

Leaves are lateral organs on the stem. As mentioned earlier, together with stem they constitute shoot system. They arise due to the activity of shoot apical meristem. They are borne on nodes. Morphologically, it is not very difficult to differentiate a leaf from the stem. However, the leaf does fulfil a rather specific function for which it is specialized both structurally and physiologically. Therefore, we shall discuss the structure of leaf separately.

The leaf is an organ of determinate growth and dorsiventral symmetry. Its flattened shape is well suited to its photosynthetic function.

Leaves are classified as **microphylls** and **megaphylls** (macrophylls). Both types of leaves originate from basically similar primordia at the shoot apex. Microphylls are of small size because of their failure to undergo any extensive subsequent growth. They occur in Psilotales, club mosses and some other pteridophytes.

Megaphylls or foliage leaves, as they are better known, are common to flowering plants. They range from a few millimeters in length to about 2 meters in some palms and bananas. Floating leaves of *Victoria amazonica* (giant water lily) may have lamina 1.83 meters in diameter.

Foliage Leaf: A typical foliage leaf (see fig. 8.46) has got three parts: (a) leaf base; (b) petiole, the stalk of the leaf, and (c) leaf lamina or blade.

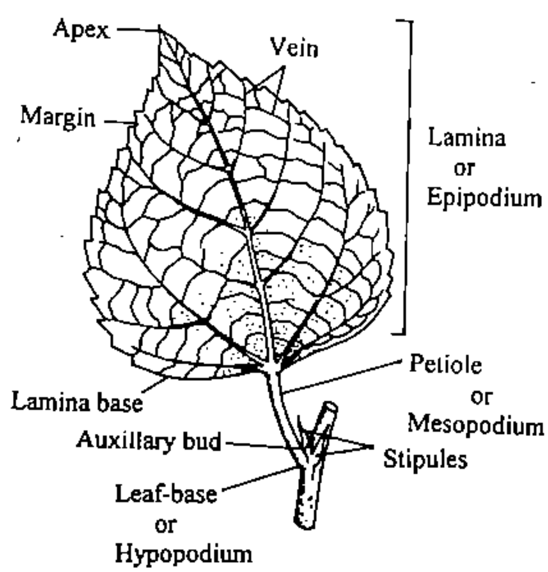

Fig. 8.46: Parts of a typical leaf.

The leaf base attaches the leaf to the stem. When a petiole is present, the leaf is called **petiolate.** A leaf without petiole is called sessile. There are various kinds of modifications of leaf bases and petioles. Here we will discuss about the lamina since this is mainly associated with photosynthesis and gaseous exchange.

Leaf lamina is normally a flat structure. The upper surface, which faces the axis of the stem, is termed **adaxial**. The lower surface, which is away from the axis, is known as **abaxial**. Such leaves are called **dorsiventral** and are common to most dicotyledons. In monocotyledons and shade plants the leaf is placed in such manner that both surfaces receive equal light and there is no difference between the two surfaces. Such leaves are called **isobilateral**. The leaves with cylindrical outline are termed **centric** (eg. onion).

8.4.1 Internal Structure

Internally the lamina of a leaf consists of three basic kinds of tissue: dermal (epidermis), ground (mesophyll) and vascular (veins). Let us know more about each.

Dermal Tissue (Epidermis)

The epidermis constitutes the dermal tissue of a leaf. Usually a single layer of epidermal cells is present. However, leaves of *Ficus*, *Nerium*, and *Piper*, show a multiple epidermis. In such leaves adaxial epidermis may have more layers than the abaxial epidermis. Whenever the number of epidermal layers on abaxial surface is more, a sub-stomatal crypt is usually present, as in the leaf of *Nerium oleander* (Fig. 8.47).

Stomata are the most characteristic feature of the epidermis of any leaf. They may be present on both the sides of the leaf (as in isobilateral leaves) or may be restricted to abaxial surface (as in most dorsiventral leaves). Rarely, as in the floating leaves of *Nymphaea*, the stomata are located only on the adaxial epidermis.

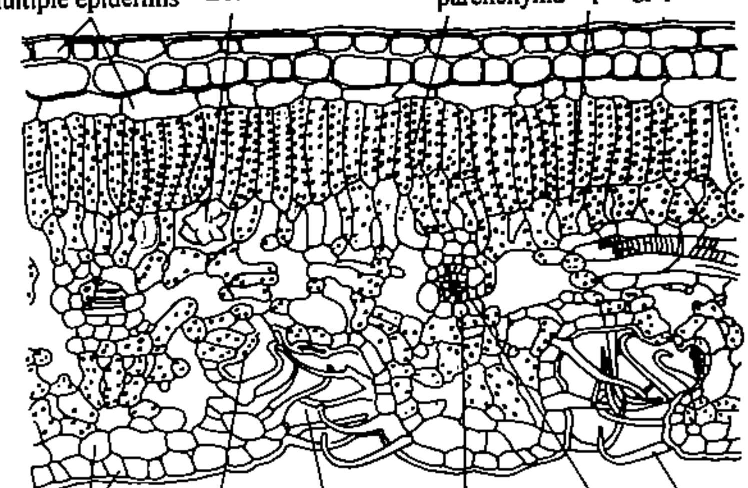

Fig. 8.47: Vertical section of *Nerium* leaf.

Epidermal cells do not contain well developed plastids. Plastids are characteristically present in the guard cells of stomata. Such plastids have only few grana. *Phyllospadix*, which grows in sea water, possesses chloroplasts in the epidermal cells.

Epidermis of many species have trichomes. Both, covering and glandular trichomes occur in the leaves. Trichomes exhibit a considerable range of form. In certain graminaceous leaves some of the epidermal cells are modified as **bulliform** cells. Such cells are hygroscopic.

Epidermal cells may contain crystals (eg. *Tamarix*, *Plumbago capensis*); cystolith of calcium carbonate (eg. *Ficus elastica*); lignin (eg. *Quercus*, *Nerium*, *Cycadaceae*, needle of conifers); coutchouc (eg., *Eucalyptus*); silica (eg. *Equisetum*, Graminaeae, Cyperaceae); and mucilage (eg. Euphorbiaceae, Malvaceae).

Ground Tissue (Mesophyll)

The ground tissue of a leaf lamina is highly specialized to carry out photosynthesis. The cells are rich in chloroplasts and comprise the **mesophyll**. The mesophyll is differentiated in two kinds of cells, **palisade** and **spongy parenchyma**. The palisade cells are cylindrical and elongatged as seen in vertical section of a leaf. They could be one to few layered. The spongy parenchyma consists of loosly arranged irregular cells with air spaces. It is generally present below the palisade parenchyma. In dorsiventral leaves (see fig. 8.48), the palisade parenchyma is restricted to adaxial surface. However, in isobilateral leaves, the palisade parenchyma occur on both the surfaces (see Fig. 8.49). In cylindrical leaves as in *Hakea*, the palisade tissue occurs all along the periphery.

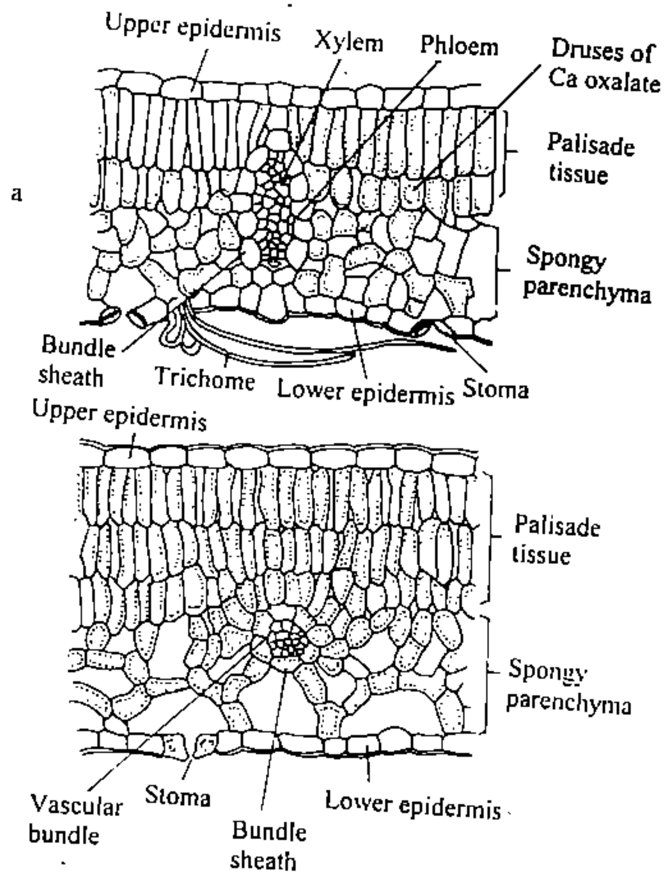

Fig. 8.48: Portions of vertical section of dorsiventral leaves a) *Quercus* b) *Malus*

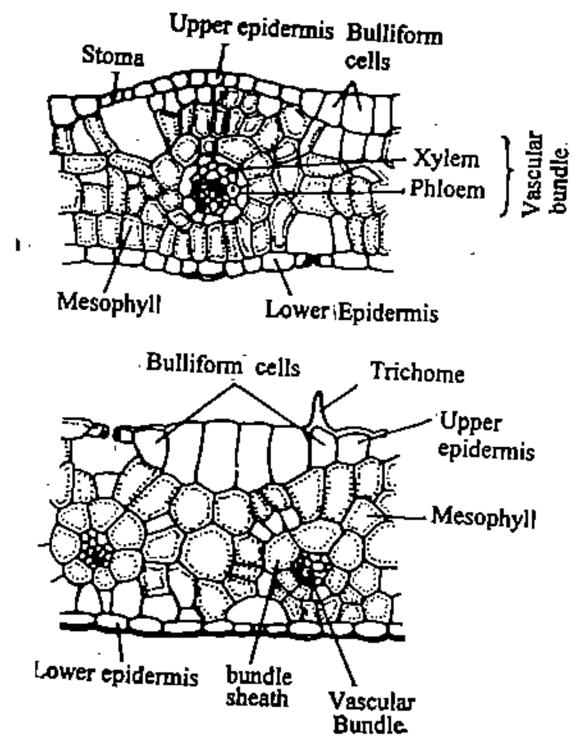

Fig. 8.49: Portions of vertical section of isobilateral leaves. a) *Avena*, b) *Zea*.

A lot of variation is seen in structure and distribution of mesophyll in the leaves.

Bundle Sheath: In some plants, the cells surrounding the vascular tissue in a leaf lamina though of similar origin are morphologically different from adjacent mesophyll cells. These cells are large and contain fewer chloroplasts. They may be thick-walled. These cells constitute the **bundle sheath** (see Fig. 8.50). When these cells extend up to the leaf surface, then they are called **bundle-sheath extension**.

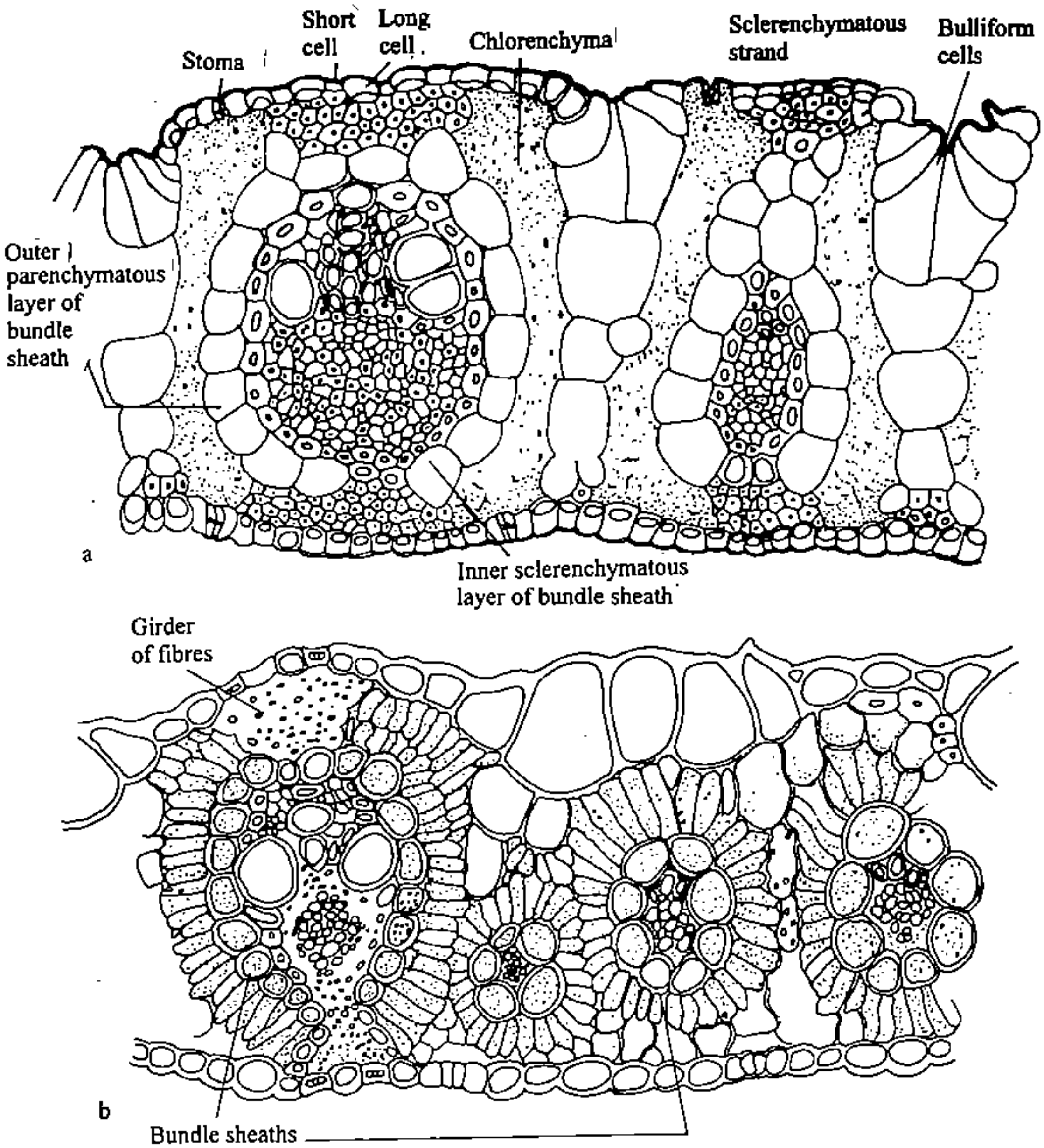

Fig. 8.50: Portions of vertical-sections of grass leaves. **a)** *Desmostachya bipinnata* in which the bundle sheath consists of two layers, the outer parenchymatous and the inner sclerenchymatous. **b)** *Hyparrhenia hirta* in which the bundle sheath consists of a single layer of chloroplast-containing cells.

Whenever the bundle-sheath cells contain starch, these are termed as **starch sheath**. When they possess casparian strips, they form an endodermis.

The bundle sheaths are very conspicuous and well studied in C_4 plants. Studies with electron microscope reveal that the chloroplasts in the bundle sheath cells of *Amaranthus edulis* and *Atriplex lentiformis*, are large and have grana and abundant starch grains. Fewer and smaller starch grains are reported in the mesophyll cells of the same leaves. Chloroplasts in bundle sheath cells of tropical grasses, however, have little or no grana at maturity.

Ginkgo leaves have open dichotomous (repeatedly forked) venation resembling two relic genera of dicotyledons *Kingdonia* and *Circaeaster*.

Vascular Tissue

The vascular tissue of a leaf is in continuation with that of the stem on which they are borne. Each leaf receives from one to many vascular traces from the stem. The traces may continue unbranched throughout the entire length of the leaf or may alternatively branch or even anastomose. The vascular bundle of a leaf is called a **vein**. The ramification and the network of these veins in a leaf is called **venation**. Lower vascular plants have **dichotomous venation** (eg. fern leaves). Venation is **reticulate**, net-like in dicotyledons. In monocotyledons, on the other hand, the leaves show **parallel venation** (see Fig. 8.51).

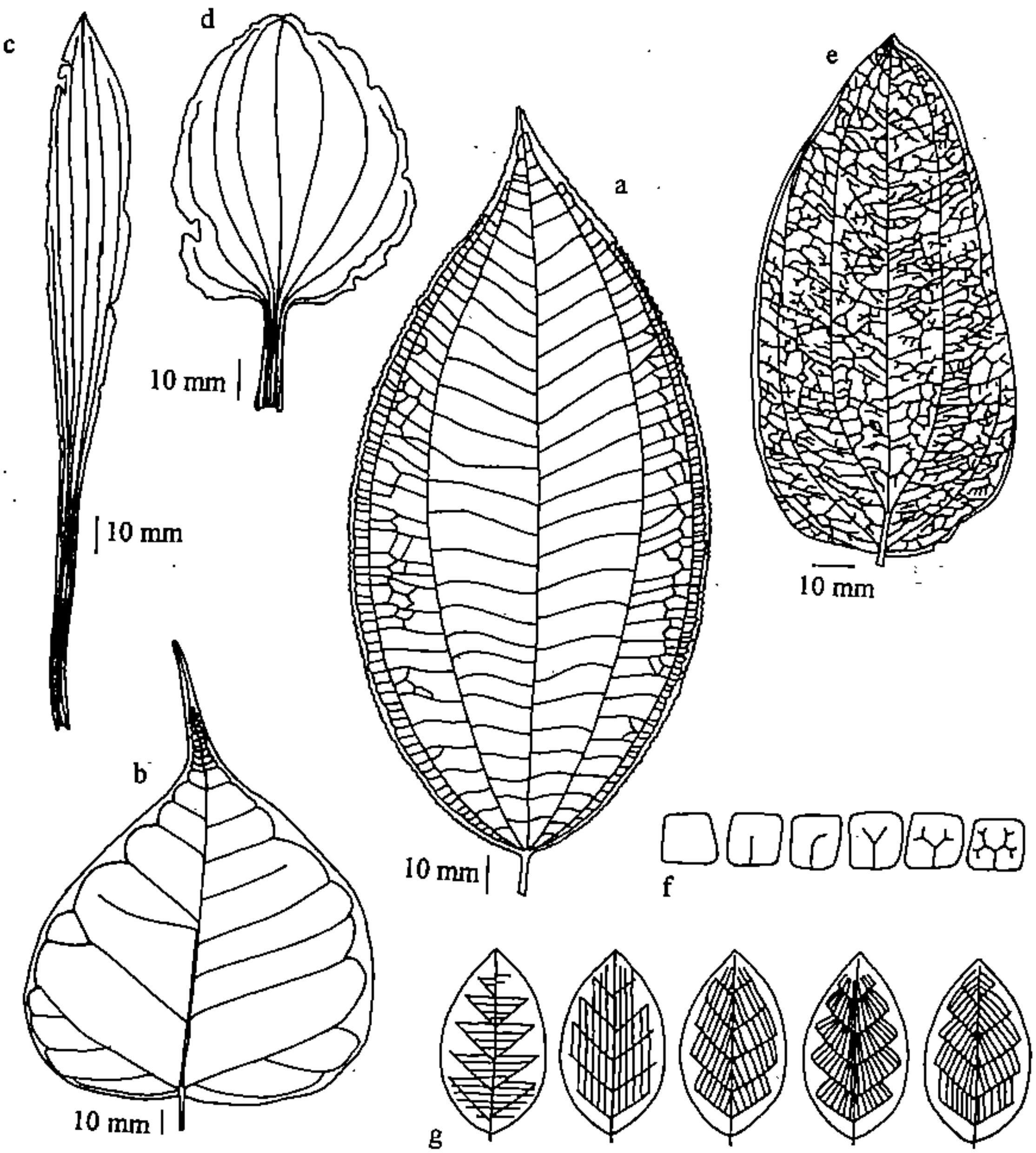

Fig. 8.51: a) *Clidemia hirta* (D); b) *Ficus religiosa* (D); c) *Plantago lanceolata*, parallel veined (D); d) *Plantago major*; e) *Smilax* sp., net-veined (M); f) typical areole patterns showing ultimate veinlets; g) variations of one type of secondary vein layout. (f and g after Hickey 1973). (D)=dicotyledon, (M)=monocotyledon.

The smallest area of the leaf tissue surrounded by veins is known as **areole**. Areole vary in shape and sizes. Leaves of certain succulents do not form an areole. The vascular bundle is generally collateral with xylem on adaxial side and phloem towards the abaxial side. A vascular cambium, if present, is restricted to the bundles of mid-vein and that too in the dicotyledons. Vascular bundles in the mid-rib region may be arranged in a ring (*Vitis*, *Liriodendron*) or in a semi-circle (*Abrosia*), or may be irregularily distributed (*Helianthus*). The petiole when present bears more or less similar anatomical features as seen in the internode of the plant.

8.4.2 Comparison between a Monocotyledon and a Dicotyledon Leaf.

	Monocotyledonous Leaf	Dicotyledonous Leaf
Epidermis:	Only single layered, xerophytic grasses have large cells with flexible cell walls helping the leaves to roll in dry weather. These are called bulliform cells.	Usually single layered or some times multi-layered. Bulliform cells absent.
Stomata:	On both sides of the leaf, generally arranged in parallel rows.	Generally restricted to abaxial epidermis.
Palisade Parenchyma:	On both the surfaces.	Mainly restricted to adaxial surface.
Spongy Parenchyma:	Sandwiched between two palisade parenchyma zones	Conspicuous, large body towards the abaxial surface.
Venation:	Generally parallel reticulate in *Smilax*, *Arum*, Some orchidaceae members Generally isobilateral, (also called unifacial)	Generally reticulate, parallel in *Plantago*, *Geropogon*, *Trapopogon* Generally dorsiventral (also called Bifacial)

SAQ 7

(a) Draw a diagram of a leaf and label the various parts.

(b) Define the following terms:

Sessile, adaxial, abaxial, petiolate, venation, Areole.

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8.4.3 Specialized Leaves

In the preceding sections you have studied about the structure of a typical leaf. However, under certain conditions the leaf undergoes some modifications to suit its environment.

Leaves of arid regions

Plants may develop structural characteristics that are adaptations to arid habitats. Such plants are called **xeromorphic** plants. Xeromorphism, however, is not confined to xerophytes and not all xerophytes exhibit xeromorphic characters.

One of the most obvious features of xeromorphic leaves is the small ratio of external leaf surface to its volume. This reduction in the external surface is accompanied by certain changes in the internal structure of the leaf such as: reduction in cell size; increase in the thickness of cell walls; the greater density of both vascular system and of the stomata; and increased development of the palisade tissue at the expense of spongy tissue. Such leaves are covered with trichomes. The stomata are sunken in small crypts. More cuticle and wax are deposited on the epidermal surface in such leaves. In certain plants the leaves possess water storing tissue to make them succulent.

Leaves of *Nerium oleander* (see Fig. 8.47), *Olea, Salicornia* and *Salsola* (see Fig. 8.52) exhibit xerophytic characters.

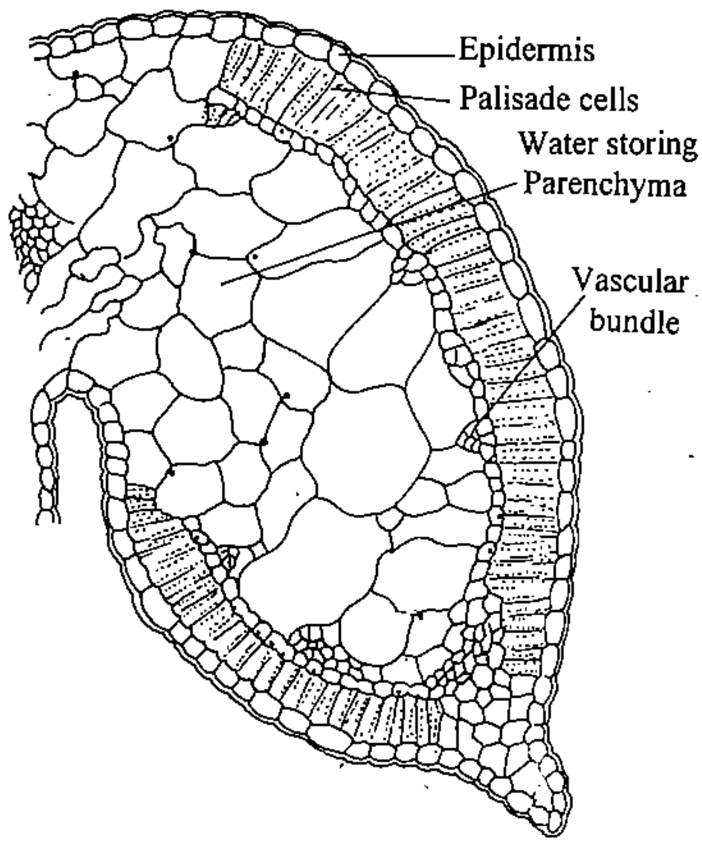

Fig. 8.52: Succulent leaf of *Solsola* in cross-section.

Tendril

The first cataphylls on a lateral branch are called Prophylls.

In many climbing plants, the leaf or portion of leaf gets modified as tendril. The tendril serves as a supporting organ. In *Lathyrus* (see Fig. 8.53 a) the entire lamina becomes a tendril. Terminal leaf-lets become tendril in *Pisum* (see Fig. 8.53 b). The leaf apex of *Gloriosa superba* (see Fig. 8.53 d) gets transformed into tendril. The tendril of cucurbits may be a prophyll (see fig. 8.53 g). Also refer fig. 8.53 for some other kinds of tendrils.

Fig. 8.53: Leaf tendrils: a) Leaf tendrils of *Lathyrus aphaca*. b) Leaflet tendril of *Pisum sativum*. c) Leaf petiole tendril of *Clematis* sp. d) Leaf apex tendril of *Gloriosa superba*. e) Stipular tendril of *Smilax*. f) Inflorescence stalk of *Antigonon*. g) Tendril in *Cucurbita* leaf.

Spines, Thorns and Prickles

Modification of certain or entire portion of a leaf into spines, thorns and prickles serves two functions. They reduce the surface area through which water is lost by the plants. In addition, they provide protection to the plant.

The stipules of *Zizyphus* get modified into spines. *Opuntia*, *Asparagus*, *Berberis* and *Ulex* all have spines which are actually the leaves (see Fig. 8.54).

Prickles, which are superficial modifications from epidermal cells, are common to the leaves of *Solanum melongena* (brinjal) and *Solanum xanthocarpum*.

Storage leaves

Some leaves, especially in xerophytes and halophytes, become fleshy because of storage of water, mucilage and food reserves. Such leaves contain a special storage tissue. Common examples are the leaves of *Portulaca oleracea*, *Aloe*, *Agave* and *Bryophyllum*.

Reproductive Leaves

When a bud grows from a position other than the normal (i.e. apex or axil) then it is called **adventitious bud.** When such buds arise from leaves they are called **epiphyllous bud.** In *Bryophyllum* leaf such buds arise on margins (see fig. 8.55). Leaves of *Begonia*, *Kalanchoe* produce such buds on their margins or surface.

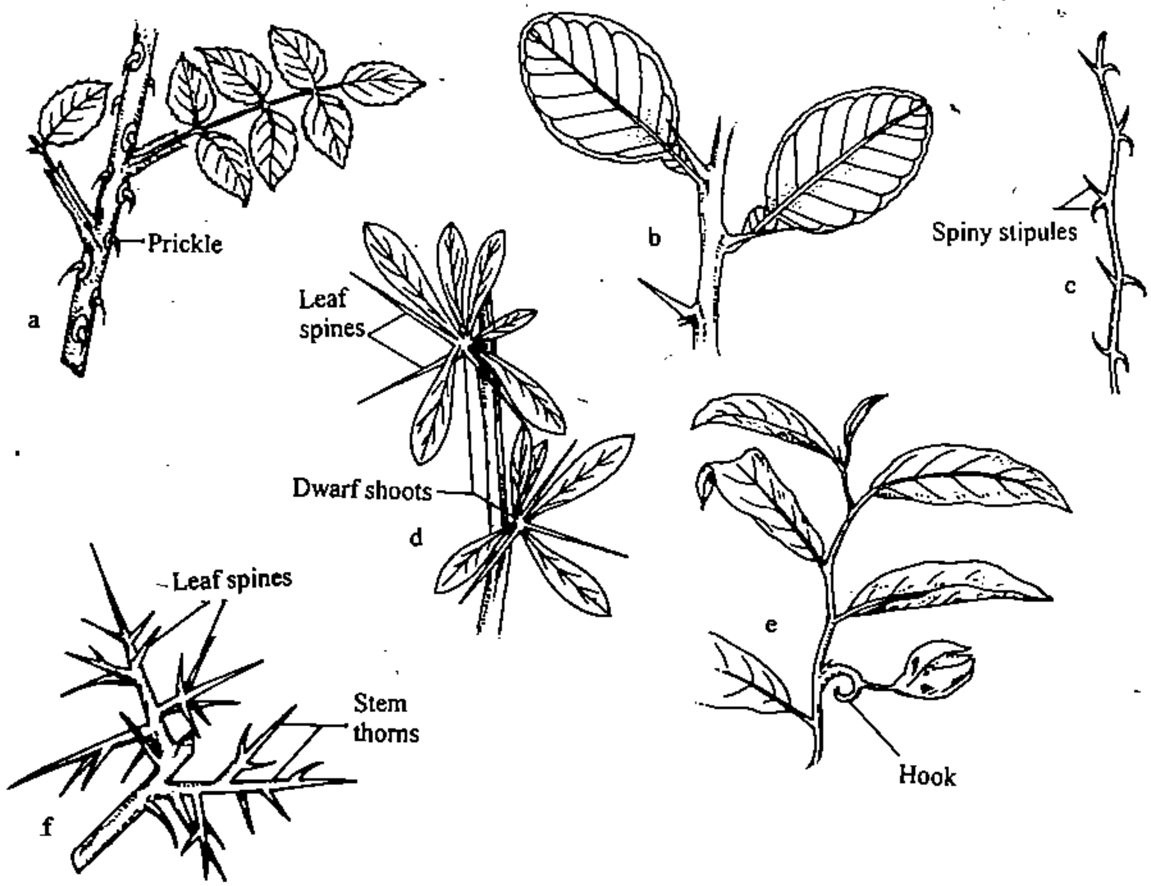

Fig. 8.54: Spines and prickles in leaf: a) Curved prickles of climbing roses. b) Spinuous prophyll in *Citrus*. c) Spiny stipules of *Zizyphus*. d) Large stem spines and small leaf spines in *Ulex*. e) Spiny hook on peduncles of *Artabotrys*. f) Leaves of *Berberis*.

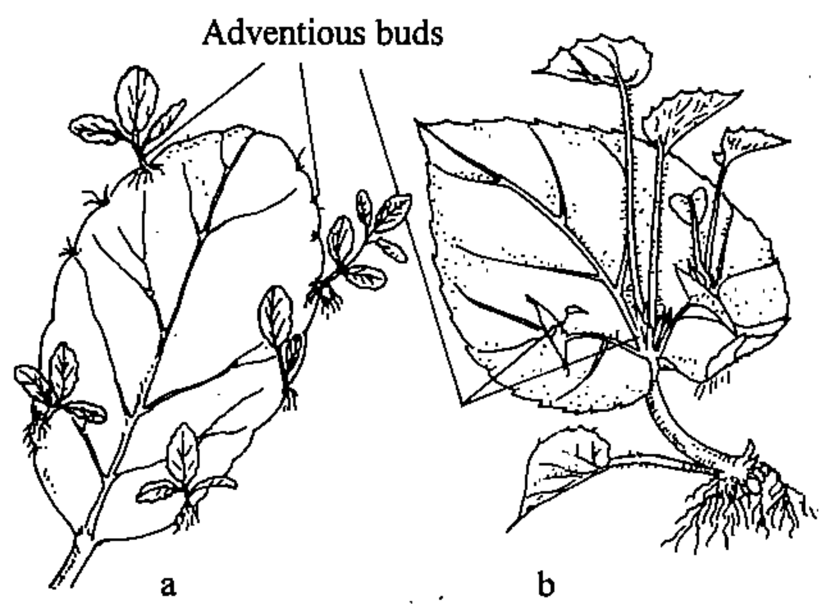

Fig. 8.55: Reproductive leaves in a) *Bryophyllum* and b) *Begonia*.

Floral Leaves

In some plants the flower arises in the axil of leaves called **bracts**. When present, they may drop off very early or may persist. Additional bract-like small and thin structures, sometimes borne on the peduncle or the pedicel between a bract and the flower, are called **bracteoles** (see Fig. 8.56).

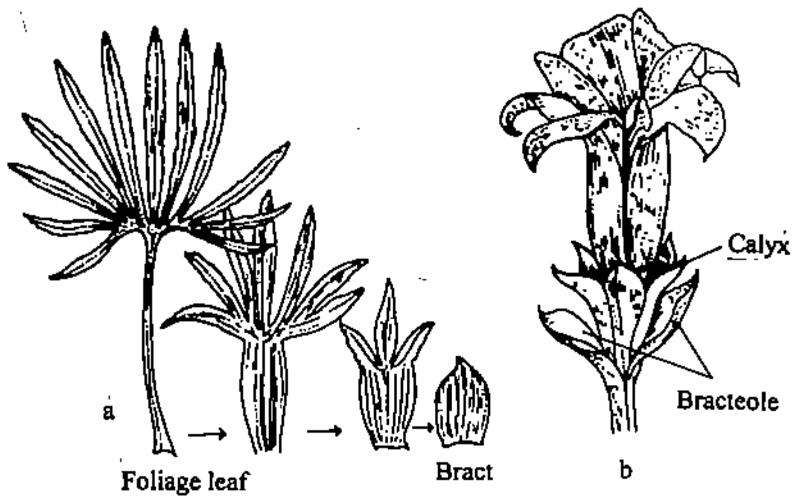

Fig. 8.56: Floral leaves: Bracts and bracteoles. a) Transition to bracts in *Helleborus foetidus*.
b) Bracteoles in *Gentiana acaulis*.

The bracts and bracteoles may be:

i) **Leafy or foliaceous:** as epicalyx of malvaceae. *Adhatoda vasica, Gynandropsis.*

ii) **Petaloid:** as in *Bougainvillea, Euphoria pulcherrima.*

iii) **Spathy bract:** as in *Amorphophallus titanum, Polyanthes.*

iv) **Involucre bract:** as in *Daucus carota*

v) **Scaly bract:** as in *Humulus lupulus.*

vi) **Cupule:** as in *Betula, Corylus.*

vii) **Glume:** as in Gramineae spikelet.

viii) **Lemma and Palea:** as in spikelet of Poaceae.

Insect trapping leaves

The pitcher of insectivorous plants are wholly or partially modified leaf lamina.

In *Nepenthes* (see Fig. 8.57 c) lower part of the petiole is winged and the upper part forms a tendrillar structure which may coil round a support to bear the weight of the pitcher-like structure. The pitcher-like structure is itself lamina. *Sarracenia* also produces pitchers.

In sundew (*Drosera*) each leaf is covered with glandular hairs called tentacles which secrete sticky fluid (Fig. 8.57, b).

In Venus flytrap (*Dionaea muscipula*) , the petiole of the simple leaf is winged and the lamina is deeply notched at the apex. The leaf margin is slightly incurved and provided with long pointed teeth. The two halves of the leaf are capable of movement with the midrib acting as a hinge. When the leaf folds, the marginal teeth interlock , to produce trap (Fig. 8.57, f).

Bladderwort (*Utricularia*) (see Fig. 8.58) has finely dissected submerged leaves looking like green roots. Numerous segments of the leaf are modified into **bladders or utricles.** Inner wall of bladder has three or four pronged digestive glands. Each bladder has a valve door. *Pingularia, Pinguicula* are other insectivorous plants.

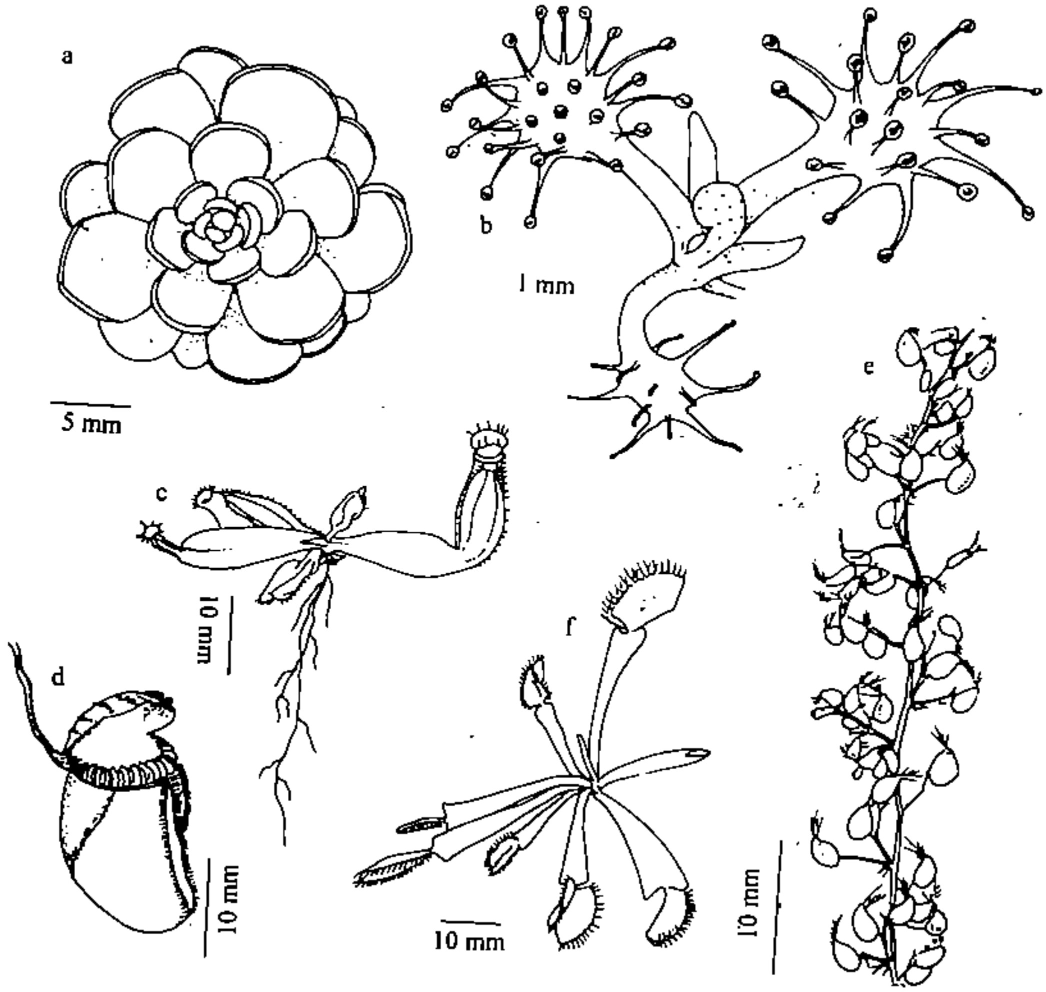

Fig. 8.57: a) *Pinguicula lauii*, leaf rosette from above. b) *Drosera capensis*, seedling. c) *Nepenthes khasiana*, seedling. d) *Cephalotus follicularis*, single leaf. e) *Utricularia minor*, portion of shoot. f) *Dionaea muscipula*, seedling.

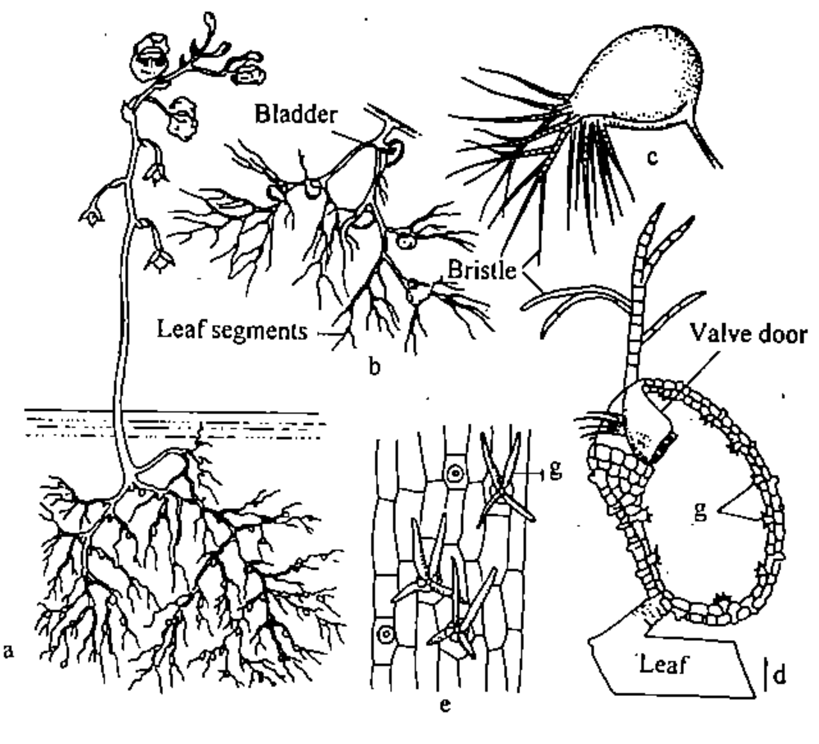

Fig. 8.58: Insectivorous plant *Utricularia*. a) A plant in flower, floating in water. b) A portion of leaf showing leaf segments and bladders. c) A magnified bladder. d) Section of a bladder showing the valve door and the digestive glands (g). e) Inner wall of a bladder showing glands (g).

SAQ 8

(a) Name atleast five kinds of specialized leaves.

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(b) Write a note on:

i) Tendril

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ii) Insectivorous plants.

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8.4.4 Abscission

Plants are known to lose their organs and this is brought about by a process called **abscission**. Leaves, floral parts, and fruits and often branchs (*Taxodium, Populus*) may be shed. In *Kochia indica* (tumble weed) the whole aerial part of the plant separates from the root.

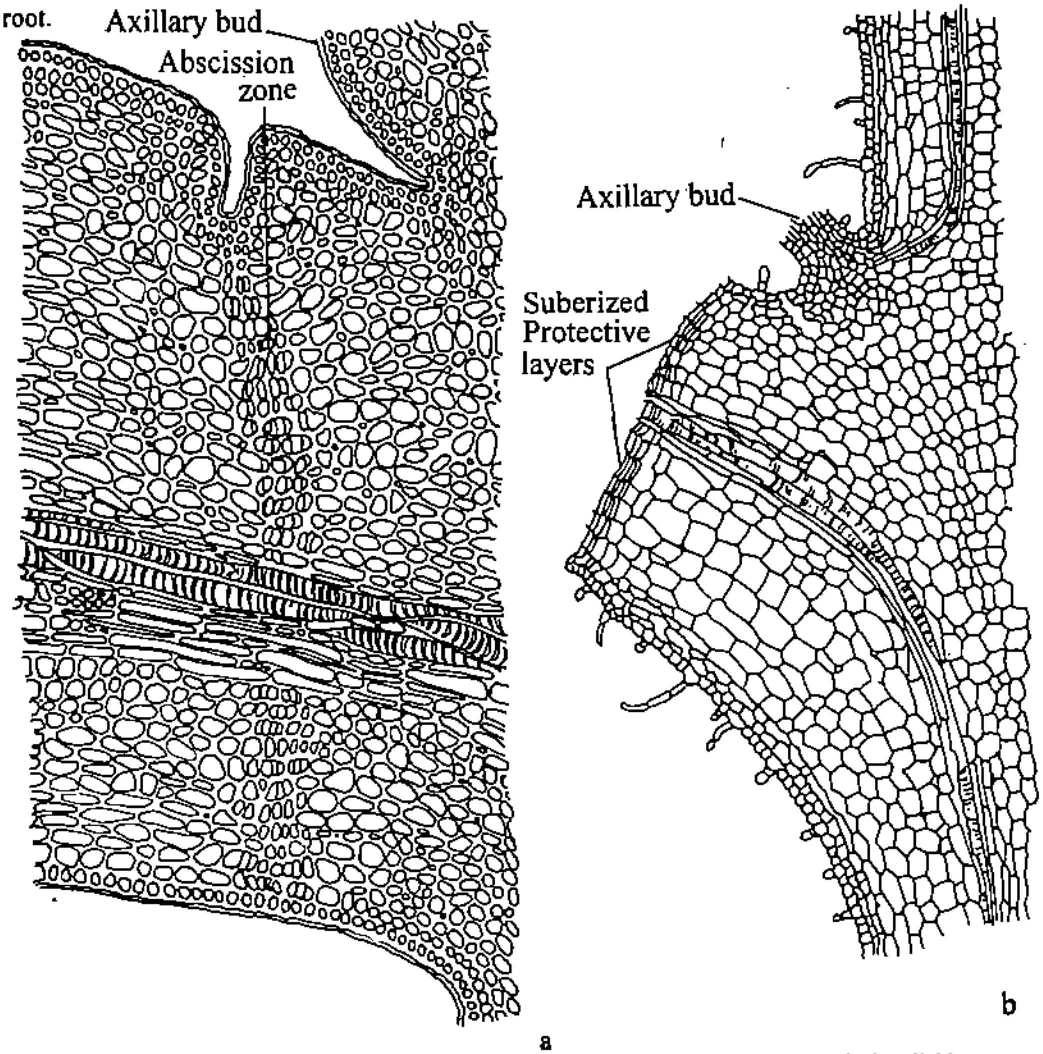

Fig. 8.59: Leaf abscission. a) Longitudinal section of the leaf base of *Prunus* showing the cells that divide to form the separation layer. b) *Coleus*, longitudinal section of portion of the stem together with the leaf base after the abscission of the leaf (Adapted from Gibbs, 1950).

Leaves of some gymnosperms and woody dicotyledons are usually shed as a result of changes that take place in the tissue of leaf base prior to leaf death.

In the base of mature deciduous leaves a narrow zone of cells is produced which helps in shedding of the organ. This is called **abscission zone**. (see Fig. 8.59). This zone can be distinguished histologically from the neighbouring cells by the presence of a shallow groove or by a difference in the colour of epidermis.

Vascular system is usually concentrated in the centre of the abscission zone and sclerenchyma or collenchyma are less developed or may even be absent.

In the abscission zone, two layers are discernible: an **abscission layer** (separation layer) through which the detachment of the organ occurs, and a **protective layer** which protects the leaf base after abscission and prevents entry of microbes through exposed area.

The protective layers are of two types: **primary** and **secondary**. In the former, lignification and suberization of parenchyma cells in the region occur, while periderm develops in secondary protective layer.

Some important events that take place during abscission are as follows:

- Enzymatic degradation of cell walls. It involves removal of calcium pectin from middle lamella followed by hydrolysis of cellulose in the walls.
- Rupture of sclerified tracheary elements.
- Middle lamella in between the tracheary vascular tissue disintegrates.
- Xylem vessels and surrounding parenchyma are weakened by hydrolysis of cell wall material.
- Golgi apparatus may be involved in secretion of abscission- specific enzymes.
- In species, where complete dissolution of cell wall does not take place, physical stresses cause abscission (eg. in monocotyledons and herbaceous dicotyledons).

Leaf **senescence** is characterized by the yellowing of tissues and various biochemical changes eg., less efficient or decreased RNA and protein synthesis. A variety of factors such as plant growth regulators (auxins, cytokinins, abscissic acid) and day lengths seem to be involved in the process of abscission.

SAQ 9

(a) Define the given words in two or three lines: Abscission, abscission zone, abscission layer, senescence and protective layers.

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(b) Give an example where following occur:

(i) Whole branch of shoot system undergoes abscission

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(ii) Whole of aerial part shows abscission.

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8.5 SUMMARY

In this unit you have learnt that:

- The primary plant body consists of root and shoot systems. The former consists of tap and adventitious roots. All the mature cells within them owe their origin to cell(s) of root apical meristem present in the root apex. Apical cell theory, histogen theory, Körper-Kappe theory, and quiescent-centre theory are some of the theories suggested to understand root apex organization.
- A typical root has: root cap; region of cell division; region of elongation, and region of maturation. The root cap is credited with geotropic growth of the root. The three primary tissue zones of a root are recognized as epidermis, ground tissue and vascular tissue. Root hairs develop from epidermis and may help in uptake of water and minerals from the surroundings. Rarely, the epidermis is multi- layered (eg. aerial roots of orchids). The cortex is multilayered, often parenchymatous and helps in water' transport. An endodermal layer demarcates the stele from the cortex. The developmental pattern of the vascular tissue is diverse. Both primary xylem and primary phloem develop centripetally, therefore, both protoxylem and protophloem elements are exarch. The primary xylem and phloem alternate with each other. Diarch to hexarch roots are found in dicotyledons while polyarch roots are characteristic of monocotyledons. Monocot roots also possess a large, conspicuous pith. Lateral roots are endogenous in origin and arise from pericycle. There is distinct relation between the site of lateral root initiation and the kind of vascular tissue organization.
- Monocot roots do not show any secondary activity. In dicotyledonous and gymnosperm roots, vascular cambia initiate at multiple places and then join to produce a ring. The vascular cambium produces secondary xylem towards inside and secondary phloem towards outside. The former accumulates over the years whereas the often degenerates. Irrespective of the extensive secondary activity, the primary xylem is always seen at the centre of the root. To offset increasing girth, the periderm replaces the epidermal system as outer protective system.
- Roots often get modified to perform various functions. Such roots include: food-storage roots; water-storage roots; propagative roots; pneumatophores; aerial roots; contractile roots; buttress roots; mycorrhiza and root-nodules.
- The shoot system consists of an axis, the stem and the laterals, the leaves (determinate growth) and the branches (indeterminate growth). The shoot arises because of the activity of shoot apical meristem localized within the shoot apex. Every shoot apex at regular intervals produces leaf primoridia. These primordia bear bud(s) in their axils. The site of leaf initiation is called node. The region between any two consective nodes is termed as an internode.
- Various theories have been put forward to explain the structure and function of shoot apex organization. Some of these theories include apical-cell theory, histogen theory, tunica-corpus theory and continuum meristematic residue hypothesis. The shoot apices of different plants vary in size, shape, and periodic activity.
- The primary stem has three fundamental regions: epidermis, ground tissue and vascular tissue. The epidermis is generally single layered and may possess trichomes and stomata. A conspicuous cuticle is always present. The ground tissue is differentiated as cortex and pith in gymnosperm and dicotyledons whereas such demarcation is absent in monocotyledons. The cortex may, sometimes, possess cells which are chlorophyllous, collenchymatous, or sclerenchymatous, or may be rich in ergastic substances. The endodermis is only partially discernible in aerial stems while it is well developed in underground stems. The endodermis may be modified as starch sheath.
- The vascular tissue of stem consists of discrete vascular bundles. These are generally conjoint, collateral (or bicollateral), open or close but always with endarch protoxylem. The vascular bundles could be amphivasal or amphicribral.

The primary phloem development is centripetal whereas primary xylem develops centrifugally.

- Stems of gymnosperm and dicotyledons exhibit secondary activity, which is conspicuously absent in monocotyledons because the bundles lack cambium. The development of interfascicular cambium marks the onset of secondary activity. The inter and intra fascicular cambia join and form a continuous ring. The vascular cambium once formed produces secondary xylem towards inside and the secondary phloem towards outside. The former accumulates over the years while the latter is replaced every season. Extensive development of secondary xylem completely destroys the pith and primary xylem. Periderm often develops to offset the girth increase following vascular cambium activity, and it soon replaces epidermal system. bark, rhytidome, and lenticel formations are associated with cork-cambial activity.
- Stems also get modified to perform various functions. Rhizome, tuber, bulb, and corms are modified underground stems for storage and perennation. Runner, stolon, offset and suckers are sub-aerial modifications for vegetative propagation. Cladophyll, phylloclade, thorns, and spines, are modifications associated with xeric environment. Tendrils help in climbing and support.
- Leaves are lateral organs produced at node by the shoot apex. They are determinate in growth, dorsiventral in symmetry and photosynthetic in function. A leaf has three parts: leaf base, petiole and lamina. A leaf could be sessile or petiolate. The lamina has two surfaces, adaxial and abaxial. When two faces have different structutes they are called dorsiventral and when no such difference occurs they are termed isobilateral.
- Internally, the leaf also has dermal, ground and vascular tissue. The epidermis has cuticle, stomata, trichomes and could be single or multilayered. The ground tissue is modified as chlorenchymatous mesophyll. The mesophyll, in turn, is differentiated into palisade and spongy parenchyma. The vascular supply constitutes venation. Smallest area of leaf tissue surrounded by veins is called aerole. The venation could be dichotomous, reticulate (as in dicots) or parallel (as in monocots). A conspicuous bundle sheath may surround the vascular bundle. It can have different structure in C_3 and C_4 plants.
- Leaves in some plants are modified to perform specific functions. Some such leaves are: succulent leaves; tendril; spines; thorns; prickles; storage leaves; reproductive leaves; floral leaves; and insect-trapping leaves.
- The plants are known to lose their organs by abscission. All lateral organs are known to abscise. Prior to abscission, an abscission zone is formed. It consists of abscission layer and protection layer.

8.6 TERMINAL QUESTIONS

1. Give some salient differences between root apex and shoot apex.

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2. Given below are a set of items (a-d) grouped under the heading "Key". A matching explanation of each item is provided in the "statements" (i-iv). All you have to do is to pick up the matching statement for each item of the key and record your answer in the space provided.

Key

a) Trichoblast
b) Velamen

c) Calyptrogen
d) Endodermis

Statements

i) A layer of barrel-shaped cells whose radial cell walls are impregnated with suberin. This layer demarcates ground tissue from the vascular tissue in the roots.
ii) A histogen layer which produces root cap.
iii) Multilayered epidermis of Orchidaceae.
iv) An initial cell, in the epidermis of root, responsible for root hair formation.

Item Statement No.

a) ....

b) ....

c) ....

d) ....

3. You are observing a C.S. of a typical primary root under the microscope. List the characters you may encounter. State the characters on the basis of which you shall identify it as a

   i) root,
   ii) Monocotyledonous root,

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4. Draw a well labeled diagram of a plant body showing fundamental parts.

5. You are provided with an organ showing extensive secondary activity, how will you confirm that it belongs to a root.

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6. List major differences between a dicotyledonous stem and a monocotyledonous stem.

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7. Following are some of the terms associated with tissues as one observes in a dicotyledonons stem which is undergoing secondary activity. Arrange them as if you are observing them from the periphery of the organ to the centre ot it. (pith, protoxylem, metaxylem, secondary xylem, epidermis, cork, cork-cambium, secondary cortex, primary cortex, secondary phloem, vascular cambium, endodermis, pericycle)

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8. Choose the correct alternative:
   a) The periderm in an organ is produced by:
      i) Phellogen
      ii) Vascular cambium
      iii) Root apex
      iv) Shoot apex

   b) Periblem gives rise to:
      i) epidermis
      ii) cortex
      iii) root cap
      iv) pith

   c) Polyarch roots are characteristic of:
      i) dicot roots
      ii) monocot roots
      iii) pteridophyte roots
      iv) primary roots

   d) Length of a plant increases by:
      i) apical meristem
      ii) lateral meristem
      iii) dermatogen
      iv) vascular cambium

   e) Mesophyll is modified:
      i) vascular tissue
      ii) dermal tissue
      iii) ground tissue
      iv) meristem tissue

8.7 ANSWERS

Self Assessment Questions

1. (a) tap (primary) root,
   (b) adventitious root,
   (c) Nägeli,
   (d) plerome,
   (e) promeristem,
   (f) quiescent centre or quiescent zone

2. (a) multilayered,
   (b) trichoblast,
   (c) multilayered,
   (d) schizogenous,
   (e) exodermis,
   (f) endodermis,
   (g) protoxylem,
   (h) polyarch,
   (i) endogenous,
   (j) root cap.

3. (a) water storage roots,
   (b) aerial roots of orchids,
   (c) mangroves,
   (d) food storage roots,
   (e) parasitic roots,
   (f) mycorrhizal roots,
   (g) nodule.

4. (a) tunica-corpus theory,
   (b) anticlinal,
   (c) distal,
   (d) Friedrick Wolff,
   (e) branch
   (f) node,
   (g) shoot.

5. (a) Dermal tissue, ground tissue and vascular tissue.
   (b) *Capparis decidua*, *Opuntia* (cacti), *Ruscus*, *Casuarina*, *Asparagus*, *Cystisus*.
   (c) Fibre (sclerenchyma).
   (d) Conjoint collateral open, conjoint bicollateral open, conjoint collateral closed, amphivasal, amphicribral.
   (e) living (extant) pteridophytes and monocotyledous.

6. (a)i) Rhizomes are underground dorsiventral stems or branches growing horizontally under the surface of the soil. They possess nodes and internodes. Nodes bear brown scaly leaves. They possess both axillary and apical buds. Adventitious roots develop at nodes. They may bear contractile roots. They are generally fleshy due to food storage activity.

   ii) Any fleshy part of the plant which stores food is called tuber. There are stem tubers and root tubers. Each stem tuber has nodes and internodes, and exhibits slow growth. Nodal points are characterized by presence of scale leaves and eyes in their axils. Eyes are arranged spirally and are more crowded towards rose end.

   iii) Bulbs are modified underground stems for food storage. They bear nodes and internodes. Leaves could be scaly, dry, and membranous. They could be tunicated (eg. onion, tulip, hyacinth) or scaly (eg. garlic, lilies).

   iv) Corms are solid bulbs. They possess condensed vertical root stocks with very large apical bud. They bear some scale leaves and produce adventitious roots from its base or from all over the body.

   (b)i) *Oxalis*, *Fragaria*, *Cynodon*.
   ii) *Mentha*
   iii) *Chrysanthemum*, *Mentha arvensis*
   iv) *Eichhornia crassipes*
   v) *Opuntia*, *Ruscus*, *Muhlenbeckia*

7. (a) refer fig. 8.46

   (b) Sessile: A leaf without a petiole.
   Adaxial: A surface (side) facing the axis.
   Abaxial: A surface (side) away from the axis.
   Petiolate: A leaf possessing a stalk, the petiole.
   Venation: A combined net-work of veins in a leaf lamina.
   Areole: The smallest area of the leaf tissue surrounded by veins.

8. (a)i) Tendril from entire lamina of *Lathyrus*
   ii) Tendril from terminal leaflet of *Pisum*
   iii) Xerophytic leaf of *Nerium oleander*
   iv) Stipular spines of *Zizyphus*
   v) Spiny leaves in *Opuntia*, *Berberis*
   vi) Reproductive leaves of *Bryophyllum*
   vii) Insectivorous pitcher leaf in *Nepenthes* (also refer section [illegible]

   (b) refer section 8.4.3

9. (a) **Abscission:** It is the process (completed event) of shedding of lateral organs by a plant.
   Abscission Zone: That portion at the proximal end of an organ which gets modified and helps in the detachment of distal part due to abscission

Abscission layer: A part (zone) of abscission zone which actually helps in abscission (detachment) of an organ.

Protective layers: A part of abscission zone which protects the leaf base from abscission and entry of microbes to exposed area.

Senescence: yellowing of tissue and all other biochemical changes credited with processes leading to abscission in a leaf.

(b)i) *Taxodium*, *Populus*

ii) *Kochia Indica* (tumble weed)

TERMINAL QUESTIONS

1)

Root Apex	Shoot Apex
1. Possesses root cap at the distal region	1. No such cap present
2. Not associated with origin of laterals	2. Laterals such as leaves always produced by the activity of shoot apex
3. Nodes and internodes absent	3. Produce nodes and internodes
4. Meristem cells are placed sub-terminally	4. Meristem cells are placed in terminal position

2)

Item	Statement
a)	(iv)
b)	(iii)
c)	(ii)
d)	(i)

3) i) It has exarch protoxylem and radial arrangement of vascular bundles.

ii) The root is polyarch with conspicuous and large pith.

4) See diagram 8.1 important parts are given below for your help.

1. Terminal bud
2. Axillary bud
3. Leaf Lamina
4. Petiole
5. Internode
6. Node
7. Lateral root
8. root cap
9. root meristem

5) Irrespective of the extent of secondary activity in the root, the primary xylem is always retained in the centre of the organ. On the other hand in stems, primary xylem may ultimately be lost forever.

6) Refer section 8.3.5

7) Epidermis

Cork

Cork-cambium

Secondary cortex

Primary cortex

Endodermis

Pericycle

Primary phloem

Secondary phloem

Vascular cambium

Secondary xylem

Metaxylem

Protoxylem

Pith

8) (a) (i);
(b) (ii);
(c) (ii);
(d) (i);
(e) (iii).

UNIT 9 FLOWERS, FRUITS AND SEEDS

Structure

9.1 Introduction
Objectives
9.2 Flower
9.2.1 Calyx
9.2.2 Corolla
9.2.3 Androecium
9.2.4 Gynoecium
9.3 Transition to Flowering
9.4 Formation of Floral Organs (Organogenesis)
9.5 Morphological Nature of Flower
9.6 Vascular Anatomy of the Flower
9.7 Anatomy of Floral Organs
9.7.1 Calyx
9.7.2 Corolla
9.7.3 Androecium
9.7.4 Gynoecium
9.8 Morphological Nature of Stamens
9.9 Phylogeny of the Carpel
9.10 Fruits
9.10.1 Simple and Compound Fruits
9.10.2 False Fruits
9.10.3 Types of Fruits
9.11 Fruits Development
9.11.1 Citrus Fruits
9.11.2 Apple
9.11.3 Banana
9.11.4 Legume
9.12 Fruit Abscission
9.13 Apomixis
9.13.1 Vegetative Reproduction
9.13.2 Agamospermy
9.13.3 Parthenogenesis
9.13.4 Parthenocarpy
9.14 Seed
9.14.1 Pseudo-seeds
9.15 Diversity in Seed Form
9.15.1 Pea
9.15.2 Castor
9.16 Seed Appendages
9.16.1 Caruncle
9.16.2 Aril
9.16.3 Hairs
9.16.4 Wings
9.17 Summary
9.18 Terminal Questions
9.19 Answers

9.1 INTRODUCTION

In angiosperms male and female reproductive organs are borne in flowers together with accessory parts for protection and ornamentation. A plant flowers after a certain period of vegetative growth, usually in response to certain environmental factors. The vegetative shoot apex undergoes certain changes so that instead of shoot elongation and leaf-bud initiation, it forms a solitary flower or an inflorescence with many flowers. The problem of homology and morphological evolution of the flower has occupied research workers for a long time. In this unit we have tried to give a comprehensive account of floral development. The size, shape, colour and smell of a flower are variously modified to ensure pollination and fertilization. The fruit represents the biological climax reached by the flower when the ovules enclosed in the ovary are fertilized and develop into seeds. Thus, it is important to understand all the possible ways in which fruit is constructed, and its various mechanisms for dispersal of seeds.

The seed develops from the ovule about which you have already read in Unit-5 of LSE-06. Development biology, anatomy and morphological details of seed will be briefly discussed in this unit.

Objectives

After studying this unit you will be able to:

- know the various parts of flower, its morphology, morphogenesis and organogenesis,
- describe anatomy of floral organs including stamens and carpels,
- discuss the phylogeny of carpel,
- discuss morphogenesis and organogenesis of fruit and seed,
- describe various types of fruits and seeds.

9.2 FLOWER

The reproductive structure in angiosperms is designated as flower. The flower has a thalamus or receptacle which resembles in ontogeny and structure a vegetative shoot tip. Later in this unit, we will study how a vegetative tip, at a certain stage and under certain conditions, changes into a floral tip. On the thalamus are borne typically both sterile and fertile appendages, either in a spiral manner or in whorls. The sterile appendages are of two kinds: (i) sepals, which together form the outer calyx; (ii) petals, which collectively constitute the corolla inside. The sepals and the petals together can be referred to as perianth or tepals, specially if both look similar. The fertile appendages are: (i) stamens, located inside the petals, and bear anthers which produce pollen grains having the male gametes; (ii) carpels, at the centre of the flower, having ovaries that enclose ovules with female gametophyte. The stamens of a flower are collectively designated as androecium, and the carpels together are termed gynoecium. A flower of *Fagopyrum* sectioned longitudinally is seen in Fig. 9.1. This flower has five sepals, five petals, five stamens (only some are seen in the section) and an ovary which is made up of three fused carpels having a single locule and three styles. When a flower has both stamens and carpels it is described as bisexual. When only stamens or only carpels are present; the flower is unisexual – male or staminate if stamens are present and female or carpellate when only carpels are present.

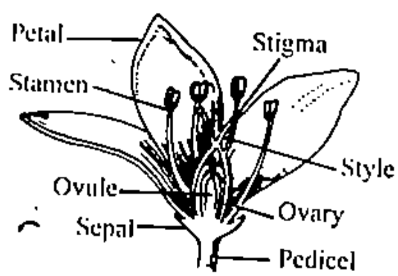


Fig. 9.1: A flower of *Fagopyrum* sectioned longitudinally. The gynoecium consists of three fused carpels with unilocular ovary and three styles.

The flower may be: (i) solitary, terminal on a branch (e.g., shoeflower) or arising in the axil of leaf (e.g., hollyhock); or (ii) arranged in groups called inflorescences (e.g., laburnum).

The flower presents a wide range of diversity in different angiosperms. In some plants the sterile appendages, particularly the petals, are prominent, brightly coloured and even fragrant (e.g., rose; Fig. 9.2). In others, such as *Ficus* spp. (Fig. 9.3), mulberry and the grasses, the perianth may be absent or inconspicuous, and the flower may consist of only stamens or carpels. The size, colour, symmetry and odour of the flower are related to the

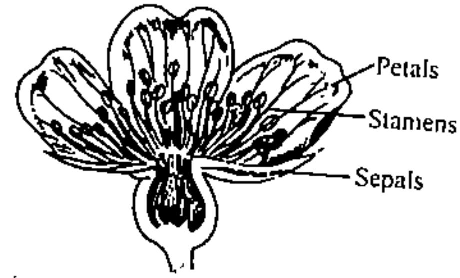


Fig. 9.2: A flower of *Rosa* species showing prominent petal.

pollination mechanism (transfer of pollen grains to stigma by air, water, insects, birds or bats). The floral characters are of great interest to botanists because these provide clues to evolution and help in classification and identification of plants. You can easily comprehend the range of this diversity by examining a few flowers in your neighbourhood. For convenience, you may pay attention to the individual floral parts.

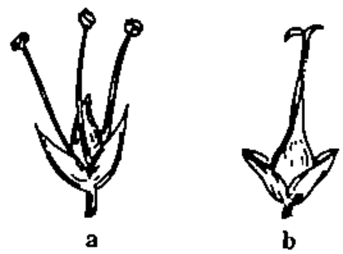


Fig. 9.3: Male and female flowers of *Ficus* showing reduced perianth.

9.2.1 Calyx

Sepals form the outermost whorl, enclosing other floral parts at bud stage. These are mostly green, but ornamental in some plants such as *Salvia splendens* where calyx is bright red like the corolla. The ornamental or petalloid condition of the sepals may be accompanied by reduction or loss of the petals, as in silver oak. In Liliaceae (e.g., *Asphodelus*) and Iridaceae (e.g., saffron and gladiolus) both sepals and petals are ornamental and are indistinguishable. On the other hand, genus *Cornus* shows reduction in sepals. In *Euphorbia* the flowers lack both sepals and petals (Fig. 9.4); the naked flowers are grouped in inflorescence called **cyathium** (plural **cyathia**) which may be surrounded by ornamental leafy bracts.

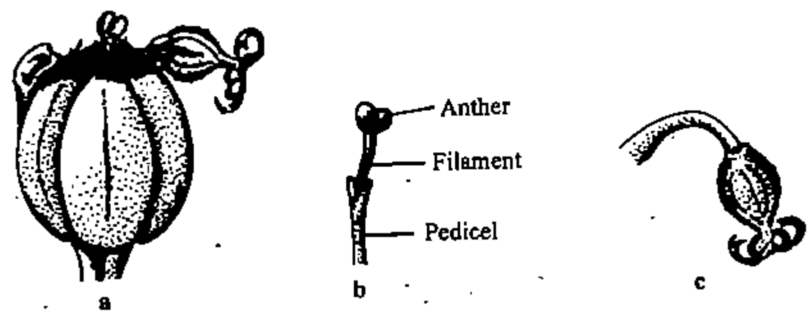


Fig. 9.4: a) Cyathium of *Euphorbia* species. b) Male flower. c) Female flower without sepals and petals.

9.2.2 Corolla

Petals are located inside the sepals and surround or subtend the stamens. These are absent or reduced in the wind and water-pollinated flowers, and are large, ornamental and often odouriferous in animal-pollinated flowers. Petals exhibit great diversity in size, shape, colour, arrangement and texture. Petals in a flower may be free as in *Fagopyrum* (Fig. 9.1) or united to form a corolla tube as in *Vinca* (Fig. 9.5).

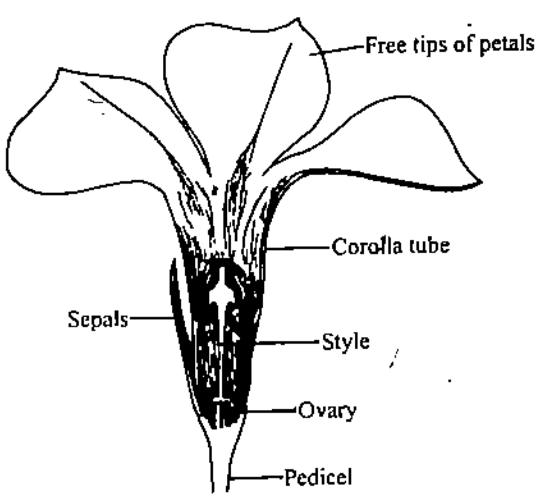


Fig. 9.5: L.S. of flower of *Vinca major* to show petals, fused in the lower half to form a corolla tube.

In the orchids the petals have colour and symmetry that mimics the moths and butterflies that pollinate the flowers (Fig. 9.6). In silk cotton tree *Bombax ceiba* and coral tree *Erythrina indica* the petals are bright, tubular and fleshy to attract the pollinating birds. In *Tropaeolum majus* the petals form a tail-like nectar spur in which nectar is present (Fig. 9.7).

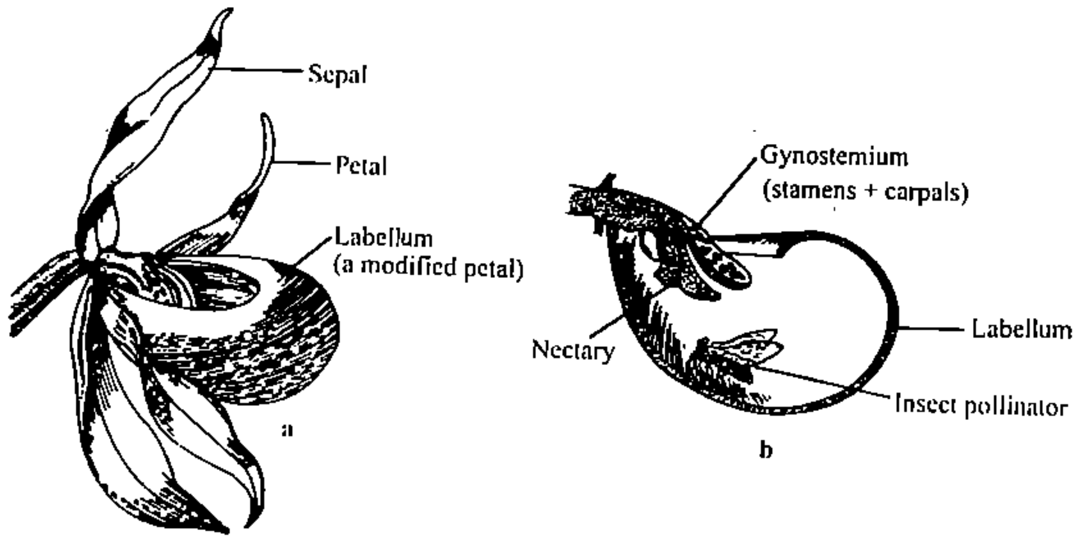


Fig. 9.6: a) A flower of orchid *Cypripedium* sp. b) Pitfall-like pouch or labellum of the flower with nectar for attraction of insect which pollinate the flower.

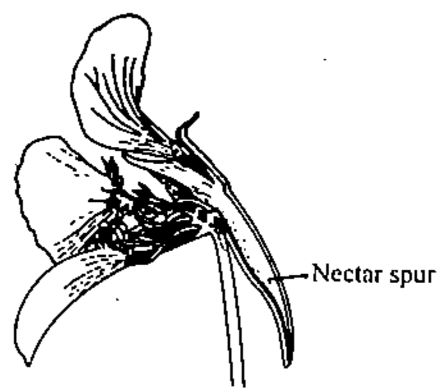


Fig. 9.7: A median section of flower of *Tropaeolum* species showing the tail-like nectar spur.

9.2.3 Androecium

Stamens occur in one, two or more whorls, free or fused among themselves or with the petals. Each stamen has a filament which bears the anther. The anther usually has four or two lobes or compartments having pollen grains. Each pollen grain produces two male gametes or sperms. Some or all stamens in a flower may be reduced or sterile (termed staminodes). The stamens may fuse to form a tube around the gynoecium to encourage self-pollination (e.g., shoe flower; Fig. 9.8).

In garden pea, *Pisum sativum* (Fig. 9.9) filaments of nine stamens are fused to form a sheath around the ovary whereas the tenth stamen is free. In *Hypericum aegypticum* the stamens are fused in three groups (Fig. 9.10). When the stamens or their filaments are laterally fused in one group the condition is known as monadelphous (*Hibiscus*), in two groups diadelphous (*Pisum*) and in several groups polyadelphous (*Rutaceae*). In some plants the stamens are large and showy (e.g., bottlebrush; Fig. 9.11). In *Canna* only one of the five stamens is fertile; others are brightly coloured constituting the conspicuous ornamental (petaloid) part of the flower.

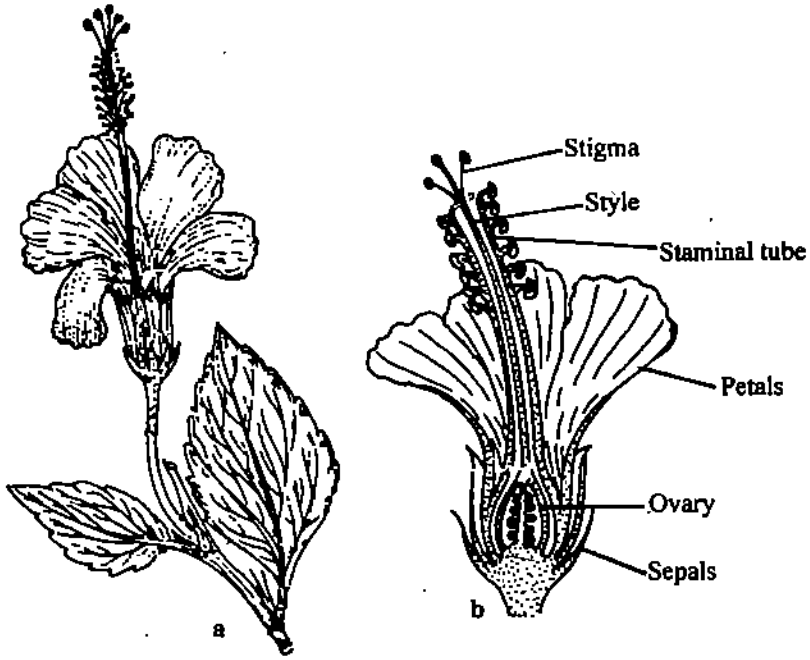


Fig. 9.8: ***Hibiscus rosa-sinensis.*** **a) A twig with a flower. b) Median section of flower showing staminal tube surrounding style. Anthers almost touch the stigma.**

Fig. 9.9: ***Pisum sativum. Androecium*** **separated to show nine fused and one free stamen.**

Fig. 9.10: Androecium of flower of ***Hypericum*** **sp. showing stamens in three groups.**

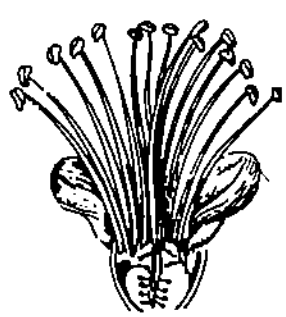


Fig. 9.11: L.S. of flower of bottle brush, ***Callistemon lanceolatus*** **showing large, showy stamens.**

9.2.4 Gynoecium

Carpels are located in the middle of the flower, terminating the flowering shoot. A flower may have a single carpel (as in wheat or maize; Fig. 9.12 a), or two or more carpels which may be either free (as in buttercup and larkspur; Fig. 9.12, b) or fused to form multicarpellary pistil (as in castor, mustard or lily; Fig. 9.13). The gynoecium or pistil is generally distinguishable into an ovary, style and stigma. The ovary encloses one or more ovules, each having the female gametophyte. The ovary continues into a cylindrical style that terminates in a stigma. Following pollination, pollen germinates on the stigma, resulting in formation of pollen tube that traverses the style and carries the sperms to the female gametophyte. A flower having both stamens and carpels is bisexual; otherwise it is unisexual – male or staminate if having only stamens or female, carpellate or pistillate if possessing only the gynoecium.

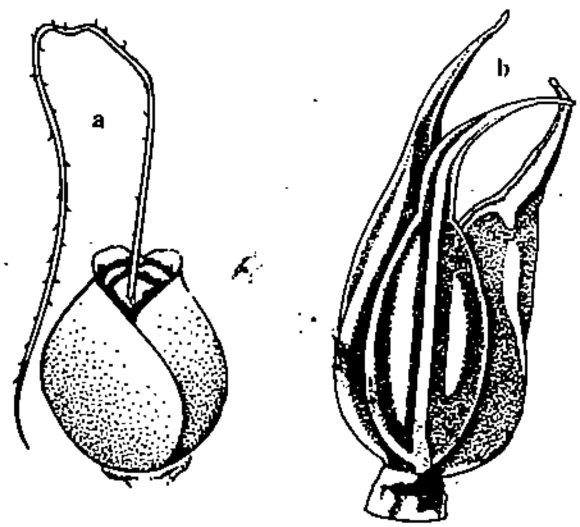


Fig. 9.12: a) Single carpel in *Zea mays*. b) Free carpels plant.

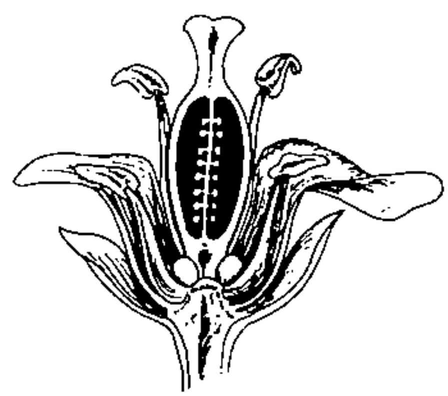


Fig. 9.13: Fused multicarpellary pistils in mustard, *Brassica*.

9.3 TRANSITION TO FLOWERING

In Unit 8 you have studied the basic concepts regarding the organisation of shoot meristem. You will recall that the vegetative shoot apex in angiosperms is widely regarded as consisting of the tunica and the corpus (Fig. 9.14). However, there are other interpretations which suggest that the meristem has more elaborate cyto-histological zonation. In some angiosperms shoot apex has a group of median surface initials, called the apical initial group. The zone below these cells, and derived from these, constitute the central mother cells (Fig. 9.15). The centrally situated derivatives of these mother cells give rise to the pith and the lateral derivatives form a densely-staining peripheral zone which forms the cortex. According to one opinion (Johnson & Tolbert, 1960) the centrally located cells of the meristem constitute a metrameristem which maintains itself and actively contributes cells to other regions of the meristem (Fig. 9.16). According to another interpretation, given by French botanist Buvat (1952), the main histogenic role is played by lateral or subterminal zone, the anneau initial or initial ring. The central cells of the apex, the m`erist`eme d'attente or resting meristem is considered to be without any histogenic role during the vegetative phase of development (Fig. 9.17). The resting meristem, it is claimed, becomes active in the formation of a terminal flower or inflorescence.

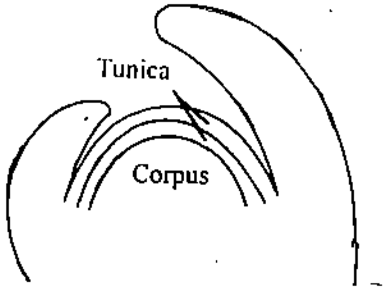


Fig. 9.14: Diagrammatic illustration of shoot apex to show tunica and corpus regions.

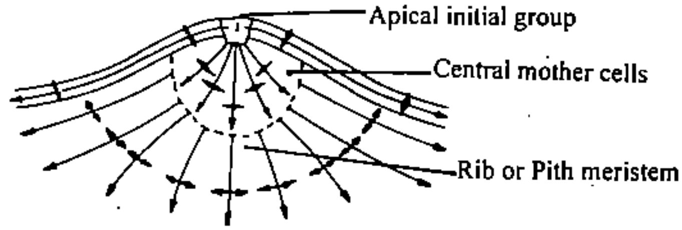


Fig. 9.15: Shoot apex with meristematic apical initial group and central mother cells.

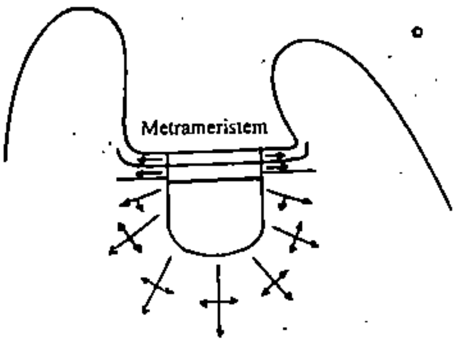


Fig. 9.16: Apical meristem in *Hibiscus* showing the centrally placed metrameristem.

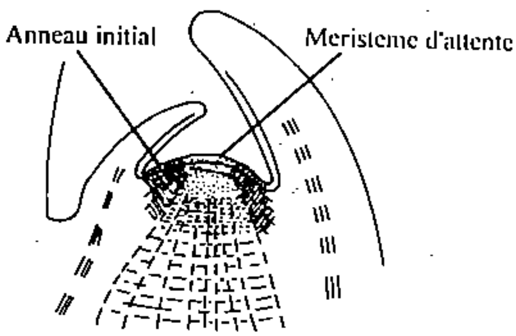


Fig. 9.17: Shoot apex with cytohistogenic differentiation.

Belgian morphologist Gregoire (1938) believed that the floral meristem is completely new structure which is not derived from the vegetative meristem. In his opinion, the flower or inflorescence is formed not from the principal vegetative meristem but from lateral buds. Gregoire claimed that a tunica-corpus organisation typical of vegetative apex is not represented in reproductive apex which, instead, has a meristematic mantle termed manchon meristematique covering the core or massif parenchymateux in the entire apex (Fig. 9.18). The superficial layers of the mantle give rise to floral parts and contribute cells to the parenchymatous core inside.

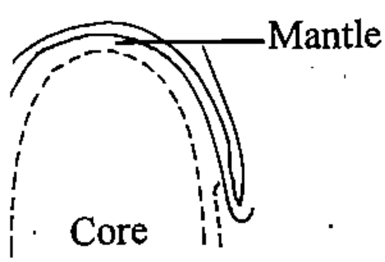


Fig. 9.18: Floral apex showing meristematic mantle and parenchymatous core.

Philipson (1947) stated that the extreme view expressed by Gregoire may not be justified and that tunica-corpus organisation exists in the reproductive apex. It is now accepted that the vegetative stem apex becomes directly transformed into reproductive apex. The changes that occur in formation of the flower or the inflorescence from vegetative meristem are identical.

Irrespective of whether the vegetative shoot meristem has a tunica-corpus organisation or cyto-histological zonation, following flower induction the reproductive apex develops certain characteristics. The apex becomes more elongated and conical than the vegetative axis. Mitotic divisions increase in frequency, with a corresponding rise in DNA synthesis. The tunica-corpus or cyto-histological zonation of the vegetative phase is modified. Gradually the cells of the central core of the apex become more highly vacuolate, in contrast to the smaller celled densely staining layers which form the outer covering or mantle. In other words, the floral apex develops a mantle-core organisation. In vegetative apex with cyto-histological zonation, the large, faintly-stained cells of the mèristéme d'attente become active and undergo rapid mitotic divisions so that this region also comes to have small, densely-stained cells. The region becomes part of the meristematic mantle which surrounds the central parenchymatous core. However, some reproductive apices retain the cytohistological zonation of the vegetative apex with minimal modifications (Vaughan, 1955). Many authors have emphasized that mèristéme d'attente participates in growth and is modified only when a terminal flower is formed. The resting meristem plays no active role in formation of lateral flowers.

According to Plantefol (1947) the reproductive apex originates by progressive transformation of the vegetative apex. The anneau initial, which in vegetative phase gives rise to foliage leaves, produces sepals and petals in the reproductive phase. Stamens and carpels are derived from the residuum of the apex, consisting of the activated mèristéme d'attente (Buvat, 1952).

Bersillon (1955), based on his studies in Papaveraceae, opined that the sepals are derived from anneau initial, whereas other floral appendages are initiated in the meristematic mantle which is mainly derived from the meristeme d'attente. A similar situation occurs in rose.

In *Cleome* (Fig. 9.19), which has an inflorescence without a terminal flower, the anneau initial gives rise to the lateral floral buds and bracts. In *Beta* (Fig. 9.20), having an inflorescence with terminal flower, the anneau initial is inactive in the reproductive phase. The meristeme d'attente is responsible for generation of the bracts as well as the flowers (Gifford & Corson, 1971). An intermediate situation exists in *Agrimonia eupatoria* of the Rosaceae which has an inflorescence with a terminal flower. Thirty to ninety lateral flowers are formed by anneau initial before the meristeme d'attente becomes active and forms the terminal flower.

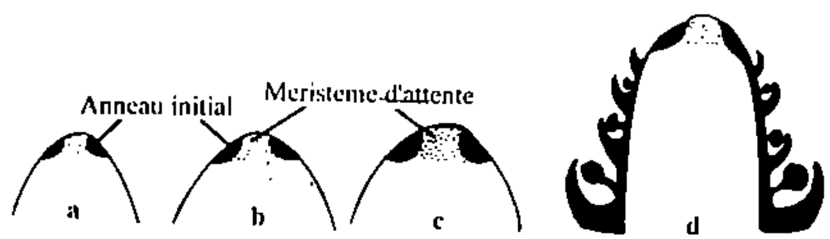


Fig. 9.19: Floral apex in *Cleome* showing initiation (dark region) of lateral buds from anneau initial.

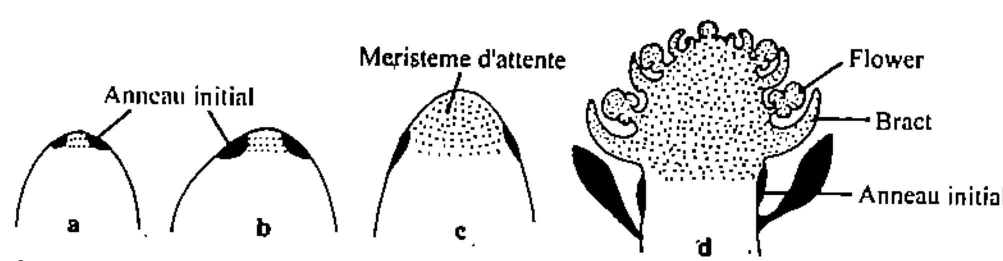
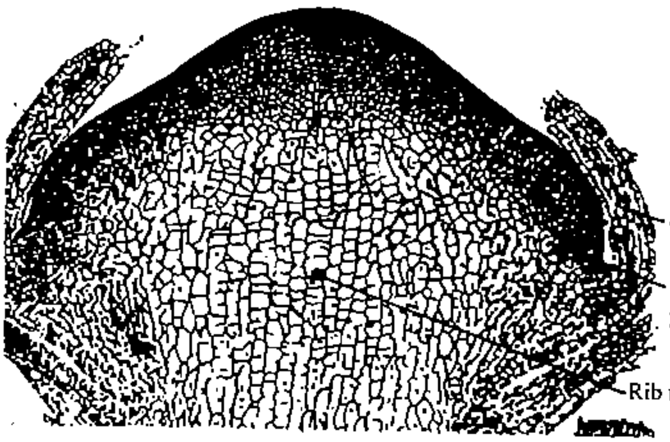


Fig. 9.20: Floral apex in *Beta*. Anneau initial is passive. Flowers and bracts are formed by me'riste'me d'attente.

Many authors disregard the significance of histological zonation of vegetative apex in generation of different parts of the flower. They comprehend the whole apex to enter a new phase of development. Philipson (1947, 49) expressed the opinion that the basic function of vegetative apex is to promote longitudinal extension of the axis, while that of the reproductive apex is to produce a broad meristematic envelope from which parts of a flower or flowers (in case of inflorescence) can develop. The first noticeable change is the increase of mitotic activity in the region between the central mother cell zone and the rib meristem zone. The division activity gradually spreads into the central mother cells zone so that the cells become smaller and richer in protoplast. Thus, all cells above the rib meristem are added to the tunica and together constitute a mantle.

Following this, mitotic activity and growth almost cease in the rib meristem and in the pith below it. Thus, the reproductive apex has a parenchymatous pith or core surrounded by a mantle of meristematic cells (Fig. 9.21, a). The floral parts, or the bracts, axillary branches and the flowers in case of inflorescence, develop from these meristematic cells (Fig. 9.21, b).



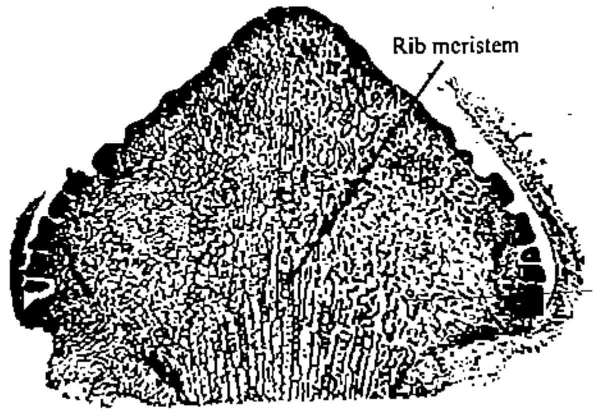


Fig. 9.21: a) L.S. young inflorescence apex of *Calendula* with mantle-core organisation. Rib meristem is conspicuous. Bracts and floret primordia have been initiated. b) L.S. Inflorescence apex of *Calendula*, floret primordia have been formed in acropetal order.

Bernier et al. (1967) observed that following flower induction in *Sinapsis alba* there is an increase in mitotic divisions followed by stimulation of DNA synthesis, increase in nuclear diameter and rise in cell volume. After this there is a second phase of mitotic activity which results in initiation of floral buds. The cyto-histological modifications are accompanied by biochemical and physiological changes too. An increase in number of ribosomes and dictyosomes and changes in endoplasmic reticulum are also reported (Gifford & Steward, 1965).

SAQ 1

1. How will you define a flower? How will you distinguish a flower from a gymnospermous cone?

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SAQ 2

Complete the sentence by matching column A with column B.

	Column A		Column B
1.	Where sepals and petals are indistinguishable we have	(a)	gynoecium
2.	Ovary, style and stigma are parts of	(b)	floral apex
3.	Mantle-core organisation of cells is seen in	(c)	perianth
4.	A part of the shoot meristem which is considered inactive in vegetative phase is	(d)	anneau initial
5.	In Papaveraceae sepals are derived from	(e)	me`riste`me d'attente

SAQ 3

List the parts of a flower and explain the functions of each.

....

....

....

....

9.4 FORMATION OF FLORAL ORGANS (ORGANOGENESIS)

Following induction of flowering phase, the inflorescence apex may give rise to a series of small leaf-like bracts and florets. In the apex forming an individual flower, the various lateral organs are formed in an acropetal sequence, i.e. the youngest organ is closest to the apex. In *Aquilegia* (Tepfer, 1953; Fig. 9.22) and *Portulaca*, sepals, petals, stamens and carpels originate by periclinal divisions in the second and/or third layer(s) of the tunica. The surface layer merely undergoes anticlinal divisions to keep pace with the growth in the interior tunica layers. Such a manner of initiation of floral appendages supports the view that these organs are lateral members of the shoot comparable to the leaves.

In periwinkle, *Catharanthus roseus* (Boke, 1948; Fig. 9.22) the reproductive apex first gives rise to five sepals in a spiral sequence. The apex then enlarges and forms five petals in a whorl. The bases of the petals unite during ontogeny forming a corolla tube. Five staminal primordia are formed next which soon unite with the basal region of the corolla tube, so that in transverse section of the floral apex the five stamens seem to be outgrowths of the petals. Following formation of staminal primordia the floral apex is considerably reduced. However, subsequently the diameter of the floral apex increases and the cells at the periphery multiply to form a raised ring. Two carpel primordia are formed in this ring at opposite sites. Primordia of sepals, petals, stamens as well as carpels are formed by periclinal divisions in the second tunica and outer corpus layers, with superficial tunica layer only dividing anticlinally. Thus, each organ is initiated in the form of a raised primordium, in which apical growth soon begins, followed by growth through sub-apical meristems. The time of initiation, location (intercalary, marginal and adaxial) and extent of activity of the sub-apical meristems determine the diversity in form of floral organs in different species.

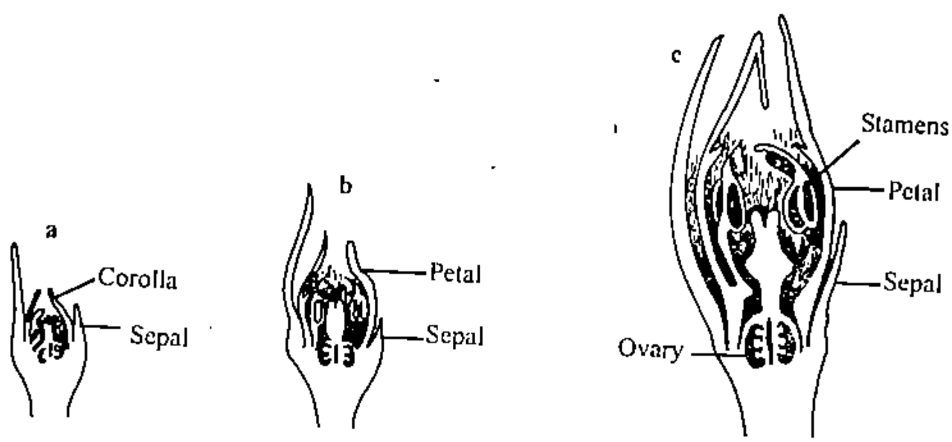

Fig. 9.22: a-c) Developing flower of periwinkle in sections with five sepals, five petals (fused at the base to form corolla tube), five stamens fused with the corolla tube, and bicarpellary ovary. Sections do not show exact numbers of all floral parts.

In a vegetative shoot, the apical meristem continues to function above the developing leaf primordia. However, in a developing flower the apex is reduced following initiation of floral organs till it is lost completely or a small, inactive residue is left.

As in the leaf, the lateral organs of the flower exhibit apical, marginal, plate and sometime adaxial meristems (Kaplan, 1968). Sepals and petals grow lengthwise by apical and intercalary meristems and expand all around by activity of marginal meristem. These organs also become thick due to plate meristem. Sepals often have, in addition, adaxial meristem. The adaxial meristem is absent in petals so that these are thinner and more delicate. Stamens show apical growth for a brief period, most of the subsequent growth is intercalary. Marginal meristematic activity is absent, except in the flattened, leafy stamens of some plants such as in *Magnolia* and *Nymphaea*. The carpels not only show apical and marginal growth but also have adaxial meristematic activity which contributes to the thickness of the carpels. The lateral organs of the flower can be compared with the leaves not only in their origin but also in the mode of their growth.

In flowers which have free carpels (apocarpous condition) each carpel primordium appears as a rounded buttress which resembles the primordia of other floral organs and leaves (Fig. 9.23). This primordium becomes peltate and then a depression is formed at the tip of primordium. As a result of unequal development, an abaxial lip is formed from which the dorsal side of the carpel is formed. The adaxial lip of the primordium develops relatively slowly to form the 'sill' of the carpel (Mclean & Ivemy–Cook, 1956, Fig. 9.24). This sill undergoes enlargement and forms the margins of the carpel. It is surmised that the sill originally consisted of two basal laminar lobes which have fused during ontogeny. The area where the two margins fuse is termed the cross zone. The dorsal side of the carpel usually folds and closes over the sill.

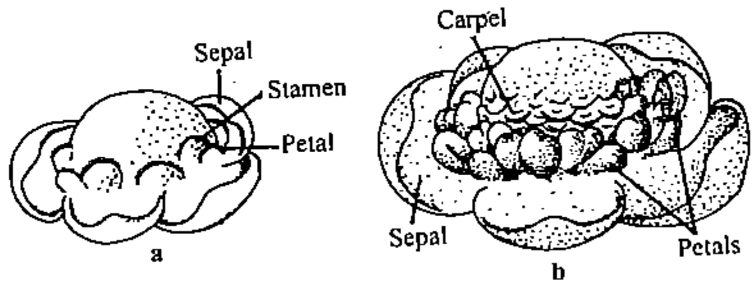

Fig. 9.23: a-b) Ontogeny of flower in *Ranunculus* showing initiation of carpel primordia as round buttresses similar to sepal, petal and stamen primordia.

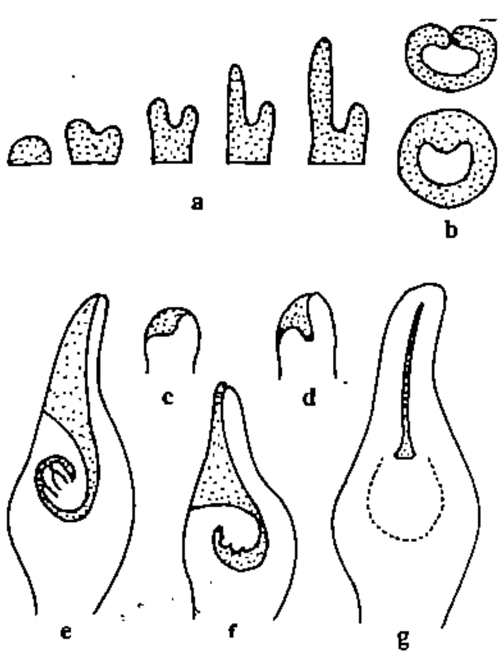

Fig. 9.24: Development of a peltate carpel in an apocarpous gynoecium. a and b) Diagrams of longitudinal and cross sections respectively of the carpel at different ontogenetic stages. c-g) Different stages in the development of the carpel in *Thalictrum* showing the development of the sill, the ovule and the portion above the sill which folds over and closes the locule.

In flowers with fused carpels (syncarpous condition) the ovary may develop in one of the following two ways: (i) carpel primordia appear separate and then fuse as a result of lateral growth (ontogenetic fusion; Fig. 9.25 a-e). Subsequently, the fused carpels grow upwards as a unit forming the syncarpous ovary; (ii) carpels are already joined when they appear (congenital fusion), so that the ovary wall rises as a ring (Fig. 9.26, a-d). The regions of fusion of the carpels are distinguishable by folds directed inwards.

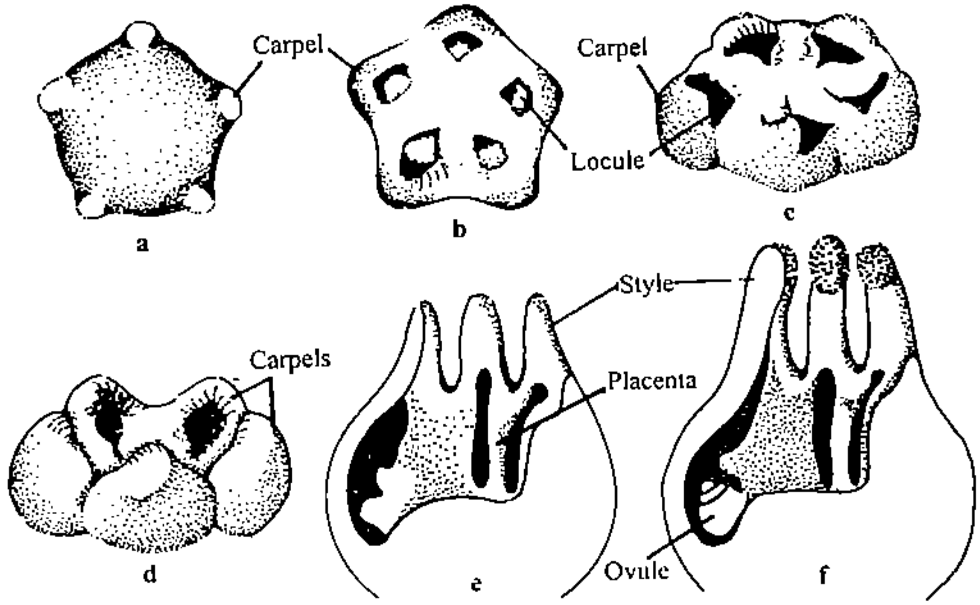

Fig. 9.25: a-f) Stages in the development of the syncarpous gynoecium from separate primordia which expand laterally and fuse to form a single ring. Part of the ovary wall is removed in e and f to expose the ovules borne on placentae.

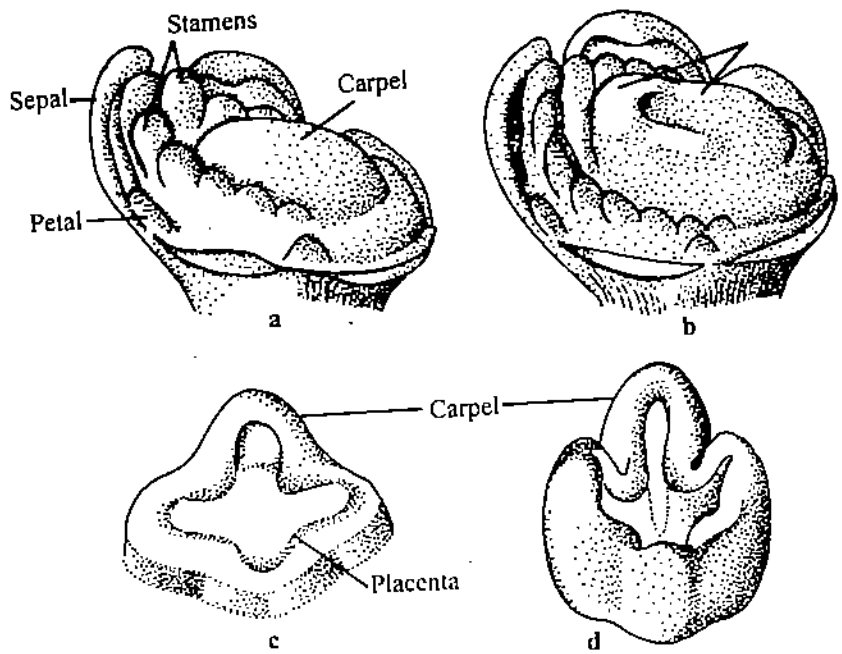

Fig. 9.26: a-d) Ontogeny of flower showing peltate carpel primordium (a) with depression (b) at the tip. The margins form the lobes which fold to form a closed carpel with placentae inside (c,d).

9.5 MORPHOLOGICAL NATURE OF FLOWER

Vascular plants which have preceded angiosperms in evolution do not have reproductive organs that could have been perceived as forerunners of the flower. The morphological nature of the flower has, therefore, poised several questions. In the past, some botanists followed Wettstein in believing that the angiosperms with catkin-like inflorescence (e.g., *Salix* and *Casuarina*) are the most primitive flowering plants. Their catkin-like inflorescences were considered similar to gymnospermous cones and their reduced flowers comparable to reproductive organs of some gymnosperms like *Ephedra* and *Gnetum*. However, evolution within angiosperms has revealed that the wind-pollinated flowering plants with catkin-like inflorescence and reduced flowers are more advanced. It is more likely that the primitive flowers were insect-pollinated and with a number of free and prominent sepals, petals, stamens and carpels. Such a flower could not have been derived from gymnospermous cones or strobili.

Most morphologists consider the flower to represent a determinate shoot. The appendages (sepals, petals, stamens and carpels) are modified leaves. These floral organs are homologous (having similar origin) to leaves but have different function and appearance. The internodes are suppressed, shortenend or obliterated so that the nodes come together. The appendages at the nodes are, thus, closely crowded.

The flower of *Magnolia* has elongated receptacle and spirally arranged appendages with leaf-like appearance. The organisation of such a flower most clearly resembles a vegetative shoot. Evolution of more advanced flowers involved compression of the receptable, reduction in number of appendages, change in symmetry and loss of leaf-like appearance of the floral organs.

Fusion of floral parts

Many flowers, both dicotyledonous and monocotyledonous, show varying degree of fusion of floral parts. When adjacent floral organs in a whorl fuse laterally it is termed connation. Sepals in some flowers are fused laterally to form gamosepalous calyx. Petals may fuse to form gamopetalous corolla (as in *Vinca*) and the stamens may fuse laterally to form a synandrous staminal tube (as in *Hibiscus*). Adnation involves fusion of different floral appendages. Gamopetalous flowers often have stamens fused with the petals. Such stamens are described as epipetalous. In Asclepiadaceae and Orchidaceae (Fig. 9.6 b) the stamens and carpels are united completely or partially to form gynostegium. In the fruit of apple all floral organs are connate as well as adnate. The outer edible part of the fruit is formed by union of sepals, petals and stamens. The core, which encloses the seeds, is made up of fused carpels.

The fusion of floral parts may be congenital (from the primordial stage) or post-genital (when primordia arise independently but fuse later during ontogeny).

9.6 VASCULAR ANATOMY OF THE FLOWER

The anatomical structure of the pedicel of a flower, or the axis of an inflorescence, is similar to that of the stem. The vascular cylinder is either entire or split. From this stele of the receptacle traces depart to the various organs of the flower, leaving gaps which divide the stele into a characteristic network of bundles. *Aquilegia* (Tepfer, 1952), a member of the Ranunculaceae, may be studied as an example of floral vascular anatomy. The pedicel of this flower has five thick bundles which alternate with five thin bundles. The bundles fuse at the base of the flower to form an uninterrupted ring (Fig. 9.27). Above this level, five groups of three traces each depart to the sepals. Each group of three traces leaves a gap in the receptacular cylinder and passes off to one sepal. At a little higher level, alternating with the traces going to the sepals, one trace goes to each of the five petals. There are

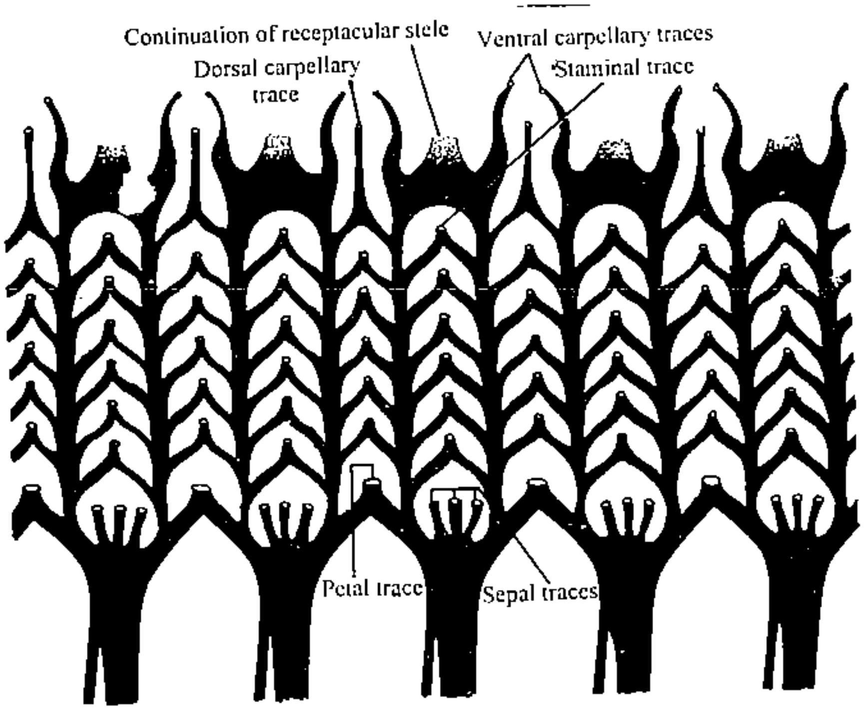

Fig. 9.27: Diagrammatic representation of the stele of *Aquilegia* flower spread out in a single plane.

several whorls of stamens. Each stamen receives one trace. Above the position of the uppermost stamens, the stele once again becomes an uninterrupted ring. At this level, each carpel receives three traces, one dorsal and two ventral. The receptacular stele may thereafter continue for a short distance and then fade away. The ventral bundles of the carpels show an inverted orientation, with their xylem facing outward and phloem inward.

9.7 ANATOMY OF FLORAL ORGANS

As you have already studied, the floral organs represent modified leaves, which are variously evolved to perform different functions. We will now discuss the anatomy of floral part.

9.7.1 Calyx

A sepal has an upper and a lower epidermis, enclosing mesophyll consisting of chlorenchyma. A palisade parenchyma is usually absent. The sepals surround and protect the young flower and is generally shed or curled back after the flower is mature. However, in many plants the sepals are variously modified to discharge other functions. For example, in *Abutilon pictum* the sepals have nectar-secreting trichomes on their inner surface near the base. In *Plumbago capensis* sepals form a short tube around the base of the petals. The calyx tube is covered with sticky glands that would not allow crawling insects like ants to approach the fertile appendages, thus ensuring cross-pollination by flying insects. In many dicots (e.g., *Helleborus* and *Tropaeolum*) as well as monocots (*Tulipa, Narcissus*) the sepals are brightly coloured and petal-like and may even produce fragrance and nectar.

Each sepal usually receives as many traces as the leaf in the same plant. Most sepals have three vascular bundles, of which one serves as the midrib and the other two become lateral veins. In flowers with connate sepals, the lateral veins of adjacent sepals often fuse to form common trunk bundle. In *Hibiscus* (Fig. 9.8), for example, five major and five minor bundles enter the base of the calyx tube. Each major bundle forms the midrib, whereas each minor bundle divides to form lateral veins belonging to adjacent sepals.

9.7.2 Corolla

Each petal, like the sepal, has an upper and a lower epidermis enclosing ground tissue consisting of parenchyma. The petals are usually thinner, more delicate and ephemeral as compared to the sepals. Each petal receives a single vascular trace, the bundle branches on entering the lamina (Fig. 9.28).

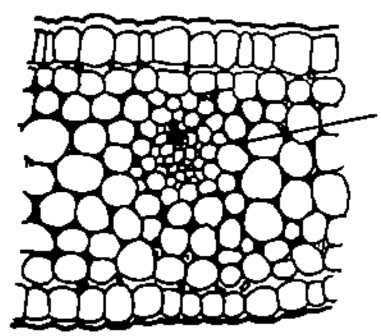

Fig. 9.28: Cross-section through a petal of *Tulipa* species showing a single vascular bundle.

In Unit 10 you will study how flowers in different species are variously modified to ensure pollination. Petals show great diversity in relation to the pollination mechanism. In wind pollinated flowers, the petals are reduced or even absent. In flowers pollinated by insects, birds or bats, the colour, texture, orientation and fragrance of the petals are adapted to attract specific pollinator. Carotenoids in chromoplasts and betacyanins in cell vacuoles are most common pigments. Many flowers have UV-absorbing flavanoids in the epidermal cells of their petals so that bees can see them and get guided to the nectar reward. Epidermal cells along the inner surface of petals of *Abutilon* secrete nectar. In *Tropaeolum majus*, the mesophyll of the tissue of tail like nectar spur formed by the petals secretes nectar. This nectar is released by open stomata and trichomes into the cavity of the nectar spur.

In most flowers, all petals have the same shape and size. Such flowers are regular or actinomorphic. In others the petals, even sepals and stamens, may be bilaterally symmetrical. Such bilipped flowers are called zygomorphic. Members of Orchidaceae, Papilionaceae and Labiatae have characteristic zygomorphic flowers which help them in attracting certain insect pollinators.

9.7.3 Androecium

A stamen usually consists of a slender stalk or filament that bears at its tip an anther. The anther is most often bilobed, and each of its two lobes has two microsporangia (Fig. 9.29, a-b). The anther thus has four microsporangia or pollen sacs, separated by a parenchymatous connective which is a continuation of the filament. The filament may be long so that the anthers extend beyond the perianth, or it may be small and even absent. In bottle brush *Callistemon lanceolatus*, the long, red filaments of the large number of stamens in each flower constitute the main ornamentation, giving the inflorescence the characteristic bottlebrush-like appearance (Fig. 9.11). In *Ricinus communis* the stamens are branched, so that each stamen bears several anthers (Fig. 9.30).

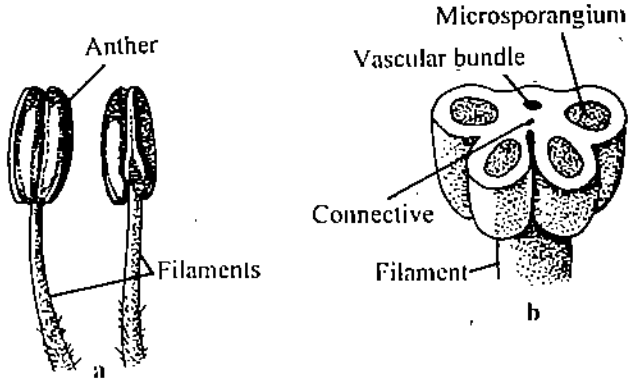

Fig. 9.29: a) A stamen with filament and two lobed anther. b) Anther in cross-section showing four microsporangia.

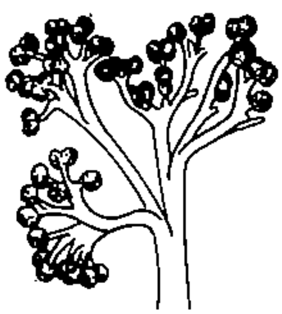

Fig. 9.30: *Ricinus communis*. A branched stamen.

Each microsporangium has a wall consisting of an epidermis, an endothecium, one, two or several middle layers and a tapetum (Fig. 9.31). Sporogenous cells in the pollen sac

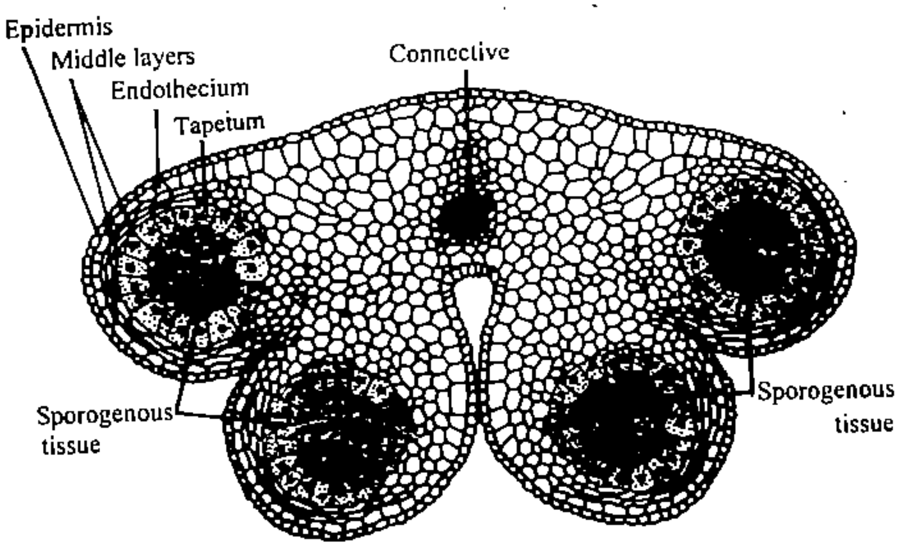

Fig. 9.31: T.S. of an anther with four microsporangia.

form microspore mother cells which undergo meiosis and produce haploid microspores or pollen grains. When the anther is mature, it dries up, endothecial cells with characteristic cellulosic thickenings shrink and each anther lobe opens along a stomium to release the pollen grains. Some anthers dehisce by means of transverse slits or pores.

The stamen has one slender vascular bundle which extends into the connective. This bundle shows little differentiation and even at maturity it has poorly organised xylem and phloem. Some primitive angiosperms, such as *Magnolia* and *Daphniphyllum*, have three bundles in each stamen.

In *Austrobaileya* and *Degeneria* (Bailey & Swamy, 1949; Fig. 9.32 a-b) the stamens are dorsiventrally flattened, leaf-like and bear the sporangia in superficial position on either side of the midvein. In *Degenaria* three vascular bundles enter the base of the stamen and in *Austrobaileya* only one. The stamens of *Degeneria* are considered the most primitive among living angiosperms. Interestingly, flowers with such primitive type of stamens also possess flat carpels of a primitive kind.

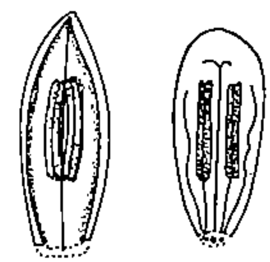

Fig. 9.32: a) *Austrobaileya* **Leaf-like stamen with superfacial anthers on both sides of midvein. b)** *Degeneria* **show leaf-like stamen with three vascular bundles.**

In many polyandrous flowers with numerous stamens, Wilson (1937) observed that the vascular supply to the stamens branches in a dendroid manner within the receptacle (Fig. 9.33). He concluded that these branched staminal bundles indicate that the stamens were branched in the ancestral flowers.

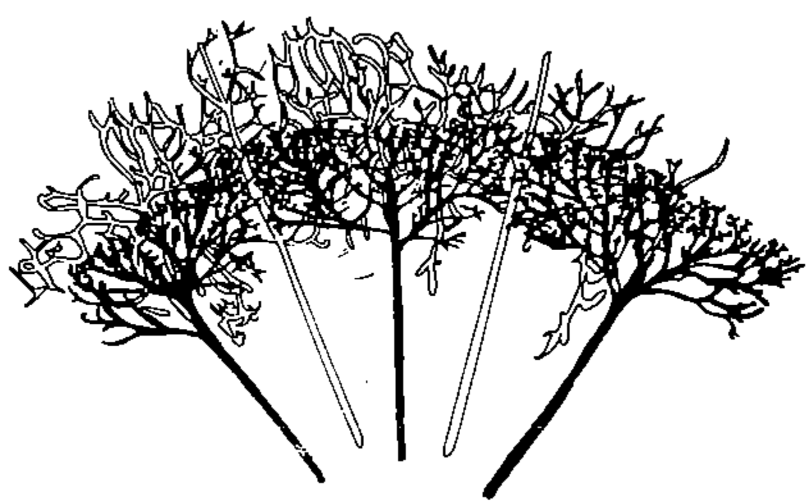

Fig. 9.33: A portion of the receptacle of *Mesembryanthemum* **viewed from within. Vascular bundles (drawn in outline) supply the perianth members and the receptacular tissue. Those in black supply the stamens and staminodes.**

9.7.4 Gynoecium

The gynoecium of a flower may consist of only one carpel, or a number of carpels which may be free or fused. In either case, it usually consists of: (i) basal ovary which contains in its cavity one or more ovules (Fig. 9.34); (ii) style, an extension of the ovary wall which is a hollow tube or has parenchymatous tissue for transmission of pollen tube; (iii) stigma, at the tip of the style, which may be dry or wet, papillate or hairy, to receive the pollen grains and provide conditions for their germination. In the ovary the ovules are attached to certain thickened regions of the ovary termed placentae. The placentae may be parietal (ovules attached to ovary wall; Fig. 9.35 a), axile (to a central axis in a multilocular ovary; Fig. 9.35 b), basal (single ovule attached to the base of the ovary; Fig. 9.35 c) or free central (many ovules on a central basal outgrowth which does not partition the ovary; Fig. 9.35 d).

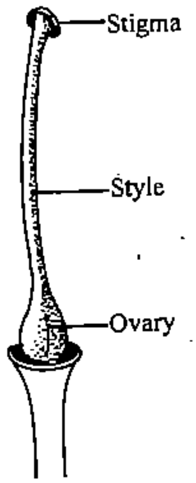

Fig. 9.34: A carpel with ovary, style of stigma.

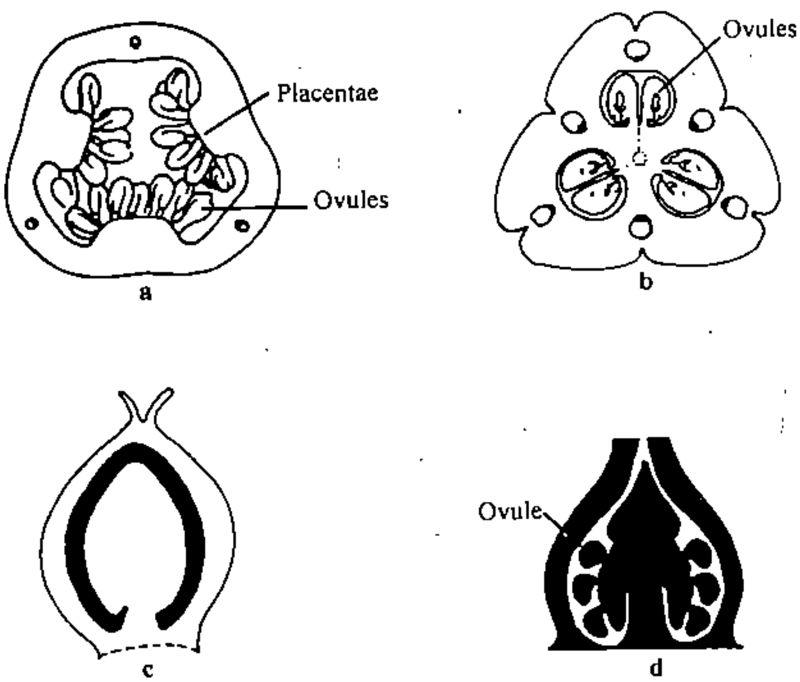

Fig. 9.35: a) An ovary with parietal placentation. b) Syncarpous, trilocular ovary with axile placentation. c) A single basal ovule. d) Free central placentation.

In most of the flowers the ovary is situated above other floral appendages. Such a flower is hypogynous and the ovary is regarded superior (Fig. 9.36 a). In some flowers (e.g., coriander, banana) the ovary is enclosed by a disc formed by fused bases of sepals, petals and stamens so that their free portions arise near the tip of the ovary. Such a flower is epigynous and its ovary is inferior (Fig. 9.36 b). Flowers that display intermediate condition are termed perigynous (Fig. 9.36 c).

Unlike other floral organs, the gynoecium persists after fertilization and its ovary forms the fruit. The carpels, therefore, more often have a thick mesophyll with a network of vascular bundles. The cells may be chlorophyllous and even in early stages some scattered cells or layers may be differentiated as sclereids.

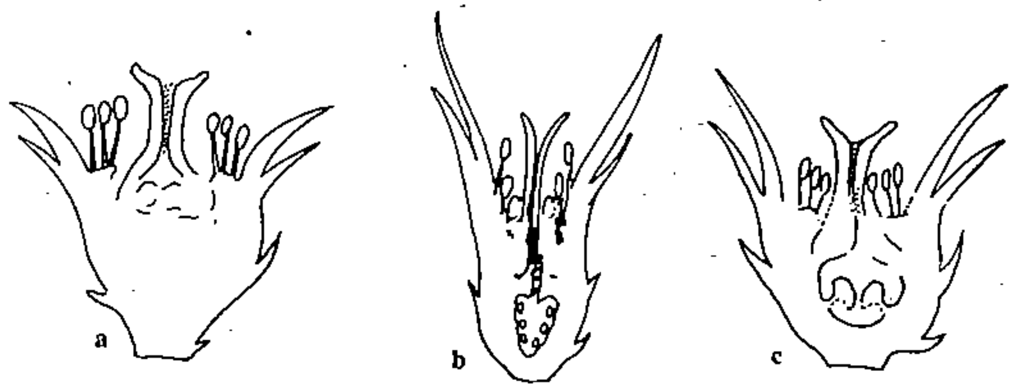

Fig. 9.36: a) Hypogynous flower (superior ovary). b) Epigynous flower (inferior ovary). c) Perigynous flower (semi-inferior ovary).

A carpel may receive one, three, five or even more traces, but most commonly each carpel receives three traces (Fig. 9.37 a-d). The median or dorsal carpel trace, leaves the receptacular stele at a lower level than the marginal or ventral traces (Fig. 9.38 a). The ventral bundles may be free (Fig. 9.37 a-b; 9.38 a), partly (Fig. 9.37 c; 9.38 b) or completely (Fig. 9.37 d; 9.38 c) fused. The dorsal bundle is regarded homologous to the midrib of the leaf. In syncarpous gynoecia, the ventral bundles may be free (Fig. 9.39 a-b) or fused (Fig. 9.39 c) and located lateral to the dorsal bundle (Fig. 9.38 a-c). If the carpels are folded inward the marginal bundles become ventrally located relative to the dorsal bundles (Fig. 9.39 a-c). As a result of the inward folding of the carpel margins the ventral bundles become inverted at an angle of 180°, i.e., their phloem is directed towards inside and xylem towards outside. Both dorsal and ventral bundles branch in the ovary wall. The ovules receive their vascular supply from ventral carpellary bundles or their branches in the placentae.

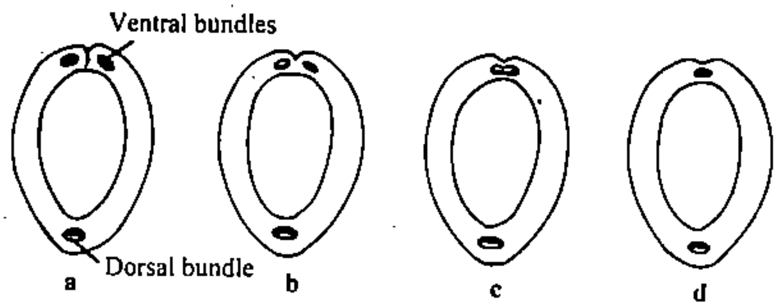

Fig. 9.37: a-d) A carpel with one dorsal bundle and two ventral free (a-b), partly fused (c) or completely fused (d) bundles.

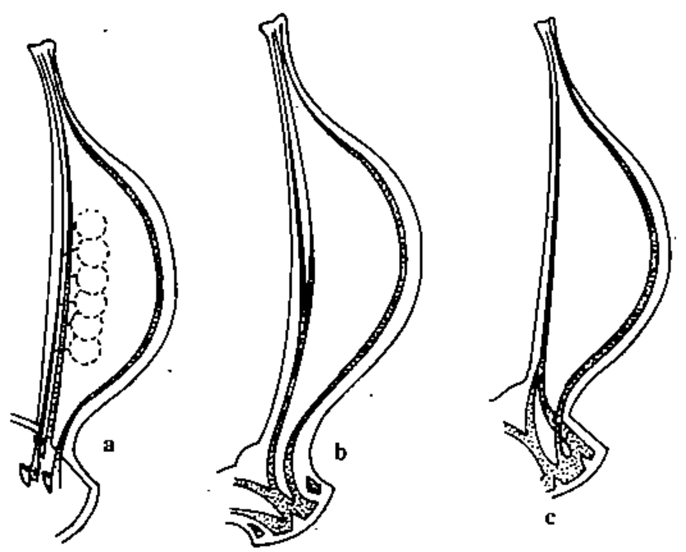

Fig. 9.38: a-c) Diagrams illustrating the carpellary vascular supply. a) A carpel supplied by three traces which remain unfused within the carpel up to the stigma. b) A carpel in which the ventral traces arise fused, but in which they separate in the basal portion of the carpel. c) A carpel in which the two ventral traces are fused from the base of the carpel.

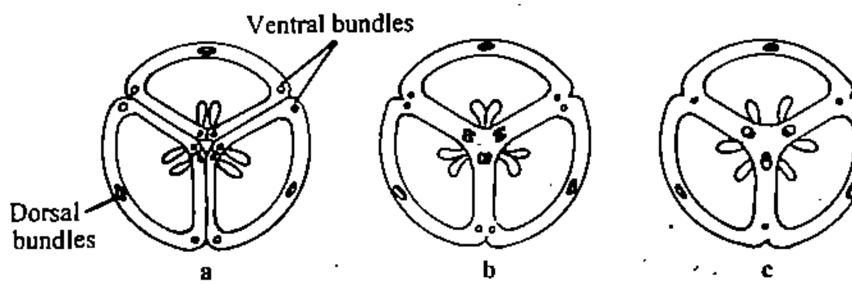

Fig. 9.39: a-c) Sections of tricarpellary, syncarpous ovaries, each carpel having a dorsal and two ventral free (a-b) or Fused (c) Bundles.

If more than three traces enter a carpel, additional traces form bundles between dorsal and ventral bundles and are designated as lateral bundles.

Bundle fusion

As a result of cohesion of floral organs, often the lateral and marginal vascular bundles and traces fuse. In calyces of species in different genera of Lamiaceae (labiatae) various stages of vein fusion are seen (Eames, 1931). In *Nepeta* each sepal has a main vein and two lateral veins (Fig. 9.40 a,b). In *Ajuga* the neighbouring lateral veins are fused (Fig. 9.40 c,d). In *Salvia* two pairs of lateral veins are fused while the others remain free (Fig. 9.40 e).

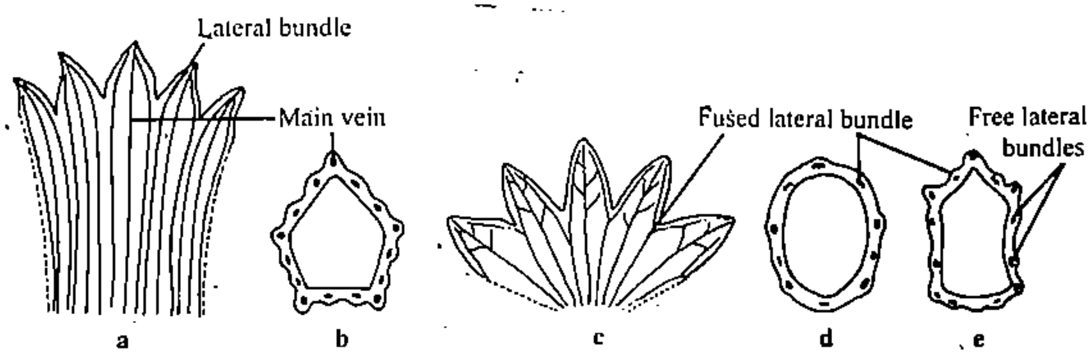

Fig. 9.40: a-b) *Nepeta* sp. A calyx spread out to show that lateral bundles are unfused. b) Cross-section of same showing five main veins alternating with unfused lateral veins. c-d) *Ajuga*. c) Calyx spread out and d) Cross-section of calyx to show fused lateral bundles. e) Cross-section of calyx of *Salvia* sp. in which two pairs of lateral bundles are fused while others remain free.

9.8 MORPHOLOGICAL NATURE OF STAMENS

In view of their similarity in origin and anatomy, there is now little doubt that the sepals and petals represent modified leaves. However, opinions still differ regarding the morphology and evolution of the stamen and carpel (Parkin, 1951). The most common interpretation is that these organs too are homologous to the leaf. On the other hand, some morphologists have tried to explain the development of the stamen on the basis of telome theory. According to this theory the stamen has developed by reduction and fusion from a primitive dichotomously branched axis that bore sporangia at their tips (Wilson, 1942). Melville (1962, 1963) has suggested that the androecium consists of basic units called gonophylls, each of which consists of a sterile leaf with an epiphyllous dichotomously branched system bearing male organs (Fig. 9.42 a). Bailey and his co-workers (Baily & Nast, 1943; Bailey & Swamy, 1951) have emphasised on the broad, leaf-like stamens of *Degeneria,* which have no distinction in filament, anther or connective. The stamen has three vascular bundles and two pollen sacs are formed between the median and lateral bundles. Similar stamens have been described in *Austrobaileya* and *Himantandra* which also belong to the Ranales and in certain genera of Magnoliaceae. In the Magnoliaceae intermediate stages are found showing transition from broad stamens with three bundles and laminar pollen sacs to stamens with distinct filaments and anthers. Based on such studies, most of the authors now agree that the stamen may be described as "a primary bifacial organ of phyllomic nature with a marginal growth zone developing into pollen sacs" (Canright, 1952). The transition from a petal to stamens in *Nymphaea* is illustrated in Fig. 9.41 a-g.

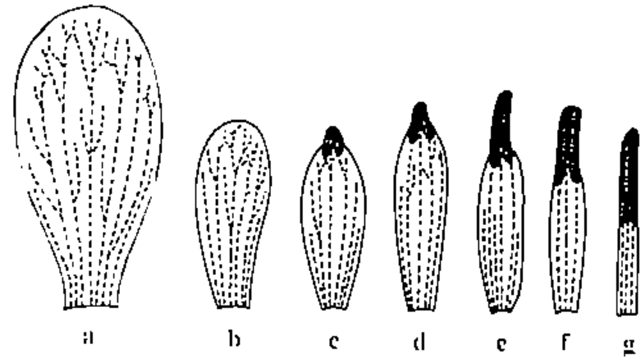

Fig. 9.41: (a-g): *Nymphaea*. Diagrams illustrating the stages in evolution of stamen from a leaf-like petal.

9.9 PHYLOGENY OF THE CARPEL

The morphological nature of the carpel has been much debated. Some of the interpretations are discussed below:

(i) Wilson (1942) proposed that the carpel, like the stamen, has developed from fertile telomes. The sporangia–bearing telomes fused to form a leaf-like organ which bore ovules on its margins. Involution of margins of such a hypothetical organ could have resulted in development of the ovary with enclosed ovules.

(ii) Melville (1962) proposed his gonophyll theory according to which both androecium and gynoecium are composed of basic units, called gonophylls, each of which consists of a sterile leaf with an epiphyllous dichotomously branched system (Fig. 9.42 a). When the fertile branch bears organs of only one sex the terms androphyll and gynophyll are used. A compound gonophyll with both male and female organs is termed androgonophyll, whereas the sterilized blade, divorced from its fertile branch, is called tegophyll. Evolution has occurred along several lines as a result of fusion and reduction of gonophylls in different patterns. For example, an ovary with free central placentation could have been formed by fusion of ovuliferous branches to form the central placental column, while the ovary wall was formed by fusion of tegophylls. The follicle represents a single condensed gynophyll in which the ventral bundles represent the two halves of the dichotomous ovuliferous branch system.

(iii) Meeuse (1965) has suggested that there are two principal morphological categories of gynoecia, the pseudoangiospermous and pseudophyllosporous. His interpretation of the gynoecium of *Engelhardia* (Juglandaceae) suggests that the stigma is a flared micropyle projecting beyond the outer envelope of a naked ovule. Such an arrangement looks remarkably similar to the strobilus of the gymnosperm *Gnetum*. Pseudophyllosporous gynoecia are interpreted in terms of gonoclads and stegoclads, in a manner comparable to Melville's use of gonophylls. The carpel wall represents the outer integument (Fig. 9.42 b).

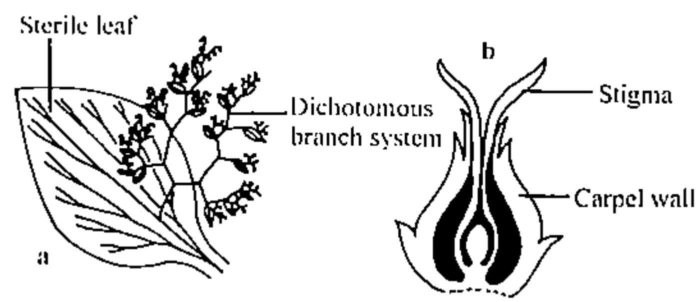

Fig. 9.42: a) Melville's gonophyll, consisting of a wide leaf with an epiphyllous dichotomously branched system bearing male organs. b) Pseudo-angiospermous gynoecium of *Engelhardia*.

(iv) According to the classical concept, traced back to Goethe in the eighteenth century, the carpel is derived from a fertile leaf, the margins of which bore ovules. The margins became involuted and fused between themselves or with the margins of other carpels, so that the ovules became enclosed in locule.

Bailey and Swamy (1951) described a carpel in *Degeneria* which, in cross section, can be seen to consist of a folded organ of which the margins flare outwards and remain unfused. This type of carpel has been termed conduplicate (Fig. 9.43 a-f). The flared margins have stigma-like characteristics and receive the pollen grains. Two rows of ovules are situated on the inner adaxial surface. These ovules are supplied with traces from both dorsal and ventral bundles (Fig. 9.44). From such a conduplicately folded carpel, the common type of angiospermous carpel has been formed by closure and restriction of the stigmatic margins to the upper part of the carpel. The number of ovules was reduced and these remained only in the lower portion of the carpel, which enlarged while the upper part differentiated to form style and stigma.

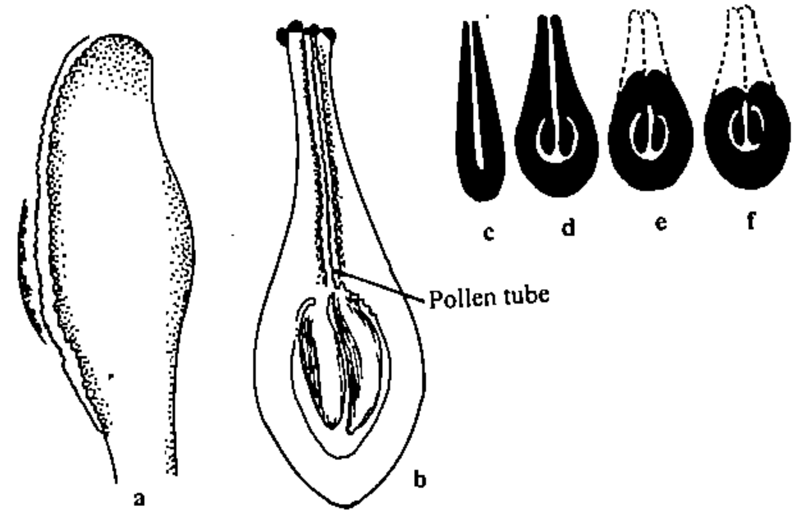

Fig. 9.43: (a) Conduplicate carpel of *Drimys* sp. a) Lateral view showing the stigmatic margins; b) Cross section showing the portion of the ovules and the penetration of a pollen tube; c-f) Diagrammatic representation of the development of the present day carpel from the conduplicate carpel.

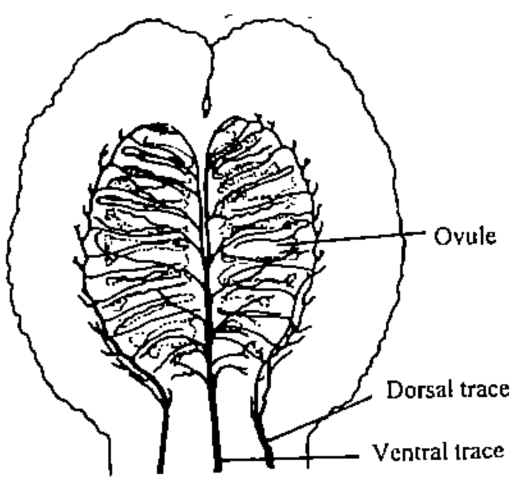

Fig. 9.44: General carpel showing ovules receiving vascular supply from both dorsal and ventral bundles.

SAQ 4

Match column A with the words/names given in column B.

Column A	Column B
1. Flowers that mimic moths and butterflies are seen in	(a) *Euphorbia*
2. Bright red, tubular and fleshy corolla occurs in flowers of	(b) Shoe flower
3. Perianth is absent or inconspicuous in flowers of	(c) bottlebrush
4. A flower with many free carpels	(d) silk cotton tree
5. Inflorescence without a terminal flower is seen in	(e) *Agrimonia*
6. Cyathium is observed in	(f) silver oak

7. Stamens fuse to form a staminal tube around the gynoecium in — (g) Orchidaceae
8. Prominent, showy stamens characterise the flowers of — (h) grasses
9. An inflorescence with a terminal flower occurs in — (i) butter cup
10. Sepals are ornamental and petals are reduced in — (j) *Cleome*

SAQ 5

Fill in the blanks:

1. Lateral fusion of floral organs in a whorl is known as ....
2. When stamens are fused with the corolla these are described as ....
3. Each carpel receives three traces, one .... and two ....
4. In *Abutilon* the sepals have trichomes which secrete ....
5. In the ovary ovules are attached at ....

SAQ 6

Describe the floral anatomy of *Aquilegia* with the help of a suitable diagram.

SAQ 7

Summarize the various theories which explain the morphological nature of the carpel.

....

....

....

....

9.10 FRUITS

In LSE-06 Unit 6 you have already studied about fruit, its formation and dispersal in detail. Here we are dealing with the diversity in fruits.

Following pollination and fertilization, the ovules get transformed into seeds. At the same time, the carpels, or more specifically the ovary which encloses the ovules, undergoes certain changes that culminate in formation of the fruit. The ovary which contains the ripe seeds is the fruit. The fruit protects the seeds till these are mature and facilitates their release or dispersal at an appropriate stage. In primitive families such as the Magnoliaceae the fruit opens while still on the tree and the seed itself is the unit of dispersal. In milkweed, *Calotropis procera* (Fig. 9.45 a) and silk cotton tree, *Bombax ceiba* the hairy seeds discharged from the open fruits fly away in the air. However, in most of the flowering plants the function of dispersal is atleast partly transferred to the fruit. For example, the coconut fruit is itself adapted to dispersal in sea water.

In *Impatiens* (Fig. 9.45 b,c) and *Euphorbia* species the fruit bursts open and throws away the seed to some distance. Fruits of several members of Compositae (Asteraceae) (Fig. 9.45 d) have hairy or prickly pappus with the help of which these are carried to long distances by animals. Fruits of the mistletoe *Viscum album* get eaten by birds and the seeds are discharged with the faeces. The structure of any fruit is, therefore, to be viewed in the light of its adaptation to protection and dispersal of seed.

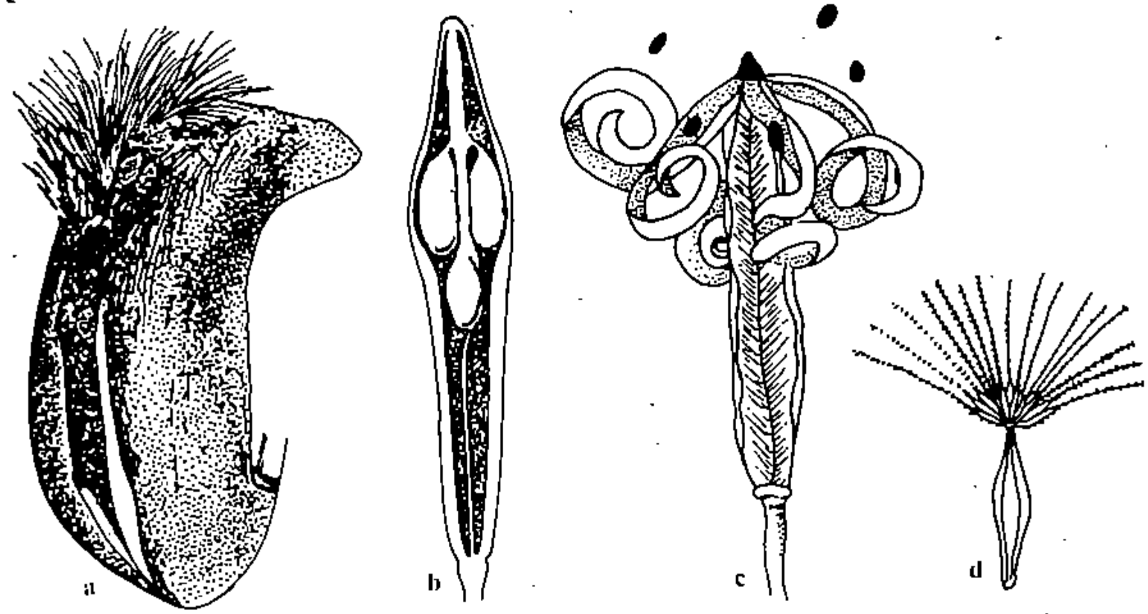

Fig. 9.45: a) *Calotropis procera.* Fruit with hairy seeds. b-c) *Impatiens* sp. b) Longitudinally sectioned closed fruit. c) A fruit of which the valves have curled inward and in doing so have ejected the seeds. d) Fruit of a member of Compositae with hairy pappus for dispersal.

9.10.1 Simple and Compound Fruits

A simple fruit is produced from a monocarpellary or multicarpellary, syncarpous gynoecium of a flower. Multiple fruit consists of gynoecia of more than one flower cohering or connate on a common axis as in pineapple, *Ananas comosus* (Fig. 9.46 a). Aggregate fruit develops from carpels of one gynoecium which are free in the flower but coherent in the fruit as in custard apple, *Annona squamosa* (Fig. 9.46 c). The term compound fruit is some time used for both multiple and aggregate fruits.

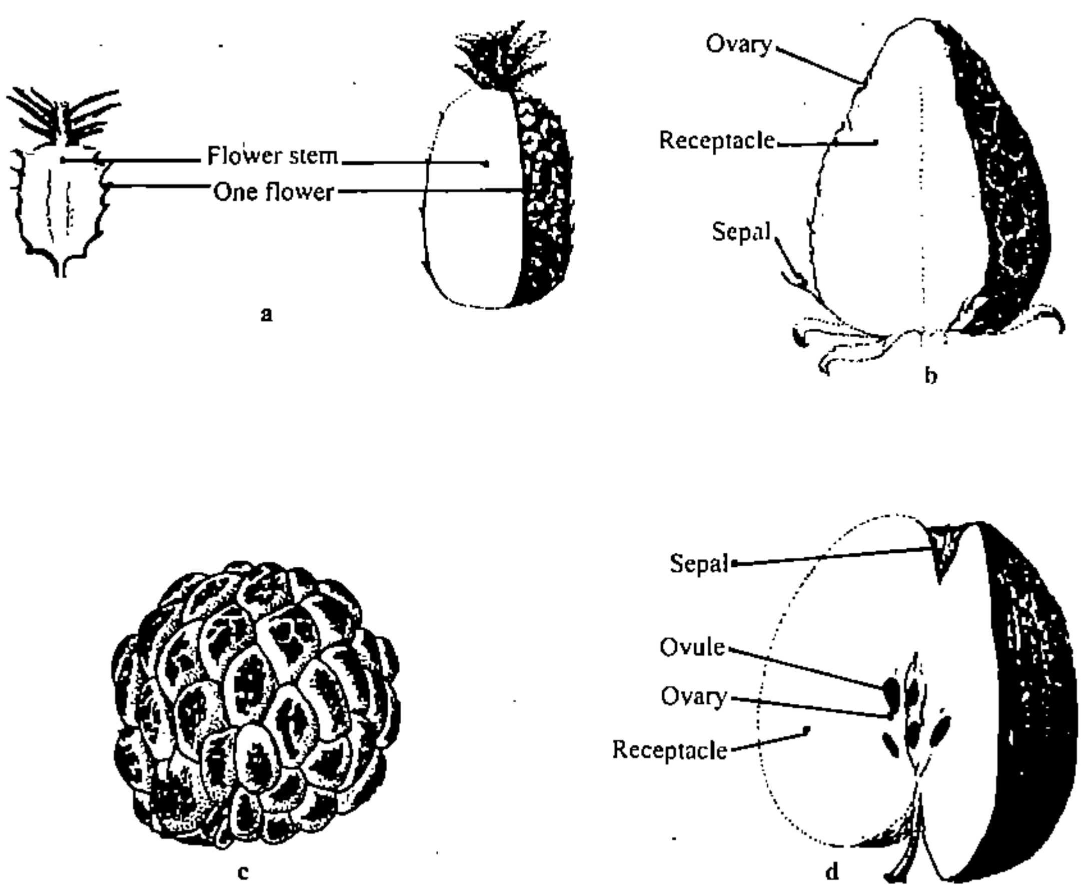

Fig. 9.46: a) Multiple fruit of pineapple. b) False fruit of strawberry. c) Fruit of *Annona squamosa.* d) L.S. of apple showing the receptacle and fused perianth surrounding the ovary with seeds.

9.10.2 False Fruits

Fruits in which floral organs other than carpels are present are termed accessory or false fruits. The accessory organs contributing to formation of false fruit (also called pseudocarp) may be the floral receptacle, pedicel, inflorescence axis, sepals, petals or bracts. In strawberry, *Fragaria* spp. (Fig. 9.46 b) the floral receptacle or thalamus extends around the ovary to form the fleshy, red edible fruit. In apple, *Pyrus malus* (Fig. 9.46 d) the floral tube formed by the floral organs and receptacle around the inferior ovary together constitute the bulk of the fruit. In jackfruit, *Artocarpus heterophyllus* the perianth, and in ananas the bracts surrounding the compactly arranged flowers in the inflorescence participate in formation of the fruit.

9.10.3 Types of Fruits

The wall of the true fruit is termed pericarp. Pericarp of the mature fruit is often distinguishable into three regions. In mango, *Mangifera indica*, for instance, the outer skin or peel represents the exocarp or epicarp. Fleshy and juicy middle portion, which is edible, is the mesocarp. Inner shell or stone is formed by the endocarp which encloses a soft seed. In pumpkin, *Cucurbita pepo* the exocarp is hard and the mesocarp and endocarp are fleshy. On the other hand, in tomato, *Lycopersicum esculentum* or guava, *Psidium guajava* the entire pericarp is soft. Mostly hard fruits such as those of almond have soft seeds, and soft fruits like grapes and guava have hard seeds.

Fruits of different plants display a rich diversity of size, shape, structure, texture, chemical composition and dispersal mechanism. The size varies from tiny caryopsis of grasses and schizocarp of fennel, *Foeniculum vulgare* to large drupe of coconut, *Cocos nucifera* and pepo of pumpkin. While a caryopsis of wheat or a drupe of coconut contain only one seed each, the berry of tomato may contain hundreds, and the capsule of poppy, *Papaver* spp. thousands of tiny seeds.

The fruits are classified mainly on the basis of whether these are dry and hard or soft and fleshy, and on the basis of whether the fruit dehisces when mature or remains intact even after ripening (see Fig. 9.47). Based on these criteria the fruits are classified into categories about which you have already read in LSE-06 Unit.

9.11 FRUIT DEVELOPMENT

The amount of growth and modification that occurs during fruit development is quite diverse in different plants. In grasses, including cereals like wheat and maize, the fruit having only one seed is quite small. The ovary wall undergoes little or no cell divisions. Cell enlargement, differentiation and sclerification are sufficient for fruit development. In grape, *Vitis vinifera* some cell divisions occur which can account for doubling of the size of the ovary, but cell expansion results in 3000 per cent increase in fruit size. On the other hand, large fruits with many seeds (e.g., brinjal, watermelon) must have considerable amount of cell divisions. In *Prunus virginiana* (Labrecque et al., 1985) the fruit development occurs in three phases. There is an initial phase of expansion of cells of the carpellary wall, then a period of cell divisions and, finally, another phase of cell expansion. In avocado, *Persea americana* the fruit wall undergoes cell divisions continuously till the fruit is mature.

It is believed that the pollen tubes during their passage from the stigma to the ovules secrete an enzyme which is capable of converting tryptophane into an active hormone. Pollen tubes growing down the style synthesize auxins which diffuse into the ovary and induce its growth. Additional supplies of hormones apparently come from young seeds, so that normally both pollination and fertilization are necessary for formation of the fruit. Nitsch (1951) showed that unpollinated flowers of tomato grown in sterile culture could be induced to form fruits if treated with auxins. In fact, this knowledge is utilized in commerce for hastening the ripening of fruits such as banana and mango by treatment with ethylene or ethrel, which helps in release of auxins.

The study of diversity of fruit structure does not require any laboratory or visit to a botanical garden. The fruits in our immediate neighbouhood, and those which we buy for consumption, are enough to reveal the rich diversity. In the present study, we should try to understand the following four easily available fruits.

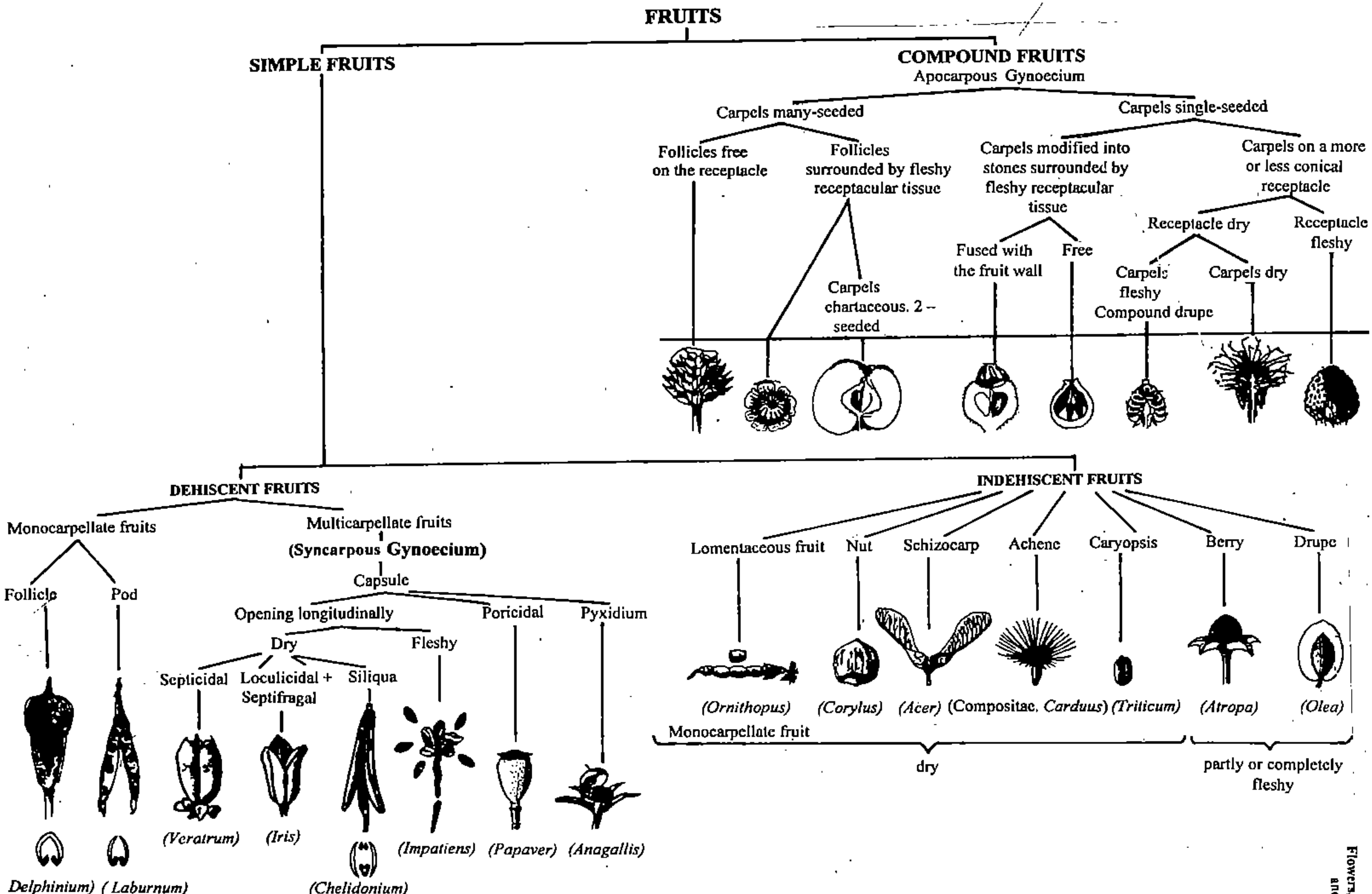

Fig. 9.47: Types of fruits.

9.11.1 Citrus Fruits

The fruit of orange or lemon is a type of berry. The exocarp, termed flavedo, includes the cuticularized epidermis and adjacent parenchyma with flask-shaped oil glands (Fig. 9.48 a,b). There is a loss of chlorophyll and increase in carotenoids in the parenchyma which gives the ripe fruit a yellow or orange colour. The mesocarp, termed albedo, has white loose, branching parenchymatous cells with plenty of intercellular spaces. It is a rich source of pectin, used for making jams and jellys. Vascular bundles ramify through the mesocarp. Inner epidermis of carpels and several layers of compact parenchyma constitute the endocarp. It forms the membrane-like locular layer which encloses the juice sacs and seeds. The juice sacs are stalked outgrowths arising from epidermal and subepidermal cells of the endocarp and projecting into the locules (Fig. 9.48 c). Their large vacuolated cells contain juice.

The peel of the citrus fruit consists of the exocarp and much of the mesocarp. In some species such as orange mesocarp tissue is easily torn so that the peel and the carpellary segments can be easily separated, whereas in others such as lemon the mesocarp is firm and the peel and segments are not easily separable.

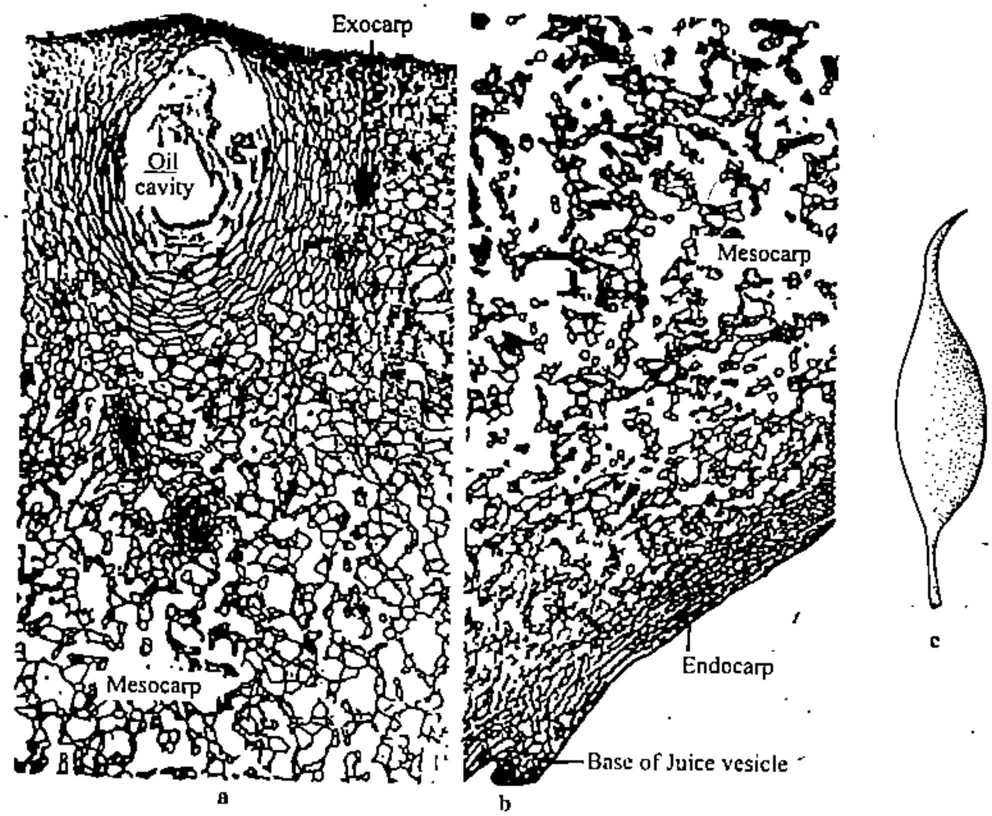

Fig. 9.48: Micrographs of portions of the pericarp of *Citrus*. a) Outer portion. b) Inner portion. c) A single juice sac.

9.11.2 Apple

The fruit of apple, *Pyrus malus* is described as a pome, a type of drupe. It is a false fruit composed of an inner core consisting of five unfused carpels, and the surrounding fleshy part (which is edible) made up of fused and enlarged basal parts of sepals, petals and stamens (Fig. 9.46 d). The receptacle participates in formation of a small portion of the basal part of the fruit. The carpellary core is separated from the outer aggregate, fleshy part by a "core line" consisting of smaller cells. The ovarian part of the compound fruit wall, termed hypanthium, has parenchymatous exocarp and mesocarp (Fig. 9.49). Cartilaginous endocarp, composed of 5-6 layers of sclereids, lines the ovarian locules which bear dark seeds. Each carpel has a dorsal bundle and two ventral bundles. The outer part of the hypanthium has ten vascular bundles, five belonging to sepals and the other five to petals. The outer epidermis has a thick cuticle. Stomata are replaced by lenticels as the fruit develops. Inside the epidermis is several layered collenchyma with thick-walled tangentially elongated cells. Internal to this zone is parenchyma with radially oriented cells having plenty of air spaces.

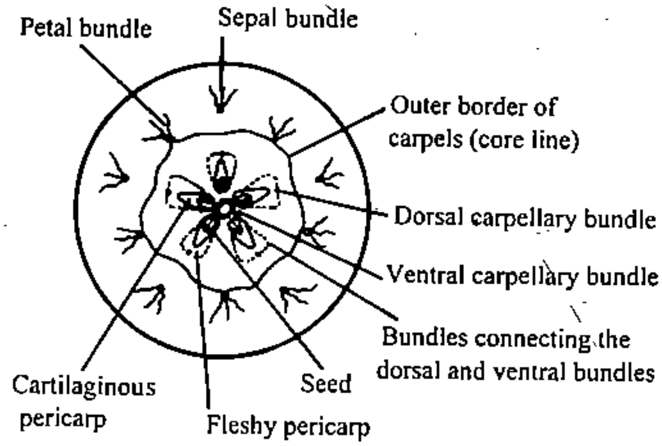

Fig. 9.49: Diagram of a cross-section of the fruit of apple.

9.11.3 Banana

The fruit of banana represents a berry. Wild banana has 3-chambered, seeded, fruits (Fig. 9.50 a,b), but cultivated banana, *Musa paradisiaca* is seedless and fleshy (Fig. 9.50 c-d). The peel of banana represents the exocarp, consisting of cuticularised epidermis, several layers of compact hypodermal parenchyma, and a broad zone of aerenchyma with vascular bundles and laticifers. Mesocarp is composed of 5-7 layers of radially elongated pulp-initiating parenchyma cells. Endocarp is represented by the inner epidermis. The septae dividing the tricarpellary ovary have outer and inner epidermal layers, central parenchyma with parallel vascular bundles and hypodermal pulp-initiating cells. Proliferation of pulp-initiating cells of the mesocarp and septae in cultivated banana results in filling up of the locules with pulp. Starch is deposited in the pulp in initial stages but, later, starch is converted to sugar in the table varieties of banana.

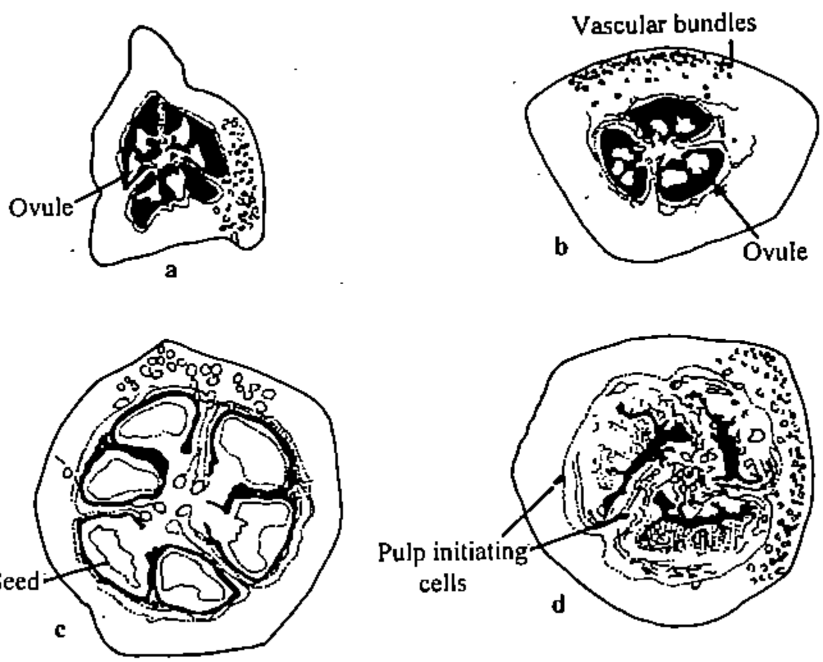

Fig. 9.50: Transverse section of wild and cultivated banana. a) An ovary of wild banana at young stage. b) Mature fruit showing three chambered condition with seeds, pulp formation is negligible. c) Ovary of cultivated banana and d) mature fruit showing pulp formation from mesocarp and septae.

9.11.4 Legume

The pod in the Leguminosae develops from a single carpel which splits open at maturity along both ventral and dorsal sutures, exposing the seeds attached along ventral margins. The exocarp consists of the outer epidermis with thick cuticle. Mesocarp has relatively thick-walled parenchyma. This region has vascular bundles which are often accompanied by some sclerenchymatous cells. The endocarp consists of sclerenchymatous tissue on the inside of which may be a few layers of parenchyma and a thin-walled inner epidermis. Sclerenchyma of the endocarp may consist of either one zone of sclereids arranged uniformly in one direction (e.g., *Astragalus macrocarpus* Fig. 9.51 a) or of two zones in which the orientation of sclereids differs (e.g., *Astragalus homosus*). Dehiscent pods usuall have cross-orientation of sclerenchymatous cells. Such pods also have soft separation tissu in the region of the sutures. The pod when dry twists in such legumes resulting in separatio of the two halves of the fruit along the sutures. Pericarp in *Acacia radiana* has sclereids in the exocarp as well as endocarp (Fig. 9.51 b) such pods are hard and indehiscent.

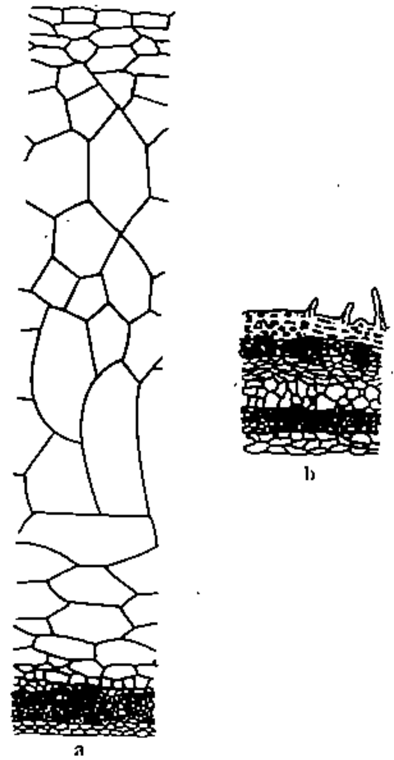

Fig. 9.51: a) *Astragalus* sp. cross-section of pericarp with sclereids in endocarp. b) *Acacia radiana*, same with sclereids in exocarp and endocarp.

SAQ 8

Write whether the statement is true or false in the given brackets. Write T for true, and F for false statement.

i) The ovary which contains ripe seeds is known as fruit. [ ]
ii) In *Impatiens* the fruit is indehiscent. [ ]
iii) Pineapple is a compound fruit. [ ]
iv) In mango the entire pericarp is soft and fleshy. [ ]
v) Hard fruits usually have soft seeds. [ ]
vi) In orange juice sacs arise from the endocarp. [ ]
vii) Pod in Leguminosae develops from two carpels. [ ]

9.12 FRUIT ABSCISSION

On any tree a number of young fruits abscise and fall. An ovary having a single ovule would usually abscise if not fertilized. For an ovary having several ovules, a certain minimum number of ovules must get fertilized for the fruit to develop and persist. Since fruit drop causes considerable loss in any orchard, the cause and mechanism of fruit abscission are of great importance. Formation of an abscission zone consisting of small, thin-walled squat cells, similar to that of the leaf pedicel, has been described in fruit stalk of mango and avocado. Tyloses, which can block the flow of water, are often observed in the stalk of abscised fruits. During the phase of ripening, dissolution of the middle lamella occurs in the cells of abscission zone resulting in shedding of the fruit.

In cotton it has been shown that abscission is accelerated by abscisic acid and gibberellins. On the other hand, auxins prevent abscission of the fruit. Auxins synthesized by the seeds inhibit abscission of the fruit. Because of this mechanism ovaries with unfertilized ovules tend to abscise, whereas ovaries with developing seeds grow into ripe fruits.

9.13 APOMIXIS

Plants in which the usual sexual process of reproduction is completely replaced by asexual method of reproduction are called apomictic. According to Winkler (1908) apomixis may be defined as substitution of the usual sexual process by a form of reproduction which does not involve meiosis and syngamy. There are two main types of apomixis.

9.13.1 Vegetative Reproduction

Propagation of the plant is by a part of the body other than the seed. For example, saffron, and gladiolus plants are propagated by their underground modified stem called corm. Being sterile, the plants do not produce fruits or fertile seeds.

9.13.2 Agamospermy

Plants in this category are propagated by seed, but the embryo is formed without the involvement of meiosis or syngamy. Three types are recognised.

a) **Adventive embryony**: Sexual embryo sac develops normally. Agamospermous embryos arise from diploid sporophytic cells of the ovule, i.e. nucellus or integument. Zygotic embryo may degenerate or compete with the apomictic embryos. Some species of *Citrus, Mangifera* (Fig. 9.52) and *Opuntia* show adventive embryony.

b) **Diplospory**: An archesporium differentiates in the ovule, but the megaspore mother cell does not undergo meiosis. Instead, it divides mitotically and develops into unreduced embryo sac (e.g., *Aerva tomentosa*). The embryo is formed by divisions in unfertilised egg (parthenogenesis) or some other cell of the embryo sac (apogamety).

c) **Apospory**: A somatic cell of the nucellus enlarges and divides to form the unreduced embryo sac. Its diploid egg develops into embryo (e.g., *Poa* spp.) without syngamy.

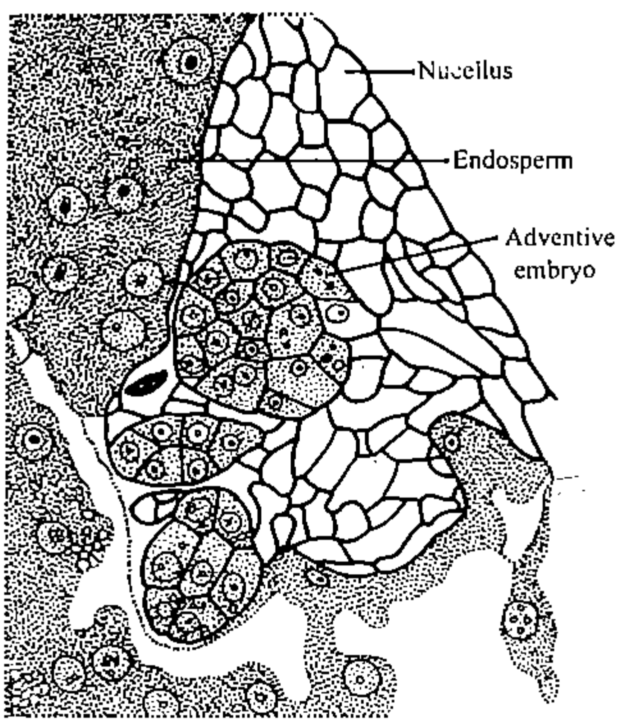

Fig. 9.52: *Mangifera odorata*. A part of section of seed showing embryos arising from nucellar cells.

9.13.3 Parthenogenesis

Development of egg into embryo without syngamy is termed parthenogenesis. Diploid unfertilized egg of diplosporous or aposporous embryo sacs can develop into embryo without the participation of male gametes. In some Asteraceae and Rubiaceae the development of apomictic embryo is independent of pollination stimulus. However, in many other apomictic species (e.g., *Citrus* spp.) embryo develops only after pollination. Such a phenomenon is known as pseudogamy. According to Heslop-Harrison (1972) pollination is required in pseudogamy for: (a) activation and growth of ovary and ovule;

(b) supply of male gamete for endosperm development; and (c) to stimulate parthenogenesis.

Most of the apomicts are of hybrid origin and are polyploid. Because of abnormal meiosis their pollen grains are usually sterile. Such pollen is capable of providing pollination stimulus but cannot contribute haploid male gamete for syngamy. Apomixis offers the possibility of indefinite multiplication of specially favourable biotypes.

9.13.5 Parthenocarpy

Development of fruit without fertilization of ovules inside is known as parthenocarpy (Nitsch, 1965). Parthenocarpic development of fruit may require pollination stimulus (stimulative parthenocarpy) or it may occur in unpollinated flowers (vegetative parthenocarpy). Edible banana, pineapple and figs are examples of parthenocarpic fruits.

Three types of parthenocarpy are recognised:

a) **Genetic parthenocarpy**: This type of parthenocarpy arises due to mutation or hybridization. The naval orange, for example, has arisen from a normal seeded *Citrus* variety through mutation in an axillary bud which grew out into a branch bearing seedless oranges.

b) **Environmental parthenocarpy** : Low temperature, frost, fog and other environmental extremes may interfere with normal reproductive phenomena and bring about parthenocarpy. Osborne and Went (1953) induced parthenocarpy in tomato with low temperature and high light intensity.

c) **Chemically–induced parthenocarpy** : Auxins and gibberellins at low concentrations have been utilized to induce parthenocarpy in plants which bear normal seeded fruits (Balasubramanyam and Rangaswamy, 1959). Auxins have been used for obtaining parthenocarpic fruits in tomato, strawberry, cucurbits, figs and guava. Gibberellic acid has been used to induce parthenocarpic development of fruit in apple, grape, figs and tomato.

Parthenocarpic fruits are of great importance in horticulture because seedless fruits are not only more convenient for raw consumption but are also in great demand in juice and jam industries.

SAQ 9

Describe the various types of fruits and give at least one example of each.

....

....

....

....

SAQ 10

What are the changes that take place in an ovary during formation of the fruit?

....

....

....

....

9.14 SEED

Following fertilization, the ovule undergoes a series of changes. The fertilized egg or zygote forms the embryo, which is the forerunner of next generation of sporophyte. The central cell nuclei fuse with the second male gamete (discharged by the same pollen tube) to form a fusion nucleus, which divides to give rise to the endosperm. The endosperm nourishes the embryo. In later stages it usually stores food which is utilized during seed germination for nutrition of the young seedling.

While the embryo and endosperm are developing inside the embryo sac, the ovule itself undergoes a series of changes. The nucellus generally degenerates and makes way for expansion of endosperm. However, in some plants such as black pepper, *Piper nigrum* the nucellus persists as perisperm and serves as a nutritive tissue in addition to endosperm. In hard fruits such as coconut, almond and groundnut, the seed coat is thin and membranous as the protective role is performed by the pericarp. However, in majority of plants, particularly those having thin or soft pericarp, one or both integuments of the ovule form the hard seed coat. If the integuments thicken due to cell divisions after fertilization these are termed multiplicative, otherwise these are described as non-multiplicative (Corner, 1976). External part of the seed coat contributed by the outer integument is termed testa, while the interior part formed by inner integument is designated as tegmen.

A true seed is, thus, a fertilized mature ovule that possesses an embryonic plant, stored food reserves in endosperm or perisperm (and in the embryo itself) and a protective seed coat. The hard seed coat renders the seed impervious to water, gases and pathogens. The seed can be in a state of inertness in soil for several years. With the availability of water and optimal temperature the seed would germinate to form a new plant. In many tropical trees (such as para rubber, *Hevea brasiliensis*) the seed has only a short period of viability, the embryo inside dies unless the seed germinates in a few days. Other seeds, particularly those in temperate and arid climates, have a dormancy period to ensure that the germination is not initiated during the unfavourable period. However, most seeds have sufficient viability period and can germinate when conditions suitable for growth exist.

9.14.1 Pseudo–seeds

In a popular sense, the term seed is also applied to small single–seeded, indehiscent fruits, such as the caryopsis of wheat or barley, cypsella of sunflower, mericarps of coriander and the berries of black pepper. In these fruits the pericarp is fused or closely adhering to seed coat. Bulb of onion (modified stem and leaves), corm of gladiolus, pieces of rhizomes of ginger and turmeric and slices of potato tubers (all modified stem) are also referred to as seeds because these are used as propagules of the plant.

9.15 DIVERSITY IN SEED FORM

The size, shape, colour and surface texture of seeds of flowering plants display a great deal of variation. The size ranges from dust particle-like seeds of orchids and pin-head like seeds of poppy and mustard to large seeds of coconut, *Cocos nucifera* and double coconut, *Lodoicea maldivica*. Colour varies from white (melon) to yellow (mustard), brown (linseed) and black (sapodilla). The seed surface may be smooth, wrinkled, ribbed, furrowed, reticulate, hairy, pulpy or winged.

Pea and castor may be studied in greater detail to understand the parts of a seed.

9.15.1 Pea

A pod of pea has several seeds arranged in two rows. Each seed is attached to the fruit wall by a small stalk, the funiculus. At maturity the funiculus separates from the seed leaving a scar called hilum. A little below the hilum is a small pore, the micropyle. The seed coat cannot be distinguished into testa and tegmen. When the seed coat is removed, the embryo is exposed as there is no endosperm in the mature legume seed. The embryonal axis bears two large cotyledons. The portion of embryonal axis extending beyond the cotyledons is the epicotyl which has at its tip the plumule or embryonic shoot axis (Fig. 9.53). The other part of the axis is the hypocotyl which has at its end the radicle or embryonic root. In pea the cotyledons function as the food storage organs. Outer epidermal cells of the seed coat form characteristic palisade shaped macrosclereids (Fig. 9.54). The hypodermal layer is made up of hand-glass shaped cells. Interior cells of the outer integument and the inner integument degenerate.

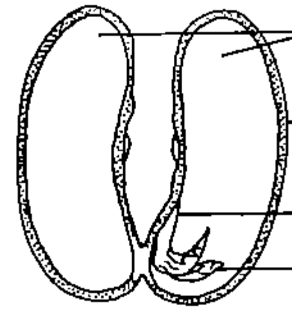

Fig. 9.53: A part of seed of pea.

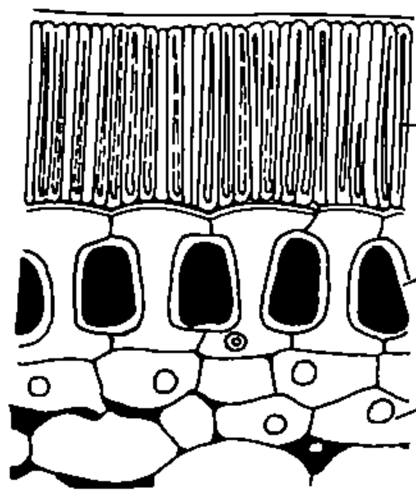

Fig. 9.54: L.S. of seed coat of pea showing outer palisade layer.

9.15.2 Castor

The seed of castor is bean–shaped and at its tip it has a white collar–like structure called caruncle. The caruncle is an outgrowth of the testa. The seed coat itself is distinguishable into an outer membranous testa, formed from outer integument of the ovule (Fig. 9.55). The tegmen inside is hard and brittle. Outer epidermal cells of the inner integument form the palisade–like sclereids. The mature seed is filled with endosperm, whose cells contain oil and protein. A straight embryo extends from one end of the seed to the other. The embryo has a radicle, hypocotyl, two leafy cotyledons and an epicotyl terminating in plumule.

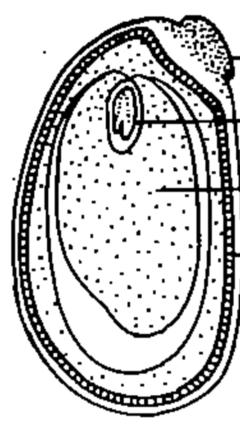

Fig. 9.55: *Ricinus communis*, L.S. developing seed showing caruncle formed by the outer integument. Outer epidermis of tegmen forms the palisade layer of sclereids.

9.16 SEED APPENDAGES

The seeds at maturity in many plants develop special structures which are useful in dispersal. These structures are called appendages.

9.16.1 Caruncle

The while fleshy collar–like outgrowth around the micropyle develops from the swollen tip of the outer integument in members of Euphorbiaceae (e.g., castor; Fig. 9.55). Being rich in starch and sugar, it is eaten by ants which help in seed dispersal.

9.16.2 Aril

It arises from testa or funiculus and surrounds the seed partly (e.g., *Pithecellobium dulce*) or completely (*Litchi chinensis*). In *Crossosoma californicum* (Fig. 9.56 a) the aril is a fimbriate outgrowth surrounding the seed. The aril often has an attractive orange or red colour (as in nutmeg) and is rich in sugar and oil. It attracts the birds which consume the aril and discard the seed, thus dispersing it effectively.

9.16.3 Hairs

In cotton and silk cotton seeds the entire surface is covered by epidermal hairs. Members of Apocyanaceae, such as oleander, have hairs on both ends of the seeds. On the other hand, members of the milkweed family Asclepiadaceae (e.g., *Calotropis procera*; Fig. 9.45 a) have hairs on one pole of the seed. The silky white hairs render the seed light and buoyant so that it is carried to long distances by wind.

9.16.4 Wings

Seeds of several plants such as *Oroxylon* (Fig. 9.56 b) and *Tecoma* species develop appendages in the form of wings. These are outgrowths of the seed coat. Winged seeds are dispersed to long distances by wind.

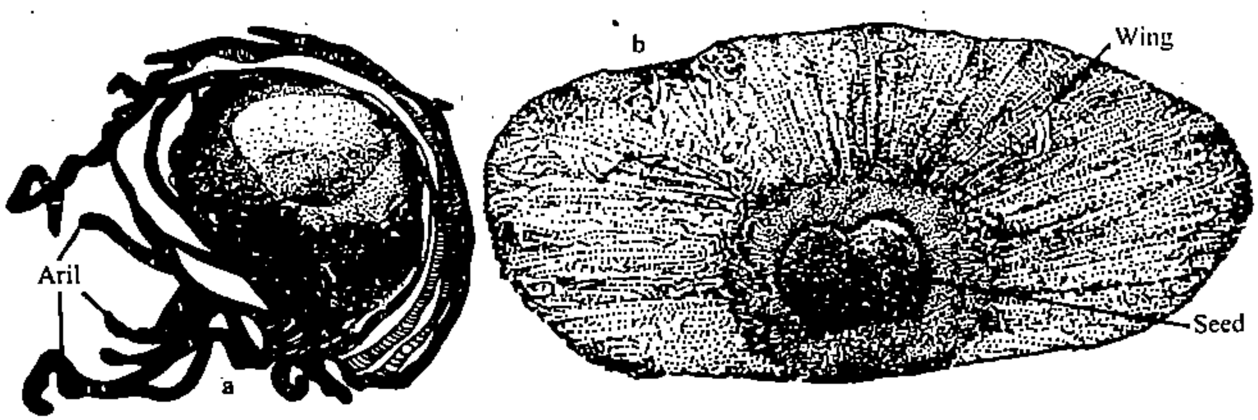

Fig. 9.56: a) A seed of *Crossosoma* having a fimbriate aril. b) Winged seed of *Oroxylon*.

SAQ 11

Fill in the blanks.

i) Saffron is propagated by ....

ii) Reproduction without meiosis and syngamy is termed ....

iii) Parthenogenesis involves formation of embryo from egg without ....

iv) Edible banana has .... fruit.

v) Caruncle is an outgrowth of ....

vi) In nutmeg the seed is surrounded by an attractive ....

9.17 SUMMARY

- After a period of vegetative growth, and often under certain climatic conditions, the stem apex is modified to form a flower or inflorescence. The reproductive apex has a parenchymatous core surrounded by a mantle of meristematic cells. The floral parts, or the bracts, axillary branches and flowers in case of inflorescence, develop from these meristematic cells. Sepals, petals, stamens and carpels arise in acropetal order by periclinal divisions in second/third layer of the tunica.
- The flower represents a determinate shoot. The appendages (sepals, petals, stamens and carpels) represent modified leaves. Primitive stamens are leaf-like and bear two superficial sporangia. These have evolved into stamens with slender filament and terminal anther (having pollen grains). The leaf-like carpels of primitive angiosperms folded conduplicately and gave rise to carpels with ovary (enclosing ovules), style and stigma.
- The flower shows considerable diversity in relation to the mechanism of pollination. Wind-pollinated flowers have reduced sepals and petals, whereas animal-pollinated flowers have large, showy, often fragrant perianth.
- Following pollination and fertilization the ovules get transformed into seeds. The fertilized egg forms the embryo. The central cell stimuli of the embryo sac, following fusion with the second male gamete, form the nutritive tissue endosperm. Nucellus usually degenerates, but sometimes it persists to form the perisperm. One or both the integument may form the hard seed coat. The seed often has appendages such as axil, caruncle, wings or hairs for effective dispersal of the seed.
- The carpels which enclose the seed(s) undergo enlargement and modification to form the fruit. The fruit protects the seeds till these are mature and helps in their release or dispersal at an appropriate stage. Fruits are classified on the basis of their composition, texture and mechanism of dispersal.
- There is considerable interest in the reproductive phenomena which can be controlled and exploited for human welfare. Fruit abscission can be accelerated with abscisic acid or gibberellins and delayed with auxins. Apomixis involves reproduction without involvement of meiosis and syngamy. For example, in *Citrus* and *Magnifera* diploid somatic cells of the nucellus/integument form apomictic embryos in the seed which are genetically similar to the parent plant. Development of fruit without formation of seeds inside is termed parthenocarpy. Edible banana and pineapple are examples of parthenocarpic fruits.

9.18 TERMINAL QUESTIONS

1. Describe the parts of a typical flower and enumerate their functions.

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2. What are the changes that occur in a vegetative shoot apex when it is converted to a floral apex?

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3. Enumerate how floral organs are initiated and how the primordia form distinct sepals, petals, stamens and carpels.

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4. The flower is a determinate shoot! Explain.

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5. What are the factors that lead to activation of the ovary to form fruit.

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6. Write short notes on the following:

i) Phylogeny of the carpel.

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ii) Morphological nature of stamen.

iii) Fruit abscission.

iv) Adventive embryony.

v) Parthenogenesis

vi) Parthenocarpy

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vii) Seed appendages.

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viii) Pseudo-seeds.

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9.18 ANSWERS

Self Assessment Questions

1. A flower represents a determinate shoot in which the internodes are shortened or obliterated. At the nodes are borne sterile (sepals and petals) and fertile (stamens and carpels) appendages which represent modified leaves. Gymnospermous cone has a central axis with spirally arranged sporophylls. Male cone has microsporophylls having microsporangia on abaxial surface. Female cone has magesporophylls with naked ovules on adaxial surface.
2. 1 – c; 2 – a; 3 – b; 4 – e; 5 – d.
3. See section 9.2.
4. 1 – g; 2 – d; 3 – h; 4 – i; 5 – j; 6 – a; 7 – b; 8 – c; 9 – e; 10 – f.
5. 1. connation
   2. epipetalous
   3. dorsal, ventral
   4. nectar
   5. placentae
   6. See section 9.6, Fig. 9.27

7. See section 9.9
8. i. T
   ii. F
   iii. T
   iv. F
   v. T
   vi. T
   vii. F
9. See section 9.10
10. See section 9.11
11. i. corm
    ii. apomixis
    iii. syngamy
    iv. parthenocarpic
    v. outer integument
    vi. aril

Terminal Questions

1. See section 9.2
2. See section 9.3
3. See section 9.4
4. See section 9.5
5. See section 9.11
6. i. See section 9.9
   ii. See subsection 9.2.3
   iii. See section 9.12
   iv. See subsection 9.13.2
   v. See subsection 9.13.3
   vi. See subsection 9.13.4
   vii. See section 9.16
   viii. See subsection 9.14.1

UNIT 10 POLLINATION BIOLOGY

Structure

10.1 Introduction
Objectives
10.2 Pollination - A Recapitulation
10.3 Floral Checks and Balances
10.3.1 Deterrents to Inappropriate Visitors
10.3.2 Attractants for Pollinators
10.3.3 Rewards to the Pollinators
10.4 Specific Pollinators and their Behaviour
10.4.1 Bees
10.4.2 Wasps
10.4.3 Bumblebees
10.4.4 Birds
10.4.5 Molluscs
10.4.6 Bats
10.4.7 Moths and Butterflies
10.5 Flower-Pollinator Coevolution
10.6 Legitimate Pollinators *vs* Illegitimate Visitors
10.7 Deception of Flower Visitors
10.8 Summary
10.9 Terminal Questions
10.10 Answers

10.1 INTRODUCTION

In this unit we shall introduce you to a fascinating subject, i.e., pollination in flowering plants which usually, but not always, involves some interaction between plants and animals/insects. From your study of Unit 3, Block-1, LSE-06 course you are already familiar with the term pollination, how it occurs, and what are the pollinating agents or vectors. In this unit you would study some more aspects of pollination biology, viz., the diverse kinds of biotic pollinating vectors, their behaviour and adaptations to the plants. You would also learn about a few instances of larceny, theft, deceit and robbery in relation to pollination, and see that how some plants have learnt to turn the table on the insects by deceiving them, yet availing their services in effecting pollination!

Objectives

After studying this unit you should be able to:

- recapitulate the meaning of pollination, describe its significance, and enlist the various vectors of pollination;
- list a few contrivances by which plants ensure cross-pollination and avoid/minimize self-pollination;
- identify, with examples, the attractants and rewards that plants offer to their pollinators;
- mention some examples of deterrents to ward off the visits of undesirable animals/insects;
- correlate the structural and functional features of certain flowers with the types of their pollinators; and
- describe a few instances of coevolution between plants and their pollinators.

10.2 POLLINATION - A RECAPITULATION

Pollination involves the transfer of pollen from the male to the female reproductive structures of plants. A flower can only produce offspring in the form of viable seeds if pollen from the same species is deposited on its stigma at the time of anthesis. The completion of this event accomplishes pollination. Depending on the source of the pollen, two types of pollination may be recognized. (1) **Self-pollination** involves the transfer of pollen from anther to stigma of the same flower or of another flower on the same plant. (2) **Cross-pollination** is the transfer of pollen from one flower to the stigma of a flower of another plant of the same species.

Many species are regularly self-pollinated. This usually occurs before the flower has opened fully, or by the growth of receptive stigma among the mature stamens. There are other species which undergo structural and functional modifications that tend to prevent or minimize the possibility of self-pollination. Some such modifications will be discussed a little later. Cross-pollination has several advantages as compared to self-pollination. Cross-pollination increases the reshuffling of genotypes which, in turn, improves the possibility of new genetic combinations. Consequently, the gene pool is diversified. The resulting variations in the gene pool equip populations to exploit any changes or counter any new stresses in the environment.

From your study of Unit-3 of LSE-06 Course, you may recall that some plant species resort to special devices to ensure cross-pollination. Of these, self-sterility is one. Another device is that the androecium and the gynoecium do not mature at the same time, and this phenomenon is called **dichogamy**. In **protogynous** flowers, the pistils mature first and the stamens afterwards, whereas in **protandrous** flowers, the stamens mature earlier than the pistils. In some species of *Primula*, cross-pollination is achieved because of **heterostyly**. In these species, some plants have flowers with long pistils and short stamens whereas others have long stamens and short pistils. Another method to ensure cross-pollination is **dicliny**, i.e., plants have separate male and female flowers either on the same plant (**monoecious**), or on different plants (**dioecious**). All of these are effective contrivances to prevent self-fertilization.

SAQ 1

Give brief answers to the following:

a) Name the key players in pollination.

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b) What is the outcome of pollination?

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c) Can pollination be accomplished at any of the developmental stages of the flower? Discuss.

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d) Cross-pollination is advantageous to plants because:

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e) Name some of the common devices that encourage cross-pollination in plants.

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10.3 FLORAL CHECKS AND BALANCES

Pollination is brought about by both living and nonliving vectors. Living vectors include bees, beetles, butterflies, and various other kinds of insects, birds, molluscs, and mammals. Non-living agents include wind and water. Flowers develop various structural adaptations in relation to the type of vector. Such adaptations are rather complex in insect-pollinated flowers.

In this unit, we shall be concentrating mainly on the living vectors. To recall the salient features of pollination by non-living agents you may read Section 3.2, Unit 3 of the LSE-06 Course. The relationship between the plants and their animal pollinators is of various kinds. A plant species may be pollinated by many kinds of insects, similarly, one kind of insects may pollinate many plant species, indicating a loose relationship. In other cases the relationship is very close, an extreme case being one in which a single plant species is pollinated by a single animal species, the latter being fully dependent on that plant and it does not even visit any other plant species. Plants pollinated by living vectors share certain characteristics. They possess coloured corollas or perianths and produce a sweet fluid called nectar. They also produce certain volatile compounds with distinct, often unique smells. These characteristics act as means for attracting pollinators.

The primitive angiosperms are believed to have been pollinated by beetles that chewed and consumed small bits of the perianth. Many plants of such primitive families as Magnoliaceae and Nymphaeaceae are still pollinated in this way. These members produce little or no nectar. Nectar-sippers such as bees, flies, and butterflies evolved later, when nectar-producing plants had evolved. Pollination by birds and bats is also more recent than beetle pollination, because here again the principal attractant is nectar.

Besides nectar, some other means of attraction in various angiosperms include scents and resins, visual patterns and pigmentation, and pollen attachment or imitation.

Nectar is a sweet fluid largely containing sugar and constitutes the raw material from which honeybees make honey. Nectaries vary greatly in structure and location, and may be associated with any of the flower parts. Nectar can be secreted from the surface of the receptacle (thalamus), from the spurs of the perianth, or from the hairs on the corolla or the ovary. In many flowers, the nectary consists of a ring around the base of the ovary. In some plants, nectaries develop from modified or reduced stamens or petals.

A large proportion of flowering plants is pollinated by insects, chiefly bees, wasps, butterflies and moths. Some flowers are also visited by beetles, flies, and other kinds of insects. You may have noticed that insect-pollinated flowers are usually brightly coloured and/or scented. Their pollen is quite heavy or sticky and is not easily blown by wind. Many insect-pollinated flowers contain nectaries. These are specialized organs or tissues that secrete nectar. Some insect-pollinated flowers have patterns on their petals that we humans cannot see but that are seen by the insects whose eyes are sensitive to ultraviolet radiations. Such patterns can be photographed using UV-sensitive films or with video cameras equipped with UV-transmitting lenses, because glass cuts off UV, and hence ordinary lenses are not suitable for this purpose.

Many examples of flower structure specifically adapted for pollination by particular agents are known (see Table 10.1; Figs 10.1, 10.2). Bee pollinated flowers usually have petals that serve as landing platforms where bees alight. These flowers secrete nectar from glands at the base of a tubular corolla. As a bee probes for the nectar with its long, slender tongue, its body hairs pick up pollen from the flower's stamens. Bees usually feed on the flowers of one species at a time and thus distribute pollen to other flowers of the same species. In bee-pollinated flowers, stamens and pistils are grouped together, this facilitates the bee in picking up abundant pollen from a flower and delivering to other flowers to effect fertilization. Figure 10.1 illustrates pollination in a bee-pollinated plant *Salvia pratensis*.

Table 10.1: Floral characteristics associated with common types of pollinators.

Floral traits	Pollinators				
	Bees	**Butterflies**	**Moths**	**Birds**	**Bats**
Size	Large	Small	Small	Long	Large
Shape (symmetry)	Bilateral	Tubular	Fringed or lobed	Tubular	Bowl or beaker shaped
Colour	Yellow, white, blue	Red, white, blue	Dull or white	Red or strong contrasts	Drab or white
Scent	Fresh, weak	Fresh, weak	Sweet, strong	Nil	Fishy, strong
Nectar hidden in open flower	Yes	Yes	Yes	Yes	No
Time of nectar production	Day	Day	Night	Day	Night

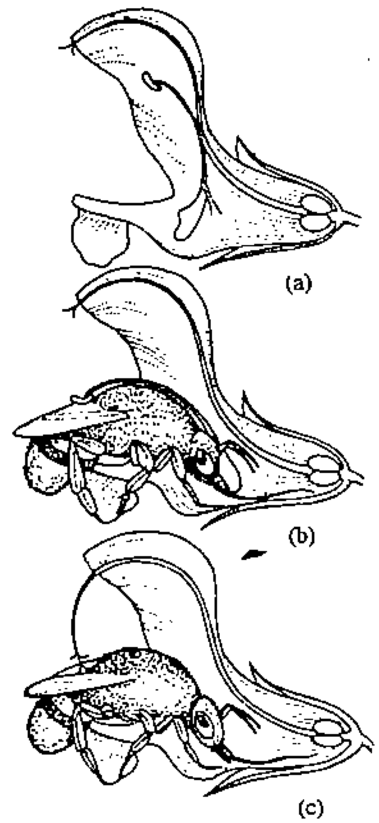


Fig. 10.1: Pollination in *Salvia pratensis*. When the flower of *Salvia* first opens, it is for all practical purposes a male flower as its pollen grains are mature but stigma is nonreceptive and is yet to mature. The bumblebee climbing into the flower in search of nectar activates a pivot mechanism (see a and b) as a result the pollen laden anther touches its back. As the bumblebee leaves the flower, the stamen springs back to its original position. When the gynoecium matures, the stigma becomes receptive and the flower becomes female. As a bee visits such a flower, the stigma gets touched by the pollen on the bee's back, brought from the other flower (c), thus effecting pollination.

In Table 10.2 some flower characters that are usually associated with common types of pollinators are compared.

Table 10.2: Plant adaptations to the pollinating agents.

Pollinating agent	Flowers pollinated by	Special adaptations/features of flowers and their distribution
Bees	Orchids, mints, *Verbena*	Nectar; bright, showy, blue or yellow petals; often closed at night when bees do not fly; stamens and pistils grouped together
Moths	*Nicotiana tabacum, Yucca, Phlox, Oenothera, Carica papaya*	Nectar; Strong fragrance; open late in afternoon and at night when moths fly; common in tropics.
Butterflies	*Fuchsia*, marigolds	Usually red or orange, open in day time.
Flies	Lilies, aroids, *Aristolochia* (see Fig. 10.2)	Dull colour, odour of dung, carrion, or humus on which flies feed; common in the Arctic, and at high altitudes.
Beetles	*Magnolia, Rosa, Eschscholzia*	Spicy, fruity, or sweet odours; very common in tropics; buried ovules.
Birds	*Eucalyptus, Hibiscus, Passiflora*	Usually red or yellow coloured but odourless; common in tropics and warm temperate areas; petals often fused in a nectariferous tube.
Bats	*Kigelia*; trumpet vines	Open at night; large, often white; fermenting or fruity odours.
Wind	Oaks, grasses, cereals, pines	Freely exposed stamens and pistils; petals usually absent; nectar, odour, bright colours absent, stigmas feathery, brushy, or fleshy; separate male and female flowers common in cold temperate regions and in the Arctic.

The butterflies, moths, bees, and wasps have their mouthparts specialized for sucking nectar and, in the case of bees, for kneading pollen. During the course of evolution, there appears to have been a progressive concealment of nectar.

Flowers may broadly be classified into three categories, viz., (1) those visited for pollen; (2) those visited for nectar; and (3) those visited for both pollen and nectar. Flowers of *Cassia* sp. produce abundant pollen to attract bees, and these usually lack nectar. In the flowers of Apiaceae (Umbelliferae) and some euphorbias, nectar is the main attractant for insects. The nectar is freely exposed and is available to short-tongued insects such as flies and beetles, or it is partly hidden by scales, e.g., in *Ranunculus*. In some taxa it is partly concealed by hairs or a short perianth tube and is accessible only to insects whose tongues are about 3 mm long. Flowers of *Ricinus* and *Thevetia* have the nectar completely concealed so that it can be only taken by insects having tongues longer than 6 mm. Concealment is usually by means of a long corolla tube, sometimes by spur formation. An extreme case of exceptionally long, about 25-30 cm, corolla tube or nectar-spur is known in the Madagascar orchid, *Angraecum sesquipedale*; only the moth called *Xanthopan morganii* can avail it.

Aristolochia elegans has protogynous flowers with brown or creamy markings on the perianth (Fig. 10.2a) which, with its distinctive smell helps attract flies. The gynoecium matures first and is pollinated by flies bringing pollen from another flower. The flies enter the perianth funnel (see Fig. 10.2b). Once inside, they are unable to escape until the hairs lining the funnel wither away by which time the stamens would have shed their pollen. It is this pollen which the trapped insect later carries to another flower.

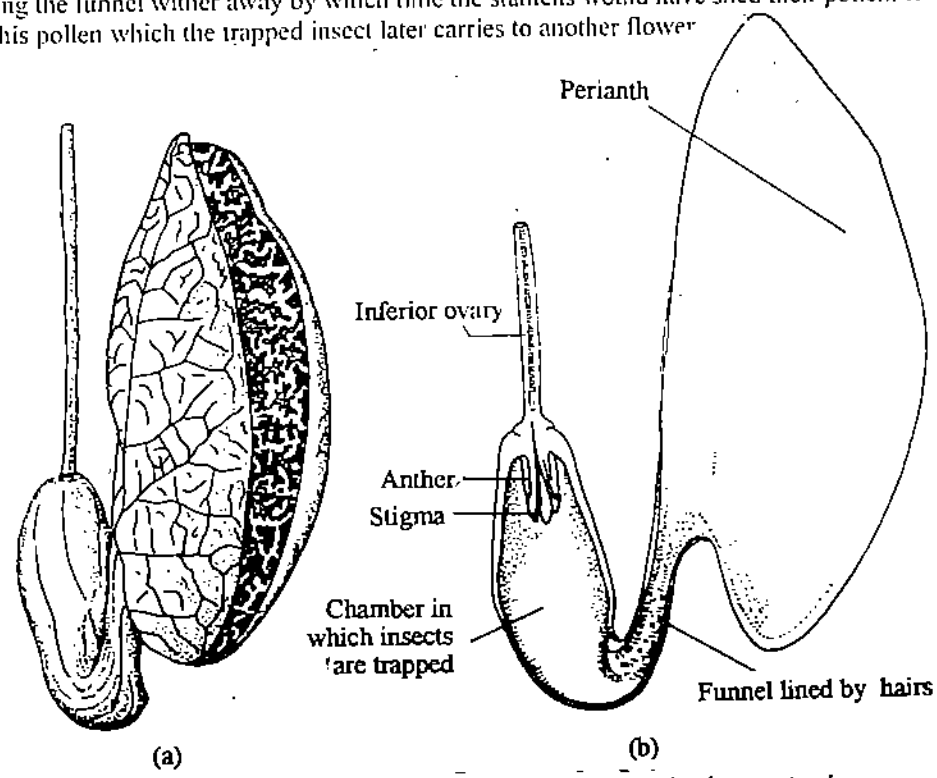


Fig. 10.2: a) A flower of *Aristolochia elegans*. b) A half-flower of the same showing structural peculiarities ensuring pollination.

10.3.1 Deterrents to Inappropriate Visitors

During the course of evolution, many flowering plants have developed a variety of deterrents of physical, chemical and biological nature to the casual visitors.

1. **Physical Deterrents:** Floral morphology has changed/adapted to suit the appropriate visitor but to deter the inappropriate ones. For instance, a long but narrow corolla tube suits Lepidoptera but deters hummingbirds – the latter require a broader tube. Long-tubed flowers protect their nectar from short-tongued bees, flies and beetles.

2. **Chemical Deterrents:** Presence of alkaloids, glucosides, non-protein amino acids and phenolics in nectar makes it unpleasant or toxic to non-suitable flower visitors. Nectars of some species specifically contain ant-repulsive chemicals.

3. **Biological Deterrents:** Some ants guard and protect flowers from the loss of their nectar to illegitimate flower visitors or herbivores but the ants themselves feed at the extrafloral nectaries. This is commonly seen in *Acacia*.

10.3.2 Attractants for Pollinators

Insect pollinators can be divided into three main groups, viz., (1) exclusive pollen seekers, e.g., carpenter bees; (2) exclusive nectar seekers, e.g., moths and butterflies; and (3) both pollen and nectar seekers, e.g., honeybees.

In the case of butterflies, their larvae live on leaves of specific host plants. On emergence from pupae, the growing butterfly has little need for feed as such but it requires some concentrated carbohydrate, one example is nectar - to trigger the cell division in its gonads. As nectaries are usually concealed in the flower, the mouthparts of butterflies have become suitably modified during evolution to reach the nectary. It punctures the nectary without inflicting injury to other flower parts, to suck the nectar. During this operation, the butterfly lands on the flower and uses its palpi and antennae as sensory probes, in the process securing numerous pollen grains.

The most significant role in the visits of butterflies on flowers appears to be played by the flower colour. Red butterflies tend to visit red-coloured flowers. Unlike honeybees which are usually blind to red colour, most butterflies are highly sensitive to red colour. In general, butterflies can perceive colours between the wavelength range of about 300 nm to 800 nm. Butterflies are usually not attracted by white flowers, but yellow, orange and lighter shades of red are effective attractants. White flowers tend to attract moths whereas yellow flowers attract butterflies. Flower colour also influences the foraging behaviour of butterflies.

As compared to visible light, a greater role in butterfly visits appears to be played by ultraviolet light. Differential absorption and reflectance of UV by flowers appear to be major attractants for pollinator butterflies, especially in the case of diurnal pollinators. White flowers tend to absorb UV whereas yellow flowers reflect UV. In general, UV-absorbing flowers mainly attract honeybees whereas UV-reflecting flowers attract butterflies.

The attractive power is often greatly enhanced by colour contrast, arising from selective UV-absorption in the nectar guides. Floral colour change is also triggered by the removal of nectar and pollen deposition on stigma by a butterfly visitor. These changes make the flowers unattractive for any future visitors.

10.3.3 Rewards to the Pollinators

1. Nectar

Nectars of diverse flowers contain not only sugars (mainly glucose, sucrose and fructose) and water but also any or all of the following additional substances: proteins; amino acids, lipids, alkaloids, phenolics, antioxidants, saponins, dextrins, organic acids and diverse other organic substances in small amounts. Their sucrose content can range from 5% to 80%.

The reward of nectar received by pollinators has important implications for population dynamics of the pollinators. Nectar volume can influence the distance travelled by pollinators to a subsequent plant and also the number of flowers visited per plant. Competition for nectar seems to be an important determinant of the extent to which various species of bees utilize the flowers of *Agave schattii*. Introduced honeybees (*Apis mellifera*) preferentially choose the most productive patches of these flowers, thereby reducing the standing crop of available nectar for the native bees (bumblebees, *Bombus sonorus*, and carpenter bees, *Xylocopa arizonensis*).

Nectaries are of two types - **floral** or **extrafloral**. The latter occur outside the flower in the inflorescence, petiole or leaves. Extrafloral nectaries also attract insect visitors, but have received less attention than floral nectaries, with which they resemble structurally. These nectaries usually secrete nectar continuously, independent of insect visits. In contrast, the activity of floral nectaries is periodical, brief, and correlated with insect visits. Floral nectaries are obviously of far greater importance in plant pollinator interactions. They are usually concealed well within the flower and their existence is known only to the special insects concerned. **Nectar guides** play a role in these interrelations.

Nectar production in floral nectaries is affected by several factors and can vary from plant to plant. The time and amount of nectar secretion is often correlated with the time of the pollinator activity. In those plants which flower at night, the peak of nectar secretion occurs in the evening and declines after midnight.

In the tropics many butterfly-pollinated plants flower during the rainy season, usually in the months of July-September, and it is during this time that only their maximum nectar production occurs. It is a general belief that the quantity of nectar increases with increasing interdependence between a flower and its pollinator.

2. Pollen

Pollen is nutritious for beetles, flies, bees and bats but, perhaps, not for birds. Pollen consumption, known as **pollinivory**, is considered the evolutionary precursor to pollination carried by vectors. It becomes a mutualistic process if the pollen-feeders deliver unconsumed pollen to the female reproductive organs of their host plant more efficiently than the alternative pollen dispersal agents such as wind, splashing rain or gravity. Pollination mutualisms require plants to sacrifice some portion of the pollen produced in order to ensure pollination.

3. Heat

While many pollinators are rewarded with energy and nutrient sources such as nectar, pollen and starch; the thermogenic flowers offer yet another form of reward - heat. As suggested by the term 'thermogenic', these flowers maintain a high, nearly constant internal temperature, while there are considerable fluctuations in temperature in the outside environment. Thermogenic flowers occur in several plant families such as Araceae, Aristolochiaceae, Nelumbonaceae, Annonaceae, Arecaceae and Cyclanthaceae. These flowers are generally large because small flowers with high surface: volume ratio are unable to retain enough heat to raise the flower temperature noticeably.

A well studied example of flowers giving heat as a reward to their pollinator is the Amazon water lily, *Victoria amazonica*. It combines heat production with a change in petal colour to control the behaviour of beetle pollinator during a two-day sequence. In this plant the flowers are about 20 cm wide and have beautiful white petals on the first day of anthesis. At this time the flower temperature rises to about 10°C above the ambient air and emits a strong fruity odour. The floral display and the scent attract a large number of beetle pollinators that crowd into the floral chamber. As the evening approaches, the petals gradually close, trapping the insects inside. By the next day afternoon, the petals reopen and allow the beetles to crawl out through the stamens which dust them with pollen. Insects are not attracted to this second day flower because it is no longer strongly scented, white or rich with food. Instead, they fly to first-day flowers, cross pollinate them and repeat the cycle.

The aquatic lotus *Nelumbo nucifera* is an indigenous example of such flowers. It also adopts the same strategy for pollination. Now the question arises, how is high temperature beneficial to the pollinator? Many beetles are endothermic and require high temperatures in their thoracic muscles for activity such as flight. Other activities that involve intense competition for mates and food also require an elevated body temperature.

4. Antibiotic-containing substances

Clusia grandiflora, a flower native to South and Central America, rewards its pollinator, the wild trigona bees with a unique gift, that is, a coat of resin spiked with powerful antibiotics, believed to help the bees in keeping their nests free of harmful bacteria. Interestingly, the resin from female plants is more potent than the one from the male plants.

SAQ 2

Strike off the incorrect word(s) given in the bracket.

a) The insect-pollinated flowers invariably develop (no/complex) adaptations.
b) The flowers of a species A are pollinated by X_1, X_2 ....X_n insects; and an insect species X pollinates a large number of flowering species A,B,C......and so on. Such plants and pollinators exhibit (closed/loose) relationships.
c) The (birds and bats/beetles) are considered to be primitive pollinators.
d) (Wind/insect) pollinated flowers usually have brightly coloured, showy flowers along with a number of attractants.

e) Flowers pollinated by (bees/beetles) have their stamens and pistils grouped. This helps the vector to simultaneously pick up pollen from a flower as well as deliver pollen from other flower to it.
f) A long, narrow corolla tube is an (attractant/deterrent) for hummingbirds.
g) (Butterflies/carpenter bees) are exclusive nectar suckers.
h) Pollinivory is beneficial for the pollinators like (beetles/birds).

10.4 SPECIFIC POLLINATORS AND THEIR BEHAVIOUR

Now that you have learnt something general about various pollinators, let us learn a few details about specific pollinator types.

10.4.1 Bees

Various kinds of bees are important pollinators of several plants. Typical bee flowers have a mint-like smell and provide nectar, pollen, or both to the visiting bees. They are usually bright yellow or blue and open during the day. They often possess **honey guides** in the form of colour or smell patterns, and some have a large, broad, lower petal which serves as a landing platform for the bee. Usually, during one bee visit, the flower both receives and delivers a pollen load. The pollen grains are sticky, spiny, or sculptured. The honeybee leaves its hive in the spring and brings back a pellet of pollen upon each trip, usually obtained (in temperate areas) from the alder or the swamp willow. Bees usually get their first supplies of pollen from the catkins of willows. If even one catkin opens anywhere within range, a bee is available that very hour to exploit it for its fresh pollen. Carrying the pollen load to the hive, the bee advances to a cell and unloads the pollen basket by kicking it off, by brushing one foot against the other. This bee then walks off but another bee, resident within the hive, comes along and rams the pollen load down with her head and packs it into the cell.

One of the most fascinating observations is that honeybees, collecting nectar or pollen, are attracted by the flower's vivid colours. Bees can readily be conditioned to a coloured disk put under a watch glass containing some scented sugar solution; on subsequent visits they reliably choose it from among other simultaneously presented colours. When visiting flowers of a particular kind, bees similarly become conditioned to their colours and selectively respond to them as long as nectar is available. Bees cannot see red but can respond to ultraviolet radiation emitted by some flowers including red poppies. In view of the facility for switching colour preferences, which is required for a forager's change from an exhausted crop to a fresh one, it is unlikely to find that bees leaving the hive for the first time show an innate preference for yellows and blues; even more remarkable is the fact that inexperienced bees recognize at least some honey guides and probe with their extruded proboscis as if they 'expected' to find nectar nearby. In one experiment, suitably cut yellow petals of *Oenothera biennis* were presented in two arrangements under a UV-transparent foil. As seen in Figure 10.3, most probing reactions were aimed at the small regions drawn black, which reflect little UV and which normally lie in the flower's center, close to the source of nectar. Such predispositions for responding selectively to particular stimuli the first time they are encountered, are said to be innate, to indicate that they are not acquired through experience of the stimuli.

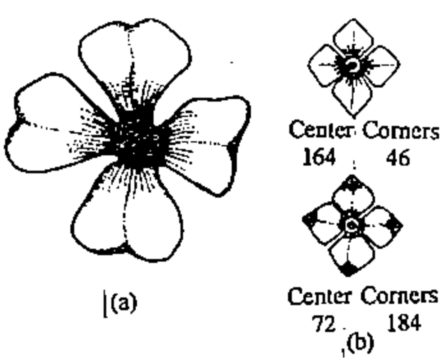


Fig. 10.3: a) *Oenothera biennis*, a photo taken through a UV filter; UV-free regions appear black. b) UV-free regions act as honey guides eliciting probing reactions in inexperienced bees. Top, normal arrangement; bottom, reversed arrangement of cut up petals under UV-transparent foil. The number of probing reactions of bees recorded in an experiment is indicated in the figure. (After Daumer, 1964).

The Waggle Dance of the Honeybee: When a bee locates a source of nectar or pollen, she conveys that finding to other individuals by means of what is called a 'waggle dance' (Fig. 10.4b). The scout who has found the new source, returns to the hive and recruits foragers by means of this very fascinating type of dance. It was this observation of Karl Von Frisch over 50 years ago that earned him the Nobel Prize. You would be interested to know more about this dance which conveys a lot of information about the food source location to the other bees. When the food source is near the hive, the scout performs a round dance (Fig. 10.4a) in which it describes a series of circles on the comb, alternating between clockwise and anticlockwise directions after every one or two circles. Some of the nearby bees follow the manoeuvres of the forager and, every now and then, the dancing bee regurgitates a drop of nectar from its stomach, offering it to the nearby bees. The dance also alerts the following bees to the presence of a rich source of food; they learn its odour from the lingering odour of the flowers still adhering to the dancer's body and also from the odour of the food regurgitated by the dancer. This information enables the bees to leave the hive in quest of food of the correct odour in its vicinity. The rate of the dance conveys to the hive mates the approximate distance of the new food source. The angle of the waggle indicates the direction of the food. Since the scout bee is dancing on a vertical comb, she must use a reference point that can be seen by the bees during flight. That point is in fact, the Sun. If food is located towards the Sun (e.g., eastward of the hive in the morning), the wagging portion is straight up on the comb. When the food is 20° to the right of the Sun, then the wagging will be 20° to the right of the straight up. These features are illustrated in Fig.10.5.

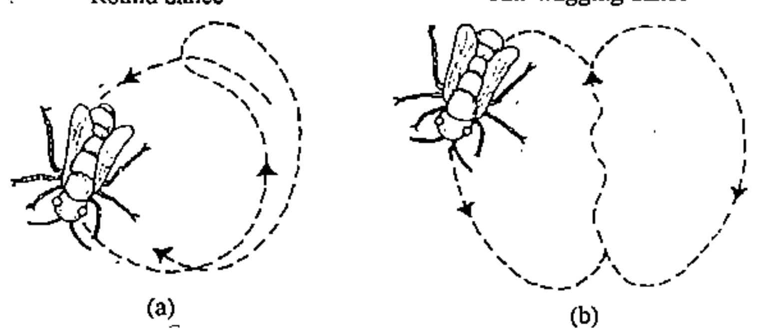


Fig. 10.4: Two types of dance performed by the honeybee. (a) round dance; (b) tail-wagging dance.

The Dance Language of Honeybees

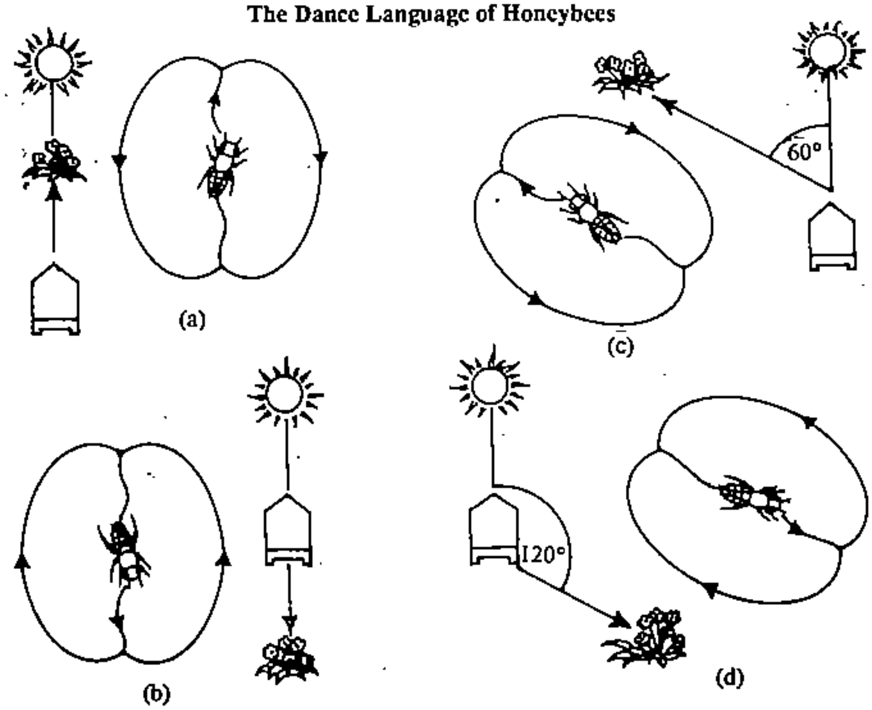


Fig. 10.5: (a-d) The sophisticated 'waggle dance' performed by scout bees informs fellow workers of the precise whereabouts of a food source. Assume that the top of this page represents the top of the hive, a few examples of the dance are shown in the figure. If the food source is found by flying towards the Sun from the hive (a), then the 'waggle' part of the figure of eight routine is danced in an upward direction. Diagrams b,c, and d show respectively the orientation of the dance if the food is directly away from the Sun, at 60° or at 120° from it.

Even in the dark a scout honeybee can indicate the distance and direction of a newly found, rich food source. She signals to her hive mates by means of a figure-of-eight dance. This is performed on the vertical face of the comb. When the bee moves through the middle of the 8 she gives a number of tail wags, quickly when the food source is nearby and more slowly when it is farther away. For example, for a food source a mile off, she gives four wags. The dancer also adds a wind correction. Flying into a headwind requires more effort, so the bee indicates a distance slightly greater than the real one. To indicate the direction of the food source, the Sun is used as a beacon. If the middle part of the dance is exactly vertical and the bee is going up (Fig. 10.5a), and down (Fig. 10.5b) they must head away from the Sun. A dance at an angle of 60°/120° to the left/right of vertical (Fig. 10.5c,d) signifies that the bees must follow a direction that forms the same angle (60° or 120°) with the line connecting the hive and the Sun. Considerable time is needed to reach a distant food source and in the meantime the Sun moves. The dancing bee makes a correction for this also. However, the dancer cannot indicate the height of the food source and her hive mates are confused when a food source is hoisted on a pole directly above the hive.

Other Attractants for Bees

Flowers not only offer nectar and pollen but also several other products to their insect pollinators; these include volatile substances, lipids, waxes and resins. Many plant genera belonging to families Iridaceae, Krameriaceae, Malpighiaceae, Orchidaceae, and Scrophulariaceae possess specialized oil-secreting organs called **elaiophores** (Fig. 10.6). Some plants belonging to Cucurbitaceae, Solanaceae and Primulaceae have 'oil-flowers'. These are particularly abundant in tropical savannas. Table 10.3 lists representative examples of oil-collecting bees and their "oil- host" plants. 'Oil-flowers' are visited by certain groups of specialized bees (Hymenoptera : Apoidea). Some 'oil-bees' use the lipid secretions in place of nectar in their pollen provisions for larval development. Others make use of oils for making water-proof linings for their hive cells.

Table 10.3: Bees that have structural modifications for harvesting and transporting floral lipids.

Oil-collecting bees		Oil-host plants	
Genera	Family	Genera	Family
Macropus	Melittidae	*Lysimachia*	Primulaceae
Rediviva	Melittidae	*Anastrabe, Diascia*	Scrophulariaceae
		Disperis	Orchidaceae
Ctenoplectra	Ctenoplectridae	*Momordica*	Cucurbitaceae
Centris	Anthophoridae	*Krameria*	Krameriaceae
Chalepogenus	Anthophoridae	*Cypella*	Iridaceae

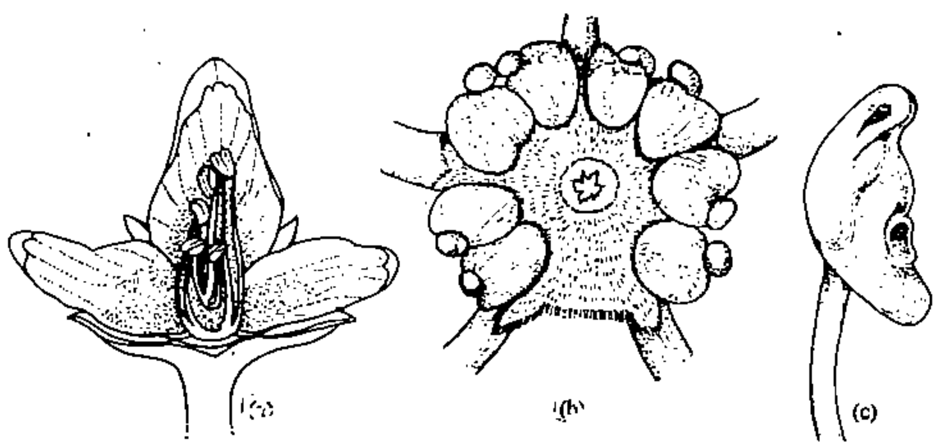


Fig. 10.6: Elaiophores (oil-secreting glands) from some angiosperms. a) Trichome elaiophore of glandular hairs on stamens and petals of *Lysimachia quadrifolia*. b) *Callaeum macropterum*, abaxial part of flower with pedicel and petals removed. Eight elaiophores are seen as lipid blisters. c) *Mouriri myrtilloides*, an anther having epithelial elaiophore as deeply concave gland.

Some other angiosperms bear flowers which have conspicuous secretory glands - elaiophores, e.g., *Karmeria* sp. Two distinct types of elaiophores can be distinguished:

i) Epithelial elaiophores, constituting small areas of secretory epidermal cells in which the secreted lipids accumulate below the thin cuticle (Fig. 10.6b) as seen in Krameriaceae and Malpighiaceae.

ii) Trichome elaiophores, consist of thousands of glandular trichomes which secrete lipids (Fig. 10.6a). These are found in the families Cucurbitaceae, Primulaceae and Solanaceae.

Some bees resort to characteristic abdominal movements such as wagging or downward rubbing, to mop up oil. Some Ctenoplectrid female bees have a crescent shaped inner hind tibial spur used for squeezing oil. *Macropus labiata* and *M. fulvipes* collect oil from flowers of *Lysimachia vulgaris* and *L. punctata* by clinging to filaments, while curled around anthers. They absorb oil from the glandular trichomes by dabbing and mopping it with their front and middle legs alternately within each pair. No mouth parts are involved in oil collection. The bees, of course, become dusted with pollen during the oil-mopping operation.

Some flowers, e.g., *Cyclanthera* (Cucurbitaceae), bear glue-producing anther hairs which facilitate pollen adhesion to bees.

Box 10.1: Economic Use of Pollinators

Bees besides being used as the source of honey, are also employed by many countries to enhance crop yield. This potential needs to be tapped in our country too. Had the services provided by bees been properly utilized or managed, our country would have become self-sufficient in oilseeds and other crops. Most pulses and oilseed-yielding plants are self-sterile. They depend on agents such as wind, insects or water to facilitate pollination. Bees, in such cases, could become important pollen transfer agents.

Field trials in Punjab have shown that proper placement/ siting of bee hives in sunflower fields can produce yields 300 per cent in excess of the average yield. Some other crop which could benefit by this technique are onions. beans, coffee, alfalfa, grapes, orange, litchi, apples and plums.

Besides aiding in pollination, bees can also be employed as sensitive biological detectors for pollutants. Bees can be effectively trained to carry out the above jobs efficiently.

10.4.2 Wasps

A close interdependence exists between the life cycle of the fig, *Ficus carica* and its pollinator wasp, known as the fig-wasp (*Blastophaga psenes*). Two types of fig trees have been recorded: one which produces edible figs, and the other which bears only small, hard, inedible fruits. the latter type of fruit is a sort of an incubator in which the larvae of the wasp develop.

In a developing fig inflorescence, the male flowers are situated near the pore, and the female flowers line the rest of the cavity. The female flowers have pistils with short styles. The female wasps enter the inflorescence through the pore and deposit eggs in each ovary. The eggs give rise to larvae which then develop into wasps. The wasps eat their way out of the ovaries, and mate within the immature fig. After mating, most males die but most females escape through the pore, and in the process become dusted with pollen from the male flowers. While out of the fig, the females start searching for ovaries of fresh edible figs. This inflorescence has only female flowers whose pistils have long styles. In this situation the wasp cannot oviposit (because of the very long styles) but it does succeed in effecting pollination. This inflorescence in due course matures into an edible fruit containing many seeds. As for the other females, after mating they sooner or later encounter inedible inflorescences, deposit their eggs, and repeat the above cycle.

You may perhaps be surprised to learn that a single branch of an inedible fig can be grafted on to an edible fig tree. This can provide sufficient pollinating wasps for the whole tree.

10.4.3 Bumblebees

An important problem that confronts the *Bombus* foragers (bumblebees) is to select the most rewarding flower species from the many that may be available in a habitat. These foragers appear to begin their foraging careers by visiting several different plant species and then concentrating on the most remunerative species. .

There has been considerable work on the influence of nectar resources on pollinator behaviour and flower choice but little work appears to have been done to identify the linkages between nectar resources and plant reproductive success. In a shrub-swamp community, interspecific differences in average nectar production can be a predictor of relative visitation rates by bumblebees. However, fruit set is seldom pollination limited even in nectar-poor species because they have long-lived flowers, self-pollination, or alternative pollinators.

Temperature and other physical factors greatly affect the foraging activity of bumblebees. The foraging activities of bumblebees are usually low around noon relative to those in the morning or evening, probably due to the higher concentration of nectar around noon than at other times in the day. Bumblebees seem to avoid flowers having too high a concentration of nectar. In general, smaller bees appear to be more efficient foragers on short-corolla flowers.

10.4.4 Birds

Birds are good pollinators in tropical areas. Over a thousand species of birds visit various kinds of flowers to feed on insects, nectar, or pollen. The bills of pollinating birds (Fig. 10.7) are usually slender and curved, corresponding to the shape of the corolla tubes of the flowers visited.

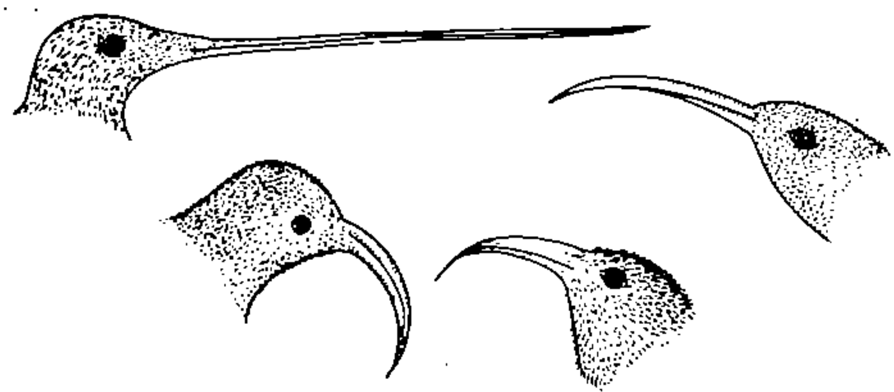


Fig. 10.7: Shapes of bills of four nectar-feeding birds.

A few examples of pollinating birds are hummingbirds, sunbirds and brush-tongued parrots (Fig. 10.8).

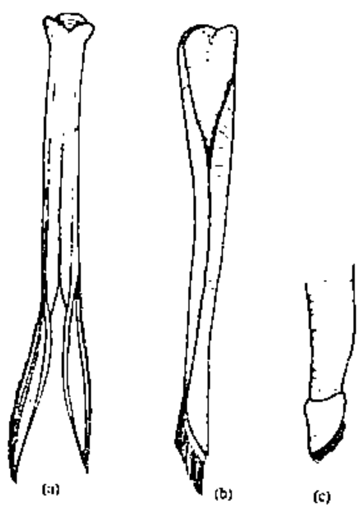


Fig. 10.8: Tongues of three bird pollinators. Note the tube-shaped tongues. a) hummingbird; b) nectar bird; and c) parrot.

Most birds have a good colour sense and excellent vision but have poor sense of smell. Hummingbirds are strongly attracted by red or orange coloured flowers. In general, bird-pollinated flowers are bigger than insect-pollinated flowers, and they open during the daytime. They usually have an inferior ovary which protects the ovules against the probing bill. The stamens brush against the head or breast of the visiting bird. In many Asian bird flowers, the birds do not hover and the flowers have a landing platform or lip on which the bird alights. The plants relying on bird pollination are known as **ornithophilous**. These include *Fuchsia*, *Hibiscus*, and many species belonging to the families Orchidaceae, Fabaceae (Leguminosae) and Cactaceae. The Indian coral tree (*Erythrina*) is mainly pollinated by parakeets and woodpeckers. Its flowers have a nontubular corolla facing a perch, with copious, sugary nectar. Species of *Bignonia* are pollinated by hummingbirds.

10.4.5 Molluscs

Flowers of *Aspidistra lurida*, *Chrysanthemum leucanthemum* and some Araceae are pollinated by snails and slugs. These flowers are described as **malacophilous**.

10.4.6 Bats

Bat pollination – **chiropterophily** is fairly common in the tropics. *Glossophaga* and *Macroglossum* virtually obtain all their food, nectar and pollen from flowers. Bat pollinated flowers are large, strong, dull and drab, and bell-shaped with a wide mouth. The bats locate the suitable flowers by the strong smell they emit, which is, usually rancid or musty. During feeding, their heads become dusted with pollen which is lodged on other flowers when the bat visits them. Some examples of bat-pollinated plants are species of *Agave*, *Areca*, *Kigelia*, *Adansonia*, *Parkia*; and *Cobaea scandens*.

10.4.7 Moths and Butterflies

Most flowers pollinated by butterflies open during the day. They are fragrant and may be white or brightly-coloured. They have a platform on which the visiting butterfly can alight. Most moths are nocturnal and the flowers pollinated by them, e.g., evening primrose and honeysuckle, are light-coloured, and they open during the evening. Hawkmoths are usually stout-bodied, fairly big insects which have streamlined body and are good fliers.

Most Lepidoptera have a long, flexible and thin proboscis which acts as a sucking tube. It remains coiled up when these insects are not sucking nectar from flowers. The latter likewise have a long, narrow corolla tube. This kind of tube is an adaptation to Lepidoptera but discriminates against other, shorter-tongued insects. These flowers produce abundant nectar, often in a hollow spur.

Flower of *Yucca* can be pollinated only by the *Yucca* moth (*Pronuba yuccasella*) and by no other animal. The female moth lays her eggs only in the ovary of the *Yucca* flower. When the moth visits a flower to deposit eggs, it carries with it a ball of pollen gathered from other *Yucca* flowers. After laying the eggs, the female deposits the pollen ball in a pit at the tip of the pistil. After some days the eggs hatch into caterpillars that consume some of the developing seeds but leave others intact. Thus both, the plant and the animal depend on one another for their survival and multiplication.

The butterflies that pollinate the flowers of *Caesalpinia* spp., carry their pollen on their wings. These butterflies flutter their wings while on the flower. The fluttering is conducive to pollen deposition on the wings, and then on the stigmas of other flowers that are visited later.

SAQ 3

Complete the blank column in the table given below. Write about the characteristic floral features, pollinator behaviour or any other interesting aspect, against each pollinator type.

S.No.	Pollinator Type	Peculiar Pollination-related Features
1.	Bees	
2.	Wasps	
3.	Bumblebees	
4.	Birds	
5.	Bats	
6.	Moths/Butterflies	

10.5 FLOWER – POLLINATOR COEVOLUTION

Coevolution may be defined as an evolutionary change in a trait of the individuals of species X in response to a trait of the individuals of species Y, followed by an evolutionary response by the species Y to the change in species X. It involves mutually adaptive or reciprocal changes in populations of different species.

Several examples of the coevolution of flowering plants and their insect pollinators are known in which each partner, that is the plant and the insect, has adjusted its life style to that of the other partner with a view to living together for mutual benefit.

The coevolution between a plant and its pollinator may be fairly loose or may be quite tight. As mentioned earlier, there are several plants which are served by a diversity of pollinators. These plants exemplify **loose coevolution** in the sense that one plant species has several pollinator species.

Euglossine bees appear to have coevolved with euglossine orchids. The latter seem to hav adapted to these bees, as these have evolved different floral fragrances which help attract these pollinators. Each euglossine orchid species has some characteristic combination of fragrant compounds. Only a particular species of euglossine bee is attracted to a particular species of the orchid depending on the particular fragrance. The bees collect the particular fragrance which enables them to signal the male bees of their species. Several males form small group that swarms together and attracts the females for mating.

A good example of coevolutionary interdependence between a plant and its pollinator is that between *Brassica rapa* and *Apis mellifera*. If you dissect the honeybee and the flower of *B. rapa*, you can observe the intimate relationship between the bee and the flower. Following the dissection, you may also explore the remarkably efficient pollen-collecting ability of the bee by making a bee-stick from the dead bee and use it as a pollinating device for the plants.

There are certain plants that support only one or a few important taxa of herbivores. Thus *Passiflora* spp. mainly support butterflies belonging to the genus *Heliconius*. These butterflies lay yellowish eggs on the plant's leaves. But during the course of insect-plant coevolution, structures resembling the yellow eggs seem to have arisen independently in species of *Passiflora*. These plant structures are thought to have evolved specifically to mimic the butterfly eggs. The female butterflies discriminate against plants with eggs (or rather the structures which look like eggs) and therefore tend to act as selective agents in the evolution of these egg-like structures. This response of *Heliconius* females to the presence of egg-like structures has mainly or wholly a visual basis. The *Passiflora-Heliconius* system constitutes a good example of a plant structural characteristic resulting from coevolution with a host-restricted group of insect herbivores.

The most specialized example of coevolution is the relationship between a single species of plant and a single species of animal, e.g., *Yucca-Pronuba* moth relationship. This moth (Fig. 10.9) transfers pollen to the stigma of the *Yucca* flower and lays eggs in the ovary. The developing larvae feed on some of the seeds produced as a result of this pollination. The relationship between the moth and the plant is strict and obligate.

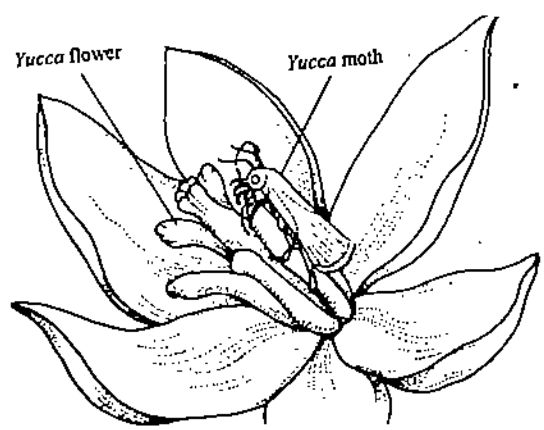


Fig. 10.9: *Yucca* moth pollinating *Yucca* flower.

Nectar has been an important factor in the coevolution of flowers and their pollinators. The amount of nectar secreted, the rate of secretion, cessation, or restoration govern the flower-pollinator relationship. The commencement of nectar secretion synchronizes with the start of activity of the pollinator. In several instances it is almost a few hours before the co-evolved pollinator becomes active.

The foraging behaviour of butterflies and other pollinators depends on their evolutionary stage. The previous foraging experience of the butterfly, in addition to external factors such as sunshine, wind, and temperature can significantly modify the foraging behaviour. This behaviour is, of course, also influenced by the shape, colour, height and abundance of the flowers.

There are considerable variations in the time spent on flower visit. Most butterflies spend an average of about 30 seconds on one blossom. *Xois actova* and *Crassida crassida* spend very little time on any single flower, whereas *Acrea andromaca* tends to spend fairly long period in a flower. Most butterflies, while landing on a flower, fold up their wings vertically erect at the time of nectar feeding.

Sometimes coevolution involves more than one step in the food web. An interesting situation is seen in the monarch butterfly *Danaus plexippus*. This species is unpalatable to vertebrate predators. It can sequester some toxic glycosides present in milkweed plants, thereby providing an effective defense against bird predators. In fact this butterfly can not only feed on a plant that is unpalatable to other insects, but it also uses the plant toxin for its own protection against predators.

Floral nectaries produce nectar whose adaptive significance lies in its attractiveness to potential pollinators for whom nectar is a source of energy-rich diet. Some nectars are particularly rich in sugars as well as amino acids. The predominant sugar in some nectars is sucrose whereas in other nectars the sugars are glucose plus fructose, and in still others the three sugars are more or less equal. Sugar-rich nectars also tend to be rich in amino acids. The important amino acids found in nectars include the 'essentials' : arginine, histidine, lysine, tryptophan, phenylalanine, methionine, threonine, leucine, and valine; the semiessentials: serine, glycine and proline; and the 'common ones': alanine, aspartic acid and glutamic acid. Nectars of most butterfly-pollinated flowers are particularly rich in the common amino acids and also in serine, glycine, histidine and lysine. Those of bee-pollinated flowers are found to be rich in serine, aspartic acid, glutamic acid, glycine, histidine and lysine. Flowers chiefly pollinated by moths, flies, birds, and other animals usually contain smaller amounts of most amino acids.

Nectars rich in amino acids also usually contain detectable amounts of some lipids and/or antioxidants. Some examples of flowers that contain lipids in their nectar are *Abronia latifolia*, *Callistemon* sp., *Jacaranda ovalifolia* and *Trichocereus* sp. Antioxidants (including ascorbic acid) occur in the nectars of, e.g., *Oenothera*, *Eichhornia*, *Datura*, *Lilium* and *Centaurea*.

Most constituents of nectar, particularly sugars, are of nutritional value to the consumers. Amino acids are good sources of food for several insects. Bees and flies can digest and assimilate the lipids in nectar. Occasionally, nectar contains alkaloids, non-protein amino acids and glycosides. These may be protective, favouring continued flower visits by more efficient pollinators through deterrence of less favourable ones.

Brightly coloured and/or scented flowers attract insects to the nectar and pollen. An interesting question that arises in the context of animal-plant coevolution is whether natural selection or coevolution has forced the pollinators to increase the frequency of their visits to the flowers? Bumblebees seem to learn to forage from the specific flowers from which they have been rewarded in respect of food.

Some bees forage upon a diversity of flowers available at a given time. Since these flowers differ morphologically, a bee must adopt different patterns of behaviour in order to be able to obtain the nectar and pollen from such flowers. Each flower has to be manipulated in a different manner in order to get at and extract the food. The flowers of *Solanum dulcamara* are vibrated forcefully to release the pollen from the tubular anthers. A bee must approach and enter a tubular passage in the flower of *Impatiens biflora* from a specific direction in order to obtain nectar. In fact, it appears that these flowers are actively sought out by the bees even when the flowers are usually dispersed, presumably because they offer good food reward to the bees. The flowers of *Iris versicolor*, *Vaccinium* sp., and several other genera must be approached and entered, each in a different and specific manner, and all these specific approaches appear to be learnt in the course of time.

Another important factor affecting the frequency and extent to which bees are rewarded is their tongue length (Fig. 10.10). Long-tongued bumblebees can visit more flowers with a long corolla tube than the short-tongued ones. The foraging preferences of bumblebees may be linked with the ease with which the nectar is gathered from the flowers.

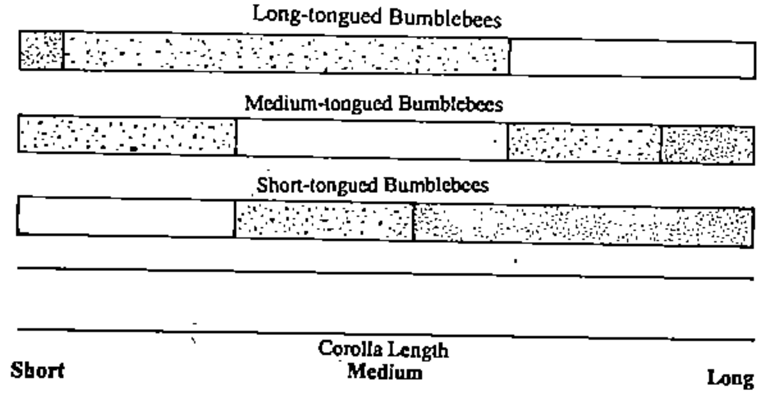


Fig. 10.10: Model showing the processes that produce a correspondence between a bumblebee's tongue length and the range of corolla lengths of the flowers visited by it.

☐ = range of corolla depths most preferred.

▒ = range of corolla depths less preferred due to low net energy intake rate caused chiefly by the absence of other bees.

▓ = Morphological limit: tongue too short or too long.

10.6 LEGITIMATE POLLINATORS vs ILLEGITIMATE VISITORS

All insect visits to flowers do not necessarily bring about pollination. The unsuccessful visits constitute a kind of floral larceny and the illegitimate visitors may be classified into 'thieves' and 'robbers'. The former only remove those resources which would normally be used by the legitimate pollinators. Some examples of such non-pollinating thieves include certain ants, thrips and other small insects. The robbers, on the other hand, not only rob their host of nectar but also injure floral tissue. Such robberies usually occur in sympetalous flowers which are structurally adapted for a pollinator. Some examples of robbers include certain bumblebees and *Xylocopa* spp. The example of 'lemon bee' found in Central America also called the 'robber bee', (*Lestrimelitta limao*) is cited below. The workers of lemon bee lack the corcubilae or other pollen carriers, and hence must attack and rob other colonies to survive. The robber's strategy consists of the use of enlarged mandibular glands that secrete a strong lemon smell; this lemon smell masks and suppresses the typical smell of the attacked colony. Of course, the latter colonies post some guard bees which prevent the invaders or robbers from gaining entry into the colony; the guards recognize their own species by means of the characteristic smell. When a few strange bees - the robbers, forcibly enter the hive they are killed by the guards, but during this process, the strong lemon smell spreads, thus making it impossible for the guards to perceive the characteristic scent of their own species; they can no longer act as guards. The result is that more robber bees freely invade the hive. In fact the lemon fragrance released by the first few robbers helps attract other members of the robber bee to the conquered colony.

Nectar-robbing insects deprive the legitimate pollinator of its share of nectar and do not play any direct role in pollination. However, they compel the pollinator to visit several flowers in search of nectar and, hence, indirectly promote pollination by the legitimate pollinator. Indeed, if the robbers were not to rob the nectar, the pollinator's needs for nectar would be satisfied by one or a few flowers only and it would then not be inclined to go to other flowers. Some butterflies can function as nectar robbers in some legumes but as legitimate pollinators in some others. Ants have been shown to act as nectar robbers in the butterfly-pollinated flowers of *Asclepias currassavica*. Some species of bumblebees are **primary nectar robbers**. They forcibly extract nectar by boring holes into the bases of corolla tubes. Other species are **secondary robbers**. They extract nectar through holes that have been bored by the primary robbers. Nectar-robbing bumblebees are effective self-pollinators for the autogamous plant *Pedicularis palustris*.

In the context of robbery or theft, it is interesting to note that, unlike bees, bumblebees are secretive and individualistic and do not communicate or advertise their finding of a good source of food to other individuals. In this respect, they contrast with bees which do advertise their finding to their hive mates.

7 DECEPTION OF FLOWER VISITORS

:ption is well-known in pollination biology, especially with respect to insects have weakly developed discriminatory faculties. The flowers of some plants interesting, even clever, deceitful tendencies. In these, true edible pollen mes replaced by attractive yellowish dummies which detract the pollinator's ition away from the relatively scarce fertile pollen. The fertile pollen tend to a cryptic colour. Note that in this process, the plant is deceiving the insect and /ice-versa.

orchid *Cypripedium calceolus* resorts to a similar deception with a view to alluring . Of the bees that are so deceived and wrongly attracted, some merely alight whereas rs are trapped but escape via the entrance. Medium-sized *Andrena haemorrhoea* ıle bees extricate themselves through the exit pores, thereby facilitating pollination ng the manoeuvre. *Himantoglossum* and *Barlia* are two other examples of orchids :h allure their pollinators by deceit.

e flowers emit deceptive odours like that of mushrooms. The deceptive odour eads the female flies to lay eggs on these flowers, which become pollinated during process. Other flower species entrap insects for pollination, holding them prisoner l such time that they have done the service!

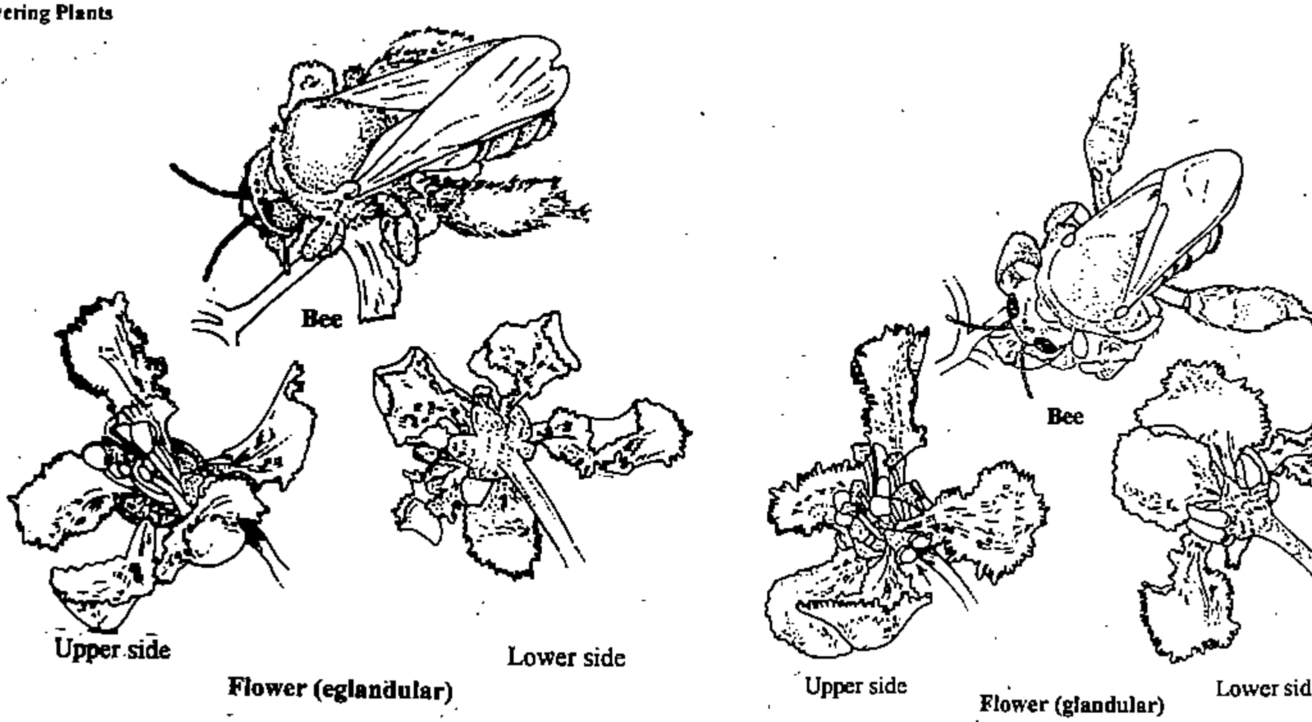
ain tropical plant species produce staminate flowers that provide some reward tar, pollen or both) but the pistillate flowers of the same species do not provide such ırds, hence they are deceptive to the flower visitors. Its well known example is *ica papaya.*

visiting behaviour of oil-gathering anthophorid bees on eglandular morphs of *isteriopsis muricata* and *Heteropterys aceroides* (both genera belonging to ily Malpighiaceae) is very interesting. The bees land on eglandular flowers . 10.11) apparently by mistake as suggested by their making one to a few pings on landing, and behaving in the same way as they scrape oil glands on ıdular flowers (Fig. 10.12). Once they realize their mistake, the bees either e the eglandular flower or start concentrating their attention on collecting en. When the large sized species of the bee genus *Centris* leave the flowers r realizing their mistake, the smaller-sized species of the same genus turn their take into a rewarding visit by switching over to pollen gathering exercise. andular flowers of both the above species thus attract oil gathering *Centris* spp. leceit. This raises the question of how do the eglandular flowers achieve ination. Evidence suggests that pollination depends mainly on the opportunistic, ed, oil-cum-pollen gathering behaviour of the deceived bees as in the case of *:haris schrottkyi.*

udocopulation: This occurs in some orchids as a device to ensure cross pollination. *irys*, a tiny orchid, found in Europe, Africa and the Middle East, has evolved a bizarre of attracting its pollinator - a male wasp. The petal shape and colour, and smell of orchid are very similar to that of a female wasp.

male wasp is attracted to the flower and adopts a copulating posture on it, ch is remarkably well-adapted to this kind of deceit. The copulating male eby loosens the orchid's pollen sacs, which stick to its body. When the male away, it carries the pollen to another flower where it makes another attempt opulate, this time inadvertently pollinating or fertilizing the flower. ıdocopulation of wasp with orchid is an instance of great specialization. vever, while the benefit to the plant is considerable, that to the wasp is not wn.

ıe above case, the wasp influences the reproduction of a plant. You may be rised to know that there exist some flowers which influence reproduction of bees. is the converse of the above relationship. They emit odours that attract a solitary which not only pollinates the flower but also helps lone male and female bees find ı other!



Figs. 10.11 & 10.12: Upper and lower sides of eglandular (Fig. 10.11, on the left-hand side) and gland (Fig. 10.12, on the right-hand side) flowers of *Banisteriopsis muricata*. Arrow sho one elaiophore. (After Sazima and Sazima, 1989).

SAQ 4

Label the following statements as true or false.

a) The relationship between the *Yucca* plant and its pollinator moth is an example of loose coevolution.

b) Nectar production in flowers has no bearing on the plant-pollinator relationship.

c) Physical factors like wind velocity, temperature and sunlight influence the foragir behaviour of the pollinator butterflies.

d) Nectars are mainly sugar-containing compounds.

e) Some kinds of butterflies are nectar robbers in some plants, whereas some are legitimate pollinators in other plants.

f) Bumblebees exhibit opposite behaviour as compared to the bees regarding the communication of the source of food.

g) The pollinators exhibit several interesting, clever and deceitful features.

h) Pseudocopulation, seen in some orchid flowers, aids in accomplishing pollination

10.8 SUMMARY

In this unit you have studied that:

- During pollination, the pollen grains are brought over to the stigmatic surface by various kinds of living and non-living vectors. Cross pollination is advantageous tc plants in many respects. The resultant offsprings are better adapted for survival in a wide range of environmental conditions. Self-sterility, dichogamy, heterostyly and dicliny are the common devices to encourage cross-pollination.
- Flowers have developed attractants in the form of bright perianth, nectar, unique smells and resins for their respective live-pollinator(s). They also possess various kinds of physical, chemical and biological deterrents to the non-pollinating casual flower visitors. Nectar, pollen grains and energy in the form of heat, and antibiotic-containing substances are the rewards for the pollinators.
- Different species of plants have one or more specific pollinators. The common pollinator categories are bees, wasps, bumblebees, molluscs, birds, bats, moths or butterflies. The plants during their evolution have developed appropriate pollinator attraction and reward systems, along with developing floral features to effect pollination.

The plants and their pollinators have co-evolved closely.

In addition to the pollinators, several other insects too visit flowers, and have definite strategies to get the benefit of floral resources that are actually meant for the pollinators.

Some flowers by practising deception on the flower visitors some of which have weakly developed discriminatory faculties, achieve successful pollination.

.9 TERMINAL QUESTIONS

List the common adaptations found in angiosperms that prevent or minimize self-pollination.

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'Flowers have coloured petals in order to attract insects'. Discuss this statement. How would you determine whether or not the colour of flowers plays any role in attracting insects?

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Flowering plants show several adaptations to the type of pollinators. Just by observing an unknown flower and/or dissecting it, can you make an intelligent guess as to the probable identity of its pollinator? Repeat this exercise for ten different flowers in your locality, and record your results in a tabular form.

4. Compare the behaviour of a honeybee with that of a bumblebee when they con across some new and rich source of food.

5. What type of symbiotic relationship occurs between honeybees and flowers? Ho does it differ from other types of symbiosis?

6. *Yucca* flowers can be pollinated only by the pronuba moth whose female deposits eggs in the ovary at the time she stuffs pollen into the hollow style. The larvae consume some of the developing seeds as food. The two species are quite interdependent on one another for reproduction. Discuss the problems involved ir the origin of such a symbiotic relationship by evolution, and the possible types of interrelations between the ancestors of the *Yucca* and the moth.

7. Angiosperms and insects are highly diverse groups of organisms. How might this diversity be stimulated by the many mutual relationships between the two groups?

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10.10 ANSWERS

Self-Assessment Questions

1. a) The male reproductive unit of the flower - its sperm; the female reproductive unit of the flower - its egg cell; and the vector, if any, of pollination.
   b) Hint: Pollination is an essential step in the sexual reproduction in plants, that eventually leads to the development of seed.
   c) No. It can be accomplished at the time of anthesis of the flower.
   d) Hint: It brings in genetic heterogeneity. This helps in making the offsprings more vigorous and better adapted for survival in diverse environmental conditions. Such plants, therefore, show wider distribution as compared to the self-pollinated plants.
   e) See Section 10.2 of this unit; and Section 3.2, Unit 3, LSE-06 Course.

2. a) no
   b) closed
   c) birds and bats
   d) wind
   e) beetles
   f) attractant
   g) carpenter bees
   h) birds

3. Hint: 1. Bees - Floral features: day opening flowers, yellow/blue coloured, honey guides present, nectar/pollen or both as rewards for pollinator. Pollinator behaviour: Waggle dance for communicating about the nectar/pollen source.

4. a) False
   b) False
   c) True
   d) False
   e) True
   f) True
   g) False
   h) True

Terminal Questions

1. See Section 10.2
2. See Section 10.3
3. See Section 10.3, 10.4
4. See Section 10.4
5. See Section 10.4
6. See Section 10.5
7. See Section 10.5

NOTES

Uttar Pradesh
Rajarshi Tandon Open University

UGBY -02
Plant Diversity II

Block

3A

ECONOMIC BOTANY

Unit 11

Cereals and Millets 5

Unit 12

Legumes (Pulses) 40

Unit 13

Fruits and Nuts 65

Unit 14

Vegetables 101

Unit 15

Plant Oils and Fats 137

Unit 16

Sugar and Straches 167

BLOCK 3A ECONOMIC BOTANY

Population explosion in the recent decades has poised an imminent strain on various resources of the world. This has put Economic Botany right in the mainstream of human concerns. In this course, we too have viewed this very relevant branch of botany in a wider perspective. As a result Block 3 that deals exclusively with Economic Botany, has turned out to be bulkier than the other blocks of the course. For your convenience in handling the study material, we have split it into two sub-blocks 3A and 3B.

The most important sources of plant food for man and the animals are cereals. All the cereals belong to the grass family Poaceae. Wheat, maize and rice are more important as they have played an important part in the development of civilizations. Cereals contain a higher percentage of carbohydrates than any other food plants together with a considerable amount of proteins, some fats and even vitamins. Unit 11, the first unit of this block deals with Cereals and Millets. Here wheat, rice and maize that are the main sources of food, have been described in detail. In addition, other cereals like barley, oats and rye have also been dealt with here. The unit provides information regarding the botanical details, origin, cultivation, breeding programmes and uses of all these cereals. *Triticale* the famous man-made grain is also described.

The grain-legume combination has formed an important part of the support system of every major civilization. This holds true for the present times too. Legumes remain the chief source of proteins particularly in the vegetarian diet. Also, the leguminous seeds are rich in carbohydrates and some are even rich sources of oils and fats. The nitrogen-fixing property, easy cultivation, rapid growth, easy storage and transportation due to the low seed-water content are some of their value-adding attributes. The twelfth unit of this course, entitled Legumes (Pulses) is about these interesting and very important group of plants. In this unit you would get detailed information about some widely consumed legumes in our country.

The Asian region is endowed with rich diversity in tropical fruits. It is a seat of domestication and diversification of several major and minor fruits whose over 400 rich species occur here. India grows almost all types of fruit crops ranging from evergreen tropical to temperate deciduous types. Unit 13 deals with the origin, distribution, ecology, botany and uses of various types of important fruits and nuts. In this unit mango, banana, pineapple, papaya, guava, fig, citrus, melons, litchi, pomegranate, apple and pear are described in detail as these are the widely consumed fruits in India. Besides this various nuts such as cashewnuts, pistachio, walnut, almond and chestnut have been described.

Vegetables make a large and varied group of plants of considerable importance in the world's commerce. They rank next to the cereals as source of carbohydrate food. The nutritive value of vegetables is increased greatly by the presence of the indispensable mineral salts and vitamins, while their roughage value aids digestion. Unit 14 deals with the origin, distribution, ecology, botany and uses of our common vegetables such as potato, sweet potato, cassava, onion, garlic, beet-root, carrot, cabbage, lettuce, spinach, cucurbits, tomato, brinjal, chillies and okra. It also gives information about their families and botanical names.

Oil and fat yielding plants constitute yet another important group of plants. These are valued not only for use in food, but also for their wide applications in our day to day life. Their demand has been steadily growing in recent years on two counts: one, many of them serve as raw material in various kinds of industries; two, these are emerging as alternative sources of energy due to the constant depletion of non-renewable energy resources. Next to the food grains the oilseeds the main source of plant oils and fats, constitute the second major category of agricultural produce in India. They are, therefore, of vital importance to our agricultural economy. Unit 15 provides an overview of the plant oils and fats, with special mention of their chemical structure, classification and importance. This is followed by a detailed discussion on the major oilseed producing crops of our country.

Carbohydrates - the primary products of photosynthesis, are one of the major constituents of our food. These are widely distributed in nature as sugars, starches and cellulose and other complex substances. Of these, sugars and starches are easily digestible, and they also provide us the necessary calories. The study of their natural sources that is the plants, is the theme of Unit 16. A number of sugar sources are available world-over. Sugarcane is the foremost source in our country. This source plant has been discussed in detail in the first part of the unit. In the later part, two starch-yielding plants, i.e., potato and cassava are dealt with in detail.

UNIT 11 CEREALS AND MILLETS

Structure

11.1 Introduction
Objectives
11.2 Wheat
11.3 Maize
11.4 Rice
11.5 Rye
11.6 Oats
11.7 Sorghum
11.8 Barley
11.9 Triticale
11.10 Summary
11.11 Terminal Questions
11.12 Answers

11.1 INTRODUCTION

Good food is essential for health as well as survival of human beings. Human beings depend on plants (and on animals that eat plants) for their food. The food we eat provides substances needed for good health. These nutrients provide materials for building, repairing or maintaining body tissues. They also regulate body processes and serve as fuel to provide energy. Nutrients are classified into five main groups: carbohydrates, fats, proteins, minerals and vitamins. All of these are important in the daily diet, and are obtained from different plants.

The cereal or grain crops are the most important sources of food for man and provide the basic or staple diet. They contain carbohydrates, proteins, fats, minerals and vitamins, and thus have good nutritive value. These were amongst the first plants to be cultivated or domesticated. They have been grown and used by man since ancient times. It is believed that barley and wheat were first grown in Western Asia atleast 9000 years ago. This provided the basis for civilisations of Mesopotamia, Sumeria, Babylon, Egypt, Rome, Italy and others. Similarly, rice served as the important cereal for the civilisations in South East Asia and maize for civilisations in the New World.

The cereals not only serve as food for man, but are also important for many industrial purposes. Cereals as well as other grasses are also used as fodder for livestock. Only a few of the more than 10,000 species of the grass family have been domesticated by man.

Interestingly no new species have been introduced into cultivation during the past 2000 years or more.

Besides cereals and millets, there are a few other botanically urelated dicotyledonous plants used as cereals. The buckwheat (*Fagopyrum esculentum*), grain amaranths (*Amaranthus* spp.) and others used to a lesser extent are sometimes called 'pseudocereals.'

Objectives

After studying this unit, you will be able to know the:

- importance of food for health and survival;
- most important sources of plant food;
- close relationship between cereals and man;
- different cereal and millet crops;
- origin and distribution; cultivation; botany; breeding and improvement; uses and other details pertaining to :

  Wheat
  Maize
  Rice
  Rye
  Oats
  Sorghum
  Barley
  Triticale.

11.2 WHEAT

Botanical name: *Triticum aestivum* Linn.
Family : Poaceae
Common name : Gehun
2n = 42, A B& D genome

Wheat is the world's most important food plant for more than one third of the world's population. Hundreds of millions of people throughout the world depend on foods made from the kernels (seeds or grains) of the wheat plant. It is also probably the oldest crop known in cultivation. Long before the beginning of agriculture, people gathered wild wheat for food. It is believed that agriculture originated in the Middle East when wheat was first cultivated in ancient times. There are several archeological evidences to show the presence of carbonised wheat grains at the Neolithic sites in Jarmo in northern Iraq, and in central and north eastern Europe dating back to the period 6750 B.C. to 7500 B.C. These and other observations suggest that wheat spread rapidly and widely throughout Asia and Europe after its domestication in the middle East.

Box 11.1: Cereal

It is interesting to know that the term cereal is derived from the Greek word 'Ceres', which was the Goddess of grain, of harvest, and of agriculture in Roman mythology. She was worshipped by the farmers and the people of Rome for her gifts. A festival called 'cerealia' honoured the Goddess each year from April 12 to April 19. In Japan, the ancient Shinto religion has many special ceremonies dealing with abundant harvest and good health. Here rice is the most important cereal. The festival called 'Baisakhi' (13th April) in northern India is also associated with agriculture and the first grain harvested is offered to the Gods. These and several other evidences show that there has been a very close relationship between the cereals and man since ancient times.

Wheat Production in India (in million tonnes)

92-93	57.2
93-94	59.8
94-95	65.8
95-96	62.1
96-97	69.3
97-98	66.0

There are various kinds of wheat and the most widely cultivated wheat today is called the common wheat or the bread wheat. We owe much to the Russian Botanist Nikolai Vavilov (1887-1943) for our knowledge of wheat. He studied more than 31,000 samples of wheat from different parts of the world to classify the wheats into different kinds. This knowledge was later supplemented with information from cytology, physiology and biochemistry obtained by Japanese and American scientists to provide us valuable data about the wheats of the world. It is therefore necessary to know about the taxonomy of the different wheats. This information will help us to understand the origin and distribution of different wheats.

11.2.1 Taxonomy, Origin and Distribution of Wheat

Vavilov classified the different wheats into 14 species. Other wheat taxonomists recognise either more or fewer species. All the wheats are classified in the genus *Triticum*. This is a member of the Family Gramineae, sub family Pooideae and the tribe Triticeae. The different species of wheat can be grouped into three categories on the basis of their cytology.

Box 11.2: Cytology of wheat

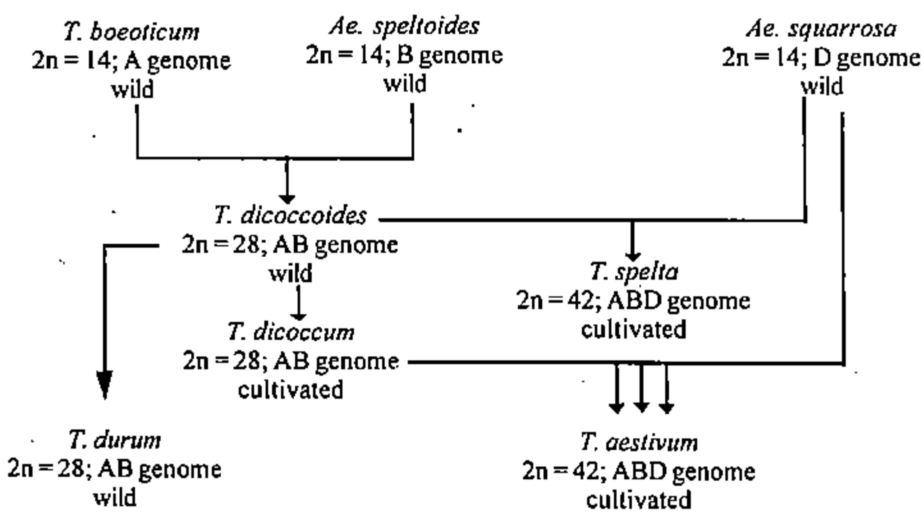
There are diploid wheats having 2n = 14 chromosomes, tetraploid wheats with 2n = 28 chromosomes; and hexaploid wheats with 2n = 42 chromosomes. Detailed cytological analysis of these wheats also revealed that there are 3 different genomes. The diploid wheats have been recognised as having the *AA* genome. The tetraploids and hexaploids are not autoploids (i.e. possessing similar genomes to the diploid). They are alloploids with dissimilar genomes. The tetraploid wheats have the *AABB* genome while the hexaploid wheats have the *AABBDD* genome. This cytological knowledge alongwith other evidences has helped us to know about the origin and evolution of wheat as well as about other grasses which contributed to this evolution.

The oldest known wheat is the diploid wheat. There are wild and domesticated (cultivated) species of these diploid wheats. The wild einkorn wheat is called *Triticum boeticum* Boiss.

This is a diploid wheat (2n = 14 ; AA genome) which was widespread in Western Asia. It exhibits considerable genetic variation. The cultivated einkorn wheat called *Triticum monococcum* L. evolved from the wild type, is also diploid and has the same AA genome. It has been in cultivation since ancient times. These wheats have one grained spikelets, the fruiting stalks are brittle and fragile, and the grains remain firmly enclosed in the glumes. Very little of this kind of wheat is cultivated today.

There are several tetraploid wheats. These have originated by Hybridization between the diploid wheat and closely related wild grasses.They have 2 distinct genomes, the AA component is obtained from the diploid wheats while the BB component was contributed by the diploid grass called *Aegilops speltoides* (2n = 14; BB genome). Hybridization followed by chromosome doubling resulted in the origin of the tetraploid wheats. The oldest known tetraploid wheat is called the wild emmer or *Triticum dicoccoides* Koern. It is found in Palestine and Syria. From this wild emmer, the cultivated emmer or *Triticum dicoccum* Schubl must have evolved by mutation, domestication and selection. Another tetraploid wheat called durum or *Triticum durum* Desf. also evolved from wild emmer. These tetraploid wheats were once widely cultivated in the Middle East. Cultivated emmer is now grown to a limited extent only, but durum is grown extensively in Italy, Spain and USA.

The most common cultivated wheats are hexaploid. *Triticum spelta* Linn. and *T. aestivum* Linn. are amongst the more important hexaploid wheats. A very large number of varieties of *Triticum aestivum* or breadwheat are cultivated in different parts of the world. The evolution of hexaploid wheat may be summarised as follows.



11.2.2 Wheat Cultivation

Wheat is cultivated in a wide range of climates and soils. It is also the most widely cultivated crop of the world. It is grown in areas from 40°S to 60°N of the equator having fairly dry and mild climates. Extreme heat or cold, or very wet or very dry weather is harmful for the crop. Thus, the weather conditions greatly influence the cultivation of wheat.

Wheat is largely cultivated in warm temperate regions having cool winters and warm dry summers. The annual average rainfall of such wheat growing regions should be between 30 and 90 cm. The crop can be cultivated from the plains to altitudes up to 3000m above sea level.

Wheat grows best on fertile clay or silt loams having adequate organic nutrients. The soil must have proper drainage as well as good water holding capacity.

Wheat is grown as a major cereal crop in Russia and its adjacent regions, other European countries particularly France, Germany and Italy and in the United States, Canada, Central and South America, China, India and Australia. It is also grown in Pakistan, Turkey and Egypt. In India, there are two main wheat growing areas: (i) The Indo-Gangetic region with

Punjab, Haryana, U.P., Bihar and parts of Rajasthan; and (ii) Madhya Pradesh, South Rajasthan, Maharashtra, Andhra Pradesh and Karnataka.

The crop grown in India is mainly the winter wheat and both the bread wheat as well as durum wheat are cultivated. It is harvested as soon as possible after the grain has ripened, before bad weather can damage the crop.

Threshers or special combines which harvest and thresh the crop are used to separate the grain from the chaff. The grain is then sent for milling.

11.2.3 Botany of the Wheat Plant

The wheat plant is a typical grass with all characteristic features of the family Gramineae. Young wheat plants are bright green. They turn golden brown when the grain is mature. The plant is an annual with numerous "Tillers" (Fig. 11.1). It has two types of roots; primary or seminal which develop from the embryo; and secondary or coronal which are adventitious and develop from the basal underground nodes of the main axis and the tillers. The primary roots live only for six to eight weeks while the secondary roots represent the permanent root system of the plant.

The main stem as well as the tillers are erect cylindrical structures. Each is made up of 5-7 nodes and grows to a height 0.3 to 1.5m. The lower internodes are short but the upper ones are longer. These are hollow and usually glabrous.

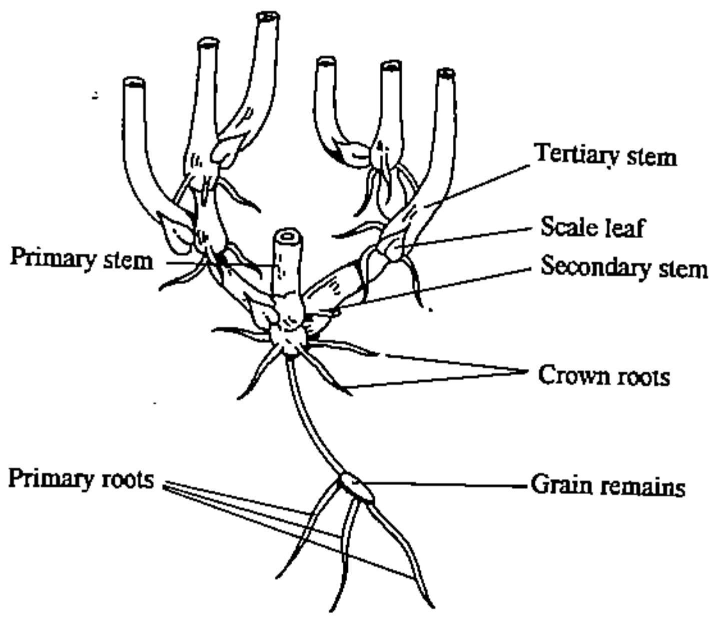


Fig. 11.1: Tillering habit in cereal.

The leaves show an alternate arrangement. Each leaf has a basal sheath. It encircles the stem and forms a complete tube in its lower region. The sheath splits higher up and continues into the lamina or blade. The lamina is flat, long, narrow with an acuminate tip. It shows parallel venation and more stomata on the upper surface. The stomata are characteristic of the family Gramineae having special 'buliform' guard cells. At the junction of the sheath and lamina, there is a colourless membraneous ligule. A pair of auricles are also present at the base of the lamina.

The inflorescence is a terminal spike made up of numerous spikelets. The inflorescence axis is tough and does not shatter (break up) when the grain is ripe. The spikelets are in two rows on alternate sides of the axis. Each spikelet is sessile with 2-5 florets (Fig. 11.2). The spikelet consists of a pair of sterile glumes, a shortened rachilla and 2-5 pairs of fertile glumes. Each pair of fertile glumes consists of an outer lemma and an inner palea (Fig. 11.3 a). These fertile glumes enclose the floret. The apex of the lemma is usually extended into an awn. The floret consists of 2 lodicules which represent the perianth and regulate the opening of the flower. There are 3 stamens with slender filaments and bilobed versatile anthers (Fig. 11.3 b). The gynoecium is monocarpellary (or according to some taxonomists tricarpellary syncarpous) with a superior ovary and 2 terminal styles having feathery stigmas. There is a single ovule.

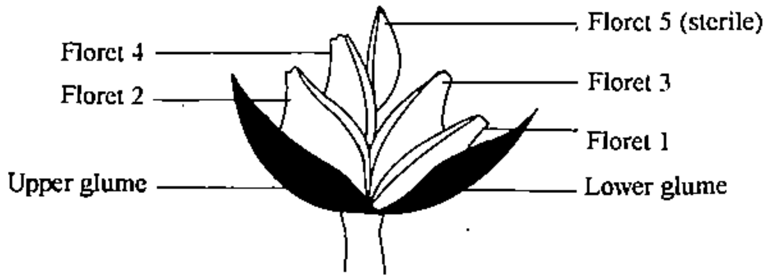


Fig. 11.2: Spikelet of wheat showing glumes, florets and floral parts.

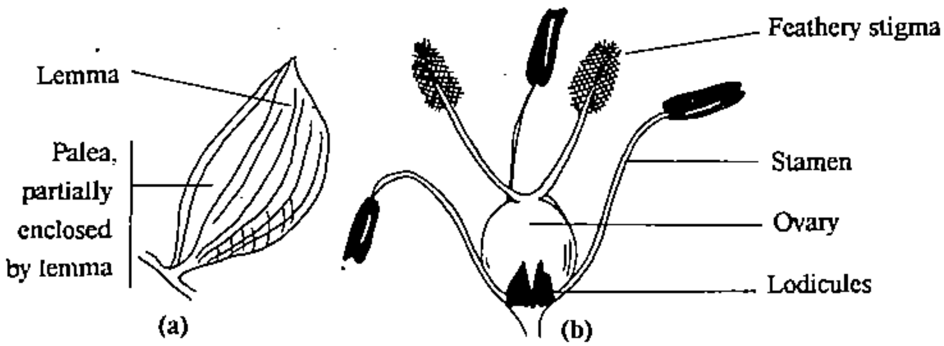


Fig. 11.3: Structure of the floret of the *Gramineae*. a) Lemma and palea intact. b) Lemma and palea removed to show the essential organs of the flower.

The fruit is a caryopsis. It is a one seeded, dry indehiscent grain. Usually 2 grains develop in each spikelet. Each grain is oval with convex dorsal surface and a centrally grooved ventral surface. A tuft of hairs is present at the tip of the grain. The fruit wall and the seed coat are completely fused and these layers constitute the bran of the grain. This encloses the endosperm which forms the major portion (about 82-86%) of the grain. This is mainly madeup of starch and gluten. The outermost layer of the endosperm is the aleurone which contains vitamins, minerals, and proteins but does not contain gluten. The small embryo is present at the basal end of the grain. It consists of the plumule and the radicle. The plumule is enclosed in a sheath called the coleoptile. A coleorhiza or root sheath encloses the radicle (Fig. 11.4). A fleshy shield like cotyledon called the scutellum is also present.

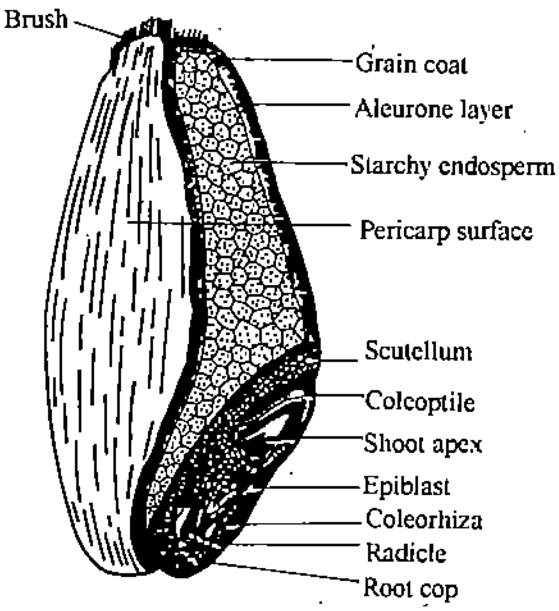


Fig. 11.4: Anatomy of wheat grain showing coleorhiza and radicle.

11.2.4 Breeding and Improvement of Wheat Plant

11.2.4.1 Ever since the beginning of agriculture, man has tried to improve the plant for his benefit. The earliest selections of plants for better growth, good grain and other useful features were unconsciously carried out. This led to greater cultivation of the selected varieties. These could also be the result of mutations or outcrossing and recognition of the better characteristics of selected varieties.

There have been many landmarks in the breeding of wheat. It is interesting to know that the famous Red Fife, Turkey wheat, Marquis, Federation and other important earlier varieties contributed immensely to the promotion of wheat breeding. In India, the Imperial Agricultural Research Institute at Pusa (Bihar) was an important centre for wheat breeding in the early 1900's. Some of these varieties of Pusa wheat such as P.4, P.6, and P.12 became internationally famous. Later, at the Indian Agriculture Research Institute in New Delhi (commonly called the Pusa Institute) work on wheat breeding has continued and New Pusa or N.P. varieties have been developed. Dr. B.P. Pal developed the N.P. 809 variety which is resistant to all three wheat rusts. This became a landmark in the history of wheat improvement. Dr. M.S. Swaminathan is recognised as the Father of the Green Revolution in India for his contributions to Wheat improvement.

11.2.4.2 In modern times, proper understanding of many aspects became a pre-requisite for breeding and improvement of wheat plant. Detailed knowledge about the cytogenetics and breeding behaviour became necessary. The damage caused to the wheat crop by diseases and pests also necessitated the need to overcome the loss to the crop. In India, the wheat crop is affected by different rust diseases caused by a basidiomycete *Puccinia graminis* and other related species. Several other fungal and viral diseases also harm the crop. It is therefore necessary to have an integrated programme for improvement of the wheat crop. Some of the objectives of wheat breeding include the following:

i) increasing the number of tillers per plant to increase the grain yield.

ii) increasing the number and size of grains per spikelet.

iii) early maturity of the crop.

iv) providing dwarf plants which are resistant to lodging.

v) providing plants which respond favourably to chemical fertilizers and irrigation.

vi) resistance to diseases and pests.

vii) producing grains of better quality.

viii) developing varieties suitable for local environment and acceptable to people of the region.

Some of the most important advances in the history of wheat have resulted from the scientific breeding of wheat during the 1900's. By developing new varieties of wheat, plant breeders have greatly increased the yield of wheat per acre or hectare of land. Some varieties have higher yields because they can resist diseases or pests. Others mature early or respond favourably towards fertilizer applications and irrigation. Breeders have also developed plants with strong stalks which can support a heavy load of grain.

One of the greatest developments in modern times has been the development of dwarf varieties of wheat at the international maize and wheat Improvement Centre in Mexico (CIMMYT). This was done by introducing dwarfing genes from the Japanese 'Norin' dwarf varieties into other varieties. This resulted in the development of new varieties which support a heavier yield of grains without collapsing of the stem. This worldwide effort to boost grain production in developing countries has been so successful that India could increase more than double its wheat yields in 3 years. This 'Green Revolution' reduced the danger of famine and in 1970, the American Agricultural Scientist Dr. Norman E. Borlaug, (Director of CIMMYT) was awarded the Nobel Peace prize.

The Mexican dwarf wheats with the Norin dwarfing genes were used for breeding varieties acceptable to Indian Wheat Consumers. Lermo Rojo 64A and Sonara 64 were introduced for cultivation. These were then supplemented with varieties such as Kalyansona, Safed Lerma, Choti Lerma, Sonalika, Sharbati Sonara and others.

11.2.4.3 Hybrid Wheat : Hybrid plants are extremely important in agriculture. They are produced to improve the quality and productivity of the crops. In maize, hybrid varieties have exceptional vigour and produce high yields. This characteristic if introduced into wheat shall bring a great breakthrough in wheat breeding. The possibility of producing hybrid wheat can be traced to the discovery of cytoplasmic male sterility in 1951 by a Japanese wheat breeder Kihara. The male sterility resulted from the interaction of a nuclear gene in *Triticum aestivum* and the cytoplasm in *Triticum timopheevi*. The fertility can be restored by genes from *T. timopheevi* and other sources. There is thus a great deal of interest in the development of hybrid wheat and it may not be long before Indian Farmers grow this crop.

11.2.5 Uses

Wheat is consumed in various forms and, in some areas, it is consumed at every meal in some form or the other. The grain is ground into flour which is used for making bread. The flour contains gluten, a protein which makes the dough elastic. This elasticity of the dough is essential in making bread, as it allows the dough to rise when it is baked with yeast. In India and other parts of the world, 'Unleavened bread' (chapaties) is made from wheat flour. Besides chapaties, it is also used for making tandoori roti, paratha, poori, etc. Refined wheat flour (maida) is used for making cakes, biscuits, pastries and other products. Coarsely ground wheat called semolina (sooji) is used for various preparations such as sweet, halwa, kharabath or upma. Wheat porridge is also made from hard grains. The tetraploid wheats such as *Triticum durum* are important for making macroni, spaghetti, vermicelli, noodles etc.

The wheat grain is rich in nutrients including protein, starch, vitamins, essential minerals such as iron and phosphorus. Whole wheat flour made from the entire grain is more nutritious than white flour made by using roller mills. Here only the soft white inner part of the grain which is mainly the starchy endosperm is ground into flour. This process removes the 'wheat bran' i.e. outer covering of the grain, as well as the 'wheat germ', i.e. the embryo. These parts of the grain contain the nutritious vitamins, minerals as well as the proteins.

Besides food, wheat is also used in several other ways. The bran is an important constituent of livestock and poultry feed. Glutamic acid obtained from wheat is used in the manufacture of monosodium glutamate (MSG). This salt has little flavour of its own but enhances the flavour of other foods. Wheat is used industrially for the manufacture of starch, gluten, alcohol, adhesives, polish etc. Wheat straw is used as a livestock feed, compost and for making baskets, hats, strawboards, paper or even simple toys.

11.3 MAIZE

Botanical name: ***Zea mays*** **Linn.**
Family : Poaceae
Common name : Makai, Bhutta
n = 10

Maize or corn is one of the three major cereals which are the chief sources of energy in the human diet. In the order of world grain production, maize ranks second, after wheat. Rice is a close third. Maize is the most widely distributed cereal crop with a very interesting history of its origin. It is perhaps America's greatest gift to mankind. Maize has an amazing number of uses as food for man, livestock feed and for making many kinds of non-food products.

The name maize is derived from a South American Indian Arawak-Carib word "Mahiz". It was first used for food about 10,000 years ago by Red "Indians" living in the area now called Mexico. For hundreds of years, these "Indians" gathered the grains from wild plants before they learnt to grow corn themselves. Thus it was also called "Indian corn" although this did not refer to our country India.

Maize is a member of the grass family Gramineae like the other cereals. There are several thousand varieties which are cultivated. They are all dependent on man for their survival as the grains are enveloped by a tough, thick husk and cannot be dispersed naturally on their own as in the case of other cereals. If the entire cob falls on the ground, all the seeds could germinate together with probably no single plant attaining maturity. It is, therefore, necessary to know more about this important cereal plant of the new world.

11.3.1 Taxonomy and the Origin and Distribution of Maize

The genus *Zea* is classified in the tribe Maydeae of the family Poaceae. There is only one species, *Zea mays* which is known only in cultivation. Closely related to this genus are two other new world genera, *Tripsacum* (called gama grass used as fodder in North America) and *Euchlaena* (called Teosinte, believed to be the closest wild relative of maize). Some taxonomists do not recognise *Euchlaena* as a separate genus and transfer all the species to the genus *Zea.*

On the basis of the structure of the grain several types of corn have been recognised. The grain structure is controlled by one or a few genetical characters and this has a bearing on the origin of the maize. The main groups are:

(i) Pod corn - *Zea mays var. tunicata*

(ii) Pop corn - *Zea mays var. everata*

(iii) Flint corn - *Zea mays var. indurata*

(iv) Dent corn - *Zea mays var. indentata*

(v) Soft corn or flour corn *Zea mays var. amylacea*

(vi) Sweet corn - *Zea mays var.saccharata*

(vii) Waxy maize - *Zea mays var. ceratina*

All these types were already in existence in Pre-Columbian times and it is necessary to find out which is the most primitive. This shall help us to know about the origin of cultivated maize. Pod corn is believed to be the most primitive. Here each grain (seed) is enclosed by glumes or floral bracts. The entire cob is again enclosed by the husk. This is not cultivated but is preserved in some localities to understand the origin of the earliest cultivated maize. The other primitive type is pop corn. Crossing pod corn with popcorn has helped in producing a genetic reconstruction of the ancestral form of maize.

Scientists have not been able to trace the ancestry of modern maize directly to a wild plant as has been done with other cereals. Archeological findings, genetic studies and other evidences have been used to support the different views on the origin of maize.

(i) Asiatic Origin of Maize

Bonafus (1836) suggested that maize may have originated in South Eastern Asia (probably in Assam) by Hybridization between *Sorghum* and another grass *Coix*. This idea was supported by Anderson (1945) who also suggested that maize spread to the new world in pre-columbian times. In 1964, Dhawan reported the occurrence of very primitive type of maize from the foothills of the Himalayas. These were called "Sikkim Primitive 1" and "Sikkim Primitive 2". They have morphological and cytological characteristics of the most primitive kind and can be called "living fossils". However, there is no other evidence to corroborate this view on the Asiatic origin of maize nor any explanation on how it spread to the new world in pre-historic times.

(ii) New World Origin of Maize

There is considerable evidence to establish the view that maize is the *'gift of the new world to mankind'*. This cereal was widely dispersed and used as the basic food plant in all pre-columbian ancient civilisations in America. Extensive research work carried out by Mangelsdorf, Reeves, Mac Neish and Wilkes, has established an American origin of maize. The region from Gautemala to Southern Mexico is believed to be the centre of origin of maize.

When we accept that maize originated in America, it is necessary to determine the ancestors of modern cultivated maize. There are many interesting observations related to the origin of maize.

(a) The ancestor of modern cultivated maize is maize itself and not any other related grass. This view is based on the discovery of maize pollen from Mexico. In 1954 when the first Skyscraper was being constructed in Mexico, fossil pollen grains were found at a depth of 70 meters. These were dated to be about 80,000 years old of the last interglacial period.

b) Excavations of archeological sites at the Bat Cave in New Mexico, have been carried out since 1948. These have identified some very primitive settlements which may have been inhabited by ancient people for several thousand years. These people practised a very primitive form of agriculture and primitive pattern of sanitation. It has been found that there were preserved corncobs in refuse heaps. These were very small measuring only 2-3 cm long and have been determined to belong to the period 3600 B.C. Several other such primitive cobs have also been excavated from other ancient sites in different parts of Mexico. An interesting discovery was made in 1960 by Mac Neish from the Coxcatlan Cave in the Tehuacan Valley in Southern Mexico. Well preserved corn cobs as old as 5200 B.C. have been identified. These could be considered as the original wild maize, because of their primitive characteristics.The pod corn which is believed to be the most primitive type of corn, is of this type. Mangelsdorf (1974) in his book "Corn, its origin, Evolution and Improvement" concludes that cultivated maize originated from ancestral maize.

(c) Extensive studies by Mangelsdorf have shown that the Pod corn is the most primitive type of corn. Each grain (seed) is enclosed in a pod or husk formed by the glumes or floral bracts. The entire cob is again surrounded by the husk. The pod character in corn is controlled by genes on the **Tutu** locus on the fourth chromosome. The **Tutu** locus is strongly pleiotropic and affects many different characteristics of the maize plant. A genetic reconstruction of ancestral maize has been possible by crossing pod corn with Pop corn and back crossing the hybrid. These studies suggest that cultivated corn originated from wild ancestral corn in the new world.

(d) The closest relatives of corn are Teosinte *(Euchlaena mexicana)* and Gama grass *(Tripsacum dactyloides)*. These are not the ancestors of wild maize, but they evolved alongwith ancestral wild maize and hybridized with it. Some of the characteristics of these grasses are found in cultivated maize.

(e) The recent discovery of a perennial grass identified as *Zea diplo-perrensis* should provide important information about relationships of *Zea mays*.

11.3.2 Corn Cultivation

United States of America is the largest producer of maize. About 40% of the total world production of maize is obtained from the U.S.A. China is the second largest producer of maize. Other leading producers include Argentina, Brazil, France, India, Mexico and Romania. Japan is the largest importer of maize.

In India, maize is grown in UP, Bihar, Punjab, Himachal Pradesh, Rajasthan, Karnataka, Madhya Pradesh, Andhra Pradesh and in Jammu and Kashmir.

11.3.3 Botany of the Maize Plant

The maize plant is an annual fast growing grass. It has a single stem which may be short (up to 1 meter) or tall (up to 5-6m). The stem is succulent and a few tillers may be formed in some varieties.

The root system is very characteristic. The first seminal root develops from the radicle.This is followed by 3 or more seminal roots which grow out sideways from the embryo. These are important because they supply the nutrients to the young seedling. After 2 weeks, they may remain functional or lose their importance. They may or may not persist throughout the life of the plant. After 2 weeks, the adventitious coronal or crown roots develop. These are fibrous roots developing from the lower nodes of the stem. They grow close together and branch profusely when the stem elongates and the plants start flowering, a second set of adventitious roots develop from the nodes just above the soil surface. These are the prop roots or brace roots or stilt roots. They are partially photosynthetic and often deeply pigmented. They provide additional support to the stem and on entering the soil they function like the coronal roots.

The stem is erect, cylindrical and solid with distinct nodes and internodes. It's height as well as thickness (diameter) vary considerably. There are usually 14 (range 9-21) nodes on each stem. The internodes towards the base are shorter and thicker, gradually elongating and tapering to the terminal male inflorescence.

The leaves are borne alternately on either side of the stem at the nodes. This arrangement is called distichous. As in other cereals, the leaf consists of the basal sheath and the terminal lamina or blade. A membraneous ligule is present at the junction of the sheath and lamina. The sheath encloses the internodes to varying lengths and splits above. The margins of the sheath usually have hairs in the upper part. The lamina or blade is linear-lanceolate acuminate and wavy. The midrib is prominent and venation is parallel. The lower surface has more stomata than the upper surface.

The maize plant is monoceious and diclinous. The male and female inflorescences are borne separately on the same plant. A single terminal panicle called the tassel is the male inflorescence. This may be compact or highly branched, erect or flexuous. The spikelets are paired and in each pair, one spikelet has a short pedicel and the other is sessile. Each spikelet has two glumes, and 2 male florets. Each floret has a lemma, palea, 2 fleshy lodicules and 3 stamens. A rudimentary gynoecium may also be present (Fig. 11.5).

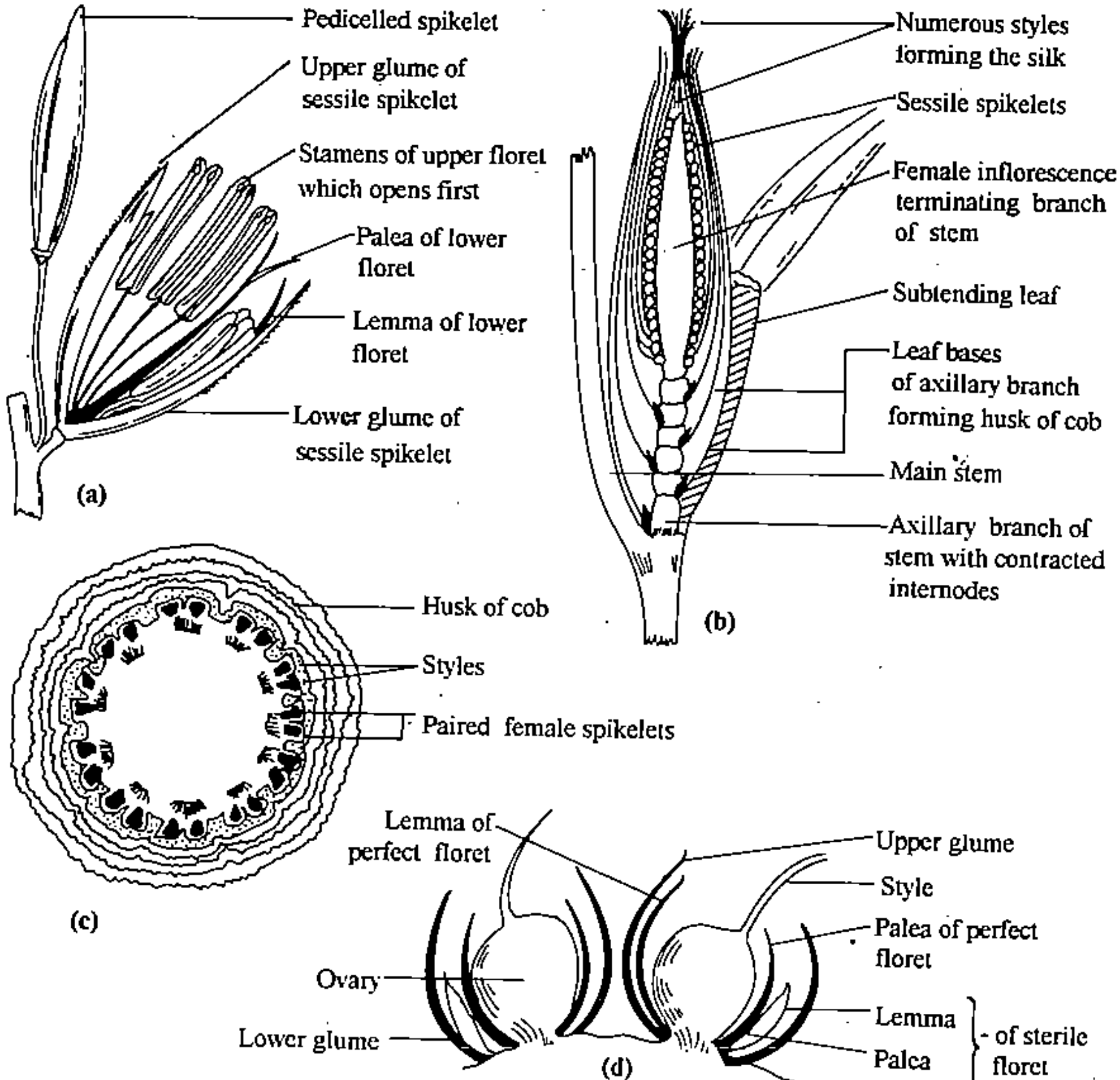


Fig. 11.5: ***Zea mays.*** **a) Sessile and pedicelled spikelets of the male inflorescence. b) Diagrammatic longitudinal section through the female inflorescence. c) Diagrammatic transverse section through the female inflorescence. d) Diagram of a pair of female spikelets.**

The female inflorescence, called cob or ear, is also terminal but it develops on a modified lateral branch. This branch develops from the axillary bud of the foliage leaf. It is like the main shoot and has nodes and internodes. Leaf sheaths arise from each node and form a protective covering or husk around the inflorescence. This consists of a thickened central axis having paired spikelets in vertical rows. The spikelets are associated with a socket like cupule in alternate rows. The spikelets are sessile and identical having 2 glumes and 2 florets The upper floret is fertile while the lower is sterile. The floret has a lemma, a palea and the ovary. The lodicules are absent and rudimentary stamens may be present. The long thread like style or "silk" is receptive along its entire length. The silk is visible above the husk of the cob.

The fruit is a caryopsis. The maize kernels are borne in an even number of rows each having developed from the single fertile flower of a pair of spikelets. Unlike other cereals, there is no mechanism for seed dispersal in maize. The mature kernel consists of four parts:

(1) Short spongy pedicel or tip cap;

(2) Pericarp or fruit wall called hull;

(3) Endosperm which comprises the major portion of the seed and contains starch. Its outermost layer is the aleurone which has little or no starch. The protein network may be thick and dense making the endosperm hard flinty and translucent. If the protein network is thinner, the endosperm becomes soft and opaque (Fig. 11.6).

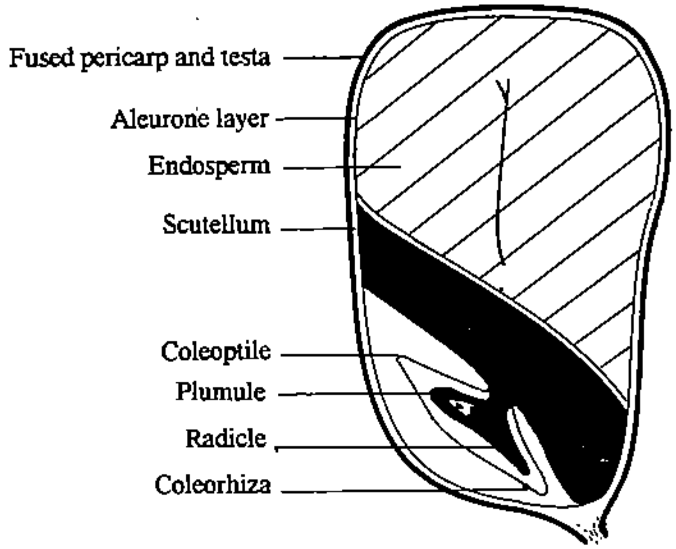


Fig. 11.6: ***Zea mays*****; Diagrammatic longitudinal section of the caryopsis.**

(4) The germ or embryo is present on one side at the base of the seed. It consists of the plumule, radicle and scutellum. This is relatively rich in fats, minerals, proteins and sugars.

11.3.4 Maize Improvement

Maize is cross-pollinated and exhibits a high degree of heterozygosity. Very few seeds, even on the same ear, will have the same genotype. Maize has, therefore, been subjected to intensive genetic and cytogenetic studies for obtaining desired varieties.

The development of hybrid maize has been one of the greatest achievements in plant breeding. It has revolutionised agriculture and increased maize yields considerably. Dr. George A. Shull (1874-1954) by using controlled self-pollination developed inbred lines. The crossing of two inbred lines produced hybrids with greater vigour. The introduction of the concept of double cross suggested by Dr. Donald F. Jones made the production of hybrid maize economically feasible. Within 10 years (1936-1945), the yield of maize increased from less than 5% to more than 90% by using hybrid seeds.

Conventional methods of plant breeding required removal of male inflorescence to ensure cross pollination from desired inbred line. It was later found that cytoplasmic male sterility lead to abortion of the pollen. Therefore, crossing of selected parents produced desired hybrids eliminating the laborious detasseling operations. The production of more vigorous inbred lines has helped to increase the yield of seed they produce.

The Indian Council of Agricultural Research launched a co-ordinated Maize Breeding Project in 1957. Several well known hybrids such as Ganga Hybrid Makka, Ranjit Hybrid Makka, Deccan Makka and others are now widely cultivated in different parts of the country.

The all Indian Co-ordinated Maize Improvement Scheme started in 1964 has led to the development of varieties such as Vijay, Kisan, Jawahar, Vikram, Shakti and Ratan. These have added a significant milestone in the history of maize research in India.

11.3.5 Uses of Maize

Maize is used for three main purposes: (i) as human food; (ii) as feed for livestock; and (iii) as raw material for many industrial products. Besides these, maize also has a number of subsidiary uses.

The maize grain is especially rich in starch. Besides starch, maize also supplies fats and proteins. Zein is the predominant protein in maize. However, maize protein is deficient in the amino acids tryptophan and lysine. Because of this, it is necessary to supplement a diet of maize with an alternative protein source to provide a balanced diet.

Tortillas are unleaved pancake like corn bread prepared from maize flour and are used as staple food.

The grain can be simply cooked and eaten. The young maize kernels (especially of sweet corn) may be boiled or roasted. Popcorn can be prepared by heating small grains, which explode or pop, turning inside out to form small white fluffy balls. These are eaten as a snack. Corn meal, corn flakes, and corn starch are consumed as staple food in various ways. Maize is unsuitable for making bread as it is deficient in gluten. Corn syrup and corn sugar are used in the manufacture of jams, jellies and confectionery. Corn oil is an important cooking medium.

Maize is an important livestock feed in most western countries. About 50% of all the maize grown in the USA is used for this purpose. Silage is made from entire maize plants (except the roots) or after the cobs have been harvested. Green and dried stalks are also used as fodder.

Maize is used in the manufacture of many industrial products. Maize starch is dried and used for the manufacture of dextrins. The oil goes in the making of soaps and glycerine. Zein, the maize protein, is used to produce fibres of good tensile strength. The fibres of the stem are utilized for making paper. The pith is used as light packing material as well as for the manufacture of explosives. When the maize cobs are cooked under pressure with acids, a substance called furfural is produced. This is an important industrial compound used for refining diesel, vegetable and lubricating oils. It is also used for making plastics and nylon.

Alcoholic beverages such as beer and whiskey are made from maize. Industrial alcohols such as ethyl, butyl and propyl alcohol are also made from maize grains. Besides these, acetaldehyde, acetone, glycerols, acetic, citric and lactic acids are also manufactured from maize.

11.4 RICE

Botanical Name: *Oryza sativa* **Linn.**
Family : Poaceae
Common Name : Chauval, Dhan.
n = 12

Rice Production in India (in million tonnes)

92-93	72.9
93-94	80.0
94-95	81.0
95-96	77.0
96-97	81.3
97-98	82.1

More than half of the people of the world eat rice as the main part of their diet. Nearly all the people who depend on rice for food live in Asia. Most taxonomists have identified about 20 species of rice, but only two are cultivated and are of economic importance. The Asian rice - *Oryza sativa* Linn. is the main cereal crop in Southern and Eastern Asia. It is also cultivated in other parts of the world. The African rice -*Oryza glaberrima* Steud is grown mostly in West Africa. The two species differ in glume pubescence and ligule size. In additon to these structural differences, the pericarp in *O. glaberrima* is red. Interestingly, intermediate forms between the two species occur. The following account deals with the more important species, *Oryza sativa.*

11.4.1 Origin and Distribution of Rice

Rice paper is not made from rice, but from the pith of *Tetrapanax papyriferum* (Hook) K. Koch, a tree from Taiwan belonging to the family Araliaceae.

Oryza sativa originated in South East Asia. The exact place and date of its origin or domestication is not known with certainity. It has been cultivated in China for nearly 5000 years. Archeological evidence from the Yung Shao excavations in China show the remains of rice. These have been dated 2600 B.C. There are many religious ceremonies associated with rice since ancient times. These and other evidences suggest that rice may have originated in China.

A second hypothesis suggests that rice may have originated in India and then spread to China and other parts of South East Asia. Archeological excavations from Lothal in Gujarat have revealed charred grains of rice. This has been dated to 2300 B.C. and is believed to be an extension of the Harappa culture of the Indus Valley Civilisation. There are also records of rice in ancient Hindu scriptures and literature. Carbonised grains of rice have also been found from Hastinapur in Uttar Pradesh.

In additon to this, the International Rice Research Institute (IRRI) was set up in the Philippines by the joint efforts of the Ford and Rockcfeller Foundations to study this important cereal crop plant. In three years, between 1962 and 1965, samples of rice from different parts of the world were collected to build up a germ plasm bank. More than 10,000 varieties of rice were recognised and interestingly about 60% of these were found in India. This suggested that there was a great genetic diversity in the rice grown in this country. From an evolutionary point of view this is important because greater the diversity, more are the chances of adaptation to the environment. The cultivation of rice in marshy areas with intervening mountains as well as the presence of wild species in the region have helped in the natural selection of different varieties.

Besides, these evidences, there are numerous traditional uses of rice in religious ceremonies in India. These are associated with birth, marriage and even death, suggesting that rice is of ancient origin in India. From India, rice may have spread to China, Indochina, Japan and other South east Asian regions. It may also have spread westwards to Iran, Iraq, Egypt and neighbouring areas.

We may also look at the origin of rice from a taxonomic angle. There are two divergent views on the origin of cultivated rice. The first hypothesis suggests that the cultivated rices originated from one ancestor. This monophyletic hypothesis suggests that the two cultivated species, *Oryza sativa* and *O. glaberrima*, have evolved from a common ancestor. The search for this ancestor has shown the occurrence of a wild rice *Oryza longistaminata* (also called *Oryza perennis*) which could be the progenitor of both cultivated species. The origin of this is traceable to the Gondwana land super continent. Due to continental drift and splitting of this super continent, the present day Africa, Madagascar, South East Asia, Australia, South America, Antarctica etc. were formed in pre-historic times. The original ancestral species of rice found in the Gondwana land adapted to the regions in West Africa and South East Asia. This led to the evolution of *Oryza sativa* on one hand and *Oryza glaberrima* on the other.

Rice is cultivated to a very large extent in China, India, Japan, Bangladesh, Thailand, Vietnam, Myanmar and other adjacent countries. It is also cultivated to a lesser extent in Africa, America and Europe. India which is the second largest producer of rice after China, often imports rice to meet its requirements. In India, rice is cultivated in almost all states. It is more common in river valleys, coastal regions and deltas. West Bengal, Tamilnadu, Orissa, Andhra Pradesh, Bihar, Madhya Pradesh, Uttar Pradesh and Assam are important rice growing states. It is also cultivated in Jammu and Kashmir, Himachal Pradesh, Punjab, Haryana, Maharashtra, Karnataka and Kerala. A Central Rice Research Institute (CRRI) has been established in Cuttack (Orissa) to co-ordinate the research in rice.

11.4.2 Kinds of Rice

Rice taxonomists have studied several characteristic features of the different kinds of rice and have recognised three subspecies. These have evolved as distinct geographical races and can be identified by a large number of characters. The three subspecies are:

a) *Oryza sativa* sub sp. *indica*

b) *Oryza sativa* sub sp. *japonica*

c) *Oryza sativa* sub sp. *javanica*

Marked sterility barriers occur between these subspecies. Of these the *indica and japonica* rices are very well known and can be differentiated on morphological as well as physiological characters as listed in the following table:

Table 11.1 : Morphological and Physiological differences between the *indica* and *japonica* rice subspecies.

Character	*indica* subspecies	*japonica* subspecies
Climatic adaptability	Tropical monsoon	Warm temperate
Tolerance to adverse conditions	High	Moderate
Resistance to disease	Fairly resistant	Less resistant
Photoperiodic response	Predominantly photosensitive (short day)	Photoperiod insensitive
Fertiliser responsiveness	Low	High
Lodging	Susceptible	Resistant
Vegetative period and growth	Long, vigorous growing, leafy (late maturing)	Short, lack vegetative vigour (early maturing)
Tillering habit	Profuse tillering	Moderate tillering
Nature of culm	Long and weak stalks	Short and stronger stalks
Foliage form and colour	Broad and pale green	Narrow and dark green
Husk pubescence	Sparse, short	Dense, long
Awns	Usually absent	Sometimes present
Shattering quality	Susceptible	Resistant
Grain size	Usually long, narrow, flattened	Short and thick
Endosperm	Translucent	Chalky
Seed dormancy	Present	Absent
Cooking quality	On cooking, grains do not turn sticky	Grains soften rapidly and become mushy
Yield potential	Medium	High
Price commanded	High	Low

From: Kochhar, 1998.

Rice varieties may also be classified on the basis of their period to maturity. In India we have:

a) Very early varieties which mature in 110 days or less

b) Early varieties maturing in 110-140 days

c) Late varieties maturing in 150-170 days

d) Very late varieties maturing in 180 or more days.

Depending on this period of maturity, farmers can grow 2 or 3 crops of rice on the same land in one year provided water is available.

11.4.3 Cultivation

Methods of rice cultivation vary in different parts of the world. In India and other South Eas Asian countries, most of the rice is cultivated by using simple techniques and using available farm labour. Four main steps are adopted for rice cultivation. These are :(i) preparin the ground; (ii) planting; (iii) controlling diseases and pests; (iv) harvesting.

Rice shows a great tolerance to wet habitats because it is basically a crop of swampy soils. grows best in regions which have adequate rainfall. However, it can also be cultivated in drie regions if irrigation facilities are assured to the farmers. Successful cultivation is dependent on the supply and control of water during the greater part of the growing period.

Compared with water supply, soils are relatively unimportant. Rice can be grown on many types of soils. Heavy alluvial soils of river valleys and deltas are more suitable for successful cultivation of rice. Adequate quantities of fertilizers containing nitrogen, phosphorous and potassium are required.

Rice is a warm season crop requiring a relatively high temperature during the growing season. The average temperature during the growing season varies from 20 - 38°C. Long periods of sunshine are essential for high yields especially during the period from panicle initiation to harvesting (about 45 days). The *indica* varieties require more temperature than the *japonica* varieties. Rice is a short-day plant.

When rice is cultivated as a dryland or upland crop, the land is ploughed repeatedly after the harvest of the previous crop. The seed is sown as in the case of other cereals. In wet paddy cultivation, the land is irrigated about one month before sowing and it is thoroughly ploughed in standing water several times. The seeds are germinated in small nurseries and the seedlings are transplanted into the flooded fields. This practice of transplanting rice seedlings has several advantages:

i) The time of growing rice on the main plot is shortened. This permits raising 2 or 3 or sometimes even 4 crops annually on the same land.

ii) It permits the selection of the most favourable season for optimum yields of the crop.

iii) Lesser quantities of seed are required, thus reducing the cost. For one hectare of land, 30-50 kg. of seeds are required under wet paddy cultivation as compared to dryland cultivation where 50-100 kg of seeds have to be sown on one hectare.

iv) Seedlings raised in nurseries develop into strong and healthy plants. They develop resistance to adverse environmental conditions. It is also easier to control diseases, pests and weeds.

v) Transplantation also facilitates effective use of soils rich in salts.

11.4.4 Botany of the Rice Plant

The rice plant is a semi-aquatic, freely tillering, annual grass. It has a cylindrical jointed stem about 50-150 cm tall. The root system is fibrous. The primary root emerges on germination and it is followed by 2 additional roots. Adventitious roots are then produced from the basal nodes of the primary stem and tillers (Fig. 11.7). The roots can grow under low oxygen concentrations. They form a dense surface mat and they are highly branched and have a profusion of root hairs.

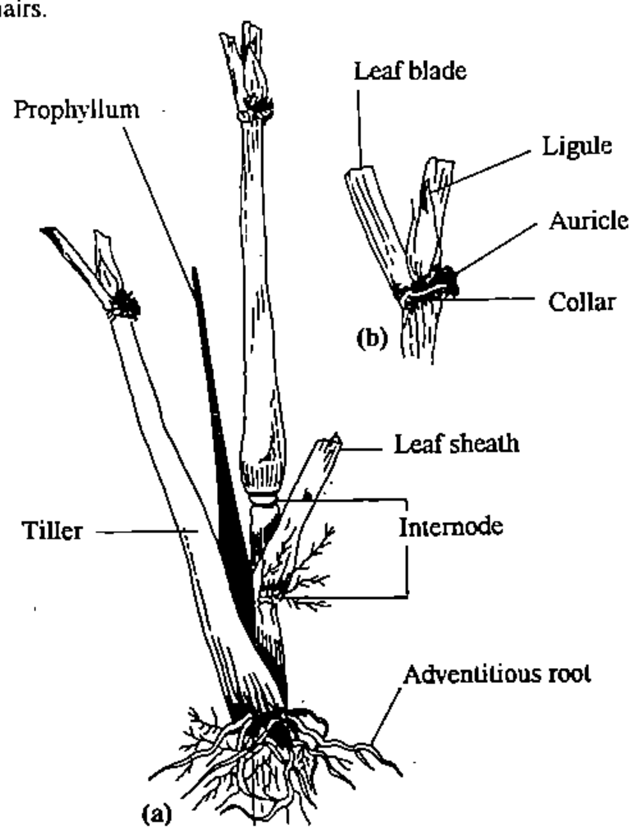


Fig. 11.7: Rice : (a) Basal part of the main rice culm shows adventitious roots, prophyllum and two-ranked leaves. (b) A leaf joint showing ligule and auricles.

The stem or culm is usually erect, smooth and 6-10 mm in diameter. The nodes are solid but the internodes are hollow. Above each node there is a prominent pulvinus and an intercalary meristem. The lower internodes are short, and become progressively longer towards the apex. There are 10-20 internodes on each stem.

The first leaf at the base of the culm and each tiller is rudimentary. It consists of a bladeless prophyll. All other leaves on the plant have a sheath and lamina. The leaves are borne alternately on the stem in 2 ranks one at each node. Each leaf consists of the sheath, blade, ligule and auricles. The sheath is split down its entire length and encircles the node. The lower sheaths are longer than the internodes but after the 10th leaf the sheath becomes progressively shorter than the internodes.

The sheath is finely ribbed and glabrous. At the junction of the sheath and blade, there is a triangular membraneous ligule. It is usually colourless and tends to split with age. On either side of the ligule there are small fringed appendages called auricles. The leaf blade is narrow. The lamina of the uppermost leaf below the auricle is wider and shorter than the other leaves. This is called the "boot or flag leaf".

The inflorescence is a loose terminal panicle 14-42 cm long. The main axis bears a variable number of primary branches. The angle at which the primary branches are borne determines the compactness of the inflorescence (Fig. 11.8). The primary branches bear secondary branches each of which has one or more spikelets. Each spikelet is bilaterally compressed and has a single bisexual floret. The pedicel is short and firm. There are 2 glumes of equal length. The lemma is large, boat shaped and rigid. It is hard, keeled and strongly 5-nerved. The apex may be pointed or extended to form an awn. The palea is narrow, keeled and 3-nerved. The apex of the palea is projected as a solid point which forms the apiculus of the caryopsis with the apex of the lemma. Each floret has 2 broad lodicules, six stamens in 2 whorls and the gynoecium with a single ovule. There are 2 styles with white or purplish plumose stigmas.

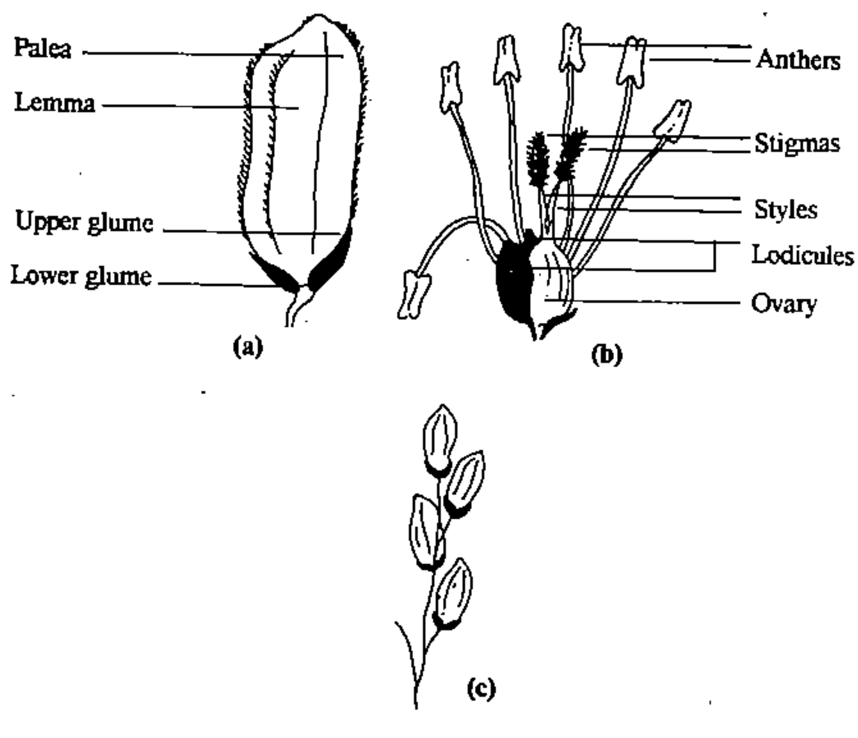


Fig. 11.8: ***Oryza sativa.*** **a) A spikelet. b) Lemma and palea removed to expose the flower with six stamens. c) A portion of the rice panicle.**

The fruit is a caryopsis closely enclosed in the husk formed by the lemma and palea. This is called paddy. During milling the hull is removed and the rice grain is separated (Fig. 11.9).

In India about half of the rice produced is parboiled. The paddy is steeped in cold or hot water for varying period upto 3 days. It is then steamed at low pressure and dried. The hull is

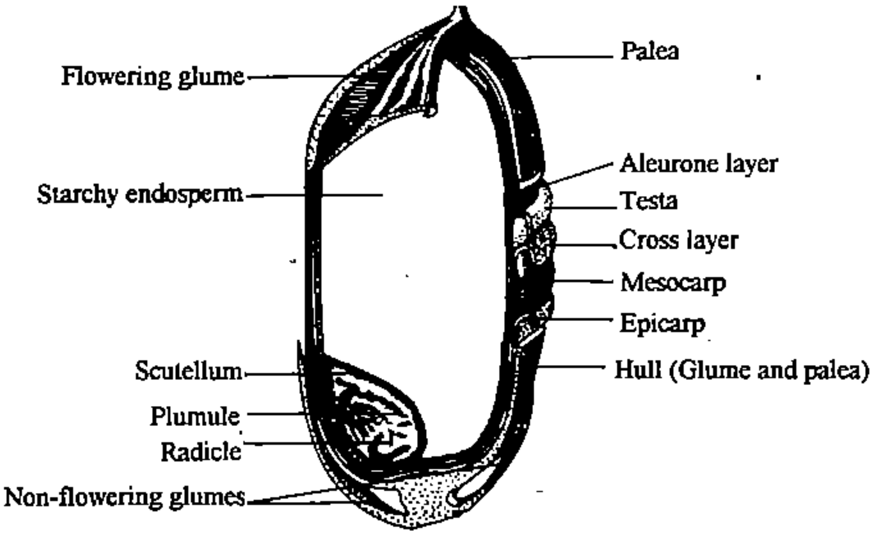


Fig. 11.9: Diagrammatic longitudinal section through a rice spikelet.

then removed by milling. Parboiling results in less breakage of the grain during milling. The important nutrients are also retained in the grain and the grain can be stored for longer period. However, it is important to ensure that clean water is used and parboiling done under hygenic conditions so as to obtain good quality grain. Improper parboiling leads to inferior colour and unpleasant odour in the grain.

11.4.5 Rice Breeding Programmes

The methods of breeding rice are similar to those used in breeding wheat and other self-pollinated crops. The objectives of these programmes are:

i) Germ plasm collection to introduce new varieties.

ii) Selection of superior genotypes for optimum benefit.

iii) Hybridization to produce new varieties with suitable characteristics.

The increasing need of providing food to the growing population has led to the search for higher production of cereal grains. In South East Asia, rice serves as the staple diet and international efforts are required to produce more grains. In 1950, the Food and Agriculture Organisation of the United Nations sponsored an International Rice Hybridization Project at Cuttack (Orissa). The Central Rice Research Institute took up the co-operative *indica* and *japonica* rices Hybridization project. The objectives of this project were:

i) to incorporate the genes for (a) fertilizer responsiveness and high productivities of the *japonica* rices with (b) the hardiness and adaptability of *indica* rices.

ii) to incorporate the genes for non-lodging and non shattering of grains of the *japonica* rices into the hybrids.

All countries of South East Asia contributed seeds of many varieties for the success of this project.

Simultaneously in Taiwan, rice breeders discovered a spontaneous dwarf mutant called **Dee-geo-woo-gen.** This has become a landmark in rice breeding. This mutant has the following characteristics:

i) a dwarf habit, growing up to 60 cm only

ii) stiff leaves which are oriented in an erect manner on the stem, thus permitting maximum utilisation of sunlight.

iii) photo insensitivity so that the crop can be grown all round the year.

iv) absence of seed dormancy so that the seeds can be sown immediately after harvest.

By hybridization of this mutant with tall drought resistant *indica* rice, an outstanding dwarf variety called Taichung native 1, was produced. After the establishment of the International

Rice Research Institute in Los Banos (in the Philippines) this dwarf hybrid was further exploited to produce a large number of new hybrids suited for different rice growing countries. This also brought about a new approach to the rice breeding project in India after 1965, many new high yielding, early maturing dwarf and semi dwarf varieties have been developed and are now widely cultivated in India. Some of the more well-known improved varieties are IR-8, IR-20, Pankaj, Jaya, Cauvery, Vijaya, Ratna, Jagannath, Padma, Kamini, Sabarmati, and Jayanti. Some varieties of *japonica* rice developed in Taiwan are also cultivated. Of these Taiwan - 3, Taichung 65 and Taichung 68 are popular.

11.4.6 Uses

Being an important cereal, rice supplies about half the calories in the daily diet of millions of people in South East Asia. It is an excellent source of carbohydrates and also has small amounts of proteins, minerals and vitamins. Rice has very little fat and is easy to digest. About 90% of the rice is cooked and eaten in various ways with pulses, vegetables, fish or meat. It may be boiled in plain water, or made into pulao. Rice may also be consumed in the form of idli, dosa and other preparations popular not only in South India but also in other parts of the world. Rice pudding can be made by cooking rice in milk and adding sugar and nuts. Powdered rice may be cooked to serve as a substitute for milk to babies. This is the only cereal which can be used in this manner. Rice flour is also used in confectionery, ice-creams, pastries etc. Rice starch is used as food, in laundry and also in the cosmetic and textile industries.

Parched rice is made by mixing the grain in hot sand in open vessels. The grain begins to crackle and swell, after which it is sieved. Rice flakes are made by soaking paddy in water for 2-3 days, followed by boiling in water for a few minutes. The water is drained, the grains are cooled and then heated until the husks burst open. The grain is then flattened and the husk removed. Puffed or popped rice is made by heating the rice in sealed containers for one hour at 288°C. The moisture of the grain is converted into steam and when the pressure is released, the grains swell or expand to several times of their original size.

Alcoholic beverages are made from rice. 'Saki' in Japan and 'Wang Esin' in China are popular.

There are several byproducts of rice which are useful in various ways.

Rice husk is used as fuel for rice mills, for making hardboard and as an abrasive. Furfural (see maize) is also made from rice hull.

Rice bran, obtained during polishing brown rice for producing white rice, is used as a livestock and poultry feed. Oil, extracted from the bran, is used for cooking and in the manufacture of soap.

Rice straw is fed to cattle. It is also used for making straw board, thatches, mats and hats.

SAQ I

1. List the six important cereals of the world.

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2. Differentiate between millets and pseudocereals.

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3. Mention the centre of origin of:

   a) Wheat

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   b) Maize

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c) Rice.

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4. Expand:

a) CIMMYT

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b) IRRI

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c) CRRI

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5. Write notes on the contributions of:

a) N. Vavilov

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b) Manglesdorf

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c) George Shull

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6. Trace the origin and evolution of the cultivated wheats.

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7. List the features to differentiate *indica* rices from *japonica* rices.

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11.5 RYE

Botanical name: *Secale cereale* **Linn.**
Family : Poaceae
Common name : Rye
n = 7

This is the nearest relative of wheat amongst the cultivated cereals. The grains resemble wheat and barley. Rye flowers, unlike those of wheat, oats and barley, open for pollination. Due to cross pollination, it is difficult to keep varieties of rye pure. Rye is distinguished from wheat by its narrow, subulate one nerved glumes. It is cultivated for the grain as well as for fodder.

11.5.1 Origin and Distribution

Cultivated rye probably originated from wild perennial weedy species of the genus *Secale* in Central and South West Asia as well as adjacent regions of Central Eurasia. There are several wild species which can be cultivated and can sometimes exist both as a weed and as a pure crop. The centre of origin of rye overlaps the centre of origin of the other bread cereals, wheat, barley and oats. However, rye is believed to be of more recent origin than the other cereals.

Rye is cultivated to a large extent in Europe and Asia. Russia and its neighbouring regions, as well as Poland are the main areas where rye is produced. In India, it is grown over very small areas in the mountainous regions of Himachal Pradesh, Jammu and Kashmir and other north-west Himalayan areas. In Jammu & Kashmir it is mainly cultivated as a host for the ergot fungus *(Claviceps purpurea)*.

11.5.2 Cultivation

Rye is a cold weather crop. It can be grown in regions of severe winter, and at high altitudes. Rye can grow on light sandy or loamy soils. It requires adequate drainage and can withstand considerable soil acidity and alkalinity. It is, therefore, an especially valuable crop in regions where other cereals cannot be cultivated economically. Rye can also be planted alongwith wheat and barley.

11.5.3 Botany

Rye is a tufted annual, 1-2 m high with a tendency towards a perennial habit, putting forth new plants from the stubble. Externally it resembles wheat. The inflorescence is awned, having 2-flowered spikelets. The mature grain is more slender than that of wheat and usually greyish yellow. The flower shows typical organisation of grass family similar to wheat flower (Fig. 11.10).

11.5.5 Uses

Rye is sometimes called the "grain of poverty" because it provides the daily bread to a vast population in areas where natural conditions provide no other alternative. Beside wheat, this is the only other cereal which can be used for making bread. The food value of rye is nearly equal to that of wheat. The bread made from rye flour is dark, almost black and bitter but nutritious. Since rye flour has less of gluten, the yeast cannot raise the rye dough as easily as wheat dough. Thus rye bread is heavier and more compact than wheat bread.

Rye is also used in the manufacture of alcoholic beverages such as whiskey, gin and beer. It's straw is long, smooth and easy to bend. It is used as packing material, for stuffing mattresses, or for making hats, mats and paper. This is also used for thatched roofs because it decays less rapidly than most other kinds of straw.

Rye, its hay and midlings (medium sized particles obtained during milling of rye grains) are also used as livestock feed. Young rye plants make good pasture. But, sometimes, cows which graze on rye pasture give milk which has an unusually strong flavour. Rye is also grown to improve or protect the soil. It has the capacity to combat weeds and is an important component in crop rotations. It is also the only cereal which can be grown on sterile sandy or acid soils. This makes it an important pioneer crop for waste-land utilization.

11.5.5.1 Rye and Ergot : Rye, wheat, barley and other grasses are attacked by a parasitic fungus called *Claviceps purpurea* or ergot. This fungus attacks the grain and long purplish structures called sclerotia are formed in place of the seeds. The spores produced by these sclerotia cause infection in human beings and cattle. The disease called ergotism was common in people who ate bread made from infected rye grains. It is no longer a major disease today.

Ergot is the source of a number of drugs. These are used to produce powerful contractions of the involuntary muscles. The most common use of these drugs is to ease migraine headaches and to prevent hemorrhage after childbirth.

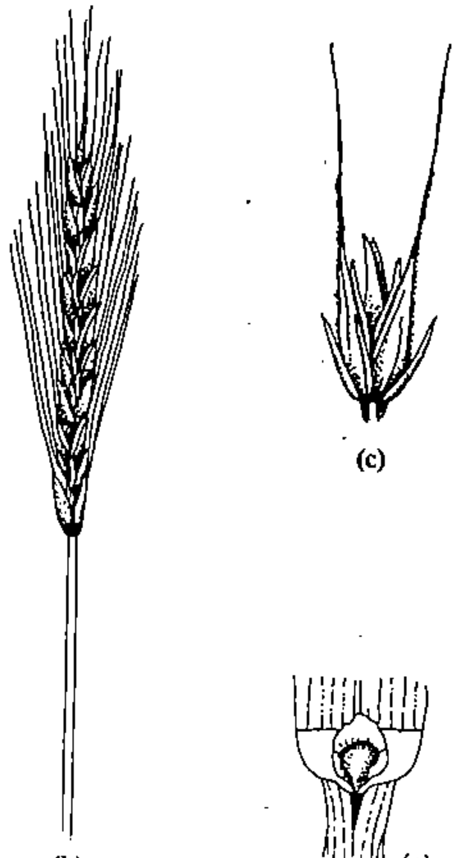

Fig. 11.10: *Secale cereale.* a) auricles and ligule, b) spike, c) spikelet.

11.6 OATS

Botanical name: (i) *Avena sativa* Linn. or the common oat.
(ii) *Avena byzantina* C. Koch or the Indian oat.

Family : Poaceae

Common name : Jai

n = 21

Oats are an important grain crop. They have a higher food value than any other cereal grain. Oats are rich in starch and high quality protein. They are a good source of vitamin B.

In India, the common oat or *Avena sativa* is generally not cultivated. Instead, *Avena byzantina* (also called *Avena sterilis* Linn. var. *culta*) is grown mainly as a fodder crop.

Coarse Cereals Production in India (in million tonnes)

92-93	36.6
93-94	30.8
94-95	29.9
95-96	29.0
96-97	34.0

11.6.1 Origin and Distribution

Oats were first cultivated in the Iron Age in Europe. Archeological remains dating from the first millennium B.C. have been found in Switzerland, Germany and Denmark. Oats were apparently unknown to the ancient Egyptians, the Hebrews, the Greeks, the Romans, the Chinese and the people of India.

It was assumed that the common oat, *Avena sativa* originated in Europe. However, Vavilov in 1926 showed that oats occurred as weeds in wheat fields in Persia and suggested that the ancestors of the cultivated oats may have been native of Asia. Oats probably originated in the Asia Minor Trans Caucasian region.

The common oat, *Avena sativa* is cultivated in the United States of America, Canada, Russsia, France, Germany, Poland, Sweden, Denmark and the Mediteranean region. It is also cultivated in South America, Australia and New Zealand. In India, the oat is a crop of minor importance. Here, *Avena byzantina* (also called *Avena sterilis var. culta*) is cultivated as a fodder crop. Uttar Pradesh, Punjab, Haryana and adjacent areas are the major regions for oat cultivation. It is also grown to a limited extent in Maharashtra, Madhya Pradesh, Gujarat, Himachal Pradesh, Orissa, Bihar and West Bengal.

11.6.2 Cultivation

Oats are grown throughout the cooler, wetter parts of the temperate regions. They are widely adapted to different agroclimatic conditions. They are relatively hardy and can survive under conditons which are too cold for other crops. In India, they are grown as a rabi season crop, mostly under irrigated conditions. The crop can be grown on all types of soils. Well prepared, well drained, rich and friable loams are best suited for good growth. The crop can withstand slight acid and saline conditions, but not water logging and alkalinity. The crop sown before the middle of November requires about 140-180 days to mature. Late sown crop matures faster.

11.6.3 Botany

The oat plant is an annual tufted grass like other cereals. It can be distinguished from the other cereal grasses by the following features:

a) The plant has a bluish appearance

b) The leaves do not have the auricles at the base

c) The inflorescence is an open spreading panicle bearing large pendulous spikelets

d) There are generally 40-50 spikelets in each inflorescence

e) The majority of the spikelets contain 2 seeds, each enclosed by a husk.

The leaf sheath firmly envelops the internode - a feature unusual in grasses. Each stem ends in a terminal panicle consisting of many small branches. The branching of the inflorescence can be broadly divided into 2 basic types:

a) Spreading type in which the branches are equally distributed on all sides of the panicle

b) Common type or 'horse-mane type' in which all the branches are on one side.

The entire inflorescence may be erect or drooping. The terminal branchlets of the inflorescence have large pendulous, long pedicelled spikelets. Each spikelet is 3-flowered, but the second flower is usually sterile. Thus only 2 flowers are fertile. The fertile glumes, lemma and palea may or may not be awned. In some varieties, the palea are awned and these are usually twisted and hygroscopic. The awns cross and when wetted, they try to uncurl. In this manner, the awns press one another till a sort of explosion occurs, jerking away the grains. The florets have the typical organisation as in other cereals or grasses (Fig. 11.11).

Oats are largely self-pollinated and only 0.5-1.0% natural crossing is reported. The grain is a caryopsis. It is narrow and more slender than the wheat grain with a length wise groove on one side. The grain is greyish yellow and firmly enclosed by the husk or hull formed by the lemma and palea. These may be of different colours. The seed which is enclosed by the hull is of the same colour as the hull. When the seed is separated from the hull, it is called a groat.

11.6.4 Uses

Oats are inexpensive, but the most nutritious of all cereals. They are rich in starch high-quality protein, vitamin B, fat and minerals. However, only a small proportion of the oats cultivated in the world are consumed as human food. Oat meal, made by coarse grinding, and rolled oats are commonly eaten as breakfast cereal. This is not suitable for making bread because it does not contain gluten.

Oats are also used in making cakes, biscuits and infant foods.

The major portion of the oat crop is consumed as feed for livestock, especially horses, cattle and poultry.

Oats grown for hay or silage are harvested when the plants are green and the seeds are soft. These are fed to livestock during winter. The straw from oats is used as bedding for livestock.

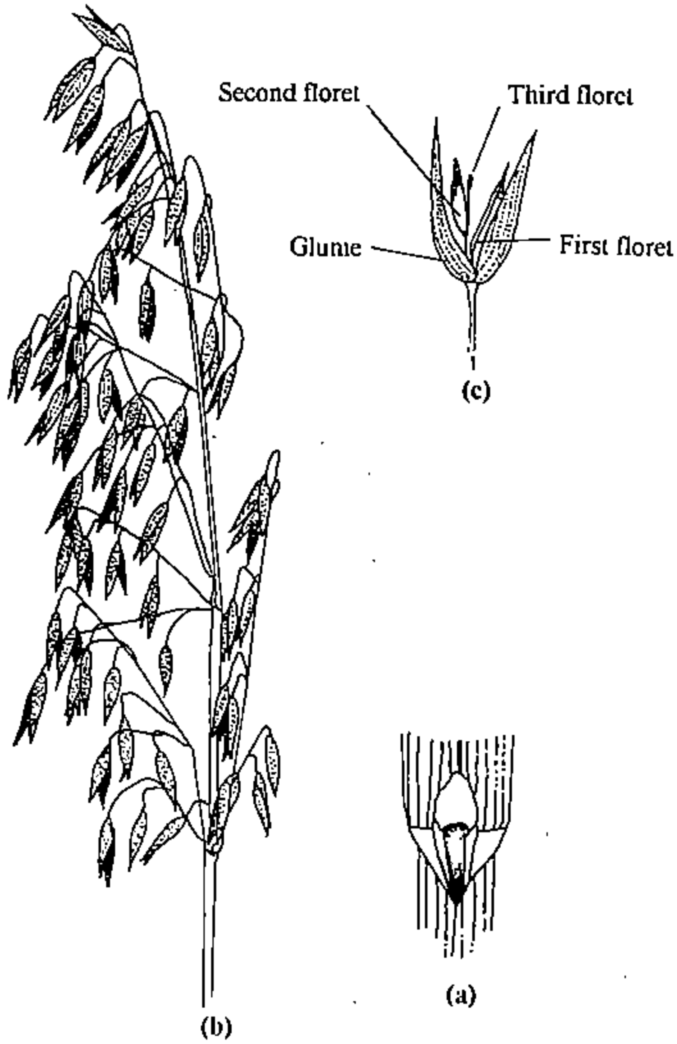

Fig. 11.11: Oats *(Avena sativa)*. (a) ligule, (b) panicle, (c) spikelet.

Besides being used as human food and livestock feed, oats also have industrial uses. Oat hulls are used as raw material for manufacture of furfural (see also maize 11.3.5). This substance is used in oil refining, nylon and synthetic rubber production as well as manufacture of antiseptic. Oat hulls can also be used as a fuel or for packing purposes.

11.6.5 Improvement

Scientists at the Indian Agricultural Research Institute, New Delhi have developed a number of promising hybrids of the cultivated oats. The main thrust of improvement has been to develop varieties which combine:

a) good grain yield,

b) profuse straw production,

c) early maturity, and profuse tillering

d) drought resistance.

11.7 SORGHUM

Botanical name: *Sorghum bicolor* (Linn.) Moench (Synonym *Sorghum vulgare* Pers.).
Family : Poaceae
Common name : Jowar
n = 10

Sorghum is a general term for a group of tropical grasses found in Africa and Asia. These drought resistant grasses are excellent crops for dry regions and for areas with unreliable rainfall. Interestingly, these grasses can also withstand temporary water logging. The plants are grown for their grains, or for their thick sweet juicy stems from which syrup is made. They are also grown for forage and broom fibre.

11.7.1 Origin and Distribution

The crop was cultivated in Ethiopia more than 5000 years ago. The vast diversity of ecological habitats in Ethiopia would have provided an ideal environment for selection of different races and varieties helping in domestication of the crop by the early settlers of this region.

Jowar or grain Sorghum is cultivated in India, China, USA, Nigeria, Sudan, Argentina, Pakistan, Mexico etc. In India, Jowar is the staple food of a large number of people in Central and Southern India. Maharashtra, Karnataka, Andhra Pradesh, Madhya Pradesh, Gujarat, Rajasthan and the Bundelkhand region of UP are major sorghum growing regions. It is also grown for fodder in other parts of the country.

Box 11.2 : Origin of sorghums.

There are many interesting aspects relating to the origin of the grain sorghums. The Babylonians grew a grain which probably refers to Sorghum. The Persian name for the crop is "Jaur-i-hindi". This suggests that the grains may have originated in India. This may also indicate that the grain was introduced into Persia from India. Linneaus believed that sorghum was of Indian origin. However, there is no Sanskrit name for sorghum to confirm the origin of this grass from India. It may have been introduced later and easily adapted itself in the unirrigated dry areas of the country.

11.7.2 Cultivation

Sorghum is adapted to a wide range of ecological conditions. It is essentially a tropical crop and can tolerate hot and dry conditions. It is grown chiefly in areas having an annual rainfall of 50-100 cm. Average temperature for optimum growth is between 26 and 32°C. Some varieties are able to produce good crop at higher temperatures of 38-44°C in semi arid conditions. The crop grows well under irrigation and the mean yield is generally more than that of a rainfed crop.

Sorghum can tolerate a wide range of soil conditions.

11.7.3 Botany

The sorghum plant in its vegetative condition has somewhat a superficial resemblance to the maize plant. It is a tall grass growing to 0.5 - 6.0 m in height. Generally there is a single, erect stem. Sometimes tillers are produced. A well developed adventitious fibrous root system penetrates upto 150 cm in the soil and spreads laterally. Stilt roots develop near the base of the stem to provide additional support to the tall stem.

Each stem has 7-24 leaves arranged in an alternate manner. Each leaf has a basal sheath, the margins of which overlap and encircle the stem. There is a short ligule and triangular or lanceolete auricles. The lamina is lanceolete, glabrous (smooth) flat or wavy, with prominent margins and midrib.

The panicle bears many paired (sessile and pedicillate) spikelets with large, distinctly - keeled glumes at the base. Each spikelet is two flowered but only one is functional.

The sessile spikelet is broad and relatively large with the lower flower reduced to a lemma, while the upper is perfect, consisting of a lemma and palea, three stamens, two lodicules and a centrally placed ovary with long styles and bifurcated pulmose stigma (Fig. 11.12). The lemma is awned. The pedicillate spikelet is longer and narrower with a sterile lower flower, consisting of lemma only, and staminate (or neuter) upper flower, having a lemma and three stamens. Neither of these two flowers has a palea.

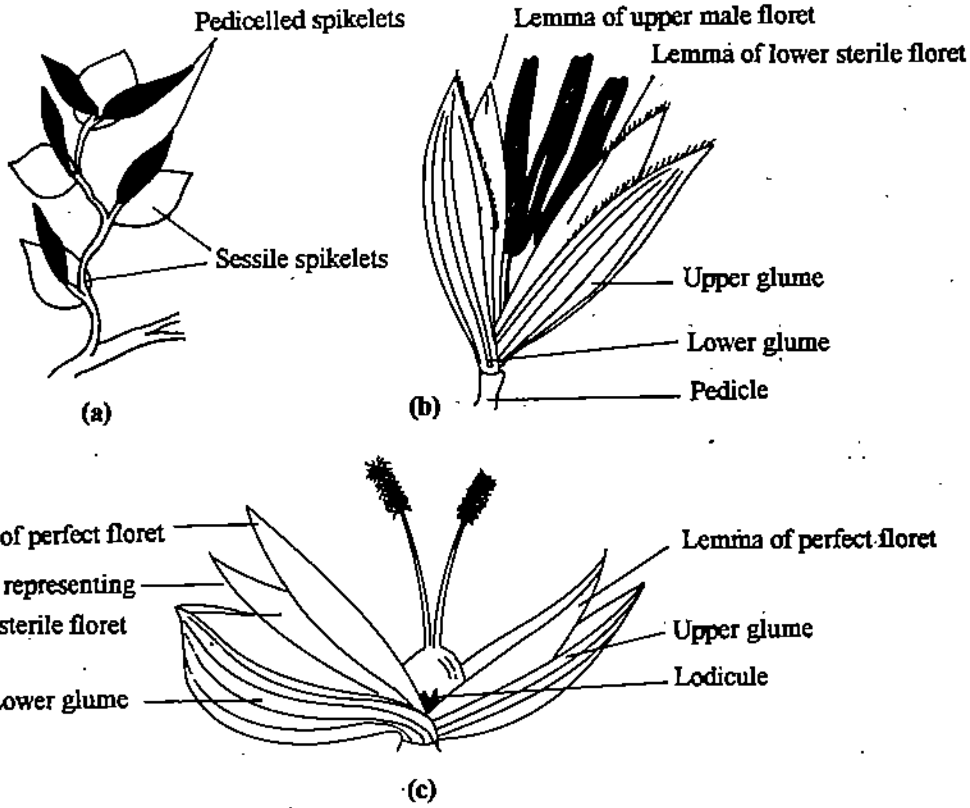

Fig. 11.12: ***Sorghum bicolor.*** **a) The arrangement of pedicelled and sessile spikelets on the ultimate branches of the panicle. b) A pedicelled spikelet with one male floret. c) A sessile spikelet with a single perfect floret from which the stamens have been shed. For the sake of clarity the hairs on the lemmas, palea and glumes have not been included.**

The fruit is a caryopsis or grain which is usually partially covered by the glumes. It is obovoid, ellipsoid or rounded. The colour may be off-white or cream to various shades of red, yellow or brown. The endosperm is hard and corneous on the outside but whiter and more flossy inside (Fig. 11.13). Dark coloured grains usually have a bitter taste.

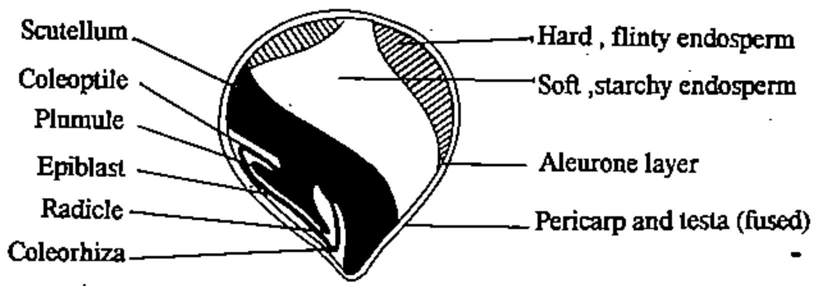

Fig. 11.13: A diagram of a longitudinal section through the caryopsis of *Sorghum.*

11.7.4 Uses

Sorghum grains have been important in world agriculture for centuries. At present, sorghum ranks 5th in acerage of crops of the world, being exceeded by wheat, rice, maize and barley. It is the staple food in the drier parts of tropical Africa, India and China. The grain can be ground into a whole meal flour. It can also be made into a thin porridge or a thick paste by boiling in water. After removing the seed coat, the grains may be cooked like rice. The protein is without gluten, hence sorghum flour may be mixed with wheat flour for bread making. Some varieties called pop sorghums have small grains with hard horny endosperm towards the periphery. These grains are prepared like popcorn and used in India. Similarly, some sugary grains are eaten like sweet-corn.

In USA and other developed countries, the grain is chiefly used as feed for livestock. Sorghum is widely used for brewing beer in Africa. This has a high vitamin B content but it becomes sour rather rapidly due to the production of acetic acid.

Varieties with large juicy sweet stems are called sargos. They contain as much as 10% sucrose and are chewed like sugarcane or used for the manufacture of syrup from the juice. The presence of sugar in the stem, makes the plant important as a fodder crop. The straw is also fed to cattle. Some varieties with shortened inflorescences are used for making brooms. The plants are harvested soon after flowering and the inflorescence is dried after removing the seeds.

11.7.5 Breeding and Improvement

Sorghum is an extremely variable crop. There is much intercrossing and hybridization amongst the wild and cultivated sorghums. This provides considerable scope for improvement by selection and breeding.

A co-ordinated Sorghum Improvement Programme initiated by the Government of India in co-ordination with the United States Department of Agriculture (USDA) and the Rockefeller Foundation has catalogued and classified the World genetic stock of sorghum. Samples showing major genetic diversity and breeding potential have been widely distributed both within and outside India. A large number of improved strains have been developed chiefly by single plant or mass-selection. Many of these represent genetic combinations with a capacity to withstand seasonal fluctuations. Several improved varieties are now grown extensively in different states of India. Of these the "Coordinated Sorghum Hybrids" CSH-1 to CSH-8 are well known. They are grown alongwith old popular varieties.

SAQ 2

1. Write the botanical names of the following:

   a) Rye

   ....

   b) Ergot

   ....

   c) Common Oat

   ....

   d) Indian Oat

   ....

   e) Great millet

   ....

2. List the features which differentiate:

   a) Wheat from rye

   ....

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   ....

   b) Oats from other cereal grasses

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   ....

   ....

c) Maize from sorghum.

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3. Mention the centre of origin of:

a) Oats

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b) Sorghum

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4. In cytogenetic terms, mention:

a) One similarity and

....

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b) One difference between wheat and oats

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5. Mention the important uses of:

a) Rye

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b) Oats

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c) Sorghum.

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11.8 BARLEY

Botanical name: ***Hordeum vulgare*** **Linn. Syn.** ***H. sativum***
Family : Poaceae
Common name : Jau, Jav
n = 7

Barley is one of the oldest cereals which was cultivated by man at the dawn of civilization. It is used as a food grain, for producing malt in the brewing of beer, and also as animal feed.

11.8.1 Origin and Distribution

This cereal grain has been closely associated with wheat. There are archeological evidences from the famous Neolithic site of Jarmo in Iraq which suggest that this cereal may have first been cultivated about 6500-7000 B.C. It is also believed that barley may have originated in Abyssinia (Ethiopia) in North East Africa; and also in eastern Asia in the region comprising China, Japan, Tibet and Nepal. These two regions can be referred to as centres of diversity and the types of barley growing in these regions are distinct. In the north-east African centre, the predominant cultivated type of barley is of the 2-rowed type. Each spike has 2 rows of grains. This is called *Hordeum vulgare* var. *distichum* (or *Hordeum distichum* L.) and it is quite similar to a wild species called *Hordeum spontaneum*. In the eastern or Asian Centre, the six-rowed barley is commonly cultivated. Each spike has 6-rows of grains. The plant is referred to as *Hordeum vulgare* var. *hexastichum*.

The antiquity of barley is also shown by other evidences. Illustrations of the Roman goddess of agriculture -Ceres - show ears of barley plaited in her hair. Ancient Greek and Roman coins also depict barley. Carbonised grains from the Swiss lake dwellings as well as a jar of grain of the six-rowed barley are amongst the oldest specimens of this cereal which are preserved in the world museum.

Vavilov suggested that barley spread out from two centres, North Africa and East Asia. This suggestion was based on botanical and ecological information. The actual centre of origin of this cereal could be in the region between North West India and Abyssinia.

Barley is cultivated in the Commonwealth of Independent States (CIS; the former USSR); other parts of Europe (particularly Germany, United Kingdom); countries bordering the Mediterranean; USA, Canada, China, Japan and India. Barley has been cultivated in northern India both on the plains as well as the hilly regions of the Himalayas. The states of Uttar Pradesh, Rajasthan, Bihar, Punjab, Haryana, Madhya Pradesh, West Bengal, Himachal Pradesh, Jammu and Kashmir, and even Maharashtra now cultivate this crop.

11.8.2 Cultivation

Although barley is basically a temperate crop, it is also grown in tropical regions. Like wheat, barley can be grown either in spring or in winter. Since it is not winter hardy, it is cultivated as a spring crop in Europe while in India it is grown as a winter crop. It grows well in areas having sunny weather and moderate rainfall.

Barley can be grown in different kinds of soils and even in alkaline conditions. Light sandy loams are generally preferred, but good quality grain is produced on fertile deep loam soils with a pH of 7 to 8.

Barley is cultivated in India as a rabi crop, sown in October - November and harvested in March - April as in the case of wheat. It may be grown as a pure crop or mixed with other rabi season crops.

11.8.3 Botany

The barley plant in its vegetative condition has a somewhat superficial resemblance to the wheat plant. It is an annual tufted grass growing up to about 1.2 m in height. Just as in wheat, tillers are produced freely. The leaves are few with a linear-lanceolate blade. The ligule is very prominent; the sheath is smooth and striate. The spike is cylindrical and long bearded. It differs from wheat and rye in having 3 one flowered spikelets arranged alternately. In the 2-rowed barley (*Hordeum vulgare* var. *distichum*) the central spikelet is fertile while the 2 lateral spikelets at each node are sterile. Thus in a mature spike, there are 2 rows of grains only (Fig. 11.14). The six -rowed barley (*H.vulgare* var. *hexastichum*) has all fertile spikelets. Therefore, the mature spike has 6-rows of grains. At each node there are 2 small, narrow, short-awned glumes enclosing the 3 spikelets (Fig. 11.15). In each spikelet, there is a lanceolate lemma which is 5-ribbed and tapers into a long straight or recurved awn. The palea is a little smaller than the lemma. Two lodicules, 3 stamens and the ovary with 2 feathery stigmas make up each floret. The fruit is a caryopsis in which the lemma and palea are fused with the grains forming the hull. In some varieties the grain is naked, smooth and free of the hull. The elliptic grain is pointed at both ends and grooved on the inner face. It is narrower than the wheat grain.

11.8.3.1 Barley is a self-pollinated crop. Non-functional anthers and genetic male sterility have also been recorded in barley. Natural crossing is very low. Hybridization of cultivated barleys is more difficult than in the case of wheat. All cultivated types of barley have 7 pairs of chromosomes.

11.8.4 Uses

Large amounts of barley grains are consumed locally by the farmers. Since it has very little gluten, barley flour on its own is not used for bread making. Its flour is mixed with wheat flour for making **chapatis**. In many parts of India, a refreshing, sweet, cooling drink called **"Sattu"** is prepared from barley grains. Both ripe and unripe grains are roasted and ground into a meal. This is then suspended in cold sweetened water and consumed as a refreshing drink in summer. A decoction of barley, called barley water is generally prescribed as an important diet for infants and invalids.

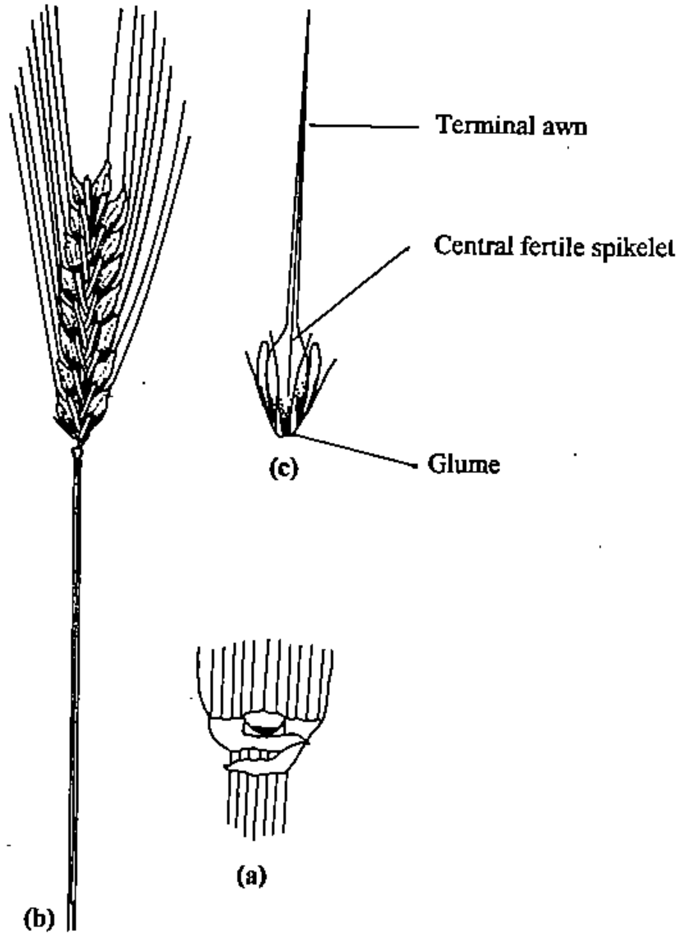

Fig. 11.14 : Two-rowed barley *(Hordeum vulgare* var. *distichum).* a) auricles and ligule, b) Spike with fertile and sterile spikelets, c) group of three spikelets.

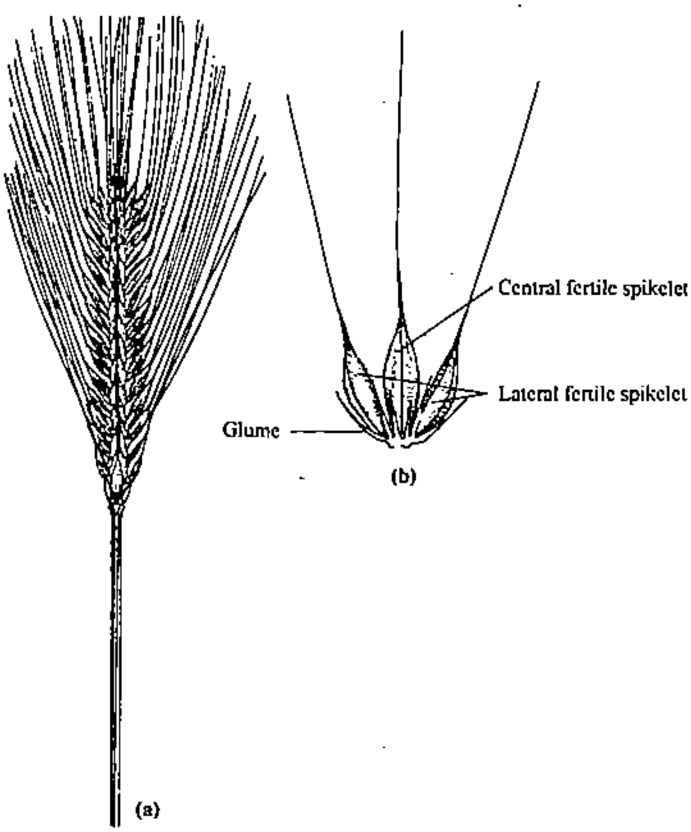

Fig. 11.15 : Six-rowed barley *(Hordeum vulgare* var. *hexastichum).* a) spike, b) group of three fertile spikelets.

Barley is also used in the malting and brewing industry. Malt is produced by germinating barley grains under controlled conditions. When the radicle becomes visible, germination is stopped by drying the grains. These grains are then dried and used as malt in brewing beer. About 80% of the malt is used in beer manufacture. A small proportion is used in the manufacture of industrial alcohol and distillation of whisky.

Besides being used as food and in malting, barley is also used as livestock feed. The young plants are also fed green or as hay. The straw is used as a packing material or in the manufacture of cellulose pulp.

11.9 TRITICALE

Botanical Name: ***Triticale***
Syn. - ***Triticosecale Wittmack***

This is not a naturally occurring cereal; it is a man-made grain produced by cross-breeding wheat *(Triticum)* and rye *(Secale)*.

Botanists first crossbred wheat and rye in 1876. The hybridization was successful, but the hybrids were completely sterile and could not produce any grains. However, by treating the seedlings of the wheat rye hybrid with colchicine, the plants became fertile and produced grains. This led to the setting up of the first *Triticale* breeding programme in Sweden. By 1950's many countries around the world became interested in producing this man-made cereal. It has a high nutritional content because it contains more usable protein than either wheat or rye. The grains are larger than wheat but less abundant on the spike.

The hybrid *Triticale* plant resembles wheat with long narrow leaves. The terminal spike has many spikelets, each with 3 to 5 grains. The plants are more winter hardy than wheat and can be grown in cold climates and in poor soils. They are more resistant to rust and have lower tendency to lodging when compared with wheat. The yield is higher than rye.

Triticale is used mainly as an animal feed and pasture crop. Research is being promoted in many countries to improve the quality of the grain so that it can be used for human consumption, and in the bread and cake industry. The grains can also be used for malting.

Fertile *Triticale* hybrids can be produced by crossing hexaploid wheat (*Triticum aestivum*) with diploid rye (*Secale cereale*) and doubling the chromosome number. The fertile plants are octaploid with $2n = 8x = 56$ chromosomes. However, hexaploid hybrids produced by crossing tetraploid durum wheat (*Triticum durum*) with diploid rye and subsequent doubling of chromosomes have become more popular.

Durum Wheat — AABB ($2n = 28$) × Rye — RR ($2n = 14$)

↓

Sterile hybrid
ABR ($2n = 21$)

↓ Colchicine treatment

Fertile hexaploid hybrid
AABBRR ($2n = 42$)

SAQ 3

1. Mention the main difference between *Hordeum vulgare* var. *distichum and Hordeum vulgare* var. *hexastichum*.

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2. Name the two centres suggested by Vavilov from where barley spread.

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3. In what ways does the inflorescence of barley differ from that of wheat or rye.

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4. How is malt produced?

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5. How did *Triticale* become an important man-made cereal?

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11.10 SUMMARY

Amongst the food plants, cereals are the most important as staple diet. It has been possible to correlate the close association of cereals with human civilization and the development of agriculture. Wheat, rice and maize have become the most important sources of food. Besides these, barley, oats and rye are the other true cereals. Some small- grained members of the grass family are also edible. These are called millets.

Besides being used as food, these plants are of importance for industrial purposes and as fodder for livestock.

Wheat is probably the oldest crop known in cultivation. The modern cultivated wheat has been shown to be a hexaploid which arose through Hybridization. The origin and evolution of the common bread wheat has been documented through cytogenetical studies.

Concerted efforts to improve the quality of the grain and increase production have established several important landmarks in the breeding and improvement of this plant. Numerous uses of wheat plant have been listed.

In the new world cereal, maize ranks second after wheat in terms of grains production.The interesting archeological discoveries together with genetic studies and other evidences help you to know about the different views on the origin of maize. The structure of the grains, which is genetically controlled, is used to classify different kinds of maize. Although maize is also a typical grass, it differs from wheat in having separate male and female inflorescences. Hybrid maize has become the most important achievement of plant breeders. Maize is used as human food, as feed for livestock, and as raw material for many industrial purposes.

Details about rice cultivation, botany, and uses have been provided. Information about rice breeding and the biotechnology of rice have also been mentioned.

Rye, barley and oats, the three other cereal crops have been also dealt with.

The great millet or Jowar, *Sorghum vulgare* is an important crop of the tropical regions. The interesting aspects of its origin have been elaborated. This plant, although not a true cereal, is of great importance. It has a superficial resemblance to the maize plant in its vegetative state. It bears a terminal paniculate inflorescence like rice and its grain is used in many ways. This crop has also been subjected to breeding and improvement studies. Finally, information has been provided about *Triticale*, the grain of the future.

11.11 TERMINAL QUESTIONS

1. Write an account of the cultivation of rice or wheat in India. Indicate the soil and climatic conditions which favour higher yields. Mention the various uses of the crop you select.

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2. Prepare a detailed account of the origin, cultivation, improvement and uses of maize.

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3. Compare the cultivation, botany and uses of maize and *Sorghum*.

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4. (a) What is par-boiled rice? Why is it considered superior to ordinary rice?

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(b) Write a brief account of malting and its importance in the brewing industry.

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5. What are cereals? Discuss the importance of cereals in(a) human diet, and(b)promoting civilization. Name the important cereals and their centres of origin. Write a general account of the botany of the cereal plants.

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11.12 ANSWERS

Self-Assessment Questions

SAQ 1

1. Wheat, rice, maize, barley, oats and rye.

2. Millets are grasses like the cereals but they produce small grains and are important source of food.

   Pseudocereals are unrelated dicotyledonous plants whose seeds are used in the same way as the cereals.

3. (a) Wheat originated in the Old World in a number of centres of genetic diversity. The diploid wheats originated in Asia minor; the tetraploid wheats in North Africa; and the hexaploid wheats in Central Asia.

   (b) Maize originated in the New World. The region from Gautemala to Southern Mexico is believed to be the centre of origin of maize.

   (c) Rice originated in South East Asia.

4. (a) CIMMYT = Centro International de mejor-amiento de Maizy Trigo

   OR

   International Maize and Wheat Improvement Centre

   (b) IRRI - International Rice Research Institute

(c) CRRI - Central Rice Research Institute

5. (a) N.I Vavilov was an outstanding Russian scientist. He was a pioneer in the field of plant exploration. He carried out investigations in crop geography and genetics. By sending expeditions all over the world, he made extensive collections of cultivated plants and their wild relatives. Vavilov made valuable suggestions on the centres of origin, of diversity and distribution of various cultivated plants. These suggestions were based on a comparative evaluation of different kinds of evidences. Besides the morphology of the plants, he also used information from anatomy, cytology, genetics, distribution and pathological responses.

   (b) Manglesdorf was a well-known maize scientist. He proposed the hypothesis that maize originated in America. This was supported by other scientists. Manglesdorf undertook detailed studies on primitive types of maize to find out a cytogenetic basis for understanding the origin of maize. He has written extensively on various aspects of maize and his book "Corn, its Origin, Evolution and Improvement" provides interesting details about this New World Cereal.

   (c) George H. Shull was a plant breeder who undertook detailed breeding studies of maize. He is called the "Father of Hybrid Corn". He used methods of controlled pollination to produce many inbred lines of maize. Then he crossed the inbredlines and produced hybrid maize which had a very high vigour. This revolutionized maize cultivation leading to production of large quantities of selected maize varieties.

6. Sec 11.2.1 - Origin and Distribution of Wheat.

7. Refer to the Table under 11.4.2 - Kinds of rice.

SAQ 2

1. (a) Rye - *Secale cereale* Linn.

   (b) Ergot - *Claviceps purpurea*

   (c) Common oat - *Avena sativa Linn.*

   (d) Indian oat - *Avena byzantina* C. Koch.

   (e) Great millet - *Sorghum bicolor* (Linn.) Moench.

2. (a) Rye is distinguished from wheat by

   (i) its narrow, subulate one-nerved glumes;

   (ii) its flowers open;

   (iii) being a cold-weather crop;

   (iv) being least exacting in its soil requirement;

   (v) capable of growing in poor soils which are unproductive for other cerals.

   (b) Oats can be distinguished from other cereal grasses by the following features:

   (i) The plant has a bluish appearance;

   (ii) The leaves do not have auricles at the base;

   (iii) The inflorescence is an open spreading panicle bearing large pendulous spikelets;

   (iv) There are about 40-50 spikelets in each inflorescence;

   (v) The majority of the spikelets contain 2 seeds

   (vi) Each seed is enclosed in a husk

   (vii) They have a higher food value than any other cereal grain.

   (c) Maize is a true cereal while sorghum is a millet. The maize grains are large, the sorghum grains are small. The two grasses show a superficial resemblance in the vegetative condition, but at the time of flowering, they are distinct. In sorghum the inflorescence is a terminal panicle. This may be contracted thus forming a compact head or it may be a loose pendant panicle. The branches bear paired spikelets in a racemose manner. One spikelet is pedicellate and has male or sterile florets. The other spikelet is sessile and bears bisexual florets. This inflorescence is thus totally different from the terminal male tassel and the female cobs of maize.

3. (a) Oats - Persia

   (b) Sorghum - North East Africa.

4. (a) Common cultivated wheat and cultivated oats are both hexaploids with 2n = 42 chromosomes. In both wheat and oats- there are diploids (2n = 14), tetraploids (2n = 28) and hexaploid species (2n = 42).

   (b) There are sterility barriers between diploid, tetraploid and hexaploid species of oats. These do not exist in the wheats. Thus, it is not possible to derive the origin of the cultivated hexaploid oats as in the case of wheat.

5. (a) Rye - See 11.5.

   (b) Oats - See 11.6.4

   (c) Sorghum - See 11.7.4

SAQ 3

1. *Hordeum vulgare* var. *distichum* or the 2-rowed barley has 2 rows of grains in each spike.

   Hordeum vulgare var. *hexastichum* or the 6-rowed barley has 6 rows of grains in each spike.

2. (i) North Africa

   (ii) East Asia.

3. The inflorescence of barley has 3 one-flowered spikelets on 2 sides of the flattened rachis, arranged alternately. The terminal inflorescence is a cylindrical spike which is long bearded.

4. Malt is produced by germinating barley grains under controlled conditions. When the radicle becomes visible, germination is stopped by drying the grains. These are dried and used as malt. Several enzymes bring about chemical changes in the grain during the process of malting.

5. *Triticale* became an important man-made cereal when the drug colchicine was discovered to prevent spindle formation during cell division so as to double the number of chromosomes. This made the sterile hybrids fertile and they thus produced grains.

   These grains have a higher nutritional value because they contain more usable proteins than either wheat or rye.

Terminal Questions

1. For Rice : Refer to 11.4

   For Wheat : Refer to 11.2

2. Refer to 11.3

3. Refer to 11.3.2 and 11.3.3 (for maize) as well as 11.7.2 and 11.7.3 (for sorghum)

4. a) 11.4.4 last paragraph

   b) 11.8.4

5. Prepare your answer by referring to the introduction (11.1) as well as to the different cereal grains discussed in this unit.

UNIT 12 LEGUMES (PULSES)

Structure

12.1 Introduction
Objectives
12.2 Legumes - An Overview
12.3 Groundnut
12.4 Gram
12.5 Pea
12.6 Soybean
12.7 Cowpea
12.8 Beans
12.9 Urd
12.10 Mung
12.11 Summary
12.12 Terminal Questions
12.13 Answers

12.1 INTRODUCTION

Food is a basic necessity of life as it supplies the nutrients that the body needs for producing energy; building and repairing tissues; and regulating body processes. The body uses proteins in the food to build and repair tissues. Proteins exist in every cell and are essential to plant and animal life. Of the various foods consumed by man, the legumes are important source of proteins. These plants of the family Fabaceae (Leguminosae) have been consumed by man since times immemorial as an important constituent of the daily diet in many parts of the world. They have been used to supplement the diet consisting of cereals (see Unit 11). In addition, their seeds have a low water content that makes them all the more suitable for long distance transportation and long storage. They can be easily cultivated and also they grow rapidly. The value of legumes in improving and maintaining soil fertility has been recognised by man since ancient times. That is why these plants are ideal candidates for crop rotation. Many species of legumes have nodules on their roots which act as nitrogen fixing sites. You can read more about these nitrogen fixing structures in Appendix 12.1 at the end of this unit.

Legumes are consumed as green vegetables, as green shelled seeds, or as dry seeds. The dry seeds of legumes are commonly called **pulses**; they are also termed as **grain legumes or beans**. The varieties of legumes used as green vegetables have fleshy-walled pods with less fibre in the younger stages. The pulses contain 17 to 30 percent proteins on a dry weight basis. This is a large amount of protein supplied by any plant food. The richest source of proteins amongst legumes is the soybean which provides more than 40% protein on a dry weight basis. Besides proteins, legumes also contain carbohydrates (mainly starch), fats, calcium and iron. When the seeds are soaked and allowed to sprout, they are an excellent source of vitamin C, although this vitamin is not present in dried seeds. The seeds however contain niacin, thiamine, and riboflavin. Interestingly, the amino acids of legumes complement those of the cereals. The legumes have adequate amounts of lysine, tryptophan and threonine but are low in methionine, cystine and cysteine. These sulphur-containing amino acids are present in adequate amounts in cereals which are low in lysine and threonine. It is for this reason that cereals and legumes have been used together in the diet of man in different parts of the world. This provides the correct balance of amino acids.

This unit gives you detailed information on the widely consumed legumes in our country: these are groundnut, gram, pea and soybean. Besides these, information on some pulse crops of India will add to your knowledge.

Objectives

After studying this unit you should be able to:

- prepare detailed accounts that includes information on origin and distribution, ecological conditions, identification features, uses, and improvements made, of the widely consumed legumes in our country;
- prepare brief account of some lesser used legumes; and
- explain the importance of legumes to man.

12.2 LEGUMES - AN OVERVIEW

The family Fabaceae is a large family of flowering plants. You shall find a detailed taxonomic account of this family in Unit 21, Block 4 of this course. The term **legume in the botanical sense refers to the entire plant as well as to the fruit** which is a simple, dry, dehiscent pod. All the cultivated legumes consumed as food are classified in the subfamily Papilionatae (also called Papilionoideae, or Faboideae, or Lotiodeae). The different pulse crops of this group are classified in three tribes - the Vicieae, the Hedysareae, and the Phaseoleae. Pulses such as lentil *(Lens esculenta)*, Pea *(Pisum sativum)*, gram *(Cicer arietinum)*, broad bean *(Vicia faba)* and others are members of the tribe Vicieae. The most common legume which is also an important oilseed crop is groundnut *(Arachis hypogaea)*. It is a member of the tribe Hedysareae. Other legumes such as the soybean *(Glycine max)*, cowpea *(Vigna unguiculata)*, pigeon pea *(Cajanus cajan)*, the green gram or mung *(Phaseolus aureus)*, black gram or urd *(Phaseolus mungo)* are classified in the tribe Phaseoleae.

Legumes are cultivated all over the world and India is the world's single largest producer of pulses. The very fact that a wide variety of pulses grow in India all around the year that makes these plants important in the agricultural economy of the country. The Directorate of Pulse Development of the Ministry of Agriculture, Government of India recognises the following as the major pulse crops (see Table 12.1).

Table 12.1: The major Pulse crops of our country.

Botanical Name	Name in English	Name in Hindi
Cicer arietinum	Chick pea or Bengal gram	Channa
Cajanus cajan	Pigeon pea	Arhar or Tur
Dolichos uniflorus	Horse gram	Kulthi
Lathyrus sativus	Chickling vetch or or grass pea	Khesari dal
Lens esculenta	Lentil	Masur
Phaseolus aureus	Green or golden gram	Mung
Phaseolus mungo	Black gram	Urd
Pisum sativum	Pea	Matar

The major legume/pulse producing states are Rajasthan, Madhya Pradesh, Uttar Pradesh, Orissa, Andhra Pradesh, Tamil Nadu, and West Bangal. Chick pea and pigeon pea are the two most important pulse crops cultivated in about 45% of the total area under legume cultivation. The remaining 55% of the area is used for cultivating all the other pulses. Chickpea and pigeon pea together provide about 55% of the total pulses produced in the country.

Besides India, pulses are also grown in different parts of the tropics and subtropics. The major pulses growing countries other than India are China, Brazil, Mexico, Nigeria and Turkey. Europe, America and Africa grow small quantities of legume crops for consumption as pulses. The groundnut and soybean which are legumes but rich in fatty oils, are generally classified as oilseeds and are usually not treated as pulses.

Although the legumes are important sources of proteins and oils many of them also contain toxic substances. Fortunately most of these toxic substances are detoxified during cooking or by just pre-soaking the seeds in cold or warm water. However, two legumes are known to cause diseases in humans. The grass pea or chickling vetch or khesari dal *(Lathyrus sativus)* contains a neurotoxin and an osteotoxin which bring about crippling or paralysis of the lower limbs. This is called **lathyrism** and is caused by prolonged consumption of khesari dal. Similarly the broad bean or Bakla *(Vicia faba)* causes an acute anaemic condition called **favism**. It is caused by eating uncooked or partially cooked seeds or by inhaling the pollen of the plant. Interestingly, this disease affects only the males and is common in the *Mediterranean region*.

To sum up, legumes or pulse crops are very important plants. They are valued for their nitrogen fixing property, high protein content, easy cultivation and rapid growth, easy storage and transportation. They enrich the soil, provide food for man and serve as excellent green fodder and feed for livestock.

12.3 GROUNDNUT

Botanical Name : *Arachis hypogaea*
Family : *Fabaceae*
Common Names : Peanut, Monkeynut, Mungphali
n = 20

Although this interesting plant is called groundnut or peanut, its fruit is not a true nut (see Unit 13 - Fruits and Nuts), but is a pod or legume which is geocarpic. A geocarpic fruit develops in the soil, below the surface of the ground. The Swedish naturalist Carolus Linneaus gave the botanical name *Arachis hypogaea* to this plant because the fruit is actually a legume (**Arachis** means legume) and it shows underground development (**hypogaea** means below ground). This interesting legume is a rich source of fat and protein, besides starch and other substances. In addition to India, this plant is also extensively cultivated in the tropical, subtropical and warm temperate regions of the world.

Origin and Distribution

The groundnut is believed to have originated in South America. According to Vavilov, this plant was first domesticated in the Brazilian-Paraguayan region. The area of the valleys of Paraguay and Parana rivers is the most likely centre of origin of this legume. No wild plants of this important crop have been found. But several other species grow in the wild and all of them produce geocarpic fruits. Excavations in coastal Peru dating back to 800 BC show that the groundnut was widely cultivated. From South America, this legume spread to other parts of the world. It was commonly found in the West Indies but not in the United States in Pre-Columbian times. Groundnuts were introduced to the Old World in the 16th century when the Portuguese took the seeds from America to Africa. From West Africa, the Spaniards introduced them into the Philippines. They then spread it to China, India, Japan, Malaysia and other parts of the world.

India is the largest producer of groundnuts, but very little of the crop enters the world market. The demand for the groundnut oil in India is greater than the quantities produced. This crop is grown chiefly in Andhra Pradesh, Tamil Nadu, Karnataka, Uttar Pradesh, Punjab, Rajasthan and Gujarat. The states of Bihar, West Bengal and Madhya Pradesh also produce groundnuts.

Besides India, the other important groundnut growing regions of the world are China, United States of America, South Africa, Sudan, Nigeria, Indonesia, Burma, Argentina, and Thailand. Nigeria is the largest exporter of groundnuts to the European nations.

Ecology

Groundnut is a warm season crop and requires abundant sunshine for normal development. It is badly affected by frost. The crop grows best on well-drained, loose, friable sandy loams containing calcium and organic matter. You may recall that groundnut is of great value in crop rotation. It is rotated with several crops and is also intercropped with cotton and pearl millet or bajra.

In India, groundnut is grown as a rainfed 'Kharif' crop, sown from April to July. It matures in 4 to 6 months and the crop is harvested when the lower leaves turn yellow. The entire plant is uprooted and the pods are removed mostly by hand. The fresh pods are thoroughly dried in the sun before they are packed and stored. The crop is commercially grown from seed.

Botany

The groundnut plant (Fig. 12.1 a-e) is a herbaceous annual which may be erect or trailing and growing 15-60 cm in height. In the erect type also called bunch type, the branches are produced close to each other. The pods are produced in bunches or clusters near the base of the plant. Each pod (Fig. 12.1 b, e) is small or of medium size and has one, two or more small, rounded seeds. In the trailing or runner type plants, the branches (or runners) are prostrate and spread on the ground. The pods are produced along the entire length of the branches and no bunch is formed. The pods are thus spread out in the soil. The pods are of medium or large size having 1-3 or more oval seeds. The shells of these pods are comparatively thick.

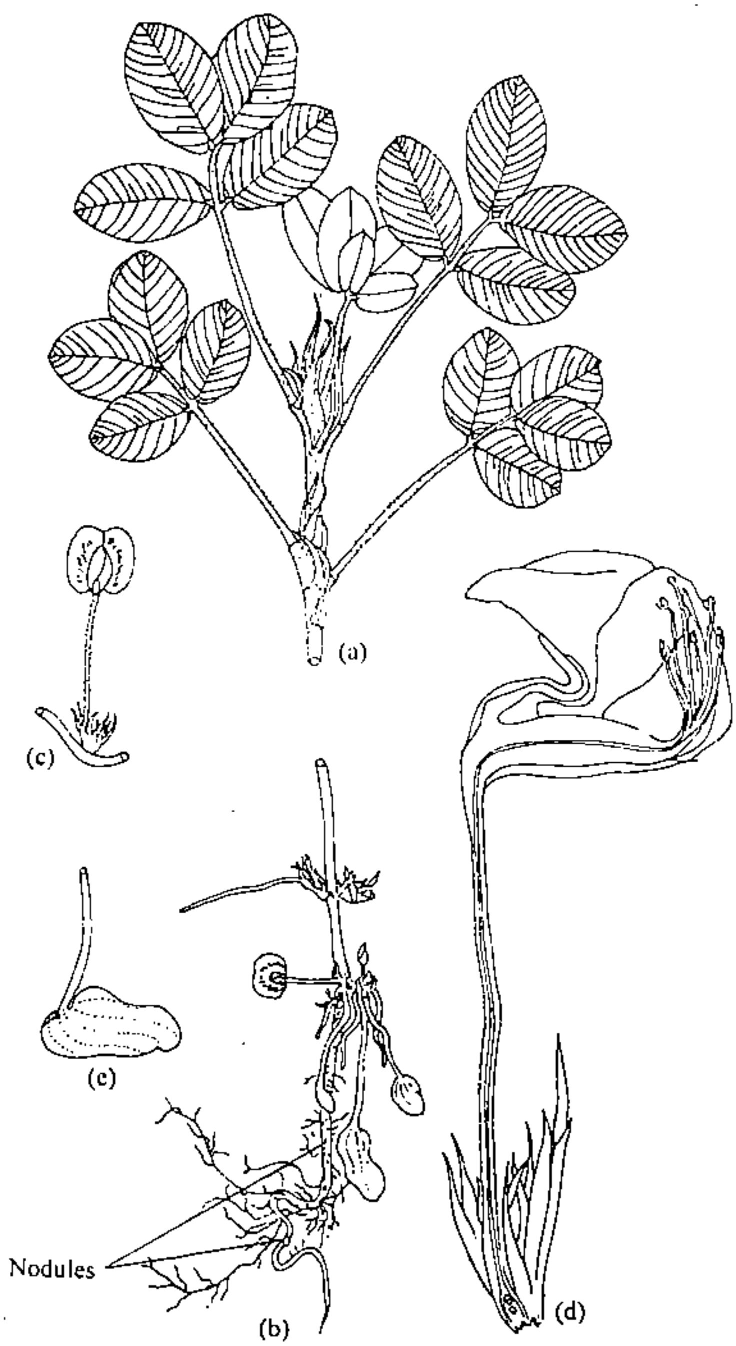

Fig. 12.1(a-e) : *Arachis hypogaea*, **Groundnut. a) A part of twig showing leaves. b) Basal portion of the plant showing a flower, and fruits at various stages of development. c) A flower. d) A flower in longitudinal section. e) A young fruit. (Redrawn from Purseglove, 1988).**

The plant has a well-developed tap root with many lateral roots (Fig. 12.1 b). Adventituous roots also develop from the hypocotyl and the spreading branches. No root hairs are present. The roots contain colonies of *Rhizobium*.

The main stem is profusely branched. Branching is dimorphic. The vegetative branches are monopodial. The flowering or reproductive branches are reduced. Young stems are angular with a completely filled pith; older stems are cylindrical and hollow in the pith region. The leaves are spirally arranged. Each leaf is compound with two opposite pairs of obovate leaflets (Fig. 12.1 a). The prominent linear stipules are adnate to the petiole for about half their length.

The flowers (Fig. 12.1 b,c,d) are yellow and sessile. They develop singly or in compressed spikes containing 2 to 4 flowers. These arise in the axils of foliage leaves on the reproductive branches. The flower has a typical papilionaceous organisation (see family Fabaceae, Unit 21). The calyx is made up of 5 fused sepals. This *tube is often mistaken as the pedicel of the flower* (Fig. 12.1 d). At the top of the calyx tube is present the papilionaceous corolla and the staminal tube. There are 5 yellow petals and 10 stamens in a monadelphous condition. Of the 10 stamens, 2 are sterile, 4 have large anthers and 4 small anthers. The ovary is monocarpellary with 1-6 ovules on marginal placenta. The ovary is superior and the style is long and filiform.

The fruit is a legume or pod (Fig. 12.1 b,e). It's development inside the soil is a very interesting feature. After fertilisation, the fruit first appears at the tip of a pointed stalk-like structure. This **carpophore** or peg elongates due to the active cell division of an intercalary meristem present at the base of the ovary. The peg becomes positively geotropic, elongates and penetrates up to a certain depth in the soil. The conical tip becomes lignified and forms a protective cap. The peg then loses its geotropism and the pod or legume develops horizontally. The fruit matures rapidly. The mature fruit is a structurally dehiscent but functionally indehiscent legume. This oblong pod has 1-3 (sometimes more) seeds. The dry pericarp of the mature pod is a fibrous structure showing a reticulate pattern on the surface. This constitutes 20-30% of the weight of the mature fruit. The parenchymatous endocarp surrounds the developing seeds and it forms a papery lining of the shell in the mature fruit. The seeds vary in size, shape and colour of the testa or seed coat. This papery covering or skin of the seed may be white, pink, red, purple or of shades of brown. There is no endosperm and the embryo consists of two massive cotyledons, a large radicle and the plumule. The fleshy white cotyledons are rich in non-drying oil and protein. They also contain starch and are rich in phosphorus and vitamins especially thiamine, niacin, and riboflavin.

Uses

Groundnuts are an important source of vegetable oils. This is grown as an oilseed crop because about 45% of the seed weight is made up by the fatty oil present in the cotyledons. This non-drying oil is edible and is used in cooking, in the manufacture of margarine, soap and lubricants. The oil can be hydrogenated to make vegetable ghee or vanaspati. The oil cake obtained after removal of oil from the seeds, is rich in protein. It is used as livestock feed or as a fertiliser. Good quality oil cake can be ground into flour and used as a protein rich food supplement for human consumption.

Groundnuts are also used for the manufacture of peanut butter. The seeds are cleaned, the testa and embryo are removed and the large white cotyledons are roasted. When these are ground, a thick butter-like substance is obtained. This is sold as peanut butter.

The seeds of groundnut have a very high calorific value. When eaten in raw, roasted, salted or sweetened form, they produce large amounts of energy in the human body. Due to this the biological value of groundnuts is among the highest of the vegetable proteins. In many parts of the world, groundnuts are consumed during winter to keep the body warm.

Technological advancements have led to the manufacture of a synthetic textile fibre from peanut protein. This is a cream coloured wool-like fibre called adril. The fibrous shell of the pod is used as a fuel or in the manufacture of a particle-board.

Improvement

There are always attempts to improve economically important plants for better yield, better quality, disease and pest resistance. In the case of groundnut, this is a very difficult task.

The crop is an inbreeder with self-pollination being the rule. Attempts have been made to achieve success in cross-pollination, but this is a very difficult and time consuming process. Anthesis (flower opening) and pollination take place at sunrise and the flowers wither within 5-6 hours after opening. There is also a tendency to cleistogamy. Another important factor is the fact that individual plants produce few seeds. This leads to poor recovery of improved types of seeds.

Selection for adaptation to local conditions, drought resistance, high oil and protein content, suitability for mechanical harvesting, is thus, a continuous process in the improvement of this important agricultural produce.

12.4 GRAM

Botanical Name: ***Cicer arietinum***
Family : ***Fabaceae***
Common Names : Chick-pea, Chana, or Bengal gram.
n = 8

This is one of the oldest pulse crops known and cultivated in Asia and Europe since ancient times. Archeological findings reveal that gram was cultivated in Turkey as early as 5450 B.C. It has also been found in prehistoric sites in Palestine and the Mediterrannean region. Today it is a very important grain legume occupying the 2nd position in area after pigeon pea. It is the 3rd important pulse crop of the world in terms of production, and the most important pulse crop of India. An interesting aspect of its botanical (scientific or Latin) name is the comparison of the seed to the head of a 'ram' (male sheep). In the roman language 'cicer' refers to the head of a 'ram' and 'aries' means 'ram'. Thus the botanical name *Cicer arietinum* is based on the appearance of the seed of this plant.

Origin and Distribution

Gram, like many other important pulses, is not known in a wild state and has been recorded only in cultivation. It is believed to have originated in western Asia – in the area lying between the Caucasus and the Himalayan mountains. From here it spread to southern Europe, Iran, Egypt and India. The plant has also been introduced into tropical America, Africa and Australia. The areas of maximum production are in India and the middle East. About 70% of the total produce is obtained from India. Other countries which are important for cultivating the chick pea include Pakistan, Ethiopia, Turkey and Morocco. In India, the crop is grown in Uttar Pradesh, Punjab, Bihar, Madhya Pradesh, Rajasthan, Haryana, and Maharashtra.

Ecology

Gram is a drought resistant winter (rabi) crop and requires a cool dry climate. It grows best on well aerated soils of alluvial origin. The seeds are planted in October after the monsoon rains are over and the crop matures in March. It is adapted to arid and semi-arid regions. It can be grown as a mixed crop with jawar, wheat, barley, linseed, mustard or pea.

Botany

Cicer arietinum (Fig. 12.2, a-f) is a herbaceous annual. The plant may be erect or spreading and is profusely branched. It grows to a height of 25-50 cm only. All parts of the plant are covered with clavate glandular hairs. These glands secrete compounds such as oxalic and malic acids. These secretions impart a sour taste to the leaves and fruits. The secretions can be collected by covering the plant at night with a cloth. The acids obtained are used in medicine for intestinal disorders.

The root system is extensive and large nodules containing bacterial colonies are formed on the lateral roots. These assist in atmospheric nitrogen fixation. The leaves are stipulate and imparipinnate with 9-15 pairs of leaflets with serrate margins. They are yellowish-green to dark bluish-green.

The flowers (see one flower in Fig. 12.2 c) are solitary and axilliary. They vary in colour from white to pink and are small. The pedicel is jointed and the flower droops in the bud stage. Each flower shows the typical papilionaceous organisation (Fig. 12.2 c). The stamens are diadelphous showing the typical (9) + 1 arrangement (Fig. 12.2 d). All anthers are of the same size. The monocarpellary gynoecium has a sessile ovary with an incurved style and a terminal stigma.

The pod or legume is small and inflated or swollen. Each pod has an obliquely placed beak and contains only one or two seeds. The seeds are angular with a pointed beak and small hilum at the anterior end. The seed coat may be smooth, wrinkled or rough. It varies in colour from white, yellow, red, brown or nearly black. Each seed contains 2 thick,yellowish cotyledons.

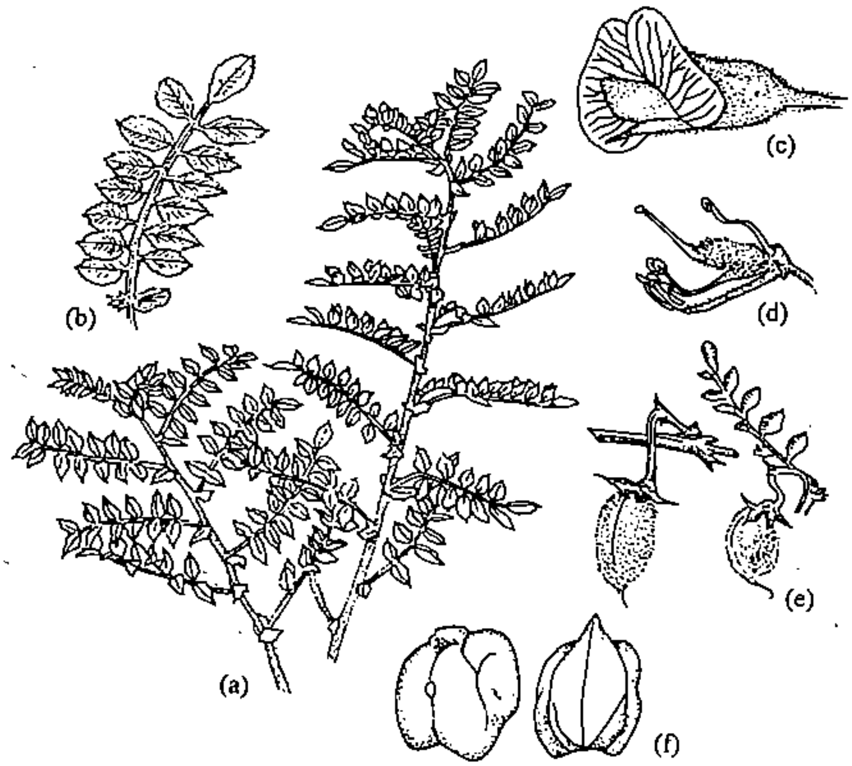

Fig. 12.2 (a-f): ***Cicer arietinum*, Chick-pea. a) Leafy shoot. b) A leaf. c) A flower. d) A flower whose sepals and petals are removed to show the stamens and pistil. e) Pods. f) Seeds in different views. (From Purseglove, 1988).**

Uses

Gram or Chick pea is the most important pulse of India. The seed is consumed in the fresh green stage as a vegetable or in the dried stage as a pulse. The seed can be split and the husk removed to form 'dhal'. The seeds or the split cotyledons can be eaten roasted, parched, boiled or cooked with spices. Flour (baisin) is made by grinding the split cotyledons. This is used in many ways for making various kinds of confectionery. Young green leaves are also cooked as a leafy vegetable. The acrid secretions from the glandular hairs can be collected and used in making medicine and vinegar. The importance of growing gram in crop rotation or as a mixed crop is well-known because of its atmospheric nitrogen fixing capability.

12.5 PEA

Botanical name : ***Pisum sativum***
Family : Fabaceae
Common names : Garden Pea, Field Pea, Matar
n = 7

Most students of biology are familiar with the pea plant through their studies in genetics. Yes, it is on the pea plant, that Gregor Mendel conducted his experiments which led to the formulation of the famous Mendel's laws of inheritance. Thus you are aware of the tall and the dwarf pea plants; the red and the white flowered forms; the round and the wrinkled seeds, the green and the yellow seeds of pea and several other opposite pairs of characters.

The pea is one of the more important seed legumes. The fresh green seeds are consumed as a vegetable, or they may be frozen or canned for later use. The ripe dried seeds are used as a pulse.

Origin and Distribution

As in the case of many other widely cultivated plants, *Pisum sativum* has not been found as a wild plant. It has been known in cultivation since ancient times. Excavations of Neolithic sites dating as far back as 7500-6500 B.C. have shown carbonised pea seeds. These were first discovered in the near east in Jarmo and other sites. Later similiar findings were made from other Neolitic sites in Europe. The Russian Botanist, Vavilov suggested that the garden pea may have originated in Ethiopia, or the Mediterranean and Central Asia with a centre of diversity in the Near East. On the other hand the French Botanist De Candolle was of the view that "this species seems to have existed in western Asia from the South of Caucasus to Persia before it was cultivated". Interestingly, wild plants of *Pisum arvense* which is closely related to *Pisum sativum* occur in Russia. An important observation about *Pisum* is that all the species are self pollinating diploids and they intercross freely. Thus the actual origin of the cultivated garden pea has not been established. The plant has been cultivated since the Greek and Roman times. It was probably domesticated in central or western Asia and it later spread to other parts of the world.

The crop is cultivated extensively in countries having a cool climate especially in the Northern Hemisphere. Europe, United States of America, Canada, China, Ethiopia, India and Japan are the major producers of pea. In India, Uttar Pradesh, Bihar, Madhya Pradesh, Maharashtra, Punjab, Himachal Pradesh, and Orissa are important pea growing states.

Ecology

The pea plant grows in cool, relatively humid climates. Therefore, it is grown as a winter crop in the plains and as a summer crop in the hills in India. Its most important requirement is fertile soil and a pH range between 5.5 to 6.5. The seed setting is greatly reduced in hot dry weather. The best yield is obtained when the crop is grown in loam or clayey loam soils. Pea is usually sown as an intercrop.

Kinds of Peas

Two kinds of peas are usually recognised. These two kinds are completely cross-fertile. Some taxonomists consider these two kinds as separate species on the basis of their morphological characters. Other taxonomists suggest that the two kinds of peas be recognised as subspecies only. These are: a) *Pisum sativum* sub sp. *hortense (= Pisum hortense)*. Its common name is garden pea. It is a robust plant, less hardy and usually grown for green pods. It has stipules without a red spot and white flowers. The pods are large and the seeds are round, soft and sweet. b) *Pisum sativum* sub sp. *arvense* (= *Pisum arvense*); its common name is field pea. It is a sprawling plant, very hardy and is usually grown for the dried seeds. It has stipules with a red spot and coloured flowers, that are usually purplish. The pods are small, and the seeds are angular.

Botany

The pea plant (Fig. 12.3, a-d)is an annual herbaceous climber. It may be a dwarf of only 10-15 cm height or a tall plant growing upto a height of 1.5 meters. The stem is hollow and the branches form a bush or a vine climbing by branched tendrils. The tap root is well-developed and the lateral roots have root nodules. The leaves are pinnately compound and have 1-3 pairs of leaflets (Fig. 12.3 a). Each leaf terminates in a branched tendril. There are large leaf like stipules at the base of each leaf. The flowers are axillary, either solitary or in 2-3 flowered racemes. They are white or coloured, usually pink or purple. The flowers show a typical papilionaceous organisation (Fig. 12.3 b), and are usually self-pollinated. The fruit or pod is a legume with 2-10 seeds (Fig. 12.3 a,d). The pods may be swollen or compressed, straight or slightly curved (Fig. 12.3 d). The seeds are highly nutritious having about 7.5% protein, 16% carbohydrates and different minerals such as iron, sulphur and phosphorus. Vitamins A,B, and C are also present in varied amounts.

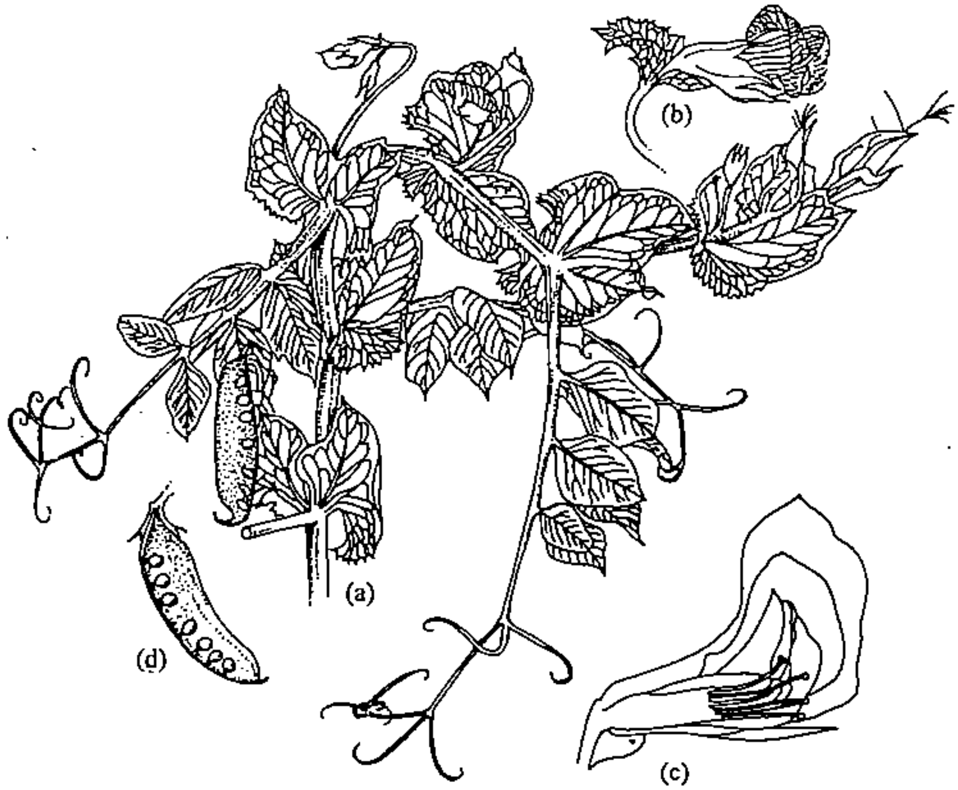

Fig. 12.3 (a-d): ***Pisum sativum*** **Pea. a) A flowering twig. b) A flower. c) A flower cut longitudinally. d) A young, opened pod. (From Purseglove, 1988).**

Uses

The fresh green seeds are cooked and eaten as a vegetable. They are also important in making rice and pea pullao. They may also be frozen and canned for subsequent use. The mature dried seeds may be consumed whole, split or used in the form of flour. Pea soup may also be prepared from mature dried seeds. The green plants can be used as fodder for cattle while the dead plants are ploughed into the soil to increase its fertility.

12.6 SOYBEAN

Botanical name : ***Glycine max***
Family : Fabaceae
Common names : Soybean, Bhat, Ramkurthi
n = 20

This ancient oriental legume has become a very important source of oil and protein, besides being used as an animal feed. In the last 30 years or so, interest in this plant has grown rapidly after the recognition of its potential as a 'wonder bean'.

Origin and Distribution

The soybean originated in China. It is perhaps the oldest crop cultivated in the Orient. Food products prepared from the seeds have been important in the diet of the people for centuries. The cultivated soybean - *Glycine max* is not found in the wild state. It is believed to have arisen from *Glycine soja* (also called *Glycine ussuriensis*). This slender, prostrate, twining legume occurs wild in many parts of Eastern Asia. Another wild species, *G. tomentella* (or *G. tomentosa*) could have contributed to the origin and evolution of the cultivated *G. max* by hybridising with *G. soja*.

After the World War II, the United States of America has become the leading producer of soybean. China now ranks second in production, followed by Brazil. Other soybean growing areas include Indonesia, Mexico, Russia, Korea, Japan, Argentina, Columbia and India.

Soybean was introduced into India in about 1880, but it is only in recent times its cultivation has started on large scale. It can be grown successfully all over the country. It is cultivated commercially in Assam, Uttar Pradesh, Himachal Pradesh, Nagaland, Manipur, Madhya Pradesh, Maharashtra and Gujarat.

Ecology

Soybean is a subtropical plant, but its cultivation extends from the tropics to temperate regions. The general climatic requirements of this legume are very similiar or almost identical to those of maize (see Unit 11, Cereals and Millets). The crop is generally grown in areas where the summer is hot and rather damp. An evenly distributed rainfall during the growing period and more or less dry weather during seed ripening are necessary. Soybean can grow on different kinds of soil, but fertile soils with high calcium content are considered to be the best. It requires a specific strain of the bacterium, *Rhizobium japonicum,* for nitrogen fixation. This must be inoculated into the soil if soybean is to be introduced into a new area.

The soybean is a short day plant. The period for maturity of the crop varies from 75-200 days depending on the variety sown and the adaptation to particular latitudes. The crop is raised from seed and may be harvested manually or with the help of combines.

Botany

The soybean plant (parts shown in Fig. 12.4, a-e) is an erect, much branched, annual herb covered with grey hairs. The plants may be creepers or twiners in some varieties and this type of habit increases in the shade. The tap root system is well developed with maximum spread in the top 30-60 cm of the soil. Small spherical nodules are present. The erect stem may grow 50 cm to 180 cm in height depending on the variety. This as well as the density of planting also determines the extent of branching. The leaves are large, hairy, alternate, stipulate and have a long petiole. Each compound leaf is usually trifoliate (sometimes 5-foliate). The leaflets are ovate to lanceolate (Fig. 12.4 a) and have short pointed stipules at the base. In many cultivars, the leaves drop when the pods begin to mature.

The inflorescences are short, axillary racemes having 3-15 flowers. A large number of flowers do not form fruits and drop off. The flowers are small and vary in colour from nearly white to deep purple. The pods arise in clusters and are hairy. Each pod is usually compressed and slightly curved. The seeds are small, globose with small hilum. Generally 2-3 seeds (sometimes 1-5) develop in each pod. The colour of the seeds varies from creamy white to yellow, various shades of grey and brown or combination of these colours.

Uses

The high protein and oil content, makes soybean one of the most valuable legumes. There are various uses of this important plant. Soybeans are grown mainly as a food crop in China, Japan and other South East Asian Countries. The unripe seeds are eaten as a vegetable. The mature dried seeds are eaten whole, split or sprouted like chick pea or gram. The mature seeds may also be ground into flour and mixed with other flours to make bread, chapatis and other baking products. The high protein and low carbohydrate content of soybean flour complements cereal grain flour to provide a balanced nourishing diet. Whole seeds can be eaten after boiling, baking or roasting them. They can be processed to make soya milk or soybean milk. This is a valuable protein supplement for preparing infant food, curds and cheese. A very tasty soyasauce is made by fermenting cooked seeds with wheat flour and salt using the fungus *Aspergillus oryzae.*

The seeds are also an important source of fat. A semi-drying edible oil extracted from them is widely used. Besides its use in the food industry, the oil also goes in the manufacture of soaps, printing inks, lubricants, greases, and other industrial products. It is also mixed with other drying oils in the paint and varnish industry.

The whole plant can be used as a forage or fodder and as green manure. The oil cake obtained after the extraction of oil is a rich protein source for cattle and livestock feed. Synthetic fibre can also be manufactured from this protein. Thus this important leguminous plant has numerous uses.

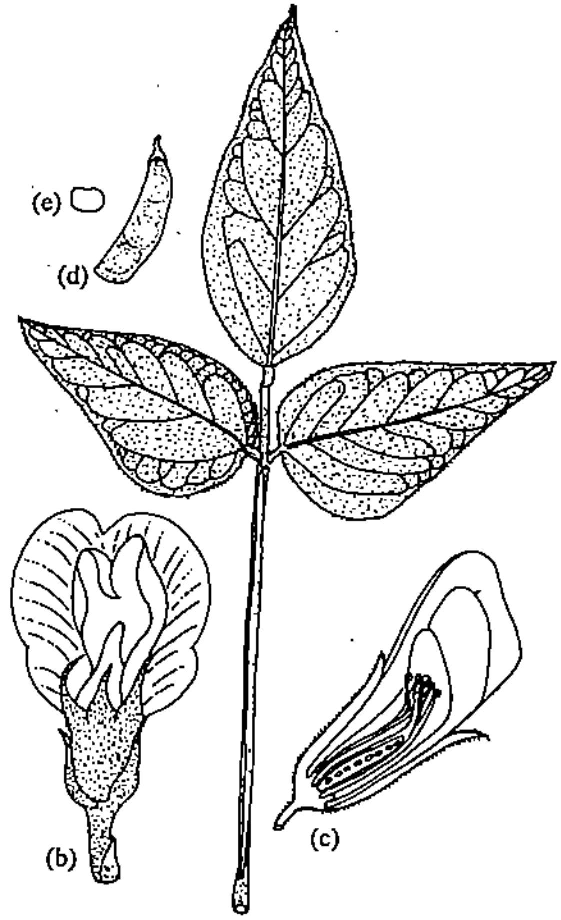

Fig. 12.4 (a-d): ***Glycine max*, Soybean. a) A leaf. b) A flower as seen from below. c) A flower cut in longitudinal section. d) A pod. e) A seed. (From Purseglove, 1988) .**

SAQ 1

1. What is a legume?

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2. Why are legumes important in crop rotation?

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3. Name:

a) the richest source of proteins amongst the legumes.

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b) the legume which causes *lathyrism.*

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4. What is favism? How is it caused?

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5. Write the botanical name and common English name of:

a) One legume classified in the Tribe Hedysareae.

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b) Two legumes classified in the Tribe Vicieae.

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c) Three legumes classified in the Tribe Phaseoleae.

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6. Write the botanical names of 5 major pulse crops of India.

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7. Write the centre of origin of the following legumes.

a) *Arachis hypogaea*

b) *Cicer arietinum*

c) *Pisum sativum*

d) *Glycine max*

8. Name two legumes which are rich sources of oil.

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12.7 COWPEA

Botanical names : i) ***Vigna unguiculata*** **- Catjang cowpea**

ii) ***Vigna sinensis*** **- Common cowpea**

iii) ***Vigna sesquipedalis*** **- Yardlong cowpea or asparagus pea**

Family : Fabaceae

Common names : Cowpea, Lobia, Chowli

n = 11

There is no agreement on the taxonomy of this important pulse crop of the tropics and subtropics. Many botanists consider the different cultivated forms of cowpea as distinct varieties because they can cross freely and there is free-gene flow. They are then all classified under the species *Vigna unguiculata* as different varieties:

a) *V. unguiculata* var. *unguiculata*

b) *V. unguiculata* var. *sinensis*

c) *V. unguiculata* var. *sesquipedalis*

Origin and Distribution

Cowpea is an important pulse crop cultivated since ancient times in Africa and Asia. There are references to this pulse crop in ancient Sanskrit literature also. In Africa this legume is widespread both in the wild state as well as in cultivation. It is believed that the cultivated varieties orginated from wild types in central Africa. According to Vavilov cowpea may have originated in India and spread to other parts of the world. Cultivated cowpeas are now common in many tropical and subtropical regions. The main cowpea producing countries are Nigeria, Uganda, United States of America, India, China, the Mediterranean region, S. Africa, and Australia.

Ecology

This pulse crop can be grown under different environmental conditions. It is a warm weather and drought resistant crop and can be grown in regions having low rainfall. It can withstand heat better than most other legume crops. Cowpeas can be grown on a wide variety of soils having adequate drainage. The crop is grown from seed and matures in about 3 months.

Botany

The cowpea (Fig. 12.5 a-d) is an annual herb showing an erect, prostrate or climbing habit. It grows vigourously becoming bushy and attaining a height of about 1.5 meters. The plants are glabrous, but sometimes hairy at the nodes. The tap root is well-developed with numerous large nodules containing bacterial colonies. The leaves are large, trifoliate and have a long petioles (Fig. 12.5 a). A pair of large stipules surround the petiole. Each leaflet is subtended by small stipels.

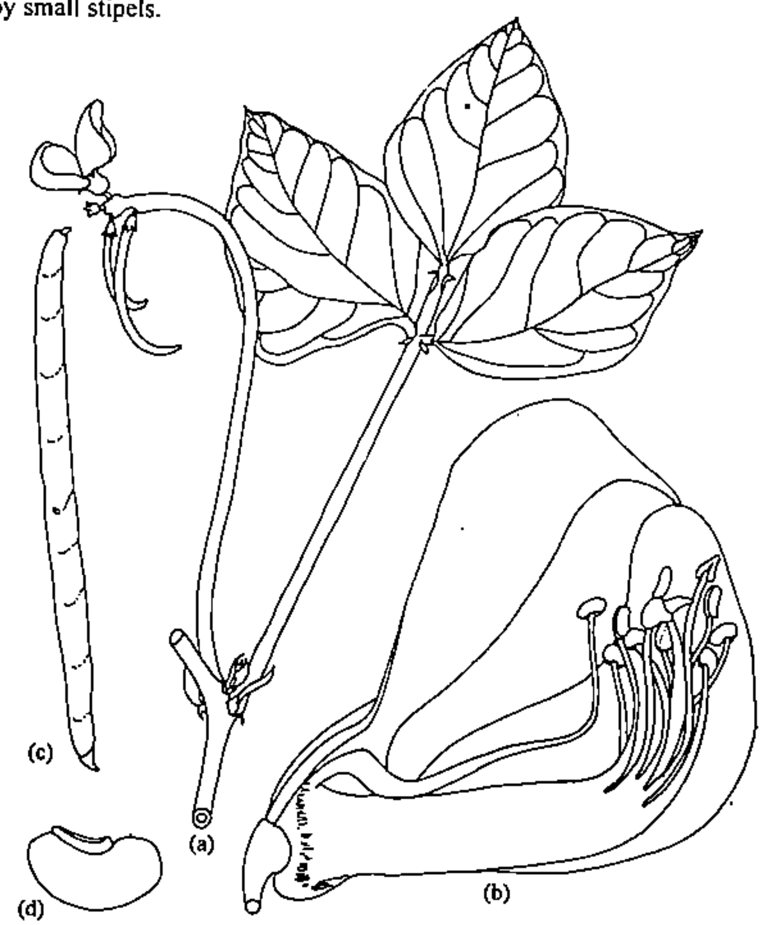

Fig. 12.5 (a-d): ***Vigna unguiculata*, Common cowpea. a) A shoot with leaves, flowers and young fruits. b) A flower in longitudinal section. c) A pod. d) A seed. (From Purseglove, 1988).**

The inflorescence is an axillary raceme or fascicle with few flowers which are generally crowded near the tip (Fig. 12.5 a). The flowers occur in alternate pairs on the thickened nodes of the inflorescence axis. The flowers have the typical papilionaceous organization (see Fig. 12.5 b). The corolla varies in colour from white, light pink, purple, violet or even light blue. The fruit is a legume or pod (Fig. 12.5 c) which varies considerably in the different varieties of cowpea. The pods are long, cylindrical and somewhat constricted between the seeds. In the yard-long cowpea (Fig. 12.6 a-c) - *Vigna unguiculata* var. *sesquipedalis* - the pod may grow from 30-100 cms in length, while in the other varieties the pods grow from 10-30 cm in length.

The number of seeds varies according to the length of the pod. The seeds are variable in shape and size (see Fig. 12.5 d; 12.6 c). They may be globular or kidney-shaped, smooth or wrinkled, and of different colours. They are white, cream coloured, yellow, green, red, brown or black. In the white seeded types which are commonly cultivated, the seeds have a characteristic black mark around the hilum and are commonly called "black eyed cowpeas" The seeds are rich in protein which constitutes more than 20% of the dry weight besides about 50% carbohydrates. They also contain minerals and small quantities of fats.

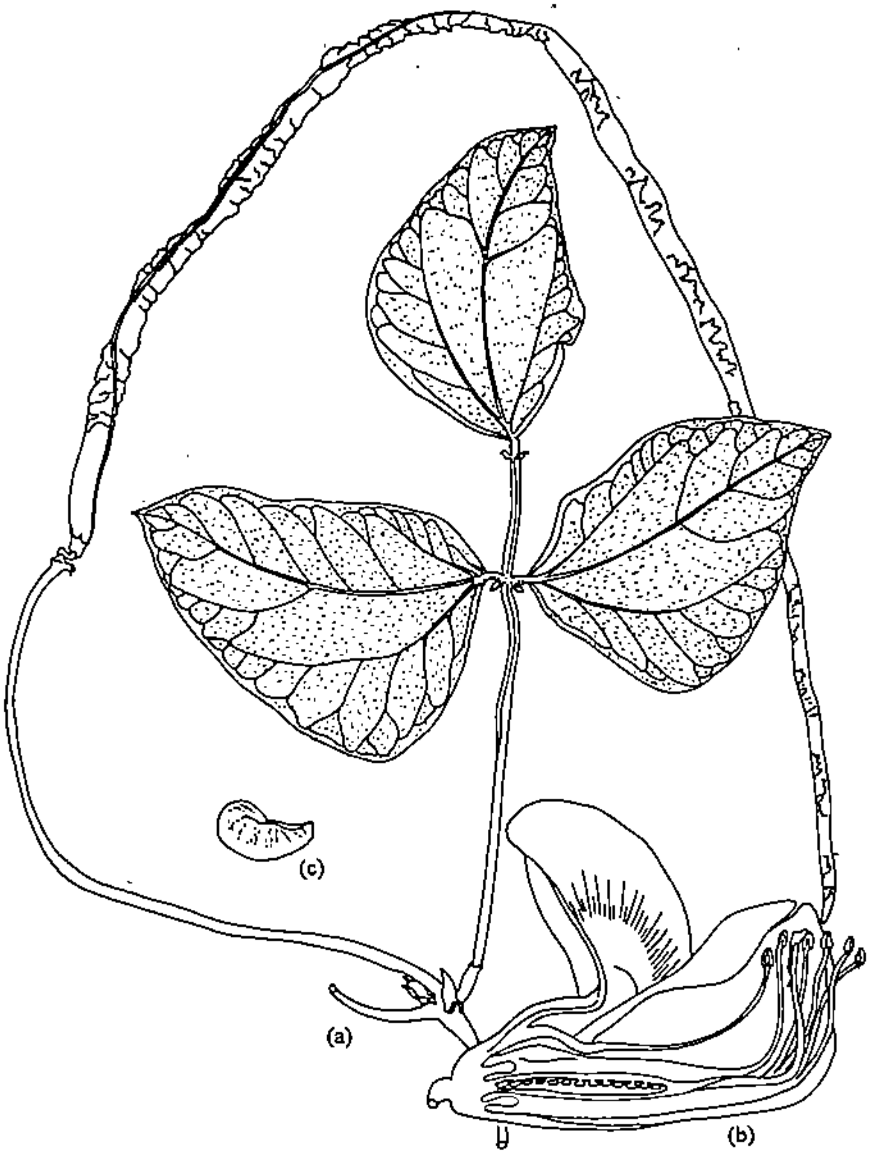

Fig. 12.6 (a-c): *Vigna unguiculata*, Yardlong bean. a) A part of a twig showing leaf and a pod. b) A flower in longitudinal section. c) A seed. (From Purseglove, 1988).

Uses

The tender pods are used as a green vegetable. The mature dried seeds are consumed as a pulse mostly whole, but sometimes also split. They can be ground into a flour which can be used in preparation of various food items. The plants are also used as green livestock feed or are dried and used as hay. The plants can also be ploughed into the land as a green manure.

12.8 BEANS

Many different kinds of beans are cultivated throughout the world. These include the kidney beans, lima beans, soybeans, wax beans, string beans, and green-shell beans. They are good sources of energy being rich in proteins and carbohydrates besides having vitamins and minerals. They can be consumed as green vegetables or as dried seeds. They, besides enriching the soil, also provide valuable green fodder for cattle.

(i) Lima Bean
n = 11

Lima bean (Fig. 12.7 a-e) is the most nutritious member of the pea family. It is high in protein value and rich in iron, calcium, and vitamins. This wide flat bean is a native of tropical America. It is grown in many warm regions of the world. The botanical name of lima bean is *Phaseolus limensis* (synonym *Phaseolus lunatus*).

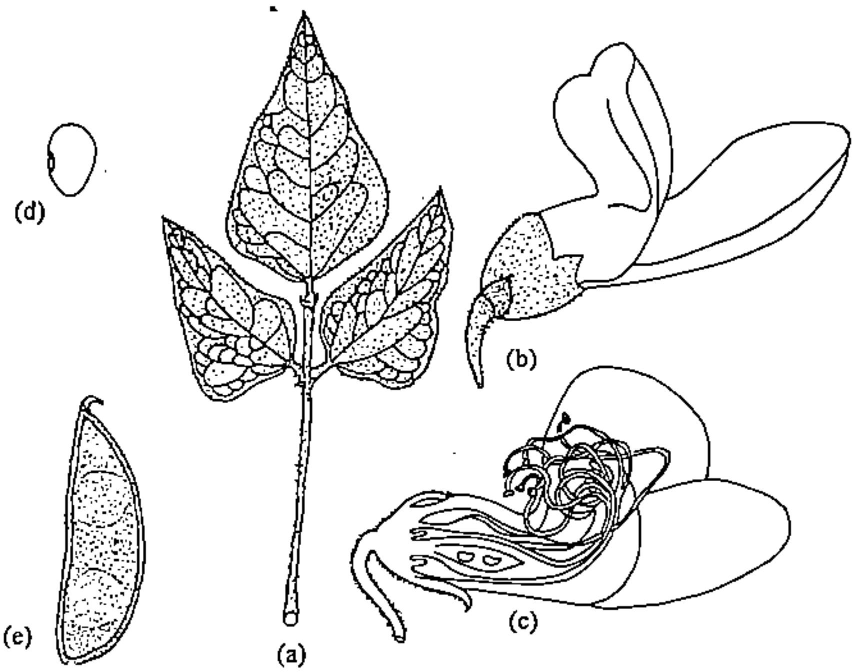

Fig. 12.7 (a-e) : *Phaseolus limensis* Lima bean. a) A leaf. b) A complete flower. c) A flower cut in longitudinal section. d) A pod. e) A seed. (From Purseglove, 1988).

(ii) Common Bean or French Bean
n = 11

Kidney bean, Runner bean, Snap bean, and Salad bean are other names used for *Phaseolus vulgaris* (Fig. 12.8 a-e). This is the best known and most widely cultivated species of the genus *Phaseolus*. It is of New World origin and is cultivated in many parts of the tropics and subtropics, and in temperate regions. There are numerous cultivated varieties which vary considerably in their habit, the pod and seed characteristics and the ecological requirements. The species is polymorphic and different varieties have adapted to local requirements. The crop is grown from seed.

(iii) Green gram or *Phaseolus aureus*
n = 11

The green gram or mung is a very important pulse crop of India. It is considered as the most wholesome amongst the pulses. The dried beans are eaten as a whole or split as a dhal. The green pods are eaten as a vegetable. The seeds are also sprouted and eaten as a salad or snack which is very nutritious. This pulse is described in detail in Section 12.10 of this unit.

(iv) Black gram or *Phaseolus mungo*
n = 11, 12

The black gram or urd is a highly prized pulse for vegetarian diet in India. It is used much the same manner as mung. It probably originated in India and spread to other tropical areas. It has an ancient cultivation history in our country. A detailed account of this is given in Section 12.9.

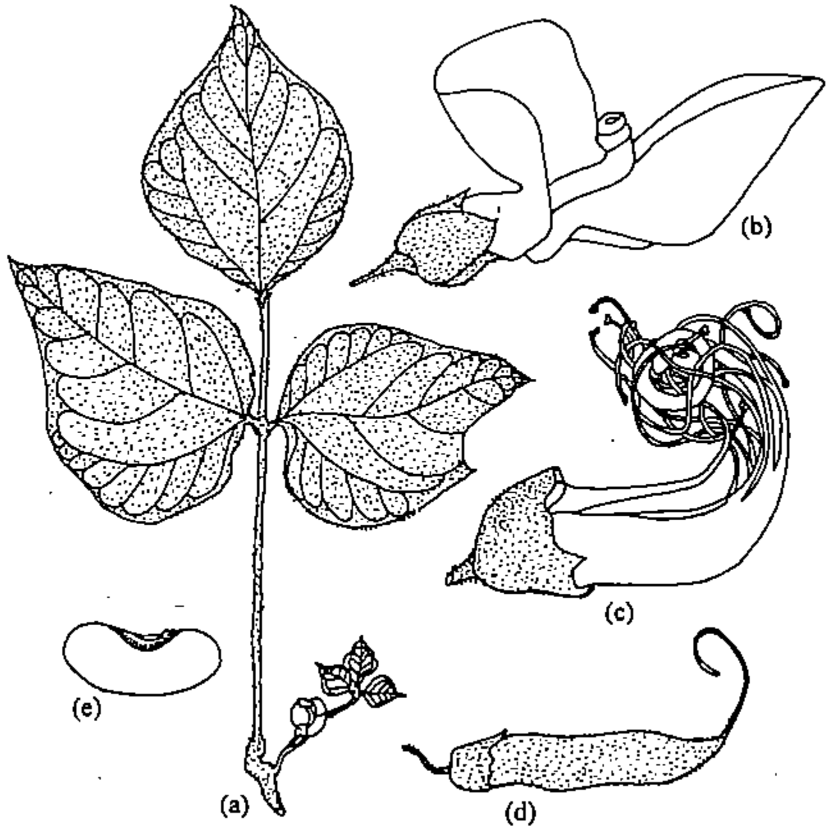

Fig. 12.8 (a-e): ***Phaseolus vulgaris*, Common bean. a) A leaf. b) A flower. c) A flower with its corolla removed. d) A pod. e) A seed. (From Purseglove, 1988).**

(v) Scarlet runner bean or *Phaseolus coccineus*
n = 11

It is a central American legume where the green and dry seeds are eaten. This bean is grown in temperate countries and in the humid uplands of the tropics. The long, fleshy tuberous roots are also boiled and eaten.

vi) Hyacinth Bean
n = 11, 12

It is also known as Lubia bean, Lablab bean, Indian bean, Egyptian bean, and Bonavist bean. This bean (Fig. 12.9 a-d) with numerous common names also has many Latin (botanical) names. It is called *Lablab niger* (Fig. 12.9) / *Lablab purpureus* / *Lablab vulgaris* / *Dolichos lablab* / *Dolichos purpureus*.

This is a native of India where it is found growing wild and also in cultivation. It is cultivated extensively in South and Central America, East and West Indies, Africa and China. This bean is a dryland crop which is drought resistant and can be grown in areas having low rainfall. It can be cultivated in different kinds of soils at various altitudes.

The young pods (Fig. 12.9 c) and tender beans are popular vegetables in various parts of India. They must be properly cooked because the raw pods contain a poisonous glycoside. The ripe and dried seeds are used as a pulse. This bean is also grown as a green manure crop and in crop rotation with cotton and sorghum.

Closely related to the hyacinth bean is the horse gram - *Dolichos uniflorus*. This is called the poor man's pulse and is an important crop in southern India. In Andhra Pradesh, Karnataka and Tamil Nadu this is as important as chick pea in northern India. It is also grown in Maharashtra and Madhya Pradesh. This is a dryland crop grown in areas having moderate rainfall.

(vii) Cluster Bean
n = 7

It is commonly known as Guar and botanically as *Cyamopsis tetragonoloba*. This bean is probably indigenous to India and has been cultivated since ancient times for fodder, green manure and as a vegetable. The plant is now cultivated in United States for gum production. The seeds contain a mucilaginous substance which is used in the paper and textile industries.

The plant is a bushy annual with stiff erect branches. These are angular, grooved and covered with white hairs. The small pinkish white flowers arise in dense axillary racemes. The pods are linear, ridged, and compressed. These arise in clusters, hence the name cluster bean.

Thus the different kinds of beans serve as important crops in different parts of the world.

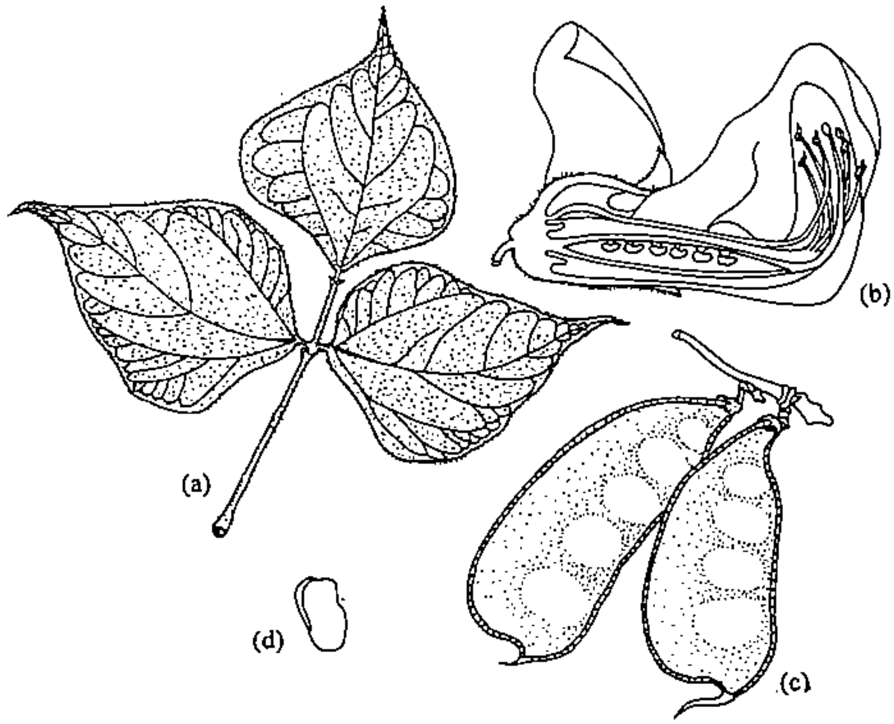

Fig. 12.9 (a-d): *Lablab niger*, Hyacinth Bean. a) A leaf. b) A flower cut longitudinally. c) Two pods. d) A seed. (From Purseglove, 1988).

(viii) **Other species of *Phaseolus***
n = 11

The species which are of lesser importance are *Phaseolus calcaratus* or Rice bean of Asia found from the Himalayas and Central Asia to Malaysia, Burma, China, Fiji, Mauritius and the Phillipines.

The mat or moth Bean - *Phaseolus aconitifolius* is a native of India, Pakistan and Burma. It is also cultivated in Sri Lanka, China and in Texas and California in the United States. The green pods are eaten as a vegetable and the dried seeds as a pulse.

12.9 URD

Botanical Name : *Phaseolus mungo*
Family : Fabaceae
Common Names : Black Gram, Woolly pyrol, Urd
n = 11, 12

This is a highly prized pulse for the vegetarian diet in India.

Origin and Distribution

This legume has been under cultivation in India since ancient times. According to Vavilov, this pulse originated in India, and Central Asia is recognised as a secondary centre for its spread. Many botanists suggested that the *Phaseolus mungo* probably originated from the wild species *Phaseolus trinervius* or *P. sublobatus* commonly growing in India. It has been introduced in many tropical and subtropical regions by Indian immigrants. The main Urd producing countries other than India are Iran, Malaysia, East Africa, Southern Europe, South and Central America and the West Indies.

In India the important Urd growing states are Madhya Pradesh, Uttar Pradesh, Punjab, Maharashtra, West Bangal, Andhra Pradesh, and Karnataka.

Ecology

Phaseolus mungo (Fig. 12.10 a-d) is a warm season crop and is grown both in kharif and rabi seasons. It is also grown in mixed cultivation with rice or other crops. It is drought resistant and is not suitable for areas with heavy rainfall. A warm climate and well distributed rainfall are ideal conditions for growing urd. It is particularly suited to clay soils and the crop does well on heavy soils such as the black cotton soils of India. The crop is raised from seeds and matures in about three months.

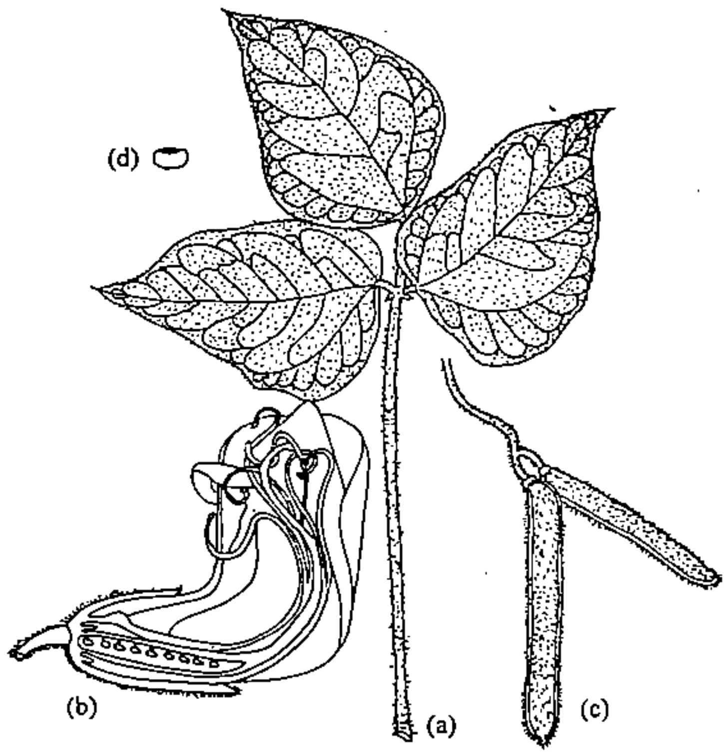

Fig. 12.10 (a-d): ***Phaseolus mungo*, Black gram. a) A leaf. b) A flower in longitudinal section. c) Two pods. d) A seed. (From Purseglove, 1988).**

Botany

This is a fast growing herbaceous legume. The plant may be an erect, sub-erect or trailing annual. The stem is diffusely branched. The stem, leaves and fruits are covered with reddish-brown hairs giving a woolly appearance (hence the common name woolly pyrol in some parts of the world). The large leaves are trifoliate and have long petioles (Fig. 12.10 a) and ovate stipules. The leaflets are ovate to lanceolate, entire and have falcate stipels. The axillary inflorescences are branched and bear 5-6 flowers in clusters. Each flower has a short hairy peduncle and is subtended by large bracteoles. The flower has a typical papilionaceous organization (Fig. 12.10 b) with a pale yellow corolla and diadelphous stamens. The fruit is a legume or pod (Fig. 12.10c). The peduncle elongates when the fruit is formed. The pod is erect, narrow, cylindrical and with a short hooked beak. In each pod there are 6-10 seeds separated by septa. The seeds are oblong with square ends and are mostly black. The seed coat or testa is smooth and the hilum is white and concave. In ancient India, the seed was used as an index of weight and was called "masha". Twelve seeds or "mashas" were equal to one "tola" which is approximately 11.66 grams. The seeds are rich in phosphoric acid and in globulins A and B. The total proteins constitute about 24% of the dry weight of the seed and about 57% is carbohydrate.

Uses

It is boiled and eaten either whole or split with or without (washed) the husk. The washed (dehusked) split seeds are ground into a flour and used for making confectionery such as pudding. A dry wafer like preparation called "papar" or "aplam" is also made from the dhal. The ground, split seeds are also made into a paste with various spices and small balls are prepared. These are dried and called "bari". The flour is an important constituent with rice for making "dosa" and "idli". The green pods are eaten as a vegetable.

The seed proteins have a gluten like property and urd is used for making bread and biscuits. The paste from the seeds is also used as a cementing material. The plant is also used as livestock feed and as a green manure. It prevents soil erosion and conserves soil moisture.

12.10 MUNG

Botanical name : *Phaseolus aureus*
Family : Fabaceae
Common names : Green gram, Golden gram, Mung, Pessara
n = 11

This is a very important pulse crop of India. It is the most wholesome of the pulses.

Origin and Distribution

Like *Phaseolus mungo, P. aureus* too is of ancient cultivation in India and has not been found in the wild state. It is supposed to be a native of India and central Asia. This is quite closely related taxonomically to *Phaseolus radiatus* which occurs wild throughout India and Myanmar (Burma) and is also sometimes cultivated. Besides India, this pulse is cultivated in South-east Asia, some parts of Africa, the West Indies and the United States of America. In India, the major green gram or mung growing states are Maharashtra, Gujarat, Tamil Nadu, Andhra Pradesh, Bihar, Uttar Pradesh, Punjab, Rajasthan, Madhya Pradesh and Karnataka.

Ecology

Mung is a dry land crop usually grown after rice. It is cultivated both as a kharif as well as a rabi crop. The plant prefers a warm weather and can withstand drought. The crop is grown in a wide variety of soils and performs best on a good loam. It is also suited for red and black soils. There are short-day as well as long-day cultivars of this pulse crop. The plant matures in 3-4 months after sowing.

Botany

In general appearance, mung is quite similar to urd, but the two pulses differ in many features. These differences in the characters are as follows (see Table 12.2) :

Table 12.2: Differentiating characters of green gram and black gram .

Character	Green gram (*P. aureus*)	Black gram (*P. mungo*)
Stem	Mostly erect or sub-erect	Mostly spreading or trailing
Leaves	Mostly green or dark green	Mostly yellowish green
Hairiness	Sparsely hairy	Densely hairy
Hair colour	Slightly brown	Ferruginous (reddish brown)
Pods	Reflexed or pendent with short hairs; shatter readily	Erect or sub-erect with long hairs; do not shatter much
Seeds	Small, globular, usually green	Large, oblong with square ends; usually black
Seed coat	Testa with fine wavy ridges; sometimes very faint but never absent	Devoid of ridges
Cotyledon	Yellow; not becoming pasty on chewing	Whitish or pale yellow and gives a paste on chewing
Hilum	Flat	Concave

Phaseolus aureus (Fig. 12.11 a-d) is an annual legume. The plant is an erect or sub-erect, much branched herb. The whole plant is hairy but the hairs are widely separated when compared to the woolly appearance of *Phaseolus mungo.* The leaves are alternate, trifoliate, with long petioles and ovate stipules (Fig. 12.11 a). The leaflets are ovate and large.

The inflorescence is an axillary raceme with 10-20 flowers. The flowers are clustered at the top of a long peduncle. The flowers have a typical papilionaceous organization (Fig. 12.11 b) and a purplish yellow corolla. The seeds are globular and usually green but sometimes yellowish or blackish. Two kinds of cultivated varieties are recognised:

a) Golden gram with yellowish seeds which produce less seeds and show a tendency to shatter;

b) Green gram with dark (blackish) or bright green seeds which produce more seeds. The pods ripen more evenly and have less tendency to shatter.

The seeds are rich in proteins, carbohydrates and minerals.

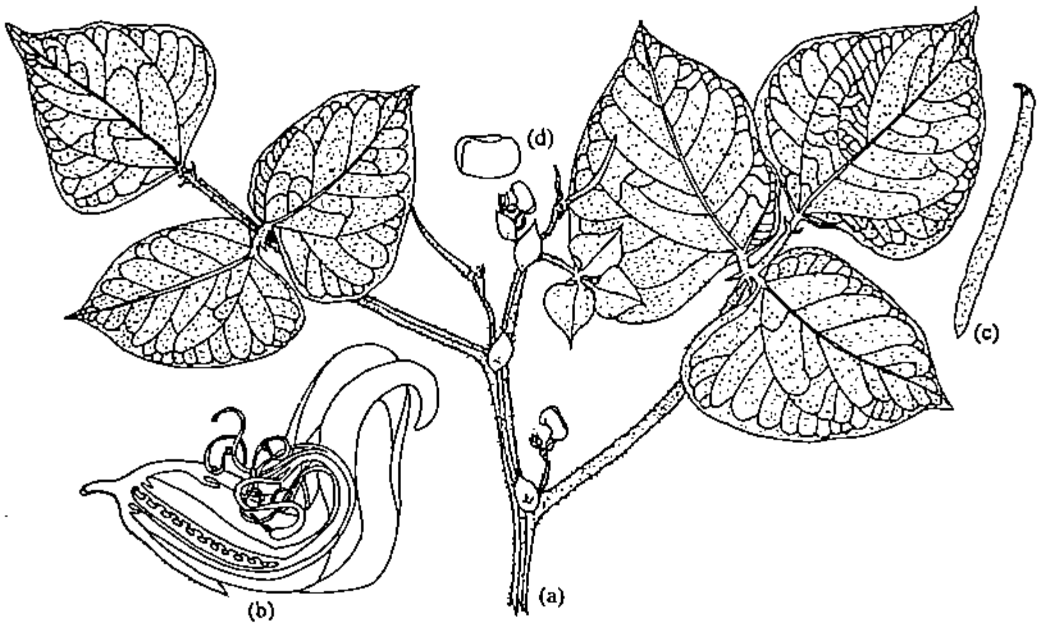

Fig. 12.11: ***Phaseolus aureus*, Green gram. a) A flowering shoot. b) A flower in longitudinal section. c) A pod. d) A seed. (From Purseglove, 1988).**

Uses

Phaseolus aureus or the green gram is one of the most wholesome pulse. The dried seeds are boiled and eaten whole or after splitting. The testa may be removed and the cotyledons or dhal may be ground into a dry flour or made as paste which is used for making various Indian and Chinese dishes. The pulse is easily digestible and is "free from heaviness and has lesser tendency to flatulence" which is associated with other pulses. The green pods are eaten as a vegetable. The whole seeds may be sprouted and eaten as a salad or snack. The seeds can be used in the same way as *Phaseolus mungo* to make the "papar or aplam" and "bari".

Besides human consumption, this crop is also grown for hay pasture, silage and as a cover crop. The plant is useful for crop rotation and in restoring the fertility of the soil.

SAQ 2

1. Match the items given in column **A** with those given as column **B**.

A	B
i) Cowpea	a) *Lablab niger*
ii) Lima bean	b) *Phaseolus vulgaris*
iii) French bean	c) *Cyamopsis tetragonoloba*
iv) Hyacinth bean	d) *Vigna unguiculata*
v) Cluster bean	e) *Phaseolus lunatus*

2. Write the botanical names of the following:

a) Horse gram

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b) Scarlet runner bean

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c) Black gram

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d) Rice bean

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e) Mat or moth bean

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3. List 4 characters to distinguish *Phaseolus aureus* from *Phaseolus mungo.*

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4. Classify the following statements as True or False.

a) Cowpea was recognised as an important pulse crop in ancient Roman literature. ☐

b) Butter bean is a common name for the kidney bean. ☐

c) The most widely cultivated species of the genus *Phaseolus* is *Phaseolus aureus* or Mung. ☐

d) The raw pods of *Lablab niger* or Lubia bean contain a poisonous glycoside. ☐

e) Cluster bean, Horse gram, and moth bean originated in India. ☐

f) The botanical name of Mung or Green gram is *Phaseolus mungo.* ☐

g) *Phaseolus mungo* is the most highly prized legume for the vegetarian diet in India. ☐

12.11 SUMMARY

In this unit you have studied that:

- The legumes or pulses are important sources of proteins in a vegetarian diet. Besides their high protein content, leguminous seeds are also rich in carbohydrates and fats. They have a low water content and can be stored and transported easily. The legumes grow rapidly and enrich the soil by fixing atmospheric nitrogen. Thus the legumes are important in crop rotation.

- All legumes are classified in the family Leguminosae. The fruit is a simple, dry, dehiscent pod or legume. The legumes consumed as food are classified in the sub-family Papilionatae. The pulse crops are cultivated all over the world. India is the single largest producer of pulses. Many different kinds of legumes are cultivated around the year in almost all the states of the country. Chick pea and pigeon pea are two important pulse crops constituting 55% of the total pulses produced in the country. Besides these there are several other useful and harmful pulses also.

- India is the largest producer of groundnut or *Arachis hypogaea* and it is mainly used for extracting an edible oil from the seeds. The groundnut oil is a very important non-drying oil that is used in cooking and in other industries. The seeds have high calorific value.

- Chickpea - chana or *Cicer arietinum* is one of the oldest known pulse crops. This is a very important legume today and 70% of the world's production is obtained from India. The angular seeds with pointed beaks contain 2 thick yellow cotyledons. These are used in many ways.
- Pea or *Pisum sativum* is a well-known legume made famous by the studies of Gregor Mendel who discovered the basic laws of genetics. The crop is extensively cultivated in the Northern Hemisphere. The seeds are highly nutritious and besides proteins, carbohydrates and minerals, they also contain vitamins A, B and C. The fresh green seeds are consumed as a vegetable.
- Soybean or *Glycine max* is an ancient oriental legume and its cultivation extends from the tropics to the tamperate regions of the world. It requires a specific strain of *Rhizobium japonicum* for nitrogen fixation. The seeds are small and globular. This is one of the most valuable legumes because of the high protein and oil content of the seeds.
- The interesting legume, cowpea or *Vigna unguiculata* is an important pulse crop of the tropics and subtropics. The tender pods as well as the mature seeds are used as food.
- Beans constitute an important category of leguminous plants and are amongst the most nourishing vegetables. These are cultivated throughout the world and the more important of these are the kidney bean, lima bean, wax bean, string bean, cluster bean, common bean, hyacinth bean, rice bean, and horse gram.
- Black gram and green gram are two important pulses of the genus *Phaseolus* which may have originated in India. Black gram *(Phaseolus mungo)* and green gram *(Phaseolus aureus)* are both warm season crops and are culivated as kharif or rabi crops in different parts of India. Although closely related, these species differ in many features. Both are used as important pulses in the vegetarian diet and also used for many culinary preparations.

12.12 TERMINAL QUESTIONS

1. Define the term legume. Write a brief account on the different types of legumes grown in India, mentioning the regions in which each type is commonly cultivated.

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2. Write an account on the importance of legumes as food, in crop rotation, and the economy of the country. List the more important legumes cultivated in India.

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3. Write a detailed account of any one of the legumes you have studied. Mention its place of origin, cultivation, and economic importance.

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4. Why are groundnuts considered to be very useful? Briefly enumerate the origin, ecology and botany of this legume.

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5. Compare and contrast the botany and economic importance of groundnut and soybean.

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6. Discuss briefly the origin, cultivation and economic importance of :

a) Gram or chick pea b) Cowpea c) Black gram d) Green gram

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12.13 ANSWERS

Self-Assessment Questions

SAQ 1

1. A legume is an important source of proteins in the vegetarian diet. The legume is a member of the family Fabaceae. This is characterised by a special kind of fruit. Legumes are pulse crops cultivated all over the world. A leguminous crop is very important in agriculture.(Also see Sections 12.1 and 12.2).

2. Legumes are important in crop rotation because they maintain soil fertility. This is due to the fact that these plants can add nitrogen to the soil. The ability of legumes to fix atmospheric nitrogen and converting it into usable nitrates is due to symbiotic nitrogen fixing bacteria which live in the root nodules of the plants. (Also see Appendix 12.1).

3. a) Soybean - *Glycine max*

   b) Chickling vetch - *Lathyrus sativus*

4. Favism is an acute anaemic condition. It is caused by eating uncooked or partially cooked seeds of the broad bean - *Vicia faba*. The diseased condition is also caused by inhaling pollen of the plant. It affects only males and is common in the Mediterranean region.

5. a) *Arachis hypogaea* - groundnut

   b) Any two of the following:

      i) *Lens esculenta* - Lentil

      ii) *Pisum sativum* - Pea

      iii) *Cicer arietinum* - gram

      iv) *Vicia faba* - broad bean

   c) Any three of the following

      i) *Glycine max* - soybean

      ii) *Vigna unguiculata* - cowpea

      iii) *Cajanus cajan* - pigeon pea

      iv) *Phaseolus aureus* - green gram

      v) *Phaseolus mungo* - black gram

6. i) *Cicer arietinum*

   ii) *Cajanus cajan*

   iii) *Lens esculenta*

   iv) *Phaseolus aureus*

   v) *Phaseolus mungo*

   vi) *Pisum sativum.* Write any five names. Also see Table 12.1.

7. a) South America, Brazilian - Paraguayan region.

   b) Western Asia - Between Caucasus and the Himalayan mountains.

   c) Near east Jarmo or Neolithic sites in Europe.

   d) China.

8. i) *Arachis hypogaea* - groundnut

   ii) *Glycine max* - soybean

SAQ 2

1. i - d

   ii - e

   iii - b

   iv - a

   v - c

2. a) *Dolichos uniflorus*

   b) *Phaseolus coccineus*

   c) *Phaseolus mungo*

   d) *Phaseolus calcaratus*

   e) *Phaseolus aconitifolius*

3. See section 12.10.

4. a) F

   b) F

   c) T

   d) F

   e) T

   f) F

   g) T

Terminal Questions

1) See Sections 12.1, 12.2, and see the areas of cultivation of each legume.

2) See Section 12.2

3) Write an account on any legume of your choice

4) See Section 12.3

5) Read Section 12.3 and 12.6. Make a table to draw out the comparisons.

6) See Sections 12.4, 12.7, 12.9 and 12.10 respectively.

Appendix 12.1: Legumes - The Nitrogen Fixers.

There are special tubercle-like structures containing bacteria which have the property of fixing atmospheric nitrogen. The symbiotic association between the soil bacteria and the roots of leguminous plants to form nitrogen fixing root nodules is of vital importance to modern agriculture. The bacteria (*Rhizobium* species) live freely in the soil but do not fix atmospheric nitrogen. However, when these bacteria live symbiotically inside these root nodules, they fix atmospheric nitrogen by converting it into nitrates and other compounds which can be used by plants. The bacteria are attracted to the roots of the legumes from the seedling stage onwards. The bacteria enter the root hairs and penetrate in the root cortex. Here the bacteria multiply rapidly using the nutrients and enzymes of the root cells. The host cells too divide and enlarge to produce nodules which become apparent on the surface of the roots. The cells of the root nodules become densely filled with millions of bacteria. The size and shape of the nodules varies considerably and several factors control the growth and efficiency of the nodules. The nodules which contain a special red pigment called leghaemoglobin is very effective and important for nitrogen fixation. The bacterial cells fix atmospheric nitrogen and the legume digests the bacteria, and utilizes the nitrogen compounds. The nodule, thus, finally dies and the large proportion of undigested bacteria become available in the soil to provide nitrogen compounds to the plants. This process of nitrogen fixation constantly adds nitrogen to soil making it available for biological circulation.

UNIT 13 FRUITS AND NUTS

Structure

13.1 Introduction
Objectives
13.2 Fruits
13.3 Nuts
13.4 Summary
13.5 Terminal Questions
13.6 Answers

13.1 INTRODUCTION

Most people use the term fruit for any juicy, edible and usually sweet food article such as mango, banana, orange or apple. However, you also eat tomatoes, cucumbers, brinjal, lady's finger etc. as vegetables and these plant structures are generally not thought of as fruits because they are not sweet to taste. It is therefore necessary to understand what is meant by the term fruit before we proceed to study some of the fruit bearing plants and their value to mankind.

Botanically speaking, a fruit is a product of that process of growth which is initiated by the act of fertilisation. A fruit is thus the ripened ovary and it encloses the seeds which are the ripened ovules. Interestingly, in horticulture, the term fruit is used for any seed-bearing fleshy structure produced by a perennial flowering plant. This definition thus excludes nuts (which are not fleshy structures) as well as the fleshy structures produced by annual flowering plants such as tomato, brinjal, melons etc. and these are classified as vegetables in horticulture.

It would be more appropriate to emphasise the botanical definition of the fruit as "a post-fertilisation" product from the female part of the flower". According to this definition, botanists recognise the importance of sexual reproduction in the life cycle of plants for survival. The fruit as a seed-bearing structure is thus of significance in many ways. You have already read about their development and classification in LSE-06. Before going through this unit read Unit 6 of LSE-06 (Block-I).

It will be interesting to know that the term fruit originated from the Latin word **'frui'** which means **'to enjoy'** because the majority of the fruits are relished for their flavour and taste. Various fruits have been used by mankind since ancient times and these are represented in different forms to indicate their antiquity. For example, the mango has been represented in the Sanchi Stupa which dates back to 150 B. C. The Bible has mention of the forbidden apple in the Garden of Eden. There are also archeological findings of different fruits indicating that fruits were consumed as food. They are nutritious and appetising plant parts rich in carbohydrates and other products. Most fruits have a high sugar content and thus provide quick energy. The indigestable carbohydrates such as cellulose and pectic substances are valuable as roughage which is essential for the proper functioning of the alimentary canal. Fruits are also rich in vitamin C and other organic and mineral substances. They have little protein and hence most fruits cannot serve as a balanced diet on their own. However, they are important as sources of energy and vitamins.

Most fruits are consumed fresh as a dessert or they may be processed before consumption. The majority of the fruits do not have a long shelf life and cannot be stored for long periods. Many fruits can be preserved in different ways and enjoyed for their taste and flavour. Besides this, air transport, cold storage and new packaging techniques are now available as a result of which different kinds of fruits from various parts of the world are available in large cities of the world.

In this unit you will study about some of the well-known fruit and nut-bearing plants and understand their importance to mankind.

Objectives

By a careful study of this unit, you will be able to know:

- the proper botanical usage of the term fruit,
- the general properties of the fruits,
- the origin, distribution, ecology, botany and uses of some important fruits and nuts.

13.2 FRUITS

Fruits have served as a source of food since ancient times. Different fruit plants have provided energy and taste to mankind and some of these have become very important economically. These are widely cultivated and are known throughout the world. There are also less-known fruits which are cultivated only for local consumption. We shall present information on the more well-known fruits.

13.2.1 Mango

Botanical Name : *Mangifera indica* Linn
Family : Anacardiaceae
Common name : Aam
n = 20

The mango is a very popular fruit relished by millions of people throughout the world. In India, it is called the "king of all fruits." It occupies about 60% of the total area under fruit cultivation in our country.

13.2.1.1 Origin and distribution : The mango originated in the Indian subcontinent in the Indo-Burma region. It has been under cultivation for more than 6000 years. There are elaborate references to the mango in ancient Sanskrit literature and the tree is also represented in the Buddhist Stupa at Sanchi dating back to 150B.C. Being one of the oldest and most important tropical fruit, the mango is now grown besides India, in Pakistan, Bangladesh, Indonesia, Philippines, tropical America including Florida, California, Tanzania and Egypt. It is cultivated in almost all parts of India and there are several hundred horticultural varieties. Each variety has its own peculiar taste, flavour, sweetness and quality of pulp. The well-known varieties of mango grown in India include the famous Alphonso, the Dasheri, Langra, Chausa, Banganpalli or Safeda, Totapari or Polymango, Neelam and Malgoa. A large number of hybrids have also been developed. Of these, Malika and Amrapali have become very popular.

13.2.1.2 Ecology : The plants have a tendency to alternate bearing, with heavy flowering and fruiting in one year followed by a light crop in the following year. This is due to mineral imbalance in the soil. Adequate fertilisation can correct the imbalance and there can be uniform fruiting every year under cultivation. Fertilisers which provide nitrogen, phosphorous and potassium must be made available in adequate amounts for good crop.

The Lalbagh (botanic garden) in Bangalore has numerous mango trees. But Zone unique, they have existed for more than 250 years. Perhaps Hyder Ali and Tippu Sultan must have eaten their fruits.

13.2.1.3 Botany : The mango plant is an erect branched evergreen tree growing 10-40 m in height and having a dense dome-shaped canopy. The tree can live for 100 years or more and continue to bear fruits.

The stem has a pronounced trunk with a greyish-brown fissured bark. The leaves are spirally arranged and form a dense glossy mass. They are dark green petiolate and have a pulvinate base. The lamina is narrowly elliptic or lanceolate undulate and coriaceous and tapers towards the apex and base.

The inflorescence is a large terminal panicle bearing numerous flowers. There are few bisexual and many male flowers in each inflorescence. In the bisexual flowers, there is a single carpel with a superior ovary and a single pendulous ovule. The style is lateral with a small simple stigma (Fig. 13.1). Only 0.1 to 0.25% of the bisexual flowers on a tree set fruit. The yield increases up to the 20th year and on an average 400-600 fruits can be harvested from each tree per year.

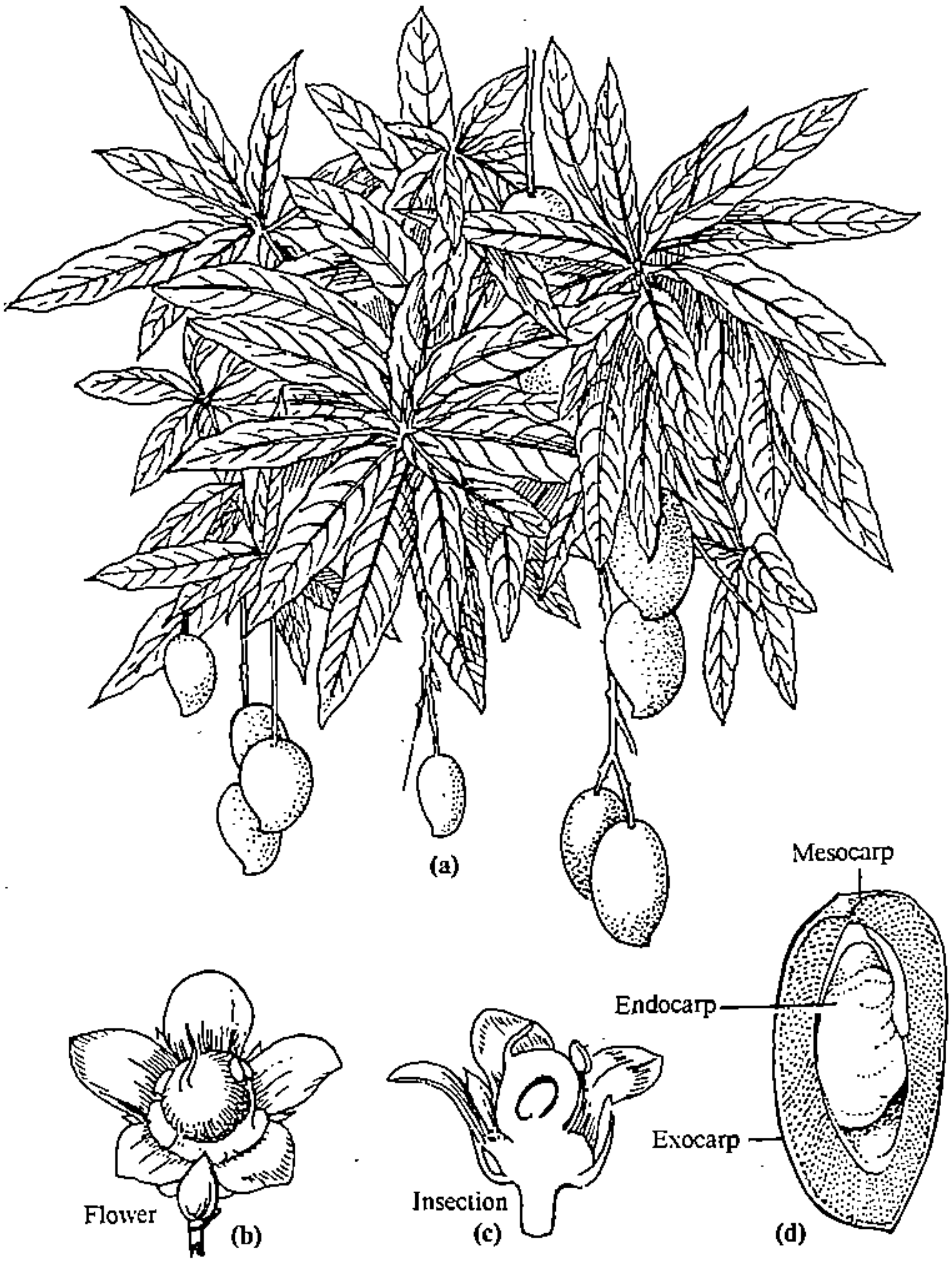

Fig. 13.1: ***Mangifera indica.*** **a) Mangoes on trees. b) a single mango flower. c) Diagrammatic L.S. section passing through a hermaphrodite flower, showing a small obliquely placed ovary with a lateral style with a pendulous ovule and conspicuous disc. d) L.S. of fruit.**

The fruit is a fleshy drupe varying in shape, size, colour and texture of the skin (exocarp), flavour, sweetness and acidity and constitution of the edible mesocarp (pulp). The pulp may be yellow, orange or reddish in colour and encloses the inner stone or endocarp. This is thick, woody and it contains a single seed. Unripe fruits are rich in starch and contain vitamins A,B and C. The starch is hydrolysed to sugars during fruit ripening and the sugar content of the ripe fruit varies from 10-20% of the total weight. Inferior fruits are fibrous and acidic.

13.2.1.4 Uses : One-fifth of the world's inhabitants eat mangoes. This popular fruit is consumed in many ways. Unripe fruits are used in pickles, chutneys and other culinary preparations. Slices of unripe fruits may be dried with or without turmeric and used either as such or in powder form as a seasoning agent for flavouring food. In India, it is called 'amchur'. Ripe fruits are eaten fresh as a dessert and also used in the manufacture of jams, jellies, squash and preserves. Mango pulp, mango-shake (with milk and sugar) and other refreshing drinks are also made from mangoes. The juice of ripe mangoes may be dried to form a solid sweet-sour sheet called 'ampapad' which can be eaten as a snack. Mango is a sacred tree in India and it's leaf is an important item at all Hindu auspicious occasions and festivals.

13.2.1.5 Propagation and improvement : Mango can be propagated by seed or vegetatively. Grafted mango plants are becoming increasingly popular because they start producing fruits early when compared with those raised from seeds.

The cultivated mango, *Mangifera indica* is of allopolyploid origin through interspecific hybridization and chromosome doubling. Selection through gene mutations has helped in improving the crop for regular and prolific bearing; fruit of good flavour and keeping quality; resistance to disease and pests; and other desirable traits. A dwarf habit to facilitate easy harvesting and extended fruiting season are other features being selected through mutations.

13.2.2 The Banana or The Tree of Paradise

Botanical Name : (i) *Musa paradisiaca* Linn. var. *sapientum* (Linn.) Kunze (Synonym : *Musa sapientum* Linn.) (bananas) (ii) *Musa paradisiaca* (Plantains)
Family : Musaceae
Common name : Kela
2n = 22, 33, 44

Bananas are the most important of the tropical fruits. When the total world production of fruits is compared, grapes occupy the first position closely followed by bananas. The cultivated bananas are broadly classified into two groups. According to Kochhar [Economic Botany in the Tropics, Macmillan India Ltd., 1998], "The fruits eaten as a dessert without any cooking are called 'bananas' while the more starchy types with a less pleasant flavour and that need cooking before they can be consumed as a vegetable are called plantains". On the other hand, according to Saldhana (Flora of Hasan District, Karnataka, Amerind Publishing Co., 1976). In South India the starchy cooking *Musa* is called 'banana' and the sweet *aessent* type is called 'plantain'.

13.2.2.1 Origin and distribution : Although the cultivated bananas are called *Musa paradisiaca* or *M. sapientum*, they are actually hybrids which have originated from a cross between two wild species - *Musa acuminata* and *M. balbisiana*. These wild species are diploid and produce large seeds. The fruits are not edible. The cultivated bananas are diploids. The numerous cultivated forms are mutants of the original ancestors or hybrids which have been multiplied by man over the ages. It is one of the oldest fruits known to mankind and therefore its origin is not known with certainty. The banana may have originated in the humid tropical regions of South East Asia somewhere in the mountainous region of North East India, Myanmar (Burma), Thailand or Indonesia. It has now spread throughout the world and the major areas of cultivation are in the continents of Africa, Asia, America and Australia.

13.2.2.2 Ecology : Bananas grow best in the humid tropics where bunches are produced in the shortest time. Adequate monthly rainfall between 100 mm and 250 mm and optimal temperatures between 25° and 30° C are important.

13.2.2.3 Botany : The banana plant is a giant perennial herb. The primary root soon dies and is replaced by adventitious roots which form a dense superficial mat. The true stem is an underground rhizome or corm which grows out through the "pseudostem" at the time of flowering. The corm has very short internodes and is covered or encircled by closely packed leafscars. The so-called vegetative stem is actually a false stem or pseudostem formed by the interfolded and tightly rolled leaf sheaths which grow from the corm. The leaves are spirally arranged, light green and appear as a crown at the apex of the pseudostem (Fig. 13.2). Triploids generally have longer leaves.

The leaves are simple and generally 20-50 leaves are formed before the inflorescence is produced. This ensures that the rate of photosynthesis is high enough for the formation of the bunch. After the bunch is ripe, the shoot dies; but the plant continues to grow by producing side shoots.

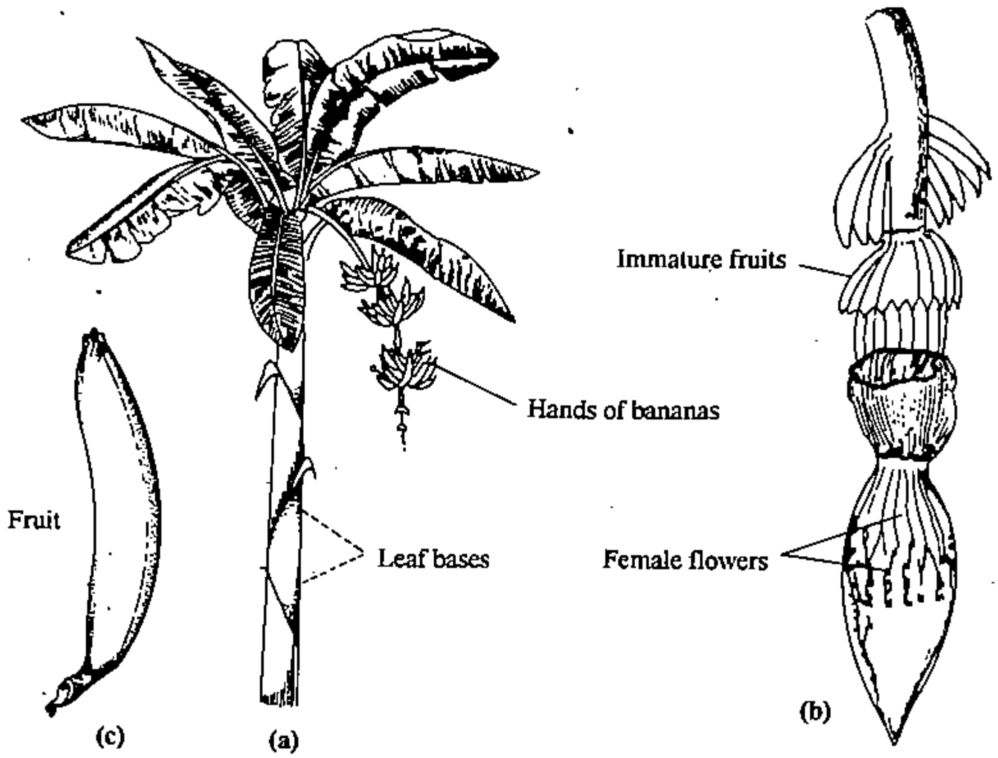

Fig. 13.2: ***Musa paradisiaca*** **Var.** ***sapientum.*** **- banana. a) entire plant perennial here b) an inflorescence showing the successive exposure of clusters of female flowers. c) fruit.**

The inflorescence arises from the corm and after growing through the pseudostem emerges through the crown. It is a complex spike. The racemose inflorescence has flowers arranged in successive layers. Each cluster of the flowers is subtended by a brightly coloured large green or red bract. This bract rolls backwards as the flowers mature and finally falls off. The many flower clusters with their subtending bracts are spirally arranged on the stout peduncle. Each cluster has 12-20 flowers. About 5-15 clusters near the base of the inflorescence bear female flowers while those towards the apex of the inflorescence have male flowers (Fig. 13.3). The emerging inflorescence is erect, but as it matures it becomes pendant due to geotropic reaction as well as its own weight.

The fruit is a berry and it generally develops parthenocarpically. The numerous ovules degenerate as the fruit matures and appear as black or brown specks in the central part of the mature fruit. Fruit clusters are also known as "hands" or "combs" and individual banana as "fingers".

13.2.2.4 Uses : The banana is a versatile fruit. The raw fruit can be cooked as a vegetable, sliced and dried and made into chips or covered with a paste of gram flour and fried. Ripe fruits are eaten as breakfast food or as a dessert. A beverage, banana beer, is prepared in different parts of the world. Ripe fruits are also used for making banana powder used in confectionery. The inflorescence, especially the terminal portion with male flowers, is cooked as a vegetable. The fleshy stem after flowering and fruiting is also consumed as a vegetable. The green leaves are used as plates. The plant is used in several ceremonial occasions like marriage. The ripeness is indicated by yellow skin and brown patches (blotched). Banana is rich in sugars, fat, proteins forming an excellent food.

13.2.2.5 Propagation and cultural practices : Bananas are propagated vegetatively from various types of side shoots or suckers or pieces of the corm. Bananas are harvested when green and ripened artificially with chemicals such as ethene (or ethylene) or ethyne (acetylene), or by exposing them to smoke.

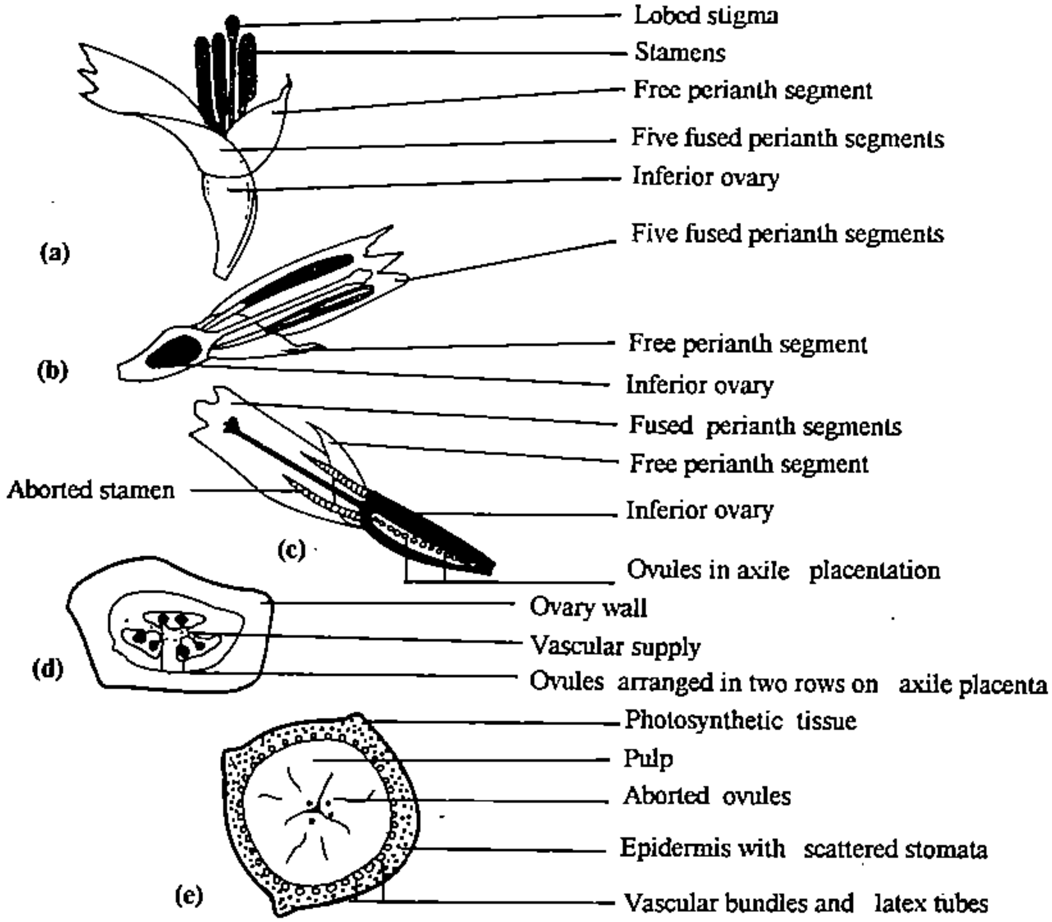

Fig. 13.3: ***Musa paradisiaca.*** **Floral organisation of banana. a) bisexual flower with perianth separated b) L.S. through a hermaphrodite flower. c) L.S. through female flower. d) C.S. young fruit e) T.S. of a mature fruit.**

13.2.3 Pineapple

Botanical name : ***Ananas comosus*** **(L.) Merr.**
Family : Bromeliaceae
Common name : Ananas
n = 25

The pineapple is a plant which is neither a pine nor an apple, but produces delicious fruits. The resemblance of the fruit to a pine cone was used by the Spaniards to call it pineapple. The generic name *Ananas* is derived from the South American "Tupi Indian" name 'Nana' for this plant.

The Hawaiian pineapple industry got its start in 1896 from selected English introductions which came by way of Australia. Hawaii now contributes a little over a third of the world's production of some 11.8 million tonnes.

13.2.3.1 Origin and distribution : The pineapple is a native of South America. It spread to other tropical areas and became a very important fruit crop. It is now cultivated in India, Philippines, Madagascar, Thailand, Mauritius, Malaysia, Hawaii, Brazil, West Africa, South Africa, Argentina, Australia and other tropical and sub tropical regions. Pineapples are also grown in heated greenhouses in Europe. A mutation for seedlessness resulted in selection of varieties for increased size, juiciness, sweetness and improved flavour.

13.2.3.2 Ecology : Pineapples are grown at low elevations between 25° N and S of the Equator. They are tolerant to drought due to the presence of special water storage cells. The plant has xeromorphic characters and the optimal temperature for growth is between 25 and 32°C) If pineapples are grown in cooler locations, the fruit will be acidic and have a low sugar content. Rainfall of 100 - 150 cm and high humidity are important.

The crop can be grown on a wide range of soils but a well drained, slightly acidic, sandy loam is desirable. Pineapples cannot tolerate frost. In Kenya they are grown at altitudes of 1400 to 1800 m.

13.2.3.3 Botany : The pineapple plant is a perennial herb with a single main stem up to 1m in height having a rosette of spirally arranged stiff leaves with pointed tips and entire or prickly margins. A terminal inflorescence develops into the fruit and growth continues after fruiting by the development of axilliary buds into branches.

The plant has a shallow adventitious root system. In addition, roots also grow in the leaf axils and these surround the stem near the base. In this manner, the plant is able to obtain moisture even under dry conditions. The stem stores starch which is later converted into sugar and transported to the developing fruit. Propagation is done through suckers, cuttings and also from seed.

The plant produces a compact terminal inflorescence having 100-200 spirally arranged flowers. The majority of the cultivated pineapples show a parthenocarpic development of the fruit.

The fruit is actually a swollen inflorescence or syncarp or multiple fruit. The axis of the inflorescence as well as the branches and the multiple fruit is fleshy and succulent. The fruit is cylindrical, large and it is surmounted by a crown of leaves (Fig. 13.4). These are formed by growth of the axis beyond the inflorescence. When the fruit matures, the crown stops growing and becomes dormant. This crown can be used for vegetative propagation. It takes about 5-6 months for the infloresence to mature into fruit.

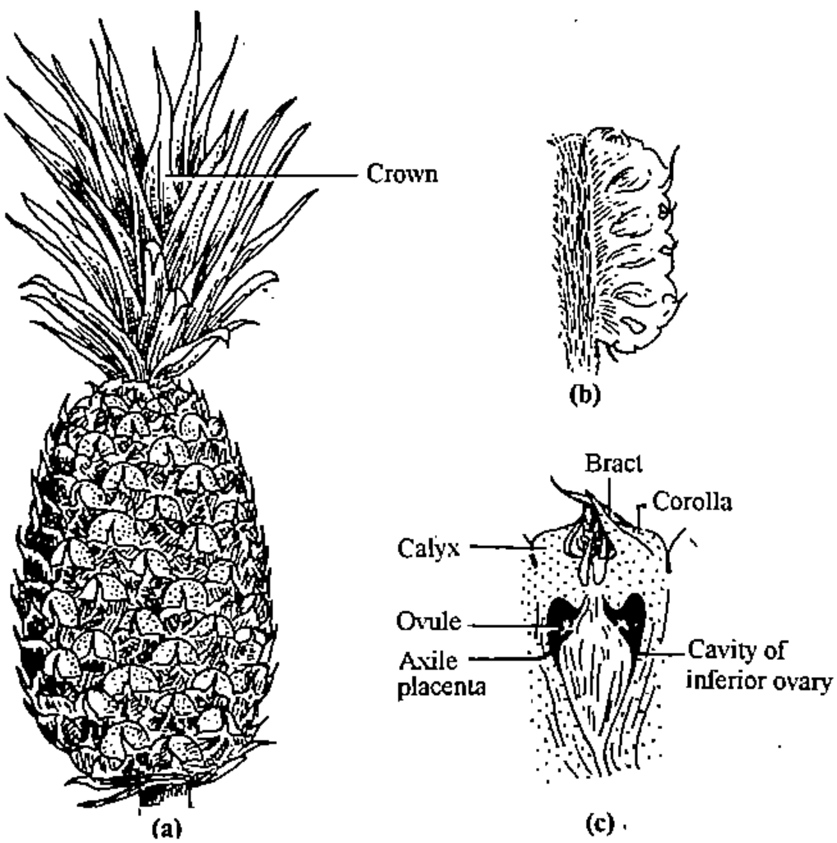

Fig. 13.4: *Ananas comosus.* a) Pineapple fruit with a terminal crown of leaves. b) A L.S. showing several fleshy flowers. c) A single flower in L.S. showing the perianth and inferior ovary.

The size, colour, juiciness, sweetness and flavour of the fruit varies with varieties. The cultivated pineapples are seedless and parthenocarpic as the ovules abort during fruit development.

13.2.3.4 Uses : The fruits of pineapple are eaten either fresh or preserved in syrup and eaten as a dessert. The fruit is also used for making jams,pineapple juice or squash which is consumed as a refreshing drink. Pineapple is mixed with other fruits for making fruit salads or fruit cocktail.

The leaves contain white silky fibre which is used for making a fine fabric (called Pina cloth in Philippines and Taiwan) and for Cordage. Some varieties of pineapples with variegated leaves are grown as ornamentals.

13.2.3.5 Harvesting and Cultural Practice : Flowering and fruiting in pineapple can be simultaneously stimulated by the use of growth harmones, naphthalene acetic acid or its sodium salts, ethylene and acetylene and produced by placing 1 gm granular calcium carbide in the terminal leaf cluster. The fruits are harvested by hand and either sold for raw consumption or sent to factories for processing into various products.

13.2.4 The Papaya or paw paw

Botanical Name : *Carica papaya* Linn.
Family : Caricaceae
Common name : Papita
n = 9

Papayas are among the most widely grown tropical fruits. They are mostly grown in small gardens or as isolated trees for local consumption.

13.2.4.1 Origin and distribution : *Carica papaya* has not been found in the wild state. It may have originated in Southern Mexico and spread to all tropical and subtropical countries.

13.2.4.2 Ecology : Papayas are locally adapted but widespread. They are grown from equatorial tropics to temperate latitudes. Growth is faster in the tropics and trees flower within 6 months and produce ripe fruits within 9 months. They are susceptible to frost. Sandy soils are best for cultivation of papaya, but the crop should not be grown successively in the same soil.

13.2.4.3 Botany : The papaya plant is a short-lived, quick growing small tree with soft wood. It is usually unbranched. The roots are soft and easily damaged. Latex vessels are present in all parts of the plant. The straight cylindrical stem has prominent leaf scars. It has soft spongy fibrous tissue and is usually hollow in the pith region. The stem supports a crown of large long-petiole, palmately lobed leaves which are spirally arranged. Papaya flowers are produced in axillary inflorescences. The trees are usually dioecious producing either male or female flowers. But sometimes bisexual flowers are also formed. In the hermaphrodite trees, both male and female flowers are produced. On the female trees, the flowers are shortly stalked generally solitary (but sometimes in few flowered cymes) and develop into fruits in succession. The male flowers are in large pendant axillary panicles on the male trees. In the hermaphrodites, the inflorescence is variable, even the female flowers being borne on long pendant peduncles (Fig. 13.5).

The flowers are fragrant, creamy white or yellow. They are pentamerous, actinomorphic and gamopetalous. The male flowers have 10 stamens in 2 whorls. The female flowers have a tri- to penta-carpellary syncarpous gynoecium with a superior ovary showing parietal placentation.

The fruit is a fleshy berry. Its shape and size vary, as also its colour (usually yellow, orange), texture and flavour of the edible flesh. The seeds may be few in the nearly seedless varieties, or they may be numerous filling the cavity of the hollow fruit. They are mucilagenous, black or greenish

13.2.4.4 Uses : Unripe (green) fruits are cooked as a vegetable. Ripe fresh fruits are eaten as a breakfast food or as a dessert or in fruit salads in all tropical countries. The fruits are sweet musky in taste. The latex obtained from young immature fruits is dried and used as papain. This contains protein digesting enzymes similiar in action to pepsin. Young fruits or prepared papain are used to tenderise meat. It is also used in the manufacture of cosmetics and chewing gum, and medicine for digestive ailments. Papaya contains about 2% pectin and this is extracted for use in making jams and jellies.

13.2.4.5 Cultivation and harvesting : Papayas are propagated by seed. The fruits are harvested at the half ripe stage, and they ripen in 3-4 days. Hard fruits with carrot-like toughness are usually processed or canned.

A large number of hybrid varieties are cultivated in different parts of the country.

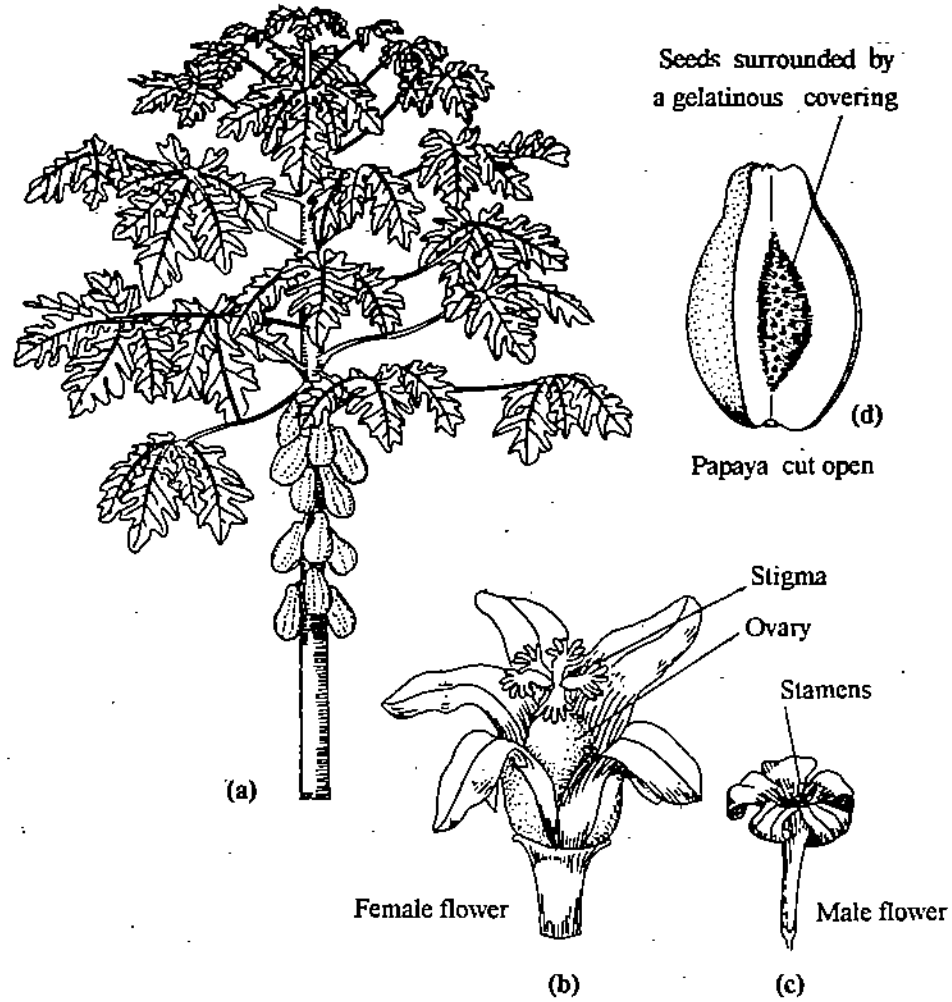

Fig. 13.5: *Carica papaya.* a) A papaya tree b) female flower c) male flower d) fruit (cut open).

13.2.5 The Guava

Botanical Name : *Psidium guajava* Linn.
Family : Myrtaceae
Common name : Amrud
n = 11

The guava is called the "apple of the tropics" or the "poor man's apple". It is listed as a "less important fruit grown in India" in several books. The fruit is a rich source of vitamin C and is relished for its flavour and aroma.

13.2.5.1 Origin and distribution : Known to the Incas, the guava *(Psidium guajava)* originated in tropical America and has now spread to all tropical and subtropical regions. It is mostly grown for local consumption. In India, guava is grown commercially in many states and the Allahabad varieties are very famous for their special taste. It is also cultivated in California and Florida (U.S.A), Brazil, British Guiana, West Indies and Philippines. It grows wild in Cuba.

13.2.5.2 Ecology : The tree is hardy and is quite adaptable to a wide variety of climate and soil conditions.

13.2.5.3 Botany : The guava plant is a shallow rooted large shrub or small tree. The branches arise close to the ground and spread outwards. The leaves are opposite, simple, shortly petioled, and oval to elliptic.

The flowers are axillary, either solitary or in cymose clusters. Each cluster has 2 or 3 flowers. They are white, actinomorphic, bisexual, tetra-or pentamerous and epigynous. There are numerous stamens in concentric rings on an epigynous disc. The syncarpous gynoecium with a 4-5 locular ovary bears numerous ovules.

The fruit is a berry variable in size, shape, texture, juiciness and sweetness of the edible pulp. The skin may be of different shades of green or it may be yellow, cream or almost white. The fleshy edible portion or mesocarp may be white, yellow, pink or red. It contains numerous stone cells as well as hard bony seeds. The fruit has a crown formed by the persistent calyx in which dried stamens may be present (Fig. 13.6).

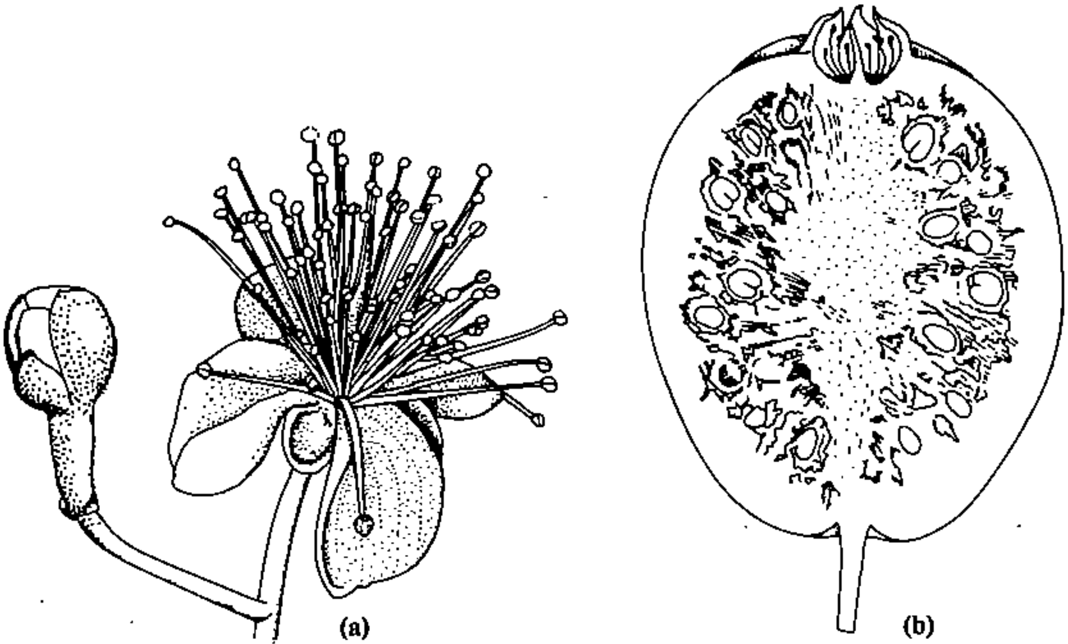

Fig. 13.6: ***Psidium guajava*. a) Guava flower b) L.S. of guava fruit.**

13.2.5.4 Uses : The ripe guava is juicy sweet, aromatic and highly flavoured. It has a fine mixture of acid, sugar and protein. The fruits are eaten fresh or mixed with other fruits in fruit salads. The fruits are also used for making jam, jelly, nectar and juice. Guavas are particularly rich in vitamin C. Guavas are also a fair source of vitamin A, iron, calcium and phosphorus.

13.2.5.5 Propagation : Guavas can be grown from seed but this results in great variability. Vegetative propagation is undertaken in cultivation for obtaining desirable varieties of fruits.

13.2.6 The Fig

Botanical name : *Ficus carica* Linn.
Family : Moraceae
Common name : Anjeer
n = 13

The fig is one of the several hundred species of the genus *Ficus*. We are familiar with the Banyan (*Ficus benghalensis*), the Peepul *(Ficus religiosa)*, Cluster fig *(Ficus glomerata)* and the India rubber tree *(Ficus elastica)*. The common fig is cultivated for its edible fruit.

13.2.6.1 Origin and distribution : *Ficus carica* originated in Asia Minor and spread to the Mediteranneari region. It is a plant of ancient cultivation in Egypt. It finds a mention in the Bible. It is now cultivated in Turkey, Spain, Portugal, United States of America, Chile, Arabian countries, Iran, India, China and Japan. In India, the fig is grown in U.P., Rajasthan, Punjab, Andhra Pradesh and Maharashtra.

13.2.6.2 Ecology : Fig wasps are necessary for cross-pollination and consequent development of the fruit. The species of fig wasp are specific to a given species of *Ficus*. Thus specific wasps must also be introduced along with the fig when it is to be cultivated in a new area.

13.2.6.3 Botany : The fig plant is a small or moderate sized often deciduous tree with latex in all parts. It grows up to 10 meters in height. The leaves are large, broadly ovate or nearly orbicular, more or less deeply 3-5 lobed and conspicuously palmately veined.

The minute flowers arise in cymose inflorescences and several such inflorescences grow very close together, fused with each other and form a cup-shaped or pear-shaped structure called the hypanthodium (Fig. 13.7). This is a fleshy hollow structure with a narrow mouth having interlocking scales. There are 3 kinds of flowers in the hypanthodium:

i) male or staminate flowers,

ii) long-styled fertile female flowers, and

iii) short-styled sterile female flowers

The sterile flowers are also called gall flowers. In these gall flowers, the fig wasp lays its eggs because of which no ovule is formed. The style is short and without stigmatic hairs.

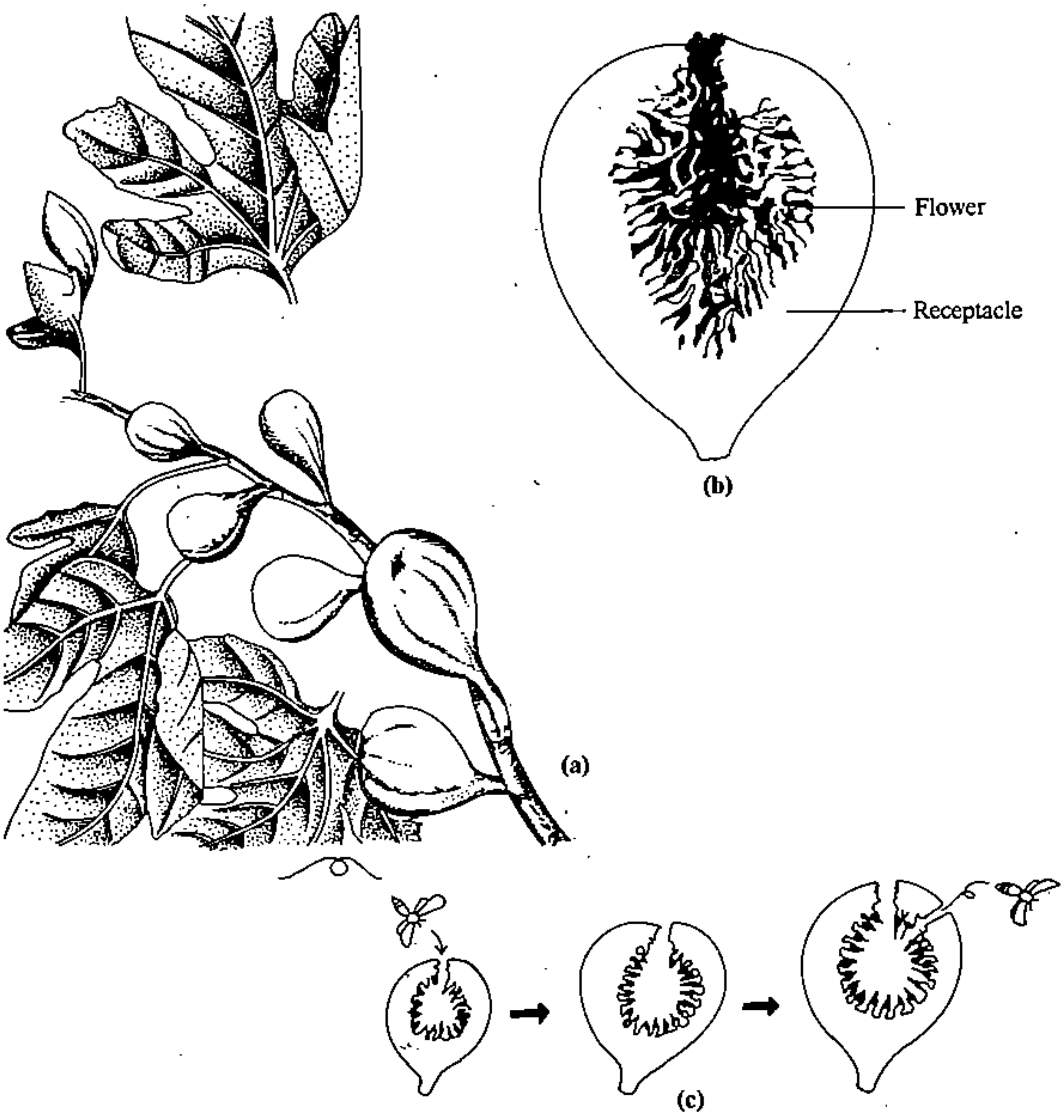

Fig. 13.7: ***Ficus carica.*** **a) A branch of fig tree. b) Fig fruit (cut open) c) pollination of fig fruit.**

Cross-pollination by a fig-wasp (*Blastophaga* sp.) is essential for fruit devlelopment. Strictly speaking, a fig cannot be called a fruit in the true botanical sense, because it does not develop from flowers. It is a syconium of fleshy receptacles containing a large number of flowers which form the hypanthodium. Thus the syconium is formed by the swelling of the entire floral shoot made up of the stem and numerous cymose inflorescences. The syconium is a pear-shaped structure variable in size and colour. It has a high sugar content. The fig matures in about 3 months and consists of seeds developed in the fertile female flowers and insect eggs contained in the gall flowers in about equal proportions. In the common figs there are no staminate flowers so that the fruits develop without pollination and have no seeds. Annually two crops are produced. In the first crop the fruit are larger and more juicy and usually eaten fresh. They are borne on the old wood. The second crop fruits are produced in the axils of the leaves. They are used fresh or are dried. The trees are usually propagated by cuttings.

The caprifigs are wild figs that grow naturally in the Mediterranean region and Western Asia and probably represent the primitive type. Although of no commercial value as fruit, they are essential to the development of the Smyrna fig. The life history of caprifig is closely connected with small wasp *(Blastophaga psenes)* that you have already read in the above section.

In Smyrna figs no staminate flowers are produced, and consequently those figs are dependent on cross pollination from caprifigs. This process is known as caprification and is brought about artificially. Branches of caprifigs of the profichi crop are suspended on the Smyrna tree. The wasps, on emerging, enter the partly developed Smyrna figs and the pollination is completed. Smyrna figs have a superior nutty flavour due to the presence of fertile seeds. They are the most important commercial fig, and are extensively grown.

13.2.6.4 Uses : Fresh fig is a delicious fruit with a high nutritive value. It is rich in sugar and minerals, and has a very short table life. Since the fruit deterioates very fast, large quantities of figs are dried, preserved, or canned. The fig has many medicinal properties and is used in the preparation of syrups and laxatives.

13.2.6.5 Cultivation : Selected high yielding delicious varieties of fig are commonly propagated vegetatively by cuttings. Fig wasps must also be introduced in the area of cultivation to ensure cross pollination.

SAQ 1

1. Write the botanical name and the family of the following fruits.

	Fruit	Botanical name	Family
a)	Banana	....	....
b)	Common fig	....	....
c)	Mango	....	....
d)	Pineapple	....	....

2. Name:

a) Two fruits which develop from a superior ovary:

i)

ii)

b) Two fruits which develop from an inferior ovary:

i)

ii)

c) Two fruits which belong to monocots :

i)

ii)

3. Match column I (name of fruit) with column II (important constituents)

Column I (Fruit)	Column II (Important consituent)
a) Fig	i) Pectin
b) Gauva	ii) Sugars and minerals
c) Mango	iii) Starch/sugars and vitamins
d) Papaya	iv) Vitamin C.

4. Name one fruit characterised by the following features:

a) Chemical control of flowering and fruiting.
Name of the fruit:

....

....

b) Cross- pollination by *Blastophaga* wasp.
Name of the fruit.

....

....

5. Write the name of the following fruits in
(a) your mother tongue
(b) any other Indian language.

Fruit		Name in mother tongue	Indian Language
Banana	-		
Fig	-		
Gauva	-		
Mango	-		
Papaya	-		
Pineapple	-		

13.2.7 Citrus Fruits

All citrus fruits are members of the family Rutaceae. They are different species of a single genus *Citrus* and the common ones are oranges and lemons. *Citrus* fruits are rich source of vitamin C and different fruit acids which are responsible for the taste and refreshing qualities of these fruits. The following table lists some of the well-known citrus fruits grown in India.

Table 13.1: Citrus fruits of India.

Botanical Name	Common English / Hindi Name
Citrus aurantium L.	Sour or Seville orange, Khatta
C. aurantifolia (Christm) Swing.	Lime, Kaghzi-nimbu
C. grandis (L) Osbeck	Shaddock or Pummelo
C. limon (L.) Burm f.	Lemon, Baranimbu
C. medica L.	Citron, Baranimbu
C. reticulata Blanco	Mandarin or Tangerine, Santra
C. sinensis (L.) Osbeck	Sweet orange, Musambi, Malta
C. paradise	Grape fruit

* A hybrid between different varieties of *C. reticulata* developed in 1915 at the Citrus Research Centre of the University of California, has become very popular and is sold as 'Kinnow' in India.

Although individual species show characteristic features, it would be convenient to provide a general account of the genus Citrus.

13.2.7.1 Origin and distribution : The cultivated species of *Citrus* originated in the drier monsoon areas of tropical and sub tropical regions of South East Asia. Natural hybridization and selection resulted in the development of those fruits which had the greatest quantity of juice storing tissue as well as the most desired flavour. Several phenomena such as hybridization, polyembryony, mutation, spontaneous production of autotetraploids, etc., have resulted in the development of numerous cultivated forms of citrus. These are grown commercially in tropical and sub tropical regions and it is often difficult to determine the correct botanical name of different species. *Citrus* fruits are commercially cultivated in the USA, Italy, Sicily, Spain, Greece, Argentina, Brazil, Mexico, Mediterranean Africa, South Africa, Japan, India, Israel, and Australia. In India, Maharashtra, Andhra Pradesh, Karnataka and the North Eastern states are the major citrus growing regions.

13.2.7.2 Ecology : *Citrus* species are cultivated in tropical and subtropical regions. Most of the commercial crop grown in subtropical countries yields better in dry climates.

13.2.7.3 Botany : The plants are small evergreen shrubs or trees. They are long-lived, much branched and aromatic due to punctate oil glands present in all parts.

The stems may have thorns or spines which arise in the axils of the leaves. These thorns sometimes develop only on rapidly growing shoots. Shoot growth is cyclic alternating between periods of rapid growth and dormancy. The leaves are apparently simple, but in their ontogeny they are trifoliate compound. Only the terminal leaflet develops fully while the two lateral leaflets are reduced. The petiole is winged and often articulated at both ends. The leaves are shiny, glabrous, fairly dark green and oval. They contain prominent oil glands in the palisade tissue.

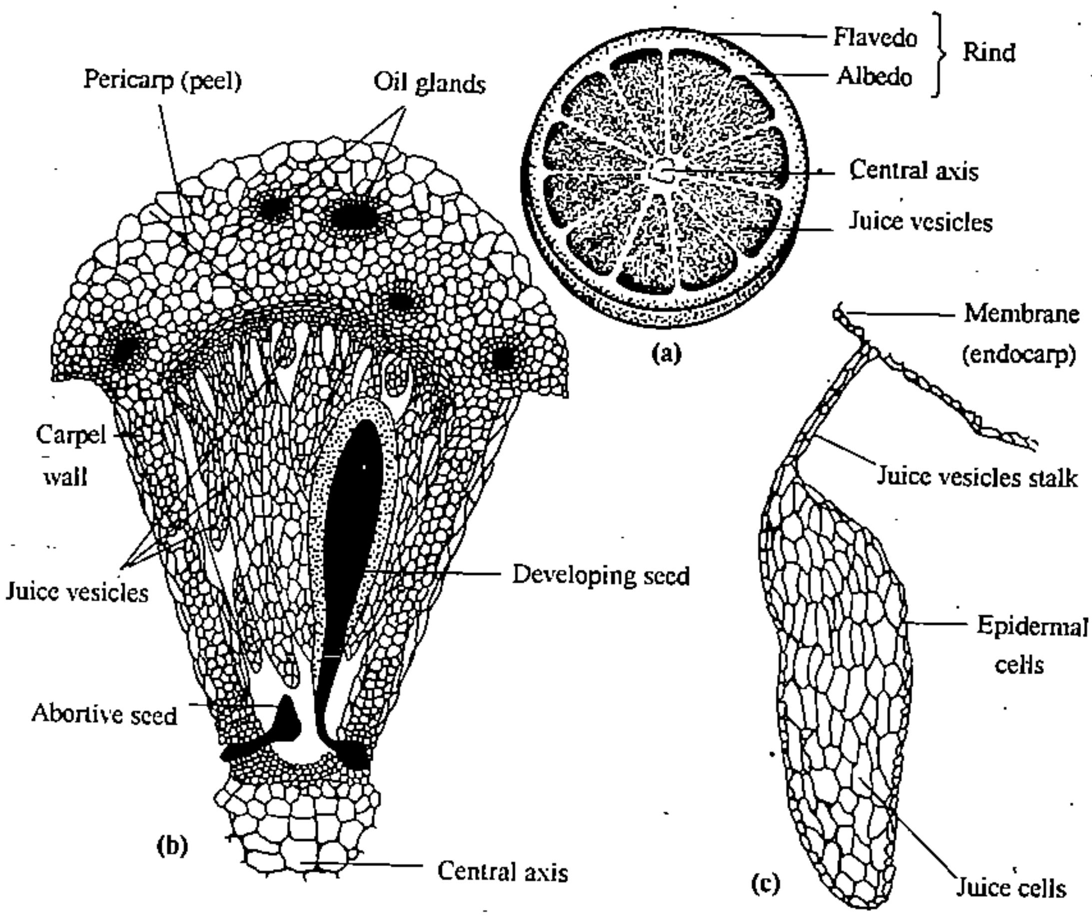

Fig. 13.8 : *Citrus* **sp. a) T.S. of fruit b) C.S. of a portion of the** *Citrus* **fruit c) A juice or pulp vesicle.**

The inflorescence is axillary on new shoots. It may consist of a solitary flower or of a small cymose cluster. The flowers show the typical organisation of the family Rutaceae (see unit 21). They are bracteate, pedicellate, complete and generally bisexual (but sometimes they are unisexual also). A prominent nectar producing disc is present between the stamens and ovary. The sweet scented flowers are generally white, but sometimes they may be pinkish. The calyx is persistent and the petals have numerous oil glands.

The fruit is a large berry of a specialised type. It is called hesperidium (Fig. 13.8). The shape, size, colour, and the consistency of the mature fruit vary in different species. Each fruit has a thick protective covering called the rind. This is made up of tissues of the epicarp and mesocarp. There are definite terms for describing the rind of citrus fruits. The exocarp is called the **flavedo** and it is the coloured portion of the peel, oil glands and crystals are found in exocarp. This also consists of thin walled photosynthetically active parenchymatous cells. In the young fruits these cells show photosynthesis, but as the fruit matures or ripens, the chlorophyll breaksdown and the xanthophyll and carotene pigments become prominent. This changes the colour of the peel to yellow or orange. Inside the flavedo is the **albedo** or mesocarp. This is the inner spongy white portion of the rind. The cells in this region are rich in sugars, pectin, vitamin C and glucosides. The edible portion of the fruit is thus protected from injury and its quality is maintained. This inner endocarp region consists of several closely packed carpel segments, each surrounded by a thin transparent membrane. Each segment contains a large number of multicellular vesicles which grow from the carpel walls. They are filled with juice which contains sugars and acids. The more acidic fruits are bitter or sour while the more sugary fruits are sweet. As the fruit ripens the amount of citric acid decreases and the sugars as well as the aromatic substances increase. A large number of seeds are embedded in these juice-filled vesicles. The segments containing the juice filled hairs form the edible portion of the fruit. The seeds may contain only one embryo (developed from the zygote) or it may contain numerous embryos. In the polyembryonic seeds, the embryos develop from the nucellus and thus these embryos have only the maternal characteristics. In some *Citrus* species, seedless fruits are produced parthenocarpically. However, pollination is necessary for inducing parthenocarpic development.

13.2.7.4 Uses : Several citrus fruits with sweet juice are eaten fresh as a dessert or in fruit salads. They may also be processed into, juices, squashes, cordials and flavouring agents. Fruits with acidic bitter taste are used for making pickles, lemonade drink and for flavouring food. Sweet and bitter fruits are used for making marmelades and in the manufacture of citric acid. Essential oils extracted from citrus peels are used in perfumery, cosmetics, flavouring and pharmaceutical industries. Pectin may also be extracted and used for making jelly and confectionery products.

13.2.7.5 Cultivation : Citrus plants can be grown from seeds, but in most good varieties seeds produce variation because of outcrossing. Besides, variation, plants grown from seed start flowering and producing fruit after many years of vegetative growth. Therefore, in commercial cultivation, selected varieties are propagated vegetatively. This ensures that the desirable characteristics are retained and there are no genetic variations. Vegetative propagation is carried out either by cuttings or by grafting. In raising plants from cuttings, a "marcott" is prepared by tying soil around a selected branch with or without ringing the bark. This encourages rooting, and the rooted cutting is then planted in the soil. This is a quick process and several uniform plants can be obtained simultaneously. Root promoting hormones may also be used.

Grafting is carried out on selected rootstocks and care must be exercised to ensure that species which are compatible are grafted. Local knowledge is essential for proper selection of a healthy combination of rootstock and the grafted variety.

13.2.8 Melons

Two kinds of melon, the watermelon and the muskmelon are commonly cultivated in India for their delicious fruits. They are members of the **family Cucurbitaceae** which also provides a large number of fruits used as vegetables in our country (see unit 14). The two melons are discussed here.

Table 13.2 : Names of some common melons.

Citrullus lanatus (Thunb) mansf.	Water melon, Tarbooz
Cucumis melo var. *momordila* (Roxb) Duthie & Fuller	Snap melon Phesnt
Cucumis melo var. *reticulatus* ser.	Muskmelon, Kharbuja

13.2.8a The Watermelon

Botanical name: *Citrullus lanatus* (Thunb.) Mansf.
Family : Cucurbitaceae
Common name : Tarbooz
n = 11

13.2.8a.1 Origin and distribution : The watermelon originated in tropical Africa and has been in cultivation since ancient times in the Mediterannean region. It has also been cultivated in India since Pre-historic times. Now, it is widely grown in the drier areas of the tropics. Watermelons are also cultivated in Southern Europe and in Central and South America.

13.2.8a.2 Ecology : Watermelons grow best in regions having a hot dry climate and plenty of sunshine.They are fairly drought resistant and do not withstand water logging. They grow best in sandy soils, such as riverbanks.

13.2.8a.3 Botany : The watermelon plant is a slender herbaceous annual spreading on the ground. It has a very extensive and superficial root system. The weak stem is angular, grooved and covered with white hairs. The plant has forked tendrils. The long petioled leaves are simple, large and pinnately lobed. The lobes are further divided, broad at the apex and have serrate margins. Unisexual flowers arise in the leaf axils. The female flowers are fewer in number when compared to the male flowers.The flowers have the characteristic organisation of the family Cucurbitaceae (see unit 21) and they are pale yellow. The fruit is a large, globose or oblong, fleshy berry like structure called the pepo. The rind (outer covering region) may be fully green, or striped or mottled, hard and glabrous. It encloses the red, green or whitish flesh which is usually sweet. It also contains many seeds which may be white, black or reddish.The seeds are flat and smooth (Fig. 13.9).

13.2.8a.4 Uses : The juicy sweet pulp of the ripe fruit is eaten fresh. It serves to quench thirst in desert areas. The seeds can be roasted and eaten. An edible oil extracted from the seeds is used in cooking. Watermelon juice is used as a growth promoter in tissue cultures.

13.2.8a.5 Cultivation : Plants are propagated by seed.The fruits are ready for harvest 4-5 months after sowing the seed. Ripe watermelons require careful handling as they are easily damaged and cannot be stored for more than 2-3 weeks.

13.2.8b The Muskmelon

Botanical name: *Cucumis melo* Linn. var. *reticulatus* Ser.
Common name : Kharbuza
n = 7, 12

13.2.8b.1 Origin and distribution : The muskmelon is believed to have originated in tropical Africa where several wild species of the genus *Cucumis* are common. It was introduced in India, China, Iran and other countries. It is now grown worldwide in warm temperate countries and in hot dry tropical areas.

13.2.8b.2 Ecology : The crop requires plenty of sunshine and a hot dry climate. It grows best in rich loamy soils and will not tolerate high acidity.

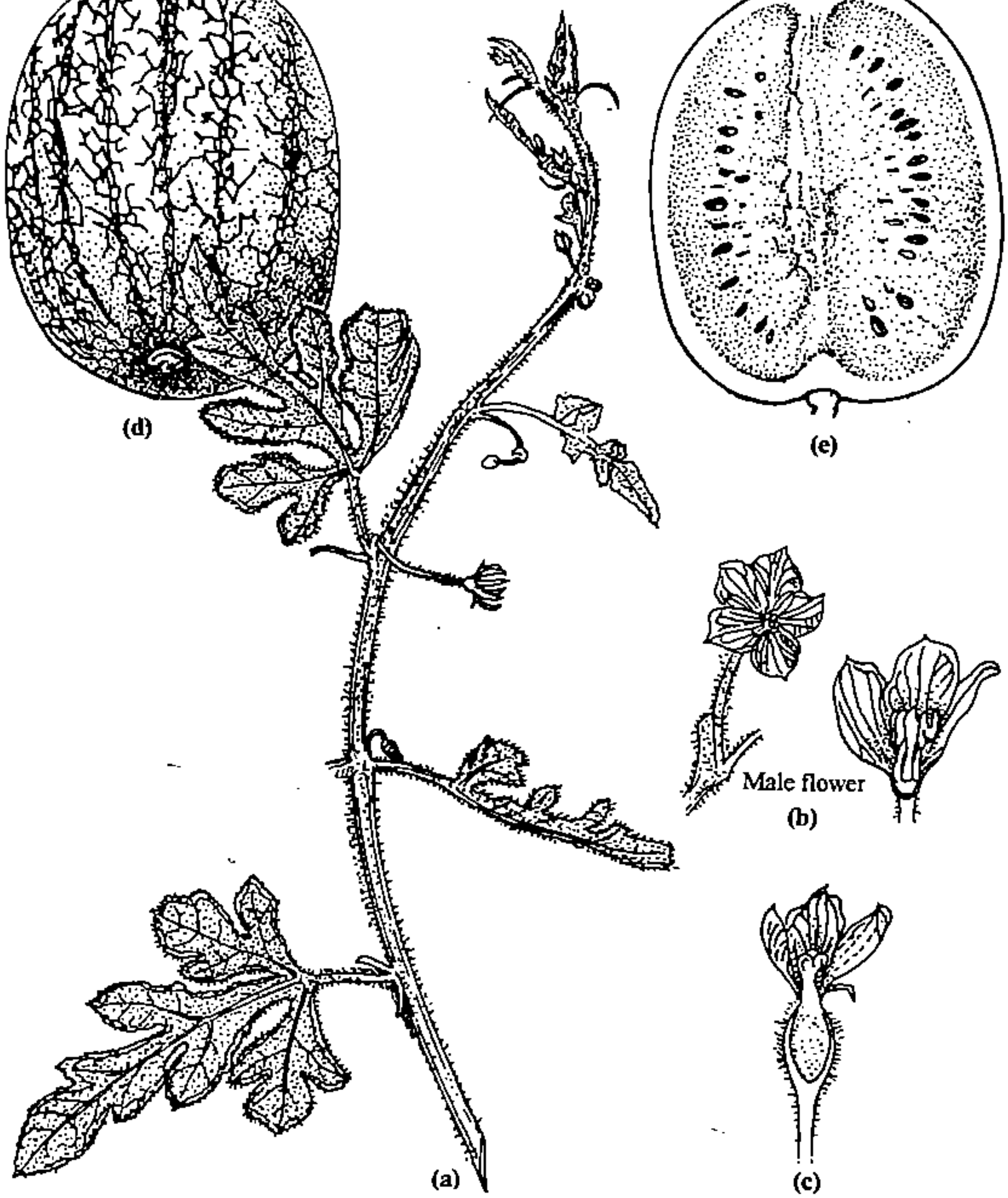

Fig. 13.9 : ***Citrullus lanatus.*** **a) flowering shoot b) male flower c) female flower d) fruit e) fruit in L.S.**

13.2.8b.3 Botany : The muskmelon plant is a very variable trailing herbaceous annual. All parts of the plant are hairy. The root system is wide spread and superficial. The stem is ridged and has bicollateral vascular bundles (a characteristic feature of the family, Cucurbitaceae). The large simple leaves are alternate and have a long petiole. The lamina is lobed, dentate, and has a cordate base. Simple tendrils arise in the leaf axils. The flowers are generally unisexual but sometimes a few bisexual flowers may also develop. The male flowers are in cymose clusters while the female flowers are solitary. They have short peduncles and a characteristic organisation of the family Cucurbitaceae. The flowers are yellow. Fruits develop from female and bisexual flowers. The fruits vary in shape and size. They may be smooth or furrowed (Fig. 13.10). The rind may be smooth, reticulate or rough and its colour may vary from green or yellowish to brownish. The delicious juicy flesh also varies in colour from yellow to pink or green. The sugar content varies in different varieties and the fruit contains vitamin A. A large number of white, flat, smooth seeds are present in the centre of the fruit.

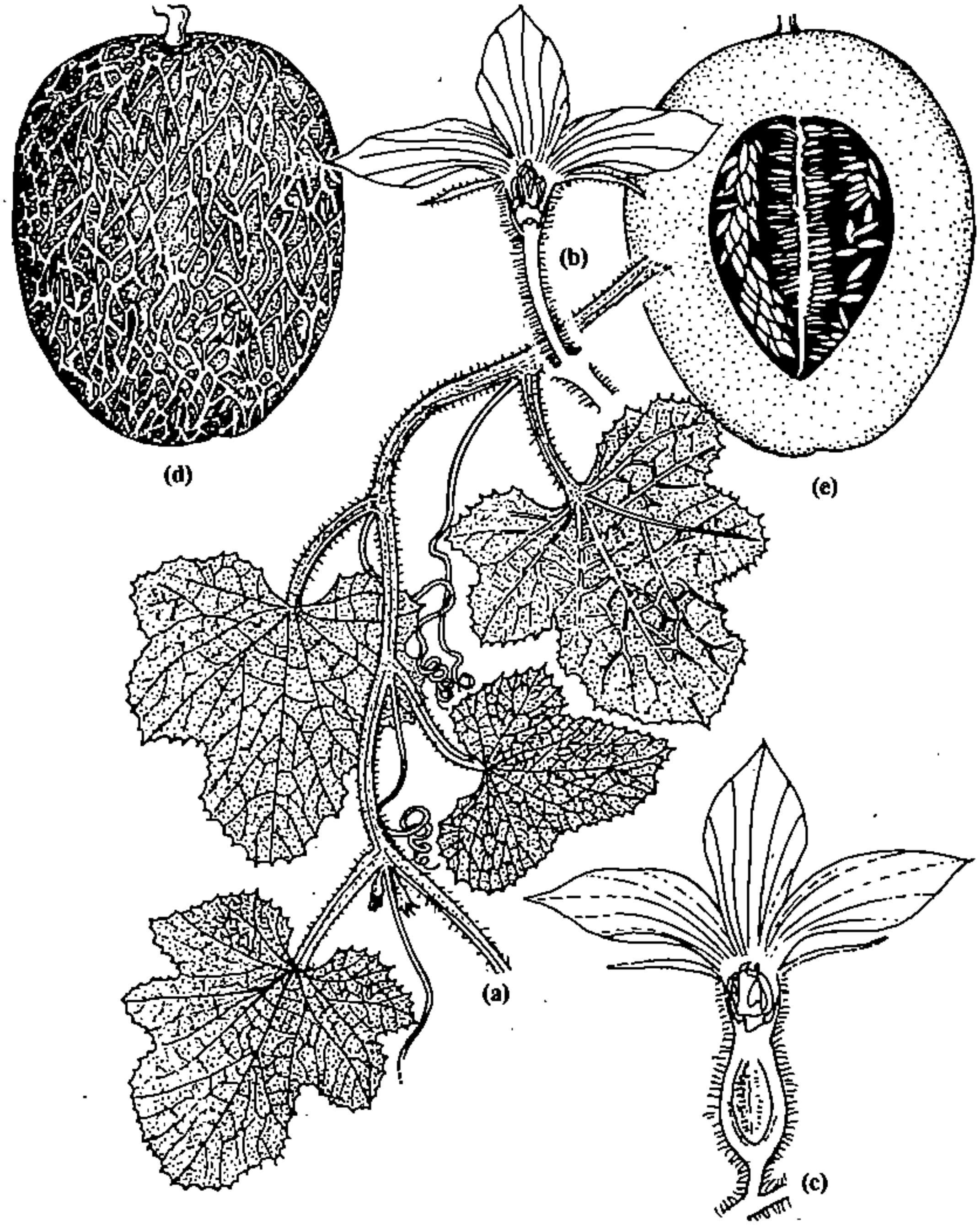

Fig. 13.10 : *Cucumis melo.* a) flowering shoot. b) male flower c) female flower d) fruit e) fruit in L.S.

13.2.8b.4 Uses : The ripe fruits are eaten raw as a delicious dessert fruit. The seeds are dried and after dehusking are used in confectionery. Some varieties of fruit are cooked and eaten as a vegetable.

13.2.9 The Litchi

Botanical name: *Litchi chinensis* Sonn.
Family : Sapindaceae
Common name : Lichi
n = 11

The litchi is an interesting fruit in which the fleshy juicy aril surrounding the seed is edible (This plant family also includes the more well known soapnut trees, *Sapindus saponaria*, the fruits of which contain saponins which form a soapy lather with water).

13.2.9.1 Origin and distribution : The litchi originated in southern China and has spread widely throughout the tropics. It grows well at higher altitudes. It is cultivated in India, Myanmar (or Burma), Indochina, Thailand, Japan, Australia, New Zealand, Hawaii, USA, Brazil, West Indies and South Africa. In India it is cultivated in Uttar Pradesh (mainly in Dehra Dun, Saharanpur and Muzaffarnagar), Bihar (mainly in Muzaffarpur and Dhanbad), the North Eastern States, West Bengal and Punjab. It has been introduced in Bangalore and other parts of South India, but it does not set good fruit.

13.2.9.2 Ecology : The plant is rather exacting in its requirements of soil and climate. Fruiting requires a cool dry season. The plant prefers a humid atmosphere but tolerates no frost. It requires abundant soil moisture and grows well in deep loamy soil.

13.2.9.3 Botany : The litchi plant is a dense evergreen tree growing 10-12 meters in height. It has a broad rounded crown with glossy-green foliage. The leaves are paripinnate with 2-9 oblong and coriaceous leaflets. The small flowers are inconspicuous, greenish white to yellowish. They arise in large terminal panicles. The flowers are unisexual. The fruit is a botanical nut which is globose or oblong. It develops in clusters on the paniculate inflorescence. Each fruit is covered by a dark or light red (or sometimes yellow) exocarp (or rind). This is faintly or sharply tubercled and brittle. It contains a single large dark brown elliptic seed, surrounded by a white, fleshy, sweet and juicy aril. This translucent structure is an appendage or outgrowth from the funiculus (Fig. 13.11). It is regarded as the third integument of the seed and it is the edible part of the litchi fruit. The seed contains a curved embryo.

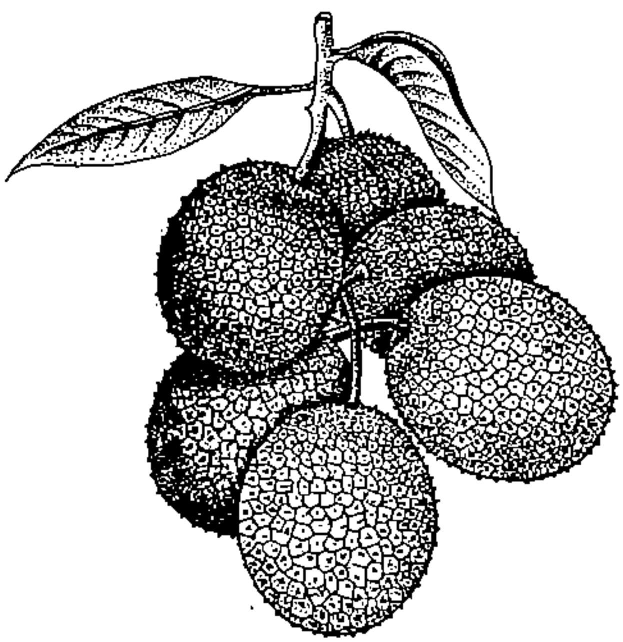

Fig. 13.11: The fruits of Litchi.

13.2.9.4 Uses : The mature fruits are consumed as a delicious dessert fruit from which the juicy sweet aril is eaten. After harvesting the fruits, the rind starts losing its colour. Simultaneously the aril becomes sweeter due to the conversion of complex carbohydrates into sugars. The aril can also be preserved and processed into a squash which is consumed as a refreshing drink.

13.2.9.5 Cultivation : The litchi is usually propagated vegetatively and such trees start bearing fruit in 4-6 years.

13.2.10 The Pomegranate

Botanical name: ***Punica granatum*** **Linn.**
Family: Punicaceae
Common name : Anar
n = 8

The well-known pomegranate or *Punica granatum* is an interesting plant in many ways. This and the species *P. protopunica* are the only two species of the family Punicaceae.

13.2.10.1 Origin and distribution : The pomegranate originated in the area from Iran to Afghanistan and Baluchistan. It was well known in ancient Egypt and was grown in the famous Hanging Gardens of Babylon. It spread around the Mediterranean regions and eastwards to India and China. It now grows wild in the warm valleys and hills of the Himalayas. It is cultivated throughout India, and Maharashtra and Uttar Pradesh are the major pomegranate producing states. It is also grown in most parts of the tropics and subtropics.

13.2.10.2 Botany : The pomegranate plant, 2-4 meters in height, is cultivated as a bush or small trees. It is highly branched with branchlets somewhat spinescent. The leaves are opposite, short petioled, shining dark green and obovate. The flowers may be orange-red, solitary or in clusters of 2-4. The fruit is berry like, brownish yellow and red. It has a leathery exocarp surmounted by a persistent calyx. The fruit contains numerous seeds. Each seed is surrounded by a pink-red juicy pulp (Fig. 13.12). The inner region of the fruit becomes septate due to the development of membraneous walls.

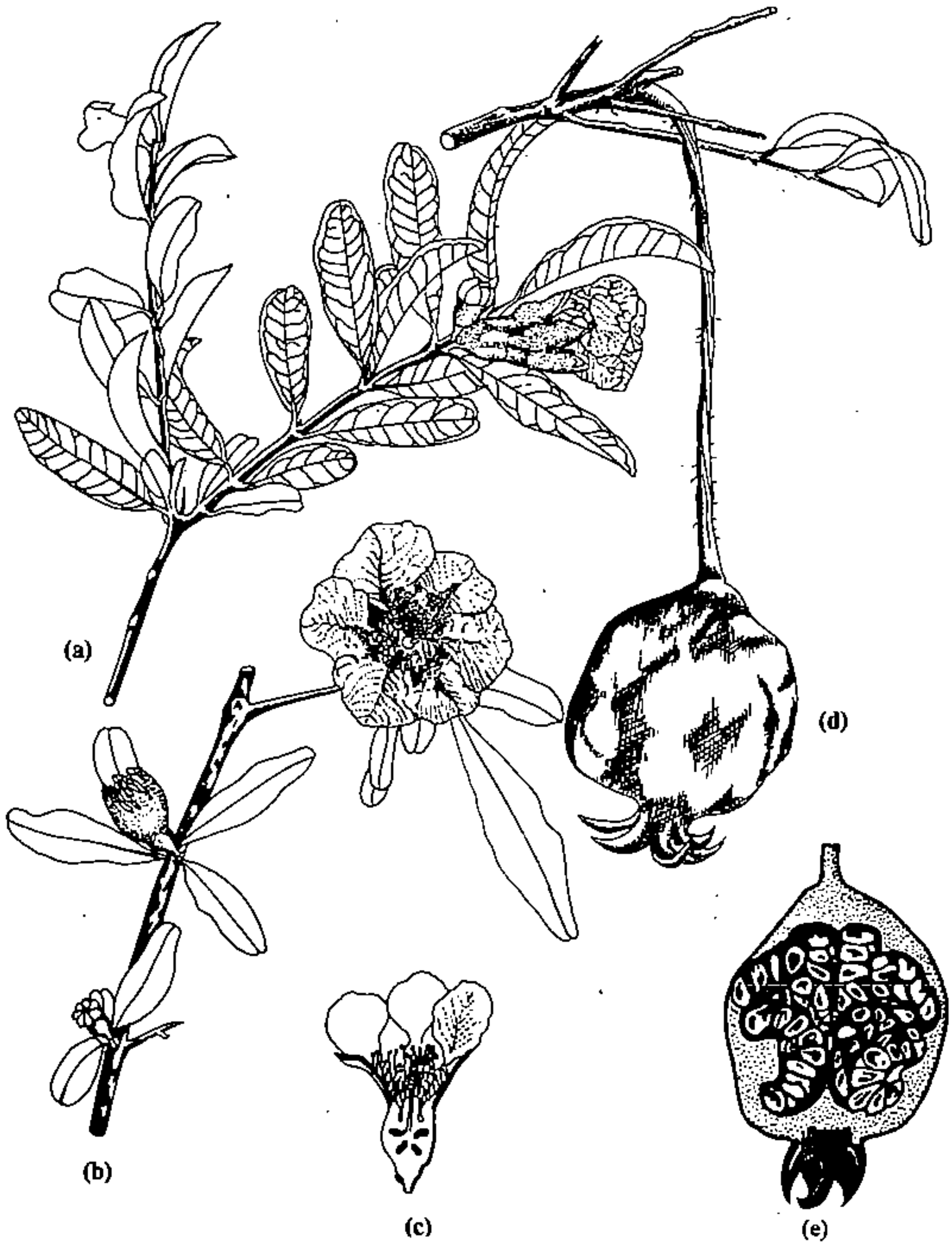

Fig. 13.12 : *Punica granatum*. a) A flowering branch b) flowers c) flower in L.S., d) fruit. e) fruit in L.S.

13.2.10.3 Uses : The juicy pulp surrounding the seeds is the edible portion of the fruit. The fresh seeds are eaten as a dessert and a delicious refreshing drink can be made by extracting the amethyst coloured juice from the seeds. The fresh seeds may also be eaten as a salad.

The dried seeds are used as a condiment for flavouring food. They may be used whole or in a granulated/powder form. It provides a delicious sweet and sour taste to the food. The roots, and seeds have medicinal properties.

Several types of pomegranate are cultivated. They vary in the shape, and size of the fruit, colour and thinness of the exocarp, taste and colour of the seeds. The so-called seedless varieties have soft seeds in which the testa is not lignified. Some varieties are cultivated as ornamentals in gardens for their showy flowers.

13.2.10.4 Propagation : The plant is propagated by seed or by cuttings. The plants start producing fruit in the 4th year and the fruit ripens in about 6 months after flowering.

13.2.11 The Pome Fruits

The family Rosaceae is one of the most important fruit family. The pome fruits include the apple and pear, species indigenous to Europe and Asia. The stone fruits belong to the genus *Prunus* - peach, cherry, plum, and apricot; The berry fruits-blackberry, raspberry and strawberry, are also important.

Here we will describe in detail apple and pear two important fruits obtained from plants of the rose family. These are characterised by a special type of fruit called pome. This fruit is a pseudocarp (false fruit) in which the mature ovaries are surrounded by the enlarged and fleshy receptacle and other accessory parts. Actually, the floral axis forms a deep cup-like structure in which the carpels are embedded. The hard or stony endocarp of the fruit encloses the united carpels. Each carpel has one or two ovules which mature into seeds. The exocarp and the mesocarp become fleshy. The edible part of the fruit is actually the enlarged fleshy receptacle or floral axis. This stores a large amount of food and water. It may be soft, crisp, or hard. In apple stone cells are not found while in pear, the stone cells are abundant in the edible flesh.

13.2.11a The Apple

Botanical name: ***Malus pumila*** **Mill. Syn.** ***Malus sylvestris*** **(L) Mill;**
Family: Rosaceae
Common name : Seb
n = 17

13.2.11a.1 Origin and distribution : The apple has been cultivated since ancient times and is the most important fruit of the temperate regions of the world. It originated in the mountainous region between the Western Himalaya and the Caucasus mountains and Asia Minor. It is widely cultivated in many parts of the world. The major apple growing countries are the U.S.A., Western and Eastern Europe, Japan, Australia and India. As an horticultural/agricultural occupation, apple cultivation was started in the hills and plains of northern India in the middle of the 18th century. An important orchard near Shimla started in 1887 has a very large number of varieties of apples. Besides Shimla, the Kullu valley is also an important apple growing region of Himachal Pradesh. Kashmir is the home of a distinct variety of apple called "Ambri". Apples are also grown in Almora, Garhwal, and Nainital districts of Uttar Pradesh. Apple cultivation has also been undertaken in Bangalore and the Nilgiri Hills in South India.

Box 13.1 : Malus - The bad.

The apple has been involved in folklore since ancient time. In the book of Genesis, Eve was tempted by a serpent and took a bite of a forbidden fruit which most people have assumed was an apple. The generic name of the apple *Malus* after the Latin "malus" meaning bad, was chosen because of the presumed role of the fruit in the downfall of man.

13.2.11a.2 Ecology : The apple is basically a cold season crop capable of withstanding low winter temperatures. Winter conditioning or chilling is essential for successful fruit development. Insufficient chilling leads to poor and uneven fruiting. A large number of flowerbuds

... is not sufficiently cold or long. This leads to abscission and fall of flowers and young fruits. Therefore, apple cultivation is carried out in regions having a low winter temperature and an annual average rainfall of 60-75 cm.

Apples grow best in well drained deep fertile loamy soils containing small amounts of lime. Adequate nitrogen and moist soil promote proper fruit development. Although hardy, they are susceptible to frost.

13.2.11a.3 Botany : The apple plant is a low spreading tree with a rounded crown. It can grow up to 15 m in height. The leaves are borne on short shoots or spurs. They are simple ovate or elliptic, have bluntly serrate margins and are dull green.

The flowers arise in umbel like cymes on short shoots which are atleast 2 years old. They are intermixed with leafbuds. The flowers are white to pink. Many of the flowers abscise soon after anthesis, while others drop after pollination as young fruits. Only one fruit matures on each inflorescence on the spur.

The fruit is a pome consisting of a fleshy edible portion which develops from the receptacle. This encloses the united carpels containing the seeds. The fleshy edible receptacle forms the pericarp (exocarp and mesocarp) while the cartilaginous or bony dry paper like centre of the fruit forms the endocarp (Fig. 13.13). The skin may be green, yellow, or red, or may develop two or all three colours. It stores large amount of water and food material. Numerous varieties of apples are classified on the basis of characteristics of the fruit.

Young fruits contain starch, pectin and malic (90-95% of total acidic content) acid while mature fruits have more sugars, minerals, proteins and other substances. The characteristic flavour of apples is due to the presence of essential oil and amyl esters of organic acids.

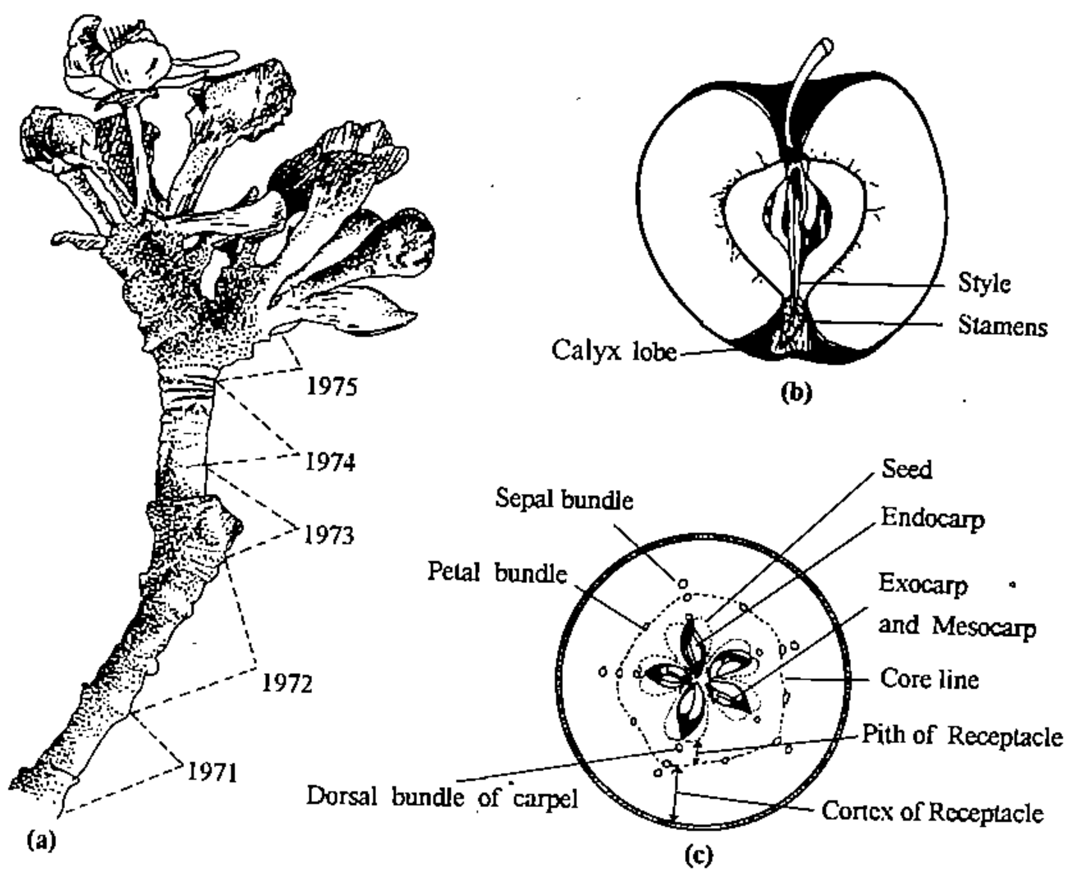

Fig. 13.13: *Malus pumila*. a) A fruit spur of apple. b) L.S. of apple fruit c) C.S. of apple fruit.

13.2.11a.4 Uses : Apples are consumed as an important dessert fruit. About half of the total world production is consumed as fresh fruit. The fruits may also be processed or made into jams, jellies, murabba, apple sauce, apple butter and apple juice. Unfermented apple juice is called sweet cider while the fermented alcoholic juice is called hard cider. Vinegar can also be manufactured from apple juice. Pectin is manufactured as a by-product of the apple juice industry. The apple wood is hard and is used for tool handle and as firewood.

13.2.11a.5 Cultural practices : Apples are usually vegetatively propagated by budding or grafting. When fruit set is heavy, thinning is necessary to maintain a balance between vegetative growth and fruit production. This practice also improves the colour, size and quality of the fruit.

Apples are harvested when fully ripe and care must be taken to avoid any injury because this initiates decomposition. Ripe fruits can be stored for long periods in cool-well ventilated storehouses.

1. Hormones sprayed to prevent premature fruit drop.
2. Bee-keeping to give plenty of pollinators.

13.2.11b The Pear

Botanical name : *Pyrus communis* Linn.
Family : Rosaceae
Common name : Nakh
n = 17

13.2.11b.1 Origin and distribution : The pear is closely related to the apple and stands next to apple amongst temperate fruits. It originated in Europe. Pears are cultivated in Germany, Italy, France, Switzerland, Japan, India and the United States of America. In India it is cultivated on a much smaller scale than the apple. It is grown in Kashmir, Uttar Pradesh and Himachal Pradesh.

13.2.11b.2 Ecology : The pear plant is less hardy and grows in a warmer climate than the apple. It grows well in deep and warm soil which is water retentive. Like the apple, it does not tolerate frost at the time of flowering. The crop is damaged if there is heavy rain or hailstorm at fruiting. Thinning helps to maintain the balance between vegetative growth and fruit production.

13.2.11b.3 Botany : The pear plant is a small tree with a pyramidal crown. The leaves are simple, orbicular or ovate to elliptic with a crenate to serrate margin. The flowers are white and similar to those of apple.

The fruit is a pome and it is variable in shape and size. It may be turbinate or globose.The skin is green while the edible portion or flesh is translucent white (Fig. 13.14). This may be soft and juicy or it may be crisp, hard and dry. It contains numerous gritty concretions or stone cells. The flavour of the fruit is not as variable as that of the apple.

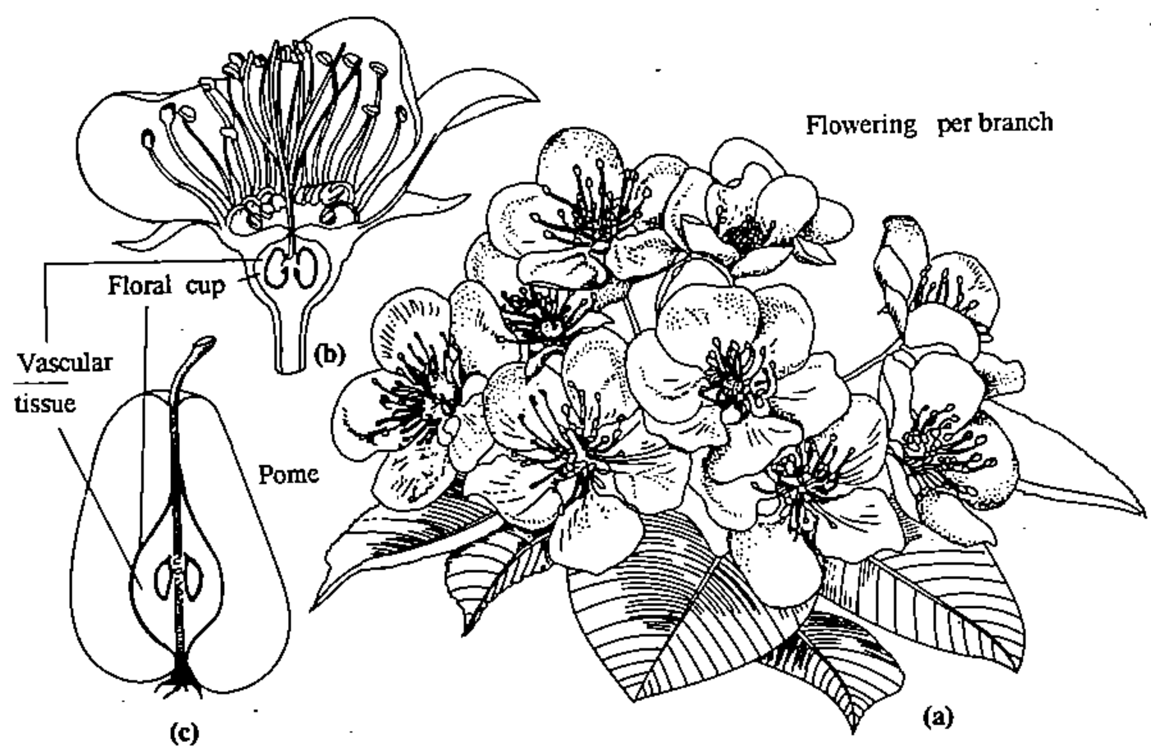

Fig. 13.14: *Pyrus* **sp. a) flowering branch of pear b) flower in L.S. c) fruit in L.S.**

13.2.11b.4 Uses : The fresh fruit is consumed as a table fruit, or it may be processed into jams and jellies like the apple.

SAQ 2

1. Match column I (fruit) with column II (centre of origin)

Column I	Column II
(a) Apple	(i) Tropical Africa
(b) Citrus	(ii) Southern China
(c) Litchi	(iii) Europe
(d) Melon	(iv) Tropical S.E.Asia
(e) Pear	(v) Iran to Afghanistan
(f) Pomegranate	(vi) Asia Minor.

2. Write True (T) or False (F) against the following statements in the box.

   (a) The lemon fruit is a special type of berry. [ ]

   (b) The edible portion of the litchi is not a true fruit. [ ]

   (c) The fruit of pomegranate is a pepo. [ ]

   (d) Apples develop on newly developed young shoots. [ ]

   (e) Pears are classified as fleshy fruits. [ ]

3. a) three fruits which develop from ovaries having axile placentation.

   (i)

   (ii)

   (iii)

b) Name two fruits which develop from ovaries having parietal placentation.

   (i)

   (ii)

4. Describe with examples:

   a) Hesperidium

   ....

   ....

   Example

   ....

   (b) Pome

   ....

   ....

   Example

   ....

5. Write the botanical name and the family of the following fruits.

Fruit	Botanical Name	Family
(a) Mango		
(b) Mandarin		
(c) Pear		
(d) Watermelon		

6. Name the fruits which have the following characteristics.

   a) Amyl esters of organic acids

   b) Fleshy Aril

   c) Polyembryonic seeds

   d) Vitamin A.

13.3 NUTS

Nut is the popular name for many kinds of dry edible seeds or fruits which grow in a woody shell. In botanical terms, a nut is a one celled, one seeded dry fruit with hard pericarp (shell). Thus the cashewnut and walnut are true nuts while the almond, coconut and pistachio nut are not true nuts in the botanical sense since the fruit in these cases is a drupe. The so-called nut is a one-seeded structure enclosed in the hard woody endocarp. You shall study about the nuts in a popular sense and not in the strict botanical sense of the term.

Most people eat nuts as snacks or use them to flavour food. The nuts are rich in protein and fat, but some contain starch also.They are good sources of vitamins and minerals and provide sufficient energy for activating the body. Nuts serve as important items of the diet of mountaineers, hikers, defence forces personnel and others.

Nuts are obtained from a large number of species of plants, but only about 25 kinds of nuts are cultivated and are of economic importance. Like the cereals (unit 11) and legumes (unit 12) nuts can be handled and stored easily. In the following pages, you shall be able to study some of the more well-known nuts.

13.3.1 The Cashew Nut

Botanical name: ***Anacardium occidentale*** **Linn.**
Family : Anacardiaceae
Common name : Kaju
n = 21

In this unit, you have studied about the mango and learnt that it is the "king of all fruits" in India. Like mango the cashew also belongs to family Anacardiaceae. The international trade in cashew and its products is monopolised by India.

13.3.1.1 Origin and distribution : The cashew nut tree originated in tropical areas of America (from Mexico to Peru and Brazil) and the West Indies. It was introduced to other countries by the Portuguese and is now widely distributed throughout the tropical regions of the world. It was first introduced in India in the 16th century to be grown as a soil-binder along coastal areas so as to control soil erosion. It is now widely cultivated in the coastal areas of Kerala, Karnataka, and Tamilnadu. It is also grown in Assam, Maharashtra, Goa, Orissa and West Bengal. India is the leading cashew producing country of the world. Mozambique and Tanzania also produce large quantities of cashew and they send the nuts to India for processing. The cashew is exported mainly to North America and Europe.

13.3.1.2 Ecology : Cashew is hardy and drought resistant. It grows in tropical climates. Proper growth is obtained in sandy soils with good drainage. Cashews are usually grown from seeds. In recent years, vegetative propagation techniques have been perfected.

In mango also only 0.1% to 0.25% of the bisexual flowers in a tree set fruit.

13.3.1.3 Botany : The cashew nut plant is a spreading medium sized evergreen tree. It grows to a height of 12 meters. The trees are shaped, for easy harvest, by removing the lower branches during the first three years of growth.The leaves are alternate, simple, obovate, with a rounded apex which is usually notched in the centre. The margin is entire and tapers to a short petiole which is swollen at the base. The veins are prominent and the leathery leaves are glabrous.The inflorescence is a terminal panicle having male and bisexual flowers in the ratio 6:1. Each terminal inflorescence has about 60 bisexual flowers of which only 5 or 6 produce fruit, the remaining 90% do not produce mature fruit. Physiological causes lead to early fruit fall.

The fruit is a greyish brown kidney shaped nut with a hard shell. It is embedded in a structure called the "cashew apple".This is an enlarged and fleshy structure formed by the growth of the receptacle and pedicel of the flower. It becomes pear shaped juicy and shiny red or yellow (Fig. 13.15). It has a characteristic odour for attracting the insect pollinators. The flowers are pollinated by flies, ants or other insects and the nut matures in 2-3 months. Each nut contains a single seed with two large white cotyledons. The seedcoat or testa is reddish brown. The fruits are harvested when they are fully ripe. They are dried for 2-3 days to reduce the moisture content and then processed before the nuts are marketed.

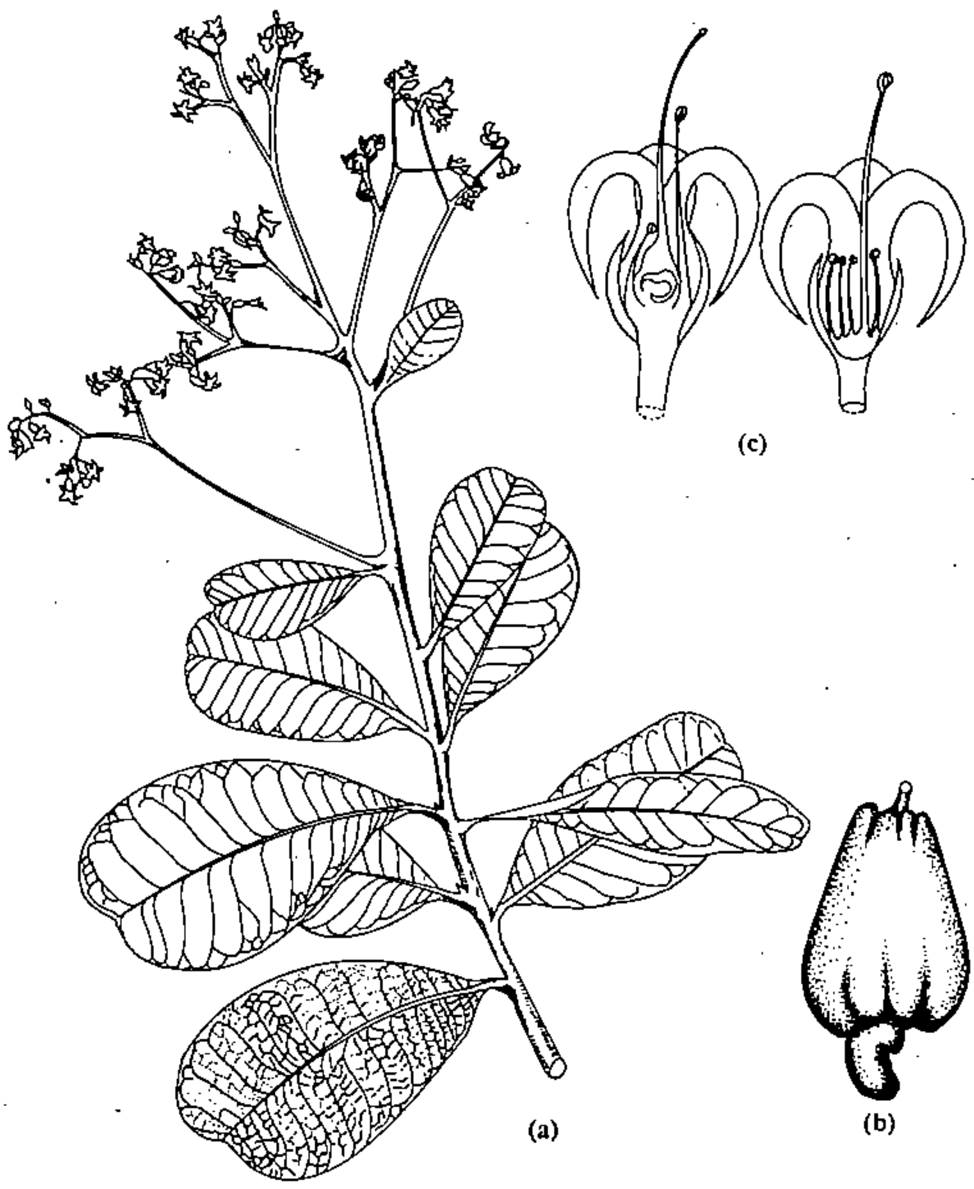

Fig. 13.15: *Anacardium occidentale.* **a) A branch of cashew nut bearing leaves and flower b) mature fruit c) male and female flower.**

13.3.1.4 Cashew processing : Raw cashew nuts contain large amounts of phenolic oils in the shell. These oils have an astringent flavour and cause burns and blisters on the skin. The oils have to be removed before the nuts can be marketed.The raw nuts are roasted in sand or ashes over a fire, to remove the oils from the cashew shells.

The shell oil can be used. Therefore, the raw nuts can also be roasted in an oilbath to extract the oil. By this method, the nuts are roasted uniformly and there is a higher recovery of the shell oil. The oil may also be extracted by passing the raw nuts through organic solvents or steam. After removing the oil from the shell, the nuts are split to obtain the seed with the seed coat. This process is carried out manually as also the removal of the seed coat. The cashew kernels are then graded and vacuum packed.

13.3.1.5 Uses : The kidney shaped cashew kernel commonly called the cashew nut is eaten as a dessert nut and used in confectionery. It may be eaten raw or it may be salted or even fried in oil. Roasted kernels are also eaten. Besides the delicious nut, the "cashew apple" is also edible.This is not a "true fruit", but it is used in the same manner as the apple.

The juicy "cashew apple" is used for making jam or it may be fermented to make a wine called "feni" or "caju wine". The oil extracted from the shell is used as a water-proofing or as a preservative. It can be distilled and used in insulating varnishes, manufacture of typewriter rolls, brake-linings, inks, oil-and acid-proof cements etc. Indelible ink (used for marking the skin during elections) is made from the sap obtained from the tree bark. Adhesives are made from the gummy exudate from the stem.

13.3.2 The Pistachio

Botanical name: ***Pistacia vera*** **Linn.**
Family : Anacardiaceae
Common name : Pista
n = 15

The Pistachio is the third economically important plant of the mango family. This is sometimes called the green almond but it is in no way related to the true almond.

13.3.2.1 Origin and distribution : The pistachio originated in Central Asia. It is commonly found in the eastern Mediterranean region, Iran, Afghanistan, and Central Asia. It is cultivated in Italy, Turkey,Syria, Iran, Afghanistan, Lebanon and other areas of the Mediterranean region. The pistachio is also cultivated in South West Asia, and in the states of California, Texas and Arizonia of the U.S.A. We import large quantities of pistachio from Iran and Afghanistan.

13.3.2.2 Ecology : The plant can be grown on poor soils, in dry locations and at high altitudes. A long winter for chilling the plants is necessary to initiate flowering and fruiting in spring. Thus the plants withstand cold climates.

13.3.2.3 **Botany :** The plant is a small branched deciduous tree growing up to 10 meters in height. The leaves are compound with 3-7 leaflets which are broadly ovate, leathery and produce a sticky resin. The trees are dioecious and produce small flowers in axillary racemose clusters. Generally, the flowers lack petals. The female flowers have 2 or 3 carpels. However, only one carpel contains an ovule which develops into the seed.

The fruit is a small drupe and its outer husk (exocarp and mesocarp) is variously coloured and separates from the bony endocarp. This hard shell tends to open at the edge when the "nut" is mature (Fig. 13.16). It encloses a single light-yellow to deep green edible kernel with a thin reddish testa. Each seed contains two large cotyledons.

13.3.2.4 Propagation : The plants are usually propagated vegetatively by grafting selected varieties on seedling rootstocks. Since the plants are dioecious, fewer male plants and more female plants are grown in orchards. Sometimes, a male branch may be grafted on a mature female tree so that there is no need for separate male trees in the orchard. The pistachio tree survives for a long period and, like the mango, it generally shows alternate bearing.

13.3.2.5 Uses : The edible kernel has a delicious nutty flavour. It may be eaten as a nut or it may be powdered and used for flavouring milk, ice-cream, confectionery and other food items. The kernel may be salted while still in the shell by placing the nuts in a salt solution (brine) and then drying them. The nuts may also be roasted. The resinous exudate obtained from the leaves contains large amounts of tannin which is used for dyeing and tanning leather.

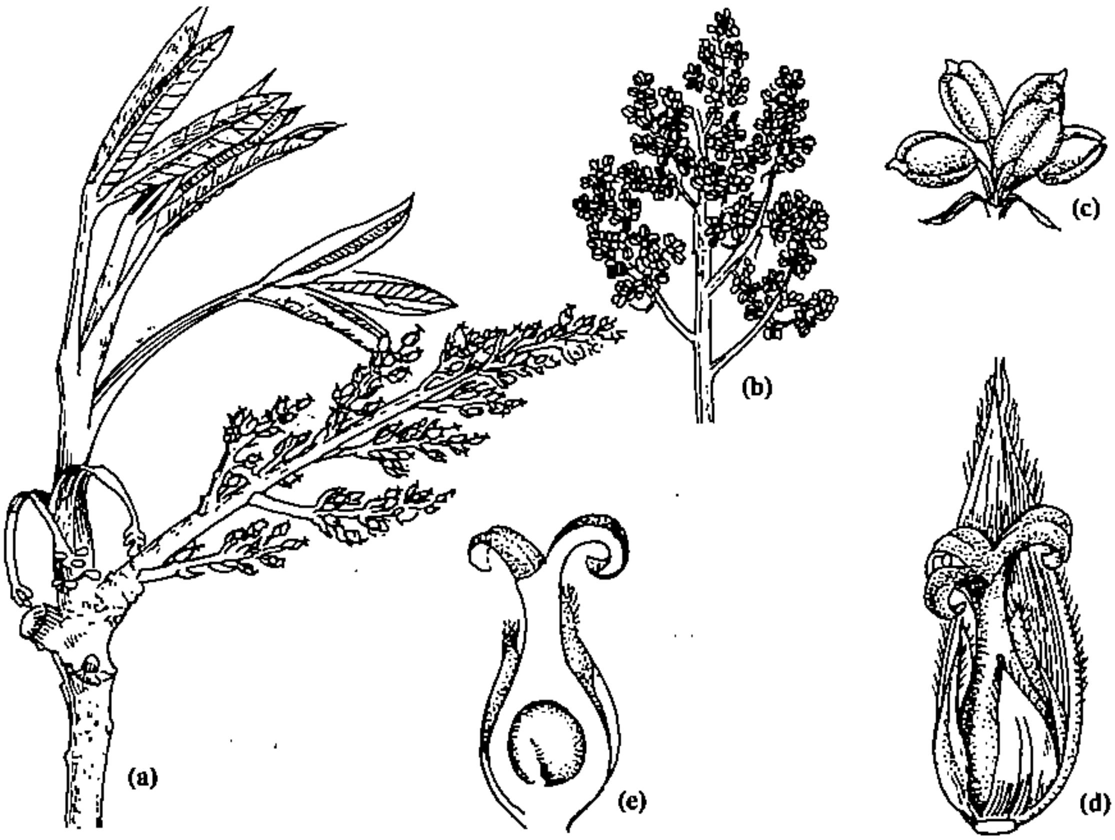

Fig. 13.16 : Pistachia vera. **(a) A flowering branch of Pistachio nuts (b) male inflorescence. (c) male flower (d) female flower (e) L.S. of ovary.**

13.3.3 The Walnut

Botanical name: ***Juglans regia*** **Linn.**
Family : Juglandaceae
Common name : Akhrot
n = 16

There are several kinds of walnuts but the common walnut is the most important. This is also called the Persian walnut or the English walnut. Besides this common walnut, the black walnut (*Juglans nigra* Linn.) and the white walnut or butternut (*Juglans cinerea* Linn.) are also grown in USA and Canada.

13.3.3.1 Origin and distribution : The genus *Juglans* has about 12 species distributed in North and South America and also from Southern Europe to Eastern Asia. The most widely known species is *Juglans regia* or the common walnut. It originated in Persia (and is therefore called the Persian walnut). This species is widely cultivated in Southern Europe (hence the name European walnut), as well as in China and other parts of Asia including India. Jammu and Kashmir is the main walnut growing region in India. It is also grown in Punjab, Himachal Pradesh and Uttar Pradesh.

The common walnut has been introduced in the states of California and Oregon of U.S.A. This is different from the black walnut which is grown for its wood in many parts of U.S.A. Sometimes the nuts of this species are also collected. The white walnut is cultivated in Canada and North America for the nuts which are used for making walnut butter.

13.3.3.2 Ecology : The walnut tree occurs at altitudes ranging from 1000 to 3500 metres. The tree requires a frost-free climate in spring and the absence of extreme heat in summer. The trees coppices well and is propagated by seed. The trees start bearing at 8-10 years and may continue to fruit for 100 years.

13.3.3.3 Botany : The plant is a large deciduous monoecious tree with tomentose shoots. It may grow 30-35 m. In cultivation, it is trained to spread out with a shorter trunk. The leaves are alternate and imparipinnate with 5 to 13 leaflets which are subsessile, elliptic to oblong lanceolate and entire. The flowers are unisexual. The male flowers develop in long pendulous catkins which the female flowers occur in 1-3 flowered terminal clusters.

The fruit is green ellipsoid or globose drupe that cracks open on ripening. The leathery exocarp encloses a hard woody endocarp which is two-valved and wrinkled, and contains a single large edible non-endospermic seed. The seed is corrugated and conforms to the interior of the nut. Two large oily cotyledons fill up the shell of the nut. Each cotyledon may become 2-lobed at the base making the seed 4-lobed. In its morphology, the cotyledon shows a superficial resemblance with the human brain (Fig. 13.17). The testa is bitter in young seeds, but in mature seeds it loses its bitter taste.

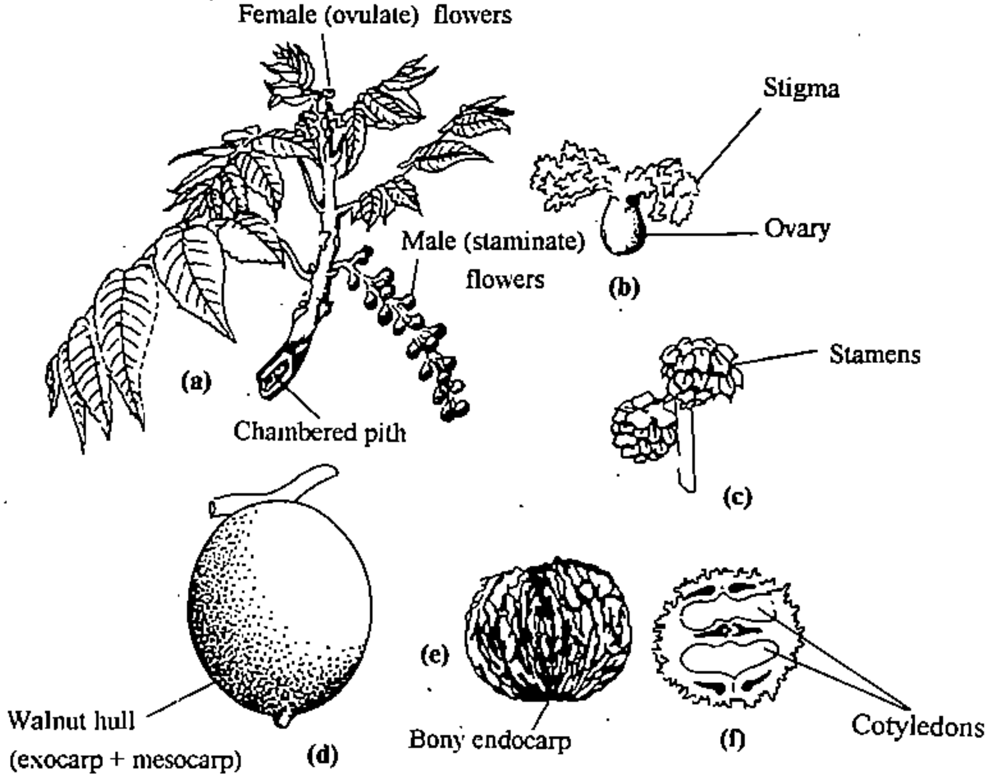

Fig. 13.17: a) branch of walnut; with male and female flower b) female flower c) male flower d) fruit e) long endocarp f) cotyledons.

13.3.3.4 Uses : The walnut has been used as a food since ancient times. The seed kernel is eaten as a dessert nut or dry fruit especially in winter in Northern India. It is also used in confectionery and ice creams. The nut contains proteins, fats, minerals and vitamins.

The immature fruits are a rich source of ascorbic acid.They may be pickled in vinegar. A pale greenish-yellow or almost colourless drying oil is extracted from mature nuts. It has a pleasant odour and a nutty flavour. It is edible and also used in the manufacture of paints, varnishes, printing inks and soaps. Walnut wood is used for making furniture and curios etc. The bark is used for cleaning teeth known as "dundasa".

13.3.4 Almond

Botanical name : ***Prunus dulcis*** **(Mill.) D.A.Webb**
(Synonym *Prunus amygdalus* Batsch)
Family : Rosaceae
Common name : Badam
$n = 8$

The family Rosaceae is economically important in many ways. You have studied about the pome fruits - the apple and the pear -in this unit. The almond, which also belong to the rose family, is the world's most popular nut used by man since ancient times. Interestingly, the fruit is not a pome, but it is drupe with a hard woody endocarp containing the seed.

13.3.4.1 Origin and distribution : The almond originated in South West Asia and is widely grown in countries of the Mediterranean region. The important almond growing countries are Spain, Portugal, Italy, Turkey, Greece, Tunisia, Morocco and Iran. Almonds are also grown in the state of California of U.S.A. and in South Australia as well as South Africa. In India, almonds are cultivated in Kashmir, Himachal Pradesh and in the hilly tracts of Uttar Pradesh. Best almonds come from Baluchistan (Pakistan).

13.3.4.2 **Ecology :** The almond plant requires a subtropical climate. A frost free growing season and fairly warm weather during fruit ripening are essential for proper growth of the plant. Adequate rainfall of about 60 cm annually is required for obtaining a good crop.

13.3.4.3 **Botany :** The almond plant is a small deciduous tree growing to a height of 8 meters. In cultivation, it may be trained to grow as a low spreading tree to facilitate easy harvest of the nuts since these are hand-picked. Gum is formed by the disorganization of the wood and this forms a shining white or pale yellow exudate on the stem and branches. The leaves are simple, alternate, oblong-lanceolate or long pointed with a minutely serrate margin. In spring, the colourful blossoms generally appear before the leaves thus making the plant (or the entire orchard) very attractive. The flowers arise in small clusters of 1 to 3. The fruit is a drupe with a green pubescent exocarp, a tough leathery mesocarp and stony endocarp. As the fruit ripens, the exocarp and mesocarp split to expose the pitted stony endocarp which may be thin or thick. It bears a longitudinal seam along which it splits. There is one (sometimes two) long, oval flattened seed with a brownish seed coat, having two large, fleshy planoconvex cotyledons. This seed is the delicious nut of the beautiful almond tree (Fig. 13.18).

There are different kinds of almonds depending upon the size of the nut, the texture (woodiness) of the endocarp and the taste of the seed. Some almonds are sweet while others are bitter. The bitter almonds contain a poisonous glycoside called amygdalin. This is easily converted into prussic acid (also called hydrocyanic acid) which is responsible for the unpleasant bitter taste of the almonds.

13.3.4.4 **Uses :** Sweet almonds are a popular delicacy. They may be eaten fresh, roasted or fried. They are extensively used in confectionery, sweetmeats, puddings, etc. In powder form or blanched kernels, almonds are added to milk to make a nutritious drink.

Bitter almonds are usually grown for extracting oil from the nuts. The prussic acid removed from the oil is used as a flavouring agent. Oil from sweet almonds is used medicinally and in cosmetics.

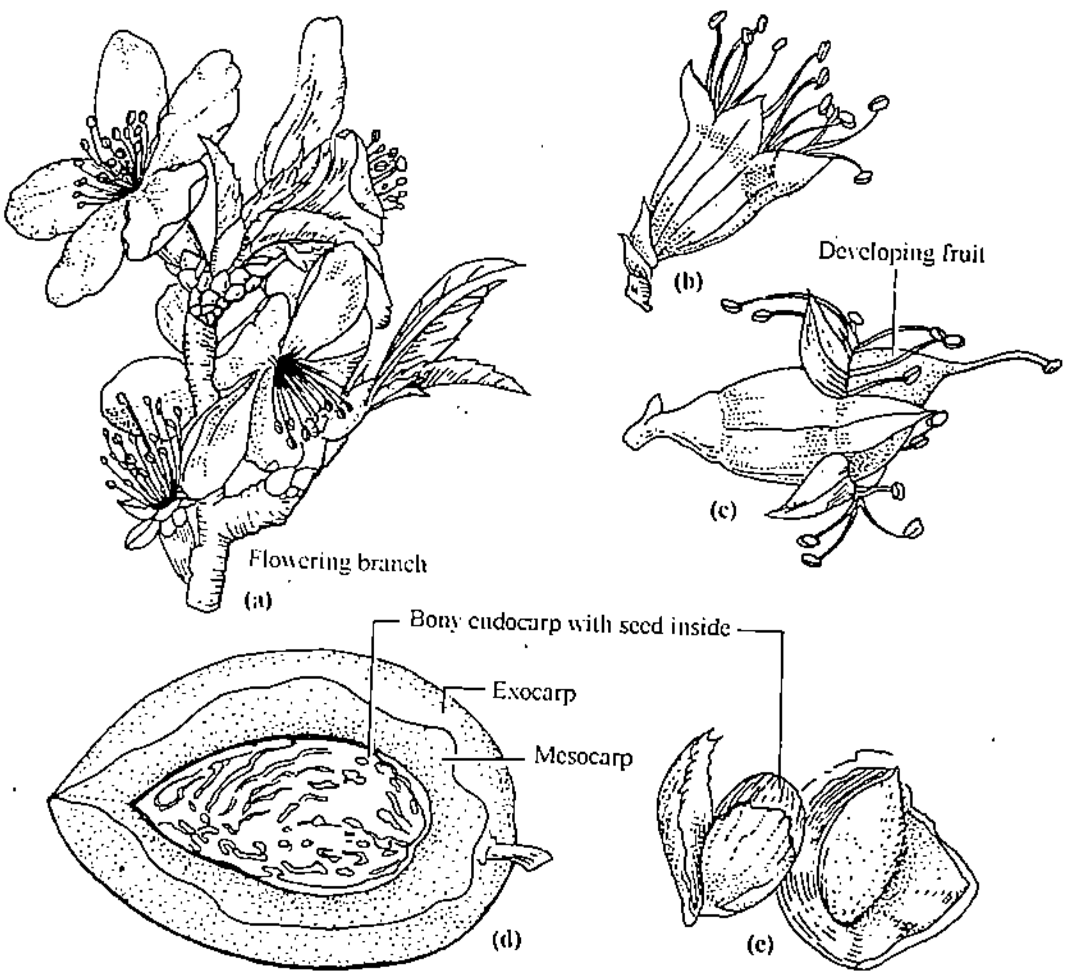

Fig. 13.18: *Prunus dulcis.* a) A flowering branch b) flower c) flower with developing fruit d) fruit with seed e) seeds.

13.3.5 Chestnut

Botanical name: *Castanea sativa* Mill
Family: Fagaceae
Common name : chestnut
n = 12

Unlike the almond, pistachio and walnut, the chestnut is a "true" nut in the botanical sense. It has more of carbohydrates and less of proteins and fats.

13.3.5.1 Origin and distribution : There are about 10 species of the genus *Castanea* which are distributed in the north temperate region.The most important of these is *Castanea sativa* which is called the sweet chestnut or the European chestnut. This species is a native of the mountain forests of western Asia, Europe and North Africa. In India, it is cultivated in many parts of the Himalayas, especially in Punjab, Darjeeling and the Khasi Hills. Italy is the leading producer of sweet chestnuts. Other countries which produce chestnuts are Spain, Portugal, Turkey,Greece, France and Japan.

13.3.5.2 Botany : The chestnut plant is a large evergreen tree attaining a height up to 45 meters. The leaves are spirally arranged oblong-lanceolate with a coarsely toothed margin.

The flowers are unisexual. The male flower occur in large catkins and the female flowers are generally borne in three's. The fruit is a one-seeded nut with a leathery or hard pericarp. Thus in each inflorescence, 3 nuts develop. These are surrounded by the cupule. The scale-like structures of the cupule become hard and spine-like. The cupule splits as the nuts ripen (Fig. 13.19). The nuts are triangular, deep brown and exalbuminous. There are two large wrinkled cotyledons which contain large amounts of starch and sugar and very little protein or fat.

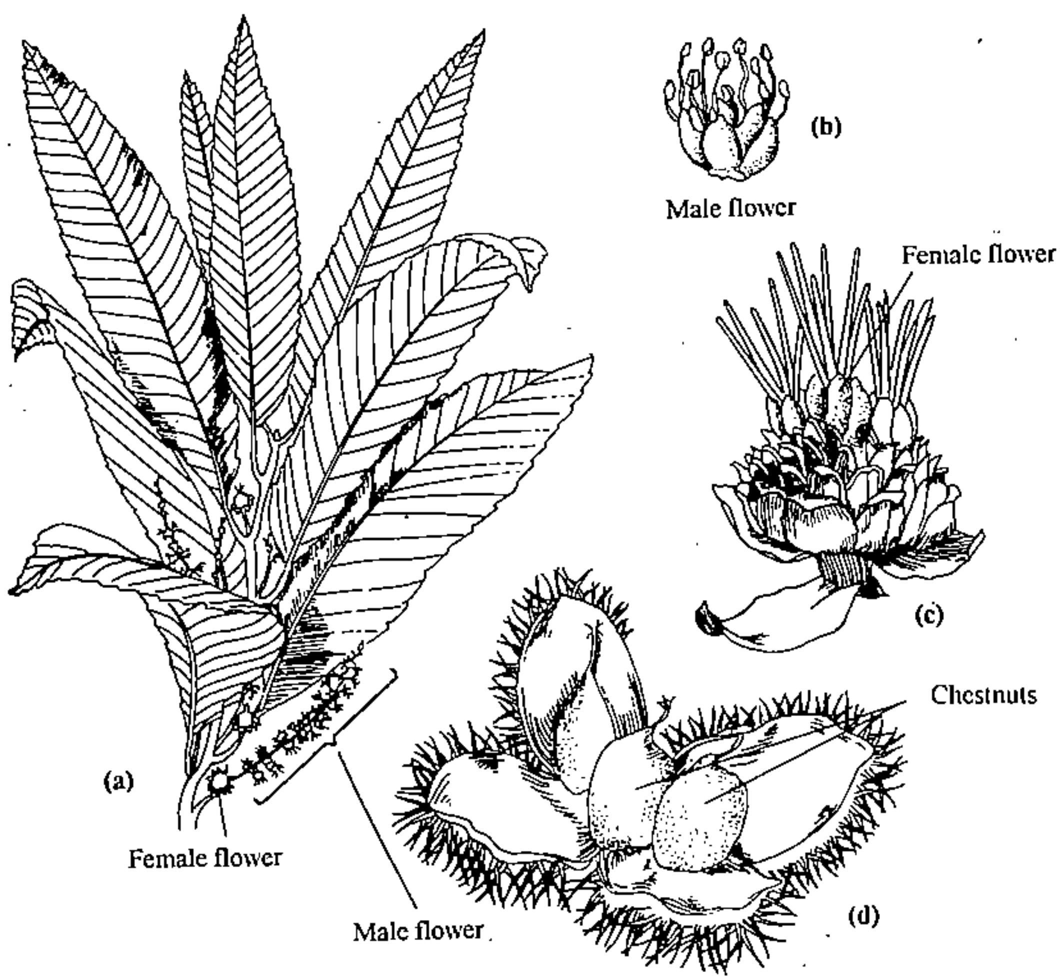

Fig. 13.19 : Castanea sativa **Chest nut. a) A flowering branch of chestnut b) male flower (c) female flower d) nuts.**

13.3.5.3 Uses : Chestnuts have been used as an article of food for many centuries. Because of their high carbohydrate content, chestnuts are as important as wheat or corn in

Europe. Like other starchy foods, these nuts are usually cooked, or boiled or roasted and then consumed. Flour is also made from the nuts and used as an article of food. It is rich in starch, other polysaccharides, sucrose and minerals. Tannin obtained from the wood is used in the tanning industry. The leaves and bark also contain tannin.

SAQ 3

1. Name

   (a) Three nut producing plants in which the fruit is botanically a drupe.

   (i)

   (ii)

   (iii)

   (b) Two nut producing plants in which the fruit is botanically a nut.

   (i)

   (ii)

2. Name the nuts which have the following constituents:

   (a) Ascorbic acid ....

   (b) Prussic acid ....

   (c) Starch, sucrose and minerals ....

3. Write a brief note on the cashew apple.

   ....

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13.4 SUMMARY

- In this unit, you have been provided detailed information about different fruits and nuts. The definition of the term fruit in common terms as well as in botanical (scientific) terms has helped you to understand this structure in a better manner. The different kinds of fruits and their botanical characteristics have been listed so that your study of fruits and nuts is facilitated.
- You have studied about the origin, distribution, ecology, botany and uses of the well-known fruits and nuts. The following table summarises some important information you have obtained.

Table 13.3 : Fruits.

Fruit/Nut	Botanical Name	Family	Centre of Origin	Botanical Characteristics
Mango	*Mangifera indica*	Anacardiaceae	Indo-Burma	Large evergreen tree; fruit is a drupe alternate bearing due to mineral imbalance
Banana	*Musa: paradisiaca* var. *sapientum*	Musaceae	S.E. Asia	Giant perennial herb; fruit is a berry
Pineapple	*Ananas comosus*	Bromeliaceae	South America	perennial herb with xeromorphic characters; fruit is a syncarp;
Papaya	*Carica papaya*	Caricaceae	Southern Mexico	Small tree with softwood; fruit is a berry.
Gauva	*Psidium guajava*	Myrtaceae	Tropical America	Large shrub or small tree with spreading branches; fruit is a berry.
Fig	*Ficus carica*	Moraceae	Asia Minor	Moderate sized deciduous tree; fruit is a syconium; special figwasps necessary for pollination and fruit formation.
Sweet Orange	*Citrus sinensis*	Rutaceae	South East Asia	Small evergreen tree; fruit is a hesperidium.
Lemon	*Citrus limon*	Rutaceae	South East Asia	-do-
Watermelon	*Citrullus lanatus*	Cucurbitaceae	Tropical Africa	Herbaceous annual, tendrils; fruit is a pepo with many seeds.
Muskmelon	*Cucumis melo*	Cucurbitaceae	Tropical Africa	Herbaceous annual; fruit is a pepo with many seeds.
Litchi	*Litchi chinensis*	Sapindaceae	Southern China	Dense evergreen tree; fruit is a nut, edible aril surrounds the seed.
Pomegranate	*Punica granatum*	Punicaceae	Iran, Afghanistan, Baluchistan	Highly branched small tree or large shrub; fruit is berry like with a leathery pericarp and numerous seeds; juicy seeds are edible.
Apple	*Malus pumila*	Rosaceae	Western Himalaya to Asia Minor	Low spreading tree; fruits produced on short shoots; fruit is a pome;
Pear	*Pyrus communis*	Rosaceae	Europe	Small tree; fruit is a pome;
Cashew	*Anacardium occidentale*	Anacardiaceae	Tropical America	Medium sized evergreen tree; fruit is a nut; cashew apple is a fleshy juicy structure; it is edible and also used for making a wine.
Pistachio	*Pistacia vera*	Anacardiaceae	Central Asia	Small deciduous tree; fruit is a drupe.
Walnut	*Juglans regia*	Juglandaceae	Iran	Large deciduous, monoecious tree; fruit is a drupe; large non-endospermic seed resembles the human brain.
Almond	*Pruns dulcis*	Rosaceae	South west Asia	Small deciduous tree; fruit is a drupe,
Chestnut	*Castanea sativa*	Fagaceae	West Asia, Europe, North Africa	Large evergreen tree; unisexual flowers in catkins; fruit is a nut with a leathery Pericarp

From the above table and from your study of the material in this unit, you have learnt that a large number of fruit and nut plants have been used by mankind since ancient times.

The majority of these plants are dicotyledonous, but two of the plants are monocotyledonous. These are the banana and the pineapple. Three of the plants (the mango, the cashew and the pistachio) are classified in the family Anacardiaceae and three (the apple, the pear and the almond) in the family Rosaceae. A large number of plants of the genus *Citrus* (family Rutaceae) provide delicious fruits.

13.5 TERMINAL QUESTIONS

1. Define the term fruit and describe the different kinds of fruits in botanical terms. Mention the important properties of fruits in general.

 ....

 ....

 ....

 ....

 ....

2. List the plants you have studied in which the fruit is a berry. Describe any two of these in detail under the headings: Origin and distribution; ecology, botany and uses.

 ....

 ....

 ....

 ....

 ....

3. Mention the features by which you can differentiate a berry from a drupe. List the plants you have studied in which the fruit is a drupe. Describe the "king of all fruits": mentioning its important botanical characteristics and uses.

 ....

 ....

 ....

 ....

4. Why is the pome called a "false fruit"? Describe the pome and illustrate its structure. Discuss the importance of pome fruits.

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5. What is a 'nut' in the popular sense of the term. Define a nut in botanical terms. Describe two plants in which the fruit is not a botanical nut, but is consumed as a nut.

 ....

 ....

 ....

 ....

Project:

List the fruit and nut producing plants whose products are consumed in your region. Consult books in your study centre and write the botanical name, the family, and the local name of each. Describe any one of these which is not discussed in this unit.

13.6 ANSWERS

Self-Assessment Questions

SAQ 1

1. Fruit	Botanical Name	Family
a) Banana	*Musa paradiasiaca* var. *sapientum*	Musaceae
b) Common Fig	*Ficus carica*	Moraceae
c) Mango	*Mangifera indica*	Anacardiaceae
d) Pineapple	*Ananas comosus*	Bromeliaceae

2. a) i) Mango
   ii) Papaya
   iii) Fig.
   (Any two).

   b) i) Banana
   ii) Pineapple
   iii) Guava
   (Any two)

   c) i) Banana
   ii) Pineapple

3. a - ii   b - iv
   c - iii   d - i

4. a) Pineapple
   b) Fig

5. Answers will vary from region to region, depending on the fruits and nuts listed by the candidate.

SAQ 2

1. a - vi   b - iv
   c - ii   d - i
   e - iii   f - v

2. a - T   b - T
   c - F   d - F
   e - T

3. a) i) Apple
   ii) Citrus
   iii) Pear

b) i) Watermelon
ii) Muskmelon
iii) Pomegranate

4. a) Describe the citrus fruit
b) Describe the apple or pear fruit.

5.
a) Mango - *Mangifera indica* Anacardiaceae
b) Mandarin-*Citrus reticulata* Rutaceae
c) Pear - *Pyrus commumis* Rosaceae
d) Watermelon -*Citrullus lanatus* Cucurbitaceae

6. a) Apple
b) Litchi
c) Citrus
d) Muskmelon

SAQ 3

1. a) i) Almond
ii) Pistachio
iii) Walnut
b) i) Cashew
ii) Chestnut

2. a) Walnut
b) Bitter Almonds
c) Chestnut

3. See 13.3.1.3 and 13.3.1.5.

Terminal Questions

1. Refer to the Introduction.

2. i) Banana
ii) Papaya
iii) Guava
iv) Pomegranate
v) Citrus fruits (the hesperidium is a specialised berry)
vi) Melons (the pepo is also a specialised berry) for description refer to the text.

3. Refer to answer 1 c of SAQ 1.
i) Mango
ii) Pistachio
iii) Walnut
iv) Almond

Describe mango fruit and list its uses.

4. Refer to 13.2.11 - The Pome fruits

5. Refer to 13.3 - The Nuts

Describe any one of the following:

Pistachio

Almond

Walnut

UNIT 14 VEGETABLES

Structure

14.1 Introduction
Objectives
14.2 Vegetables from Roots and other Underground Parts
14.3 Vegetables from Leaves
14.4 Vegetables from Fruits and Seeds
14.5 Summary
14.6 Terminal Questions
14.7 Answers

14.1 INTRODUCTION

Vegetables constitute an important part of a vegetarian diet. The consumption of fresh vegetables and fruits is much more than ever before, and they provide variety, flavour, minerals and much needed vitamins to our diet.

Vegetables are defined as one of the many nutritious foods obtained from plants or plant parts. Thus, roots, stems, leaves, infloresences, seeds and food fruits, are all used as vegetables in different ways. They may be eaten raw as salads or cooked in various ways. Vegetables may constitute the main course of a meal, or they may be consumed as snacks or in soups.

Vegetables are an important part of a healthy diet. They are an excellent source of vitamins, especially niacin, riboflavin, thiamin and vitamin E. The precursor of vitamin A is abundant in several vegetables. They also supply minerals such as calcium and iron. The cellulosic cell walls of plant cells are not of direct nutritional value to man. But this material is essential in the human food. It provides the roughage necessary for the proper functioning of the alimentary canal.

Most vegetables contain large amounts of moisture and a vegetarian diet contains fewer calories. Interestingly, studies have shown that vegetarians are healthier and live longer. This is due to judicious planning of nutritious diet. Most vegetarians therefore, eat foods in defined combinations that furnish a balanced diet. For example, rice and beans when taken together provide a more balanced nutrition than when eaten alone. In view of the significance of vegetables in the human diet, it is worthwhile to first know about the vegetable-yielding plants.

Different plants have been used as vegetables since the dawn of civilization. Alongwith cereals, early man started domesticating different vegetable crops also to provide a balanced diet. Some of these plants have gained world-wide importance and are well-known. These have been discussed in great detail by botanists, agriculturists and dieticians. There are also vegetables which are of local importance, and consumed by fewer people. They are also important in the economy of these regions. Some of these grow naturally while others are cultivated on a limited scale. However, in recent years (as in the case of fruits - see unit 13) cold storage, air transport, and packaging techniques have led to the availability in large cities of different kinds of vegetables from various parts of the world.

Vegetables may be classified in various ways. Here we follow a classification based on morphology and recognise different vegetables by their botanical (Latin) names and the family in which the plant is classified. It is also convenient to group different plants on the basis of the morphological nature of the part used as vegetables:

a) underground plant parts such as roots, rhizomes, tubers and bulbs eg., onion, potato, carrot, etc.

b) leaves and young shoots, eg. spinach, cabbage, lettuce.

c) inflorescences and flowers, eg. cauliflower

d) fruits and seeds, eg. tomato, brinjal, cucumber, chillies.

In the following unit, you will study some of the well-known vegetable yielding plants to understand their importance to mankind.

Objectives

After studying the unit you will be able to know :

- the importance of vegetables in human diet;
- the classification of vegetables;
- the general properties of vegetables;
- the botanical names of vegetables and their families,;
- about the origin, distribution, ecology, botany and uses of the following vegetables:

Potato, Sweet Potato, Cassava, Onion, Garlic, Beetroot, Carrot;

Cabbage, Lettuce, Spinach; Cucurbits, Tomato, Brinjal, Chillies and Okra.

14.2 VEGETABLES FROM ROOTS AND OTHER UNDERGROUND PARTS

A large number of plants store their food in underground organs of various kinds. Besides serving as storage organs, these structures are also important for vegetative propagation. These swollen organs may be modified roots, underground stem tubers or bulbs. They remain protected in the soil and contain large amounts of parenchymatous tissue which stores large amounts of water and food material, particularly carbohydrates which provide energy. Besides carbohydrates, the cells of these organs also contain minerals, vitamins, some pigments (eg carotene in carrots, betacyanins in beetroots etc) and protein. These vegetables have a greater calorie value per unit area of land when compared with the cereals. Amongst numerous vegetable plants known to mankind carrot, beetroot, radish, sweet potato, and cassava are short term root crops. In these, the tap root is modified to store large amounts of food material. Potato, onion, garlic, *Colocasia,* and *Amorphophallus* have modified underground stems which are used as vegetables.

14.2.1 The Potato or the Irish Potato

Botanical name : ***Solanum tuberosum*** **Linn.**
Family : Solanaceae
Common name : Alu
n = 12

14.2.1.1 Origin and distribution : Potato is a gift of the New World. It was not known in the Old World before the sixteenth century. It originated in the Andes mountains of South America and dominated the life of the people in this region. It was not known in Central and North America when Columbus reached the New World. Potato was introduced to other parts of the world only after the sixteenth century. This is called the Irish Potato because in 1845-46 the worst famine in Ireland and many other parts of Europe occurred because of the failure of potato crop due to *Phytophthora* infection.

Box 14.1: Ireland Famine.

By the 1840's, in Ireland, potato was staple diet on which the Irish peasants survived until 1845-1846. The entire country had essentially adopted a monoculture of the tuberous plants. About 1845 disaster struck, when Potato blight, caused by a fungus *Phytophthora infestans* reached Europe, and within 5 years, virtually all the Irish (and British) potato crops were destroyed. It is estimated that during this period people (some say 2 million) died of starvation and over another million emigrated. This was the worst famine in the history of the western world, followed by an unparalleled migration.

The cultivated potato is a tetraploid. It may have originated by a doubling of the chromosomes in an ancient diploid species, or it may have been derived by hybridization between two ancient diploid species followed by amphidiploidy.

The potato is cultivated all over Europe, Russia, Asia, Africa and America. In India, potato is an important crop in Uttar Pradesh, West Bengal, Bihar, Punjab, Madhya Pradesh, Tamilnadu and some other states. It is mostly grown for local consumption.

14.2.1.2 Cultivation : The potato grows in cool moist climates in temperate regions. It requires warm days alternating with cool nights when tuber formation takes place. Rainfall or irrigation for 3-4 months promotes tuber formation. Frost is harmful for the crop. Short days or nitrogen deficiency also promote tuberisation. The crop can be grown in a variety of soils. Porous, well drained acid soils (pH 5.0) are good as they enhance tuber growth.

The crop is propagated vegetatively from small tubers (called seed potato) or from parts of large tubers. These parts must include 'an eye' or axilliary buds which develop into new plants. The crop is harvested after about 4 months.

14.2.1.3 Botany : The potato plant is a herbaceous perennial but is cultivated as an annual. It has a well-developed adventitious fibrous root system and underground stolons which bear the tubers. These underground stems are short and thick structures having scale like leaves. In the axils of these scale-like leaves, there are axillary buds which are called the "eyes" of the potato. The scale-like leaves are shed and a leaf scar is formed near each "eye". The "eyes" actually represent axillary branches (Fig. 14.1). These are arranged spirally around the tuber. The potato tuber is a typical stem in its anatomical structure. The outermost layer is the periderm and this encloses the cortex. Inside the cortex is a ring of vascular bundles which surrounds the central pith. The tuber stores starch. The shape, size and colour of the tubers vary in different varieties.

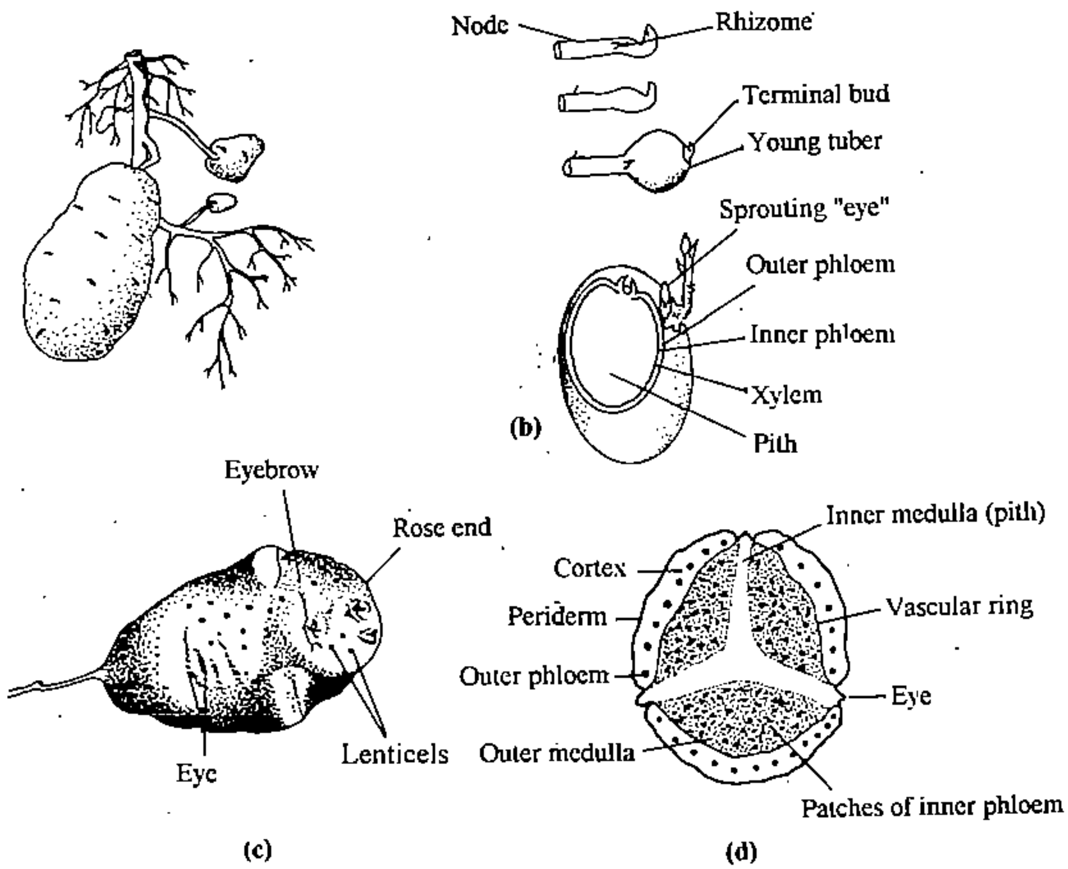


Fig. 14.1: ***Solanum tubersoum*** **The Potato. a) A tuber of potato b) diagrammatic representation of tuber formation in potatoes. c) External feature of potato tuber d) C.S. of potato tuber.**

The aerial branches may be up to 1 m tall. They have spirally arranged leaves. The first few leaves near the base of the stem are simple, but other leaves are pinnately compound. These compound leaves have leaflets of varying sizes and there may be some very small leaflets called pinnules (folioles) between the longer leaflets also.

Flowers may or may not be produced. When flowers are produced, they arise in terminal inflorescences. The flowers are typically solanaceous and the fruits are small inedible berries (called seeds or potato ball) which look like small green tomatoes. They contain numerous seeds.

14.2.1.4 Uses : The potato is the most widely grown vegetable crop and plays an important role in the world's food economy. Potatoes have a high nutritional value. A tuber consists of about 80% water and 20% solid matter. Of the later starch is up about 85% and the rest is mostly protein. Potatoes are excellent source of vitamin C. They also contain minerals such as calcium, iron, magnesium, phosphorus, potassium, sodium and sulphur.

The tubers are used in many ways, both as a fresh vegetable and as processed food. Fresh potatoes may be eaten after boiling, roasting, frying or baking. They may also be cooked with other vegetables. The tubers may be processed as potato chips, crisps, and wafers or may go into the production of starch, alcohol (Vodka) or glucose.

Green potatoes contain a poisonous glycoside, solanin, which in appreciably high concentration may cause sickness and even death in both humans and livestock.

Vodka, a Russian alcoholic beverage, is prepared by the fermentation of cooked potatoes

Fig. 14.2: *Solanum tuberosum* A potato plant.

14.2.2 The Sweet Potato

Botanical name : *Ipomoea batatas* (Linn.) Lam.
Family : Convolvulaceae
Common name : Shakarkandi
n = 45

14.2.2.1 Origin and Distribution : The sweet potato plant is known only in cultivation. It probably originated in tropical America, and was grown in Mexico, Central and South America and the West Indies in pre-Columbian times (before Columbus' discovery of America). It has now spread to other parts of the world. This plant reached the Old world before the Irish potato and became popular.

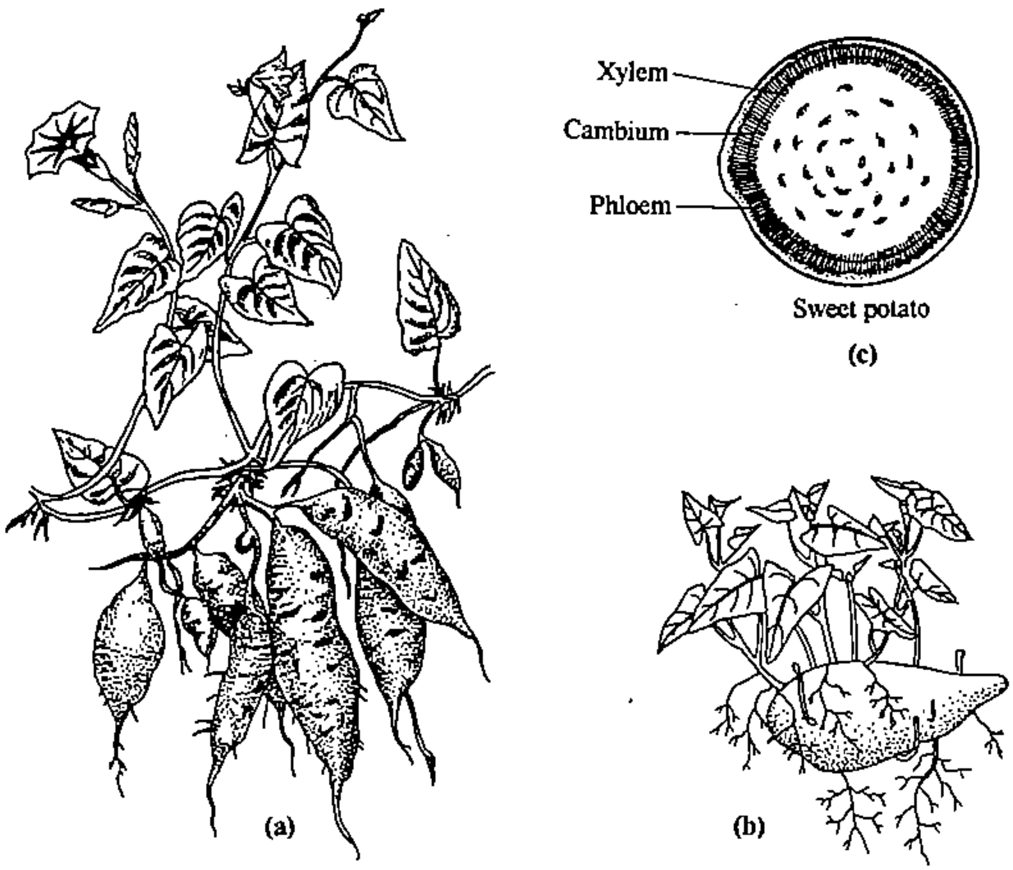
Ipomoea batatas is a hexaploid (2n = 90). It could have arisen as a hybrid by amphidiploidy from a tetraploid (2n = 60) and a diploid (2n = 30).

14.2.2.2 Cultivation : Sweet potatoes are cultivated throughout the tropics. The major producers are Africa, China, Indonesia, India, Korea, Japan, southern United States, Polynesia and New Zealand. It grows best where the mean temperature is around 25° C or higher. There must be plenty of sunshine and a rainfall of atleast 300 mm over a growing period of 4 months.

The crop can be grown in a wide range of soils. A well-drained sandy loam with a sunny climate and a liberal supply of moisture in growing season, is ideal for cultivation of the sweet potato. This is a short day plant and a photoperiod of 11 hours or less promotes flowering.

Sweet potatoes are propagated by stem cuttings or portions of the tuber. The plant needs little care and the tubers are ready for harvesting after 4-6 months. The tubers are stored or they may be sliced and sun-dried.

14.2.2.3 Botany : The sweet potato plant is actually a perennial herb, but like the Irish potato, it is cultivated as an annual crop. It is a vine-like plant with trailing or twining stems. These grow up to 1.5 m in length, and all parts of the plant contain latex. The plant has an extensive fibrous root system. The tubers are secondary thickenings of some of the adventitious roots. Each plant produces about 10 tubers in the upper crust (25 cm) of the soil. Each tuber consists of large amounts of parenchymatous cells, the vascular tissue and latex vessels (Fig. 14.3, c). The outer region is called the periderm and it replaces the ruptured epidermis. About 70% of the weight of the fresh tuber is due to moisture. The solid matter consists of starch, sugars, proteins, vitamins A and C, small amounts of fat and minerals. The tubers vary in shape, size and colour. Individual tubers generally weigh 200 to 500 grams, although exceptionally large tubers weighing several kilograms may also be produced.



In Japan and Taiwan, sweet potato is regarded as a 'typhoon or hurricane insurance', where rice or other starchy crops are destroyed it will be still available for food.

Fig. 14.3: *Ipomoea batatas.* a) A plant of sweet potato b) Most of the shoot sprout from the top of the storage root. c) Cross section of root.

14.2.2.4 Uses : Sweet potato is a vegetable with large, fleshy edible roots. These tuberous roots are used as an important source of food in , many parts of the world. They can be eaten after boiling or roasting. The tubers are also used for manufacturing starch, flour, glucose, or alcohol. They are also given to livestock.

14.2.3 The Cassava or Manioc

Botanical Name: *Manihot esculentus Crantz* {Synonyms: *M. utilissimus* Pohl; *M.aipi* Pohl; *M dulcis*_Pax; *M. Palmata* Muell Arg.}
Family: Euphorbiaceae.
Common name: Tapioca, sagu
n = 18

14.2.3.1 Origin and distribution : *Manihot esculenta* has been known to man only in cultivation and does not occur in the wild state. It is known to have been domesticated independently in Central America as well as in South America but introduction from South to Central America seems more likely. This plant was introduced in other parts of the world after the sixteenth century. It has now spread to all tropical areas. South and Central America, West and Central Africa and South East Asia are the main regions where cassava is cultivated. The first record of its introduction in India is in 1794 when it was brought to the Indian Botanic Garden, Sibpur, Calcutta. In India, this crop is mainly cultivated in Kerala, Tamilnadu, Meghalaya, Andhra Pradesh and Assam.

According to a Tupi legend, there was once a mother with no food who had to watch her starving child die. Sadly, she buried the child under the floor of her hut. That night, a wood spirit, or "mani", came and transformed the child's body into the roots of a plant that grew up to feed future generations of Indians. The plant was called "mani" "oca" (root) for the root that the wood spirit brought.

14.2.3.2 Cultivation : Cassava is a lowland tropical crop which grows best in sandy or sandy loam soils of moderate fertility. High fertility of the soil leads to excessive vegetative growth and less tuber formation. The crop cannot withstand water-logging, cold or frost.

The cassava crop is grown from stem cuttings which sprout shoots and roots producing new plants. Short season varieties can be harvested in 6-10 months after planting. Long season varieties of cassava are grown for about 2 years. The crop is mostly harvested by hand. Individual tubers are dug out from the soil for consumption.

14.2.3.3 Botany : The Cassava plant is a shrub growing 1-5 m in height and has latex in all its parts. The edible tubers are swollen adventituous roots. Each plant produces 5-10 cylindrical tubers. The extensive parenchymatous pith region of the tuber stores large amounts of starch. The erect stem shows prominent leaf scars in the lower region. The leaves are spirally arranged, and petiolate. The lamina is deeply palmate with 3-9 (usually 5-7) lobes. The leaves are usually green, but variegated leaves or red, purple or yellow leaves also occur (Fig. 14.4).

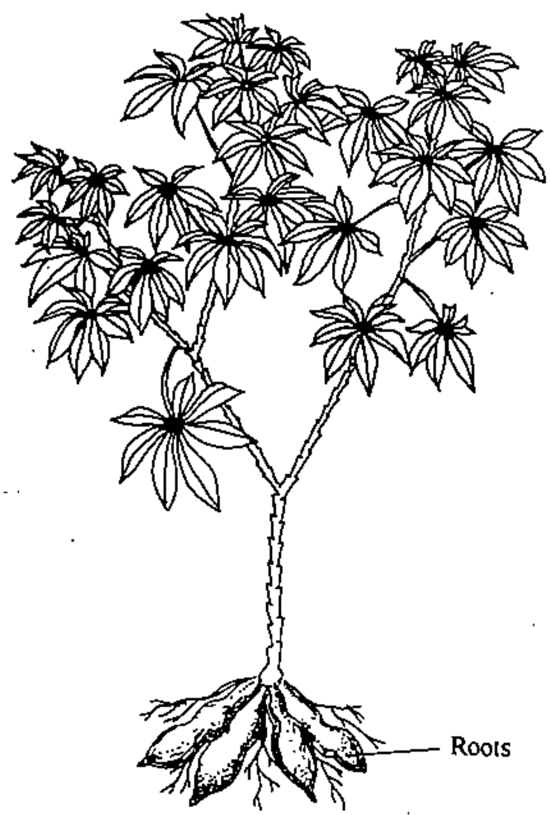


Fig. 14.4: *Manihot esculenta* a Cassava plant with roots.

14.2.3.4 Uses : Cassava is the staple food of many people. These people generally belong to the weaker sections of the society and cannot afford to consume cereals as staple food. The root tubers are rich in carbohydrates and used as an important food in many tropical regions.

There are two types of cassava-sweet and bitter. The sweet tubers have low amounts of hydrocyanic or prussic acid. This alongwith other chemical substances is usually present in the cortical region of the tuber. In the bitter cassavas, large amounts of hydrocyanic acid are present. This is distributed throughout the tuber. Sweet tubers can be eaten raw after peeling. Bitter cassava must be washed, boiled, roasted or specially treated to destroy the hydrocyanic acid.

High grade starch is prepared from the tubers. It can be used as food for making puddings, biscuits, and confectionery. This starch is also used in the manufacture of adhesives, cosmetics, paper, and in laundering. Cassava tubers are also used as livestock feed or for manufacturing glucose and sodium glutamate.

14.2.4 The Onion

Botanical name: ***Allium cepa*** **Linn.**
Family: Alliaceae

{earlier the genus *Allium* was classified either in the family Liliaceae (because of the superior ovary) or in the Amaryllidaceae (because of the structure of the inflorescence) but now they are considered to belong Alliaceae a family which is intermediate between these two.}

Common name: Piyaz
n = 8

14.2.4.1 Origin and distribution : Onions have been cultivated since ancient times in India and the Middle East. *Allium cepa* is not known with certainity as a wild plant. It is believed to have originated in the mountainous regions of Iran or Pakistan. There are refrences to this plant in ancient literature and it was used in religious ceremonies. It is now widely cultivated in all parts of the world. Large quantities of onions are produced in the Asian countries. China, Japan and India are leading producers. India also exports large quantities of onion. The United States, Turkey, Spain, Italy, and the Netherlands are other onion growing areas. In India onions are grown in Maharashtra, Tamilnadu, Andhra Pradesh, Bihar and Punjab.

14.2.4.2 Cultivation : Onions can be grown under a wide range of climatic conditions. Most varieties are adapted to grow in the colder parts of the temperate region. A warm dry season is necessary for maturation of the bulbs and harvesting. They should not be grown in regions having heavy rainfall.

The crop can be raised in different kinds of soils which do not retain water. Fertile loam soils having a pH between 5.8 and 7.0 is good for crop. The crop is ready for harvest after 3 to 5 months of sowing the seed. Bulb formation is controlled by photoperiod and temperature. Bulbs vary in shape from flat to globose, oval or even spindle shaped. The colour also varies from silvery white to brownish, purplish or reddish.

The intact onion is odourless, but when it is cut or injured, organic sulphur compounds are released due to enzymatic changes. This releases the characteristic odour and pungent flavour of the onion. Onions may be mild, pungent, or sweet and these features besides shape and colour, are used for classification.

14.2.4.3 Botany : The onion plant is a biennial herb, storing food in the bulb during the first year of growth and flowering in the second year. For commercial production of bulbs, the crop is cultivated as an annual. The plant has a superficial, shallow, adventitious root system. The stem is short, flattened and produced at the base of the plant. It increases in diameter as growth continues. This is the actual bulb of the plant and it gets surrounded by the concentric layers of fleshy leaf bases which store the food material thus making the bulb an important storage organ (Fig. 14.5 d).

The leaves are produced in succession from the broadening stem apex. Each leaf consists of 2 parts: a tubular or ring-like sheathing base and a hollow, linear, cylindrical or flattened blade. The outer leafbases of the bulb are dry, thin and fibrous. They form a protective covering around the inner fleshy leafbases. The formation of the bulb and thickening of the leaf bases are controlled or regulated by daylength and temperature. Under very short photoperiod or at low temperatures, bulbs are not formed. When the bulbs have attained maturity, the meristem stops producing new leaves and instead produces a terminal inflorescence (Fig. 14.5).

Fig. 14.5: ***Allium cepa.*** **a) A young onion plant. b) onion inflorescence c) onion flower d) onion bulbs e) Fleshy leaf base of onion that store nutrients.**

A leafless flowering stem, called scape pushes out through the bulb. The developing inflorescence is protected by a membranous spathe, a feature *Allium* shares with members of the family Amaryllidaceae. The inflorescence may have 50-2000 greenish white flowers.

14.2.4.4. Uses : The immature and mature onion bulbs are eaten raw or they may be cooked and eaten as a vegetable. They are used in soups and sauces and for seasoning many foods. Onions also flavour food and are used in canned meat products. They form an important component of many pickles and chutneys. Small bulbs are pickled in vinegar or brine. They may also be fried and used in preparation of different kinds of snacks. Onion leaves are also used as a vegetable. Onions are also reported to warn off heat stroke.

14.2.5 The Garlic

Botanical Name: ***Allium sativum*** **Linn**
Family : Alliaceae
Common name : Lahsuin
n = 8

14.2.5.1 Origin and distribution : Garlic originated in the eastern Mediterranean region and is known in cultivation in India and China since ancient times. India is the largest producer of garlic in the world. It is also an important crop in Spain, Egypt, Korea, Argentina, Italy, China and U.S.A.

14.2.5.2 Cultivation : Garlic can be cultivated in a variety of soils. Bulb formation requires longer days and high temperature. But once bulb initiation takes place, it can progress even at low temperatures. It is propagated vegetatively by planting single "cloves". Most of the crop is grown in irrigated regions. The crop responds to fertilizer application and is ready for harvest 4-6 months after planting. The bulbs are dried in the fields for about one week.

14.2.5.3 Botany : The garlic plant is a herbaceous annual resembling the onion plant in many ways. It differs from onion in having flattened solid leaf bases producing a composite or compound bulb. The erect herb has a superficial and adventitious rootsystem. The flat disc like stem has a varying number of smaller bulbs or bulblets called "garlic cloves". These are formed from the axillary buds of the younger foliage leaves. The bulb of garlic is thus a composite structure consisting of several small densely crowded bulblets. The entire compound bulb is enclosed within a multilayered protective sheath formed by the sheathing bases of the storage leaves. Each bulblet also has its own protective single layered sheath. The bulblet consists of a single thickened storage leaf sheath and a small central bud. Sometimes, a single large solid "clove" is formed in each plant (bulb). This is due to either the crop being grown on poor soils, or grown from very small "cloves" (Fig. 14.6).

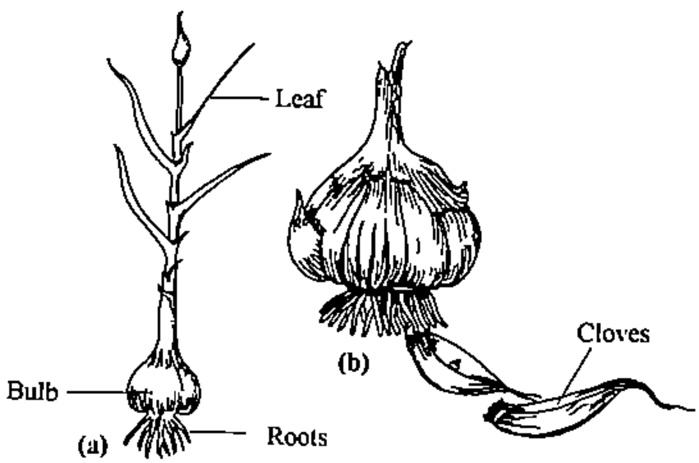


Fig. 14.6: ***Allium sativum.*** **(a) Garlic plant (b) Garlic bulb with cloves.**

Some cultivated varieties of garlic do not show any flowering while others do. The inflorescence is terminal as in onion. A leafless smooth white scape grows out through the centre of the bulb. It is coiled at first but then becomes erect, and bears a membranous spathe. This encloses either small bulblets only or both bulblets and flowers. The flowers of garlic are whitish to pinkish.

14.2.5.4 Uses : Closely related to the onion, this is the second most widely cultivated species of the genus *Allium*. It is used as a condiment for flavouring food. Garlic is an important constituent of curries in India and also in Chinese food. Many medicinal properties of garlic are mentioned in different systems of medicine. Garlic has medicinal value as an antiseptic and bactericide. Both garlic and onions contain compounds such as ajoene that reduce the tendency of blood to clot and some what improves one's odds against arteriosclerosis and heart attack.

Intact bulbs contain an amino acid called allinine. When the bulb or "clove" is cut or injured, enzyme allinase acts on allinine to produce allicin. This compound is responsible for the pungent smell of garlic. The pungent quality common to all alliums is linked with the compound that makes us cry when cutting onions. These are volatile sulphur compounds (including methyl di - and trisulfides and n - propyl di - and trisulphide). The bulblets may be dehydrated or made into "garlic pearls". These can be used in place of the fresh garlic. Garlic has a strong flavour and its smell stays in the mouth for a long time.

14.2.6 The Beetroot, The garden beet

Botanical name : ***Beta vulgaris*** **Linn.**
Family : Chenopodiaceae
Common name : Chukander
n = 9

Several cultivated varieties of *Beta vulgaris* are economically important. The beetroot or gardenbeet is grown for the large red roots which are eaten as a vegetable. Another variety with white or light brown roots called sugarbeet is an important source of sugar. Both these and other varieties are cultivated commercially in different parts of the world.

14.2.6.1 Origin and distribution : The cultivated beetroot as well as the sugarbeet are both classified as *Beta vulgaris*. They have been derived from a wild ancestor *Beta maritima* which grows naturally on sea shores in Britain, throughout Europe, and Asia to India. The different varieties of the cultivated beets have evolved by continuous selection.

14.2.6.2 Cultivation : The beet is mostly cultivated in temperate regions. Sometimes it may be grown in tropical areas at higher altitudes. They require cool nights during the growing season. Beets grow best in friable deep, moist loamy soils; it does not tolerate water logging, therefore the soil must have good drainage. They are grown from seed and thinning of seedlings is necessary to provide sufficient growing space. It is a labour intensive crop.

14.2.6.3 Botany : The beetroot plant is a true biennial. This glabrous herb has a conspicuously swollen fleshy root which is the economically most important part of the plant.

The plant produces the conspicuously swollen root with deep red colour due to pigment betacyanin and a rosette of leaves during the first year of growth (Fig. 14.7). The leaves are simple, large and often with a thick midrib. Red pigments may be present in the leaves. Some varieties of beetroot, especially the little beet or beet leaf *(Beta vulgaris* var. *bengalensis)* are cultivated for the leaves which are eaten like spinach.

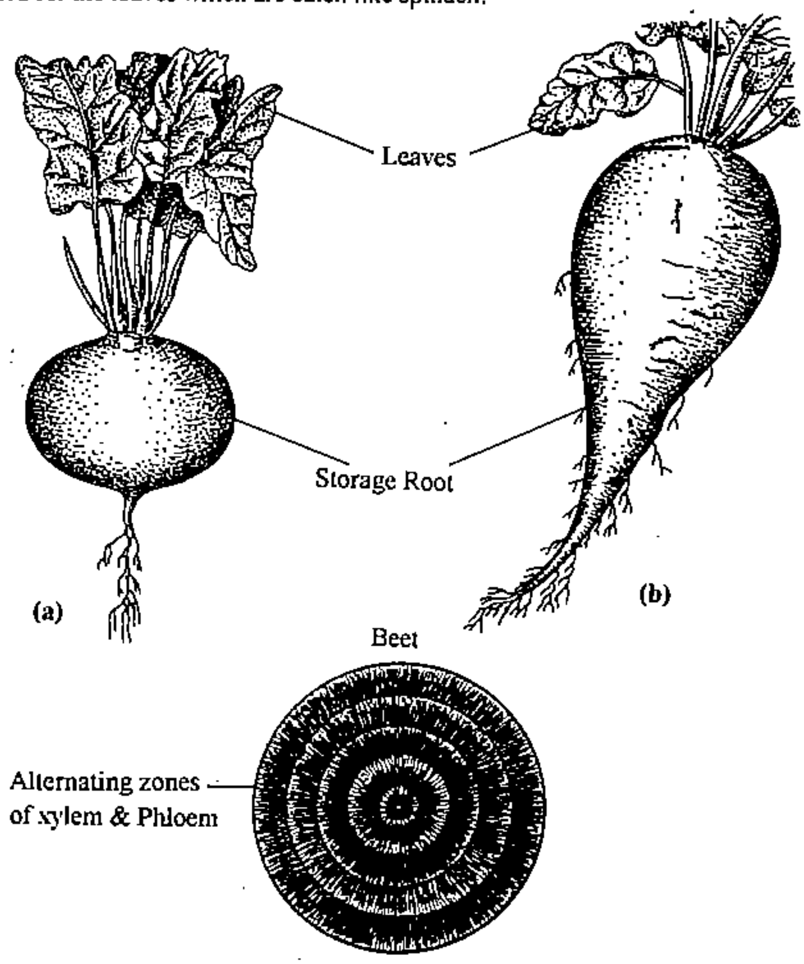


Fig. 14.7: ***Beta Vulgaris.*** **a) A plant of beet root b) The plant of sugar beet c) T.S. beet root.**

14.2.6.4 Uses : Different varieties of beetroots are used in different ways.

A. *Beta vulgaris* var. *vulgaris* is the common beetroot. It is also called the garden beet. The red roots provide a low-calorie, low-carbohydrate food containing iron, calcium and the red pigment betacyanin. These are eaten as a vegetable or as a salad, and are sweet to taste. They may be eaten raw, boiled or baked. Red beetroots may also be pickled and canned. The crop is harvested after 3-4 months of sowing the seed to obtain sweet tender roots.

B. *Beta vulgaris* var. *rapa* is known as the sugar beet. This has light brown or white roots and is an important source of sugar. The roots are smaller in size than the garden beet. In USA, sugar beet provides half of the sugar produced. The sugar content may be as high as 15 to 18%. The roots are washed and cut into thin strips. These are put in hot water to extract the sugar. The solution is then purified, filtered and boiled to form crystals of sugar.

C. *Beta vulgaris* var. *bengalensis* is the beet green or beet leaves or Indian spinach. The tender succulent leaves and young shoots are cooked as a green leafy vegetable and are an excellent source of calcium, iron and vitamin A.

14.2.7 The Carrot

Botanical Name : *Daucas carota Linn*
Family : Apiaceae (Umbelliferae)
Common name: Gajar
n = 9

14.2.7.1 Origin and distribution : Carrot has been cultivated since ancient times in the Mediterranean region. It was first used as a medicinal plant by the ancient Romans and Greeks. The cultivated carrot originated from wild relatives which occur naturally in Europe, Asia and Africa. It has now spread throughout the world, and Europe is the largest producer of the crop. North and Central America and Africa are other areas where carrots are cultivated. Different kinds of carrots are grown in different parts of the world. In India also, there are the common orange carrots with hard roots, the softer more juicy reddish carrots and the purplish or almost black carrots. These are grown in different parts of the country.

14.2.7.2 Cultivation : Carrot grows best in well-drained, loose loamy soil. It requires wet climate for the proper development of the roots. Large amounts of potash are required for proper growth of the crop. The crop is grown from seed which is sown in raised beds or on ridges. Thinning the crop at the seedling stage promotes good growth and the crop can be harvested after 3-4 months. The young roots are harvested and can be stored for several months without loss in quality. Being a labour intensive exercise, carrot cultivation is expensive.

14.2.7.3 Botany : The carrot plant is a herbaceous biennial but is cultivated as an annual for its thickened taproot. The root may be short and stumpy or long and tapering. The colour of the root ranges from pale white to yellow, orange, purple, deep red or almost black. The colour and growth of the root vary with the temperature and age of the crop. The broad cortical region stores the food material and the pigments especially carotenes. The human body uses carotene to produce vitamin A. Carrots also contain vitamins B_1, B_2 and C, sugars and iron.

The stem forms a plate-like crown above the root and this bears a crown of leaves. In the second year of growth, the stem elongates and bears the terminal inflorescence. The leaves are long-petioled and pinnately compound. The segments are pinnatified with lanceolate lobes (Fig. 14.8).

The fruits are oblong-ovoid schizocarps 3-4 mm. long. Each schizocarp consists of two mericarps. The primary ridges of each mericarp are ciliate while the secondary ridges have hooked spines. These characteristics of the fruit help in identification of the plant. The pericarp contains essential oil canals because of which the seeds are aromatic.

14.2.7.4 Uses : In recent times, carrots have become a widespread human food. The roots are used as vegetables, in soups, curries and other dishes. They can be eaten raw in salads or cooked in various ways. Tender roots can also be pickled alongwith other vegetables. Juice can be pressed out from fresh roots and it is consumed as a refreshing drink either alone or mixed with orange juice. Grated carrots can be boiled in milk and made into a delicious sweetmeat (called 'Gajar Ka Halwa'). The roots being a rich source of carotene are used for obtaining colouring for butter and other foods. Carrots can also be canned in syrup or dehydrated. In North India, "black" carrots are used to prepare an appetising beverage called "Kanji".

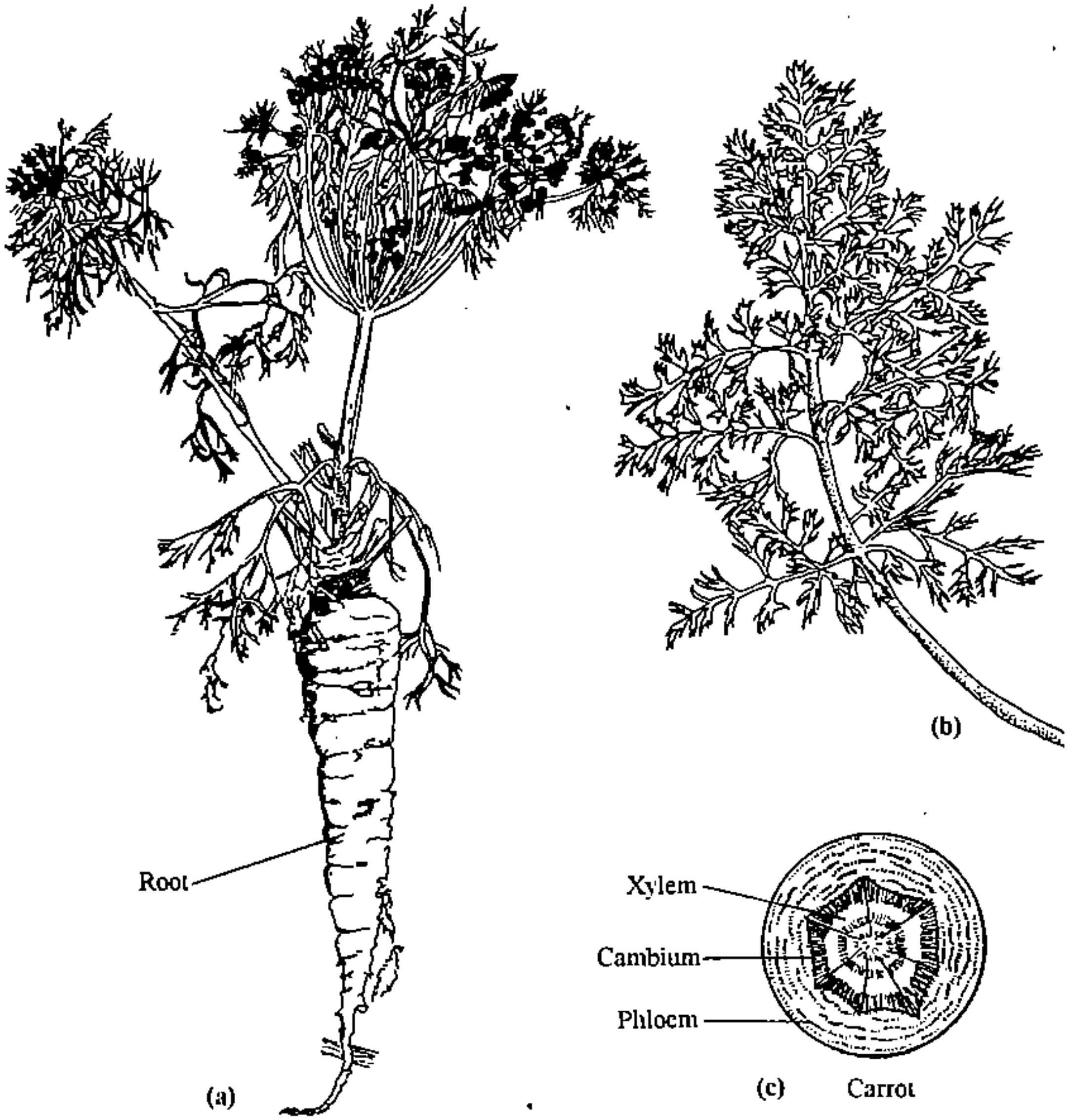


Fig. 14.8: *Daucas carota.* a) Carrot plant with roots b) a leaf c) T.S. of carrot.

SAQ 1

1. Write the botanical name of the following plants and the family to which they belong.

   a) Potato

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   ....

   b) Sweet Potato

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   c) Cassava

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   d) Onion

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   ....

e) Garlic

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f) Gardenbeet

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g) Carrot

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2. a) Which of the above are specialised roots?

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b) List the plants in which the stem is modified and describe the modification in each case.

....

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3. Mention T or F to indicate whether the following statements are true or false respectively.

a) The potato and the sweet potato can be classified as "true root crops". ☐

b) Cassava produces tuberous roots. ☐

c) The tubers of potato differ in structure from the tubers of Cassava. ☐

d) The gardenbeet is rich in calories, iron, calcium and anthocyanins. ☐

e) Bulb formation in onion is regulated by daylength and temperature. ☐

f) Allicin is acted upon by the enzyme allinase to produce Alliinine. ☐

4. Fill in the blanks

a) The ______________ pigments are present in carrots in large amounts.

b) *Beta vulgaris* var. *rapa* is a rich source of ________________.

c) Hydrocyanic acid is present in the tubers of ___________________.

d) The pungent odour of onions and garlic is due to _________________ compounds.

e) Potatoes and sweet potatoes can be classified as ___________________ foods.

5. Classify the crops obtained from underground organs into Old World and New World on the basis of their centres of origin.

   a) Old world crops

   b) New world crops

   ....

   ....

6. Define the term vegetable and write a note on the importance of vegetables in the human diet.

   ....

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14.3 LEAFY VEGETABLES

The leaf is an important organ of the plant. It is the chief region of photosynthesis and manufactures food not only for the plant itself, but also for all other organisms. Herbivorous animals depend on plant leaves for their food. Man has also used leaves of different plants for obtaining his nutritional requirements. Leaves contain adequate amounts of minerals such as iron, calcium, potassium and several vitamins. The amount of vitamins A and C increases with the green colour of the leaves. The energy value of leaves is low because of high water content. However, their large surface area provides roughage in the diet. This is very essential for the proper functioning of the alimentary canal. About 100 grams of leafy vegetables are recommended for daily consumption in a balanced diet. This can be obtained from raw leafy vegetables eaten as salads, or from cooked leafy vegetables.

The more important and well-known leafy vegetables are cultivated mostly for local consumption as fresh vegetables. Some plants growing in wild state are used as leafy vegetables by the economically weaker sections of the society especially in rural area. In India leafy vegetable largly contribute to the vegetable portion of food. In winter season palak, methi, sarson, bathua, cholai are the major 'sag' used as vegetable. Besides leaves, young tender shoots and flowerbuds are also eaten as vegetables.

14.3.1 Cabbage

Botanical Name : *Brassica oleracea* Linn. var. *capitata* Linn.
Family : Brassicaceae (Cruciferae)
Common name : Bandh gobhi, Pattagobhi
n = 9

14.3.1.1 Origin and distribution :- The cabbage has been cultivated in Europe since ancient times. It is believed to have originated in the Mediterranean region and spread to other parts of Europe. It is closely related to cauliflower, kale and broccoli, and these are called "Cole crops". They are all different varieties of a single species *Brassica oleracea*, and have originated from a wild cabbage called colewort. Cabbage is now cultivated thoughout the world. The major producers of this vegetable are Europe, Japan, USA, Korea, Turkey, India, and China.

14.3.1.2 Cultivation : Cabbage is cultivated in temperate regions having a cool moist climate. It is grown mainly as a winter crop in the plains of Northern India. It is grown from seed and the cabbage "head" develops in 2 to 4 months after transplanting of the seedlings which must establish themselves properly. The harvested crop is either sold immediately for consumption as a fresh vegetable, or it may be put in cold storage.

14.3.1.3 **Botany :** The cabbage plant is a biennial but is cultivated as an annual. It has a well-developed taproot system which supports a very short stout stem. The stem is closely packed with thick fleshy overlapping leaves. This forms a compact "head" of the cabbage. Different kinds of cabbage are recognised by the shape, size, colour and texture (Fig 14.9). Some cabbages are white or red. They have smooth leaves with prominent veins. Savoy cabbages have wrinkled or crinkled leaves. The white cabbage which actually has pale green leaves is the most popular. The plant is not allowed to flower and the "head" is harvested for use as a vegetable.

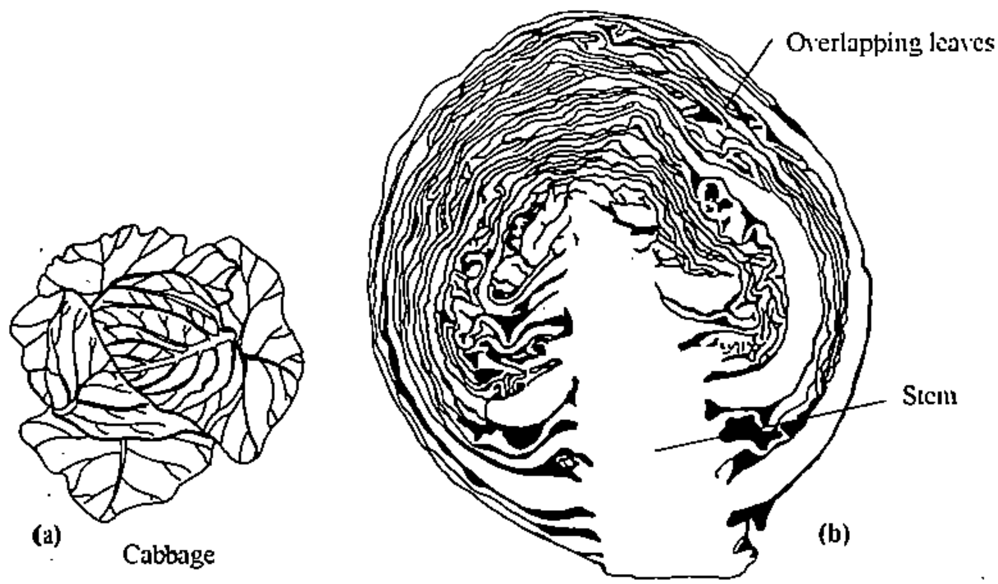

Fig. 14.9: ***Brassica oleracea*** **var.** ***capitata.*** **a) Compact head of cabbage b) A half cut of a cabbage.**

14.3.1.4 Uses : Cabbage may be eaten raw as a salad or it may be cooked as a vegetable. It is a rich source of minerals and vitamins,and helps in digestion.

14.3.2 Lettuce

Botanical Name : ***Lactuca sativa*** **Linn.**
Family : Asteraceae (Compositae)
Common name : Salad
n = 9

14.3.2.1 Origin and distribution : Lettuce has been known in cultivation since ancient times. There are records of lettuce leaves in Egyptian tombs dated 4500 B.C. It was also grown by the ancient Romans and Greeks. The cultivated lettuce is believed to have evovled from a wild species called *Lactuca serriola* Linn. This is common in Europe, Western Asia and Northern Africa. There is also a second view on the origin of the cultivated lettuce. On the basis of cytological and genetic studies, Lundqvist (a Swedish botanist) suggested that *Lactuca sativa* probably originated by hybridization of other species. Although it originated in the temperate region, lettuce is also cultivated in the tropics. It is now grown in all parts of the world.

14.3.2.2 Cultivation : Lettuce is a cool season crop and requires adequate irrigation to prevent flowering. It grows better in the higher altitudes in tropical regions. High temperature promotes flowering and this makes the leaves bitter. Light, well-drained and properly manured soils promote good growth of the crop. Lettuce is grown from seed and can be harvested in about 3 months. Small sowings at regular 2 week intervals ensures good success of the crop.

14.3.2.3 Botany : The lettuce plant is an annual glabrous herb with milky latex in all parts of the plant. It has a well developed taproot, slender at first but becoming extensive later on. At first a short fleshy stem is formed and this produces a large number of spirally arranged leaves which form a compact radical rosette called the "lettuce head". The shape and compactness of this "head" vary in different cultivars (Fig. 14.10). These leaves are almost sessile, 12 - 25 cm. long, with a broad delicate or crisp lamina. These "lettuce heads" are harvested for consumption as salad.

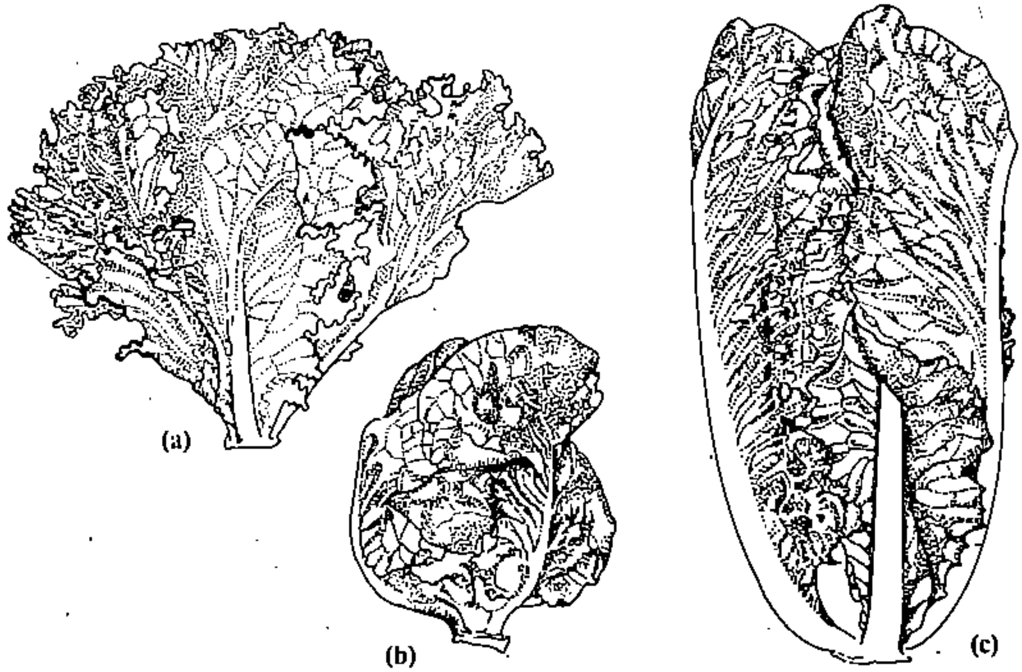

Fig. 14.10: Various types of lettuce. (a) leafy variety (b) a head-forming variety (c) romaine variety.

After the vegetative phase of growth, if the "head" is not harvested, the plant shows elongation of the stem (bolting). This elongating stem bears a few leaves and a terminal large paniculate inflorescence. Each branch of the paniculate inflorescence terminates in a capitulum. Bolting and flowering change the chemistry of the leaves. They develop a bitter taste and become unfit for use as a salad.

14.3.2.4 Uses : Lettuce is the most widely cultivated salad crop. The leaves contain vitamins A and E as well as minerals like calcium, phosphorus, sodium, magnesium and potassium. They are eaten raw or they may be boiled. Lettuce seeds are used in plant physiology experiments to study the effect of light on seed germination.

14.3.3 Spinach

Botanical Name : *Spinacia oleracea* Linn.
Family : Chenopodiaceae
Common name : Palak
n = 6

This plant shows a somewhat superficial resemblance to "beet greens" or Indian Spinach - *Beta vulgaris* var. *bengalensis* (see 14.2.6). Both plants are members of the family Chenopodiaceae, but are classified in different genera. The two genara differ in the foliage and floral structure. The genus *Beta* has bisexual flowers while the genus *Spinacea* has unisexual flowers.

14.3.3.1 Origin and distribution : *Spinacea oleracea* has been cultivated since ancient times in South Western Asia. It probably originated in Iran. It was introduced into North Africa and Europe and is now widely cultivated in temperate regions of the world. It is a very popular leafy vegetable in USA, Canada and Europe. *Spinacea oleracea* is cultivated on a limited scale in the hill stations of India, but Indian spinach (*Beta vulgaris* var. *bengalensis*) is widely cultivated all over the country.

14.3.3.2 Cultivation : Spinach shows wide adaptability to varying soil and climatic conditions. The cool and short day conditions are ideally suited for good leafy growth. Long days and higher temperatures lead to flowering.

The spinach crop is grown from seed and is ready for harvest in 6 - 8 weeks after sowing. Leaves are harvested 3-4 times before the plants begin to flower.

14.3.3.3 Botany : The spinach plant is an erect herb 30 - 60 cm. in height. The vigorous, quick growing plant is a biennial, but is cultivated as an annual. It bears a very short plate like stem from which arises a crowded rosette of leaves. The leaves are large, ovate-oblong, simple, smooth, soft and somewhat succulent (Fig. 14.11).

Fig. 14.11: Leaves of Spinach.

When the plant is allowed to continue growing, an erect stem grows out from the centre of the flat plate-like basal region. This bears alternate leaves which are smaller in size than the basal leaves. In the axils of these smaller leaves arise clusters of female flowers. The stem terminates in a spike bearing male flowers. The flowers are small greenish structures, pentamerous and actinomorphic. The fruit is a hard unpressed utricle. It is enclosed in a spinescent capsule like structure.

14.3.3.4 Uses : In ancient times, spinach was used as a medicine. The large amount of fibre present in the leaves served as a mild laxative. It is now a popular leafy vegetable because of its high yield. The leaves are rich in minerals such as calcium, magnesium, potassium, iron, phosphorus, sodium, copper, vitamins A, B-complex and C, and carotene. They are also an important source of natural vitamin K. The succulent leaves are eaten raw or cooked. They contain more protein than any other leafy vegetable. They are also used in soups and salads.

SAQ 2

1. Match column I (Plant) with column II (Family)

Column I	**Column II**
Cabbage	Chenopodiaceae
Lettuce	Brassicaceae
Spinach	Asteraceae

2. List three features which make leafy vegetables important components of a balanced diet.

   i) ....

   ii) ....

   iii) ....

3. Write a note on the cultivation of lettuce.

....

....

....

....

4. Indicate whether the following statements are true (T) or false (F)

a) All leafy vegetables can be cultivated in weakly acidic soils ☐

b) Blanched leafy vegetables are less nutritious ☐

c) Flowering of Cabbage or Spinach enhances the taste of the leaves ☐

d) *Lactuca sativa* originated through hybridization of wild species. ☐

14.4 FRUIT AND SEED VEGETABLES

You have learnt in the introduction of this unit, that a vegetable is defined as a nutritious food obtained from any part of the plant. In this context, true botanical fruits of many plants are also consumed as vegetables. The majority of these fruits consumed as vegetables are produced on herbaceous annuals. Interestingly, in horticulture, true botanical fruits produced by annual flowering plants are classified as vegetables. Following this definition, many fruits produced by herbaceous plants have been consumed as vegetables since ancient times. A large number of cucurbitaceous plants that produce edible fruits are eaten as vegetables. There are also the melons which although produced on herbaceous annuals are consumed as fruits (see unit 13.2.8). Besides the cucurbits, tomatoes, brinjals and chillies are important plants of the family Solanaceae whose fruits are used as vegetables. Other important fruits which are grown as vegetables, include the lady's finger (Okra) and various beans (see unit 12).

Most vegetables do not have fats or protein but they are source of vitamins, minerals, roughage etc. They are important as vegetable crops and we will discuss here some important plants whose fruits are consumed as vegetables.

14.4.1 The Cucurbits

The family Cucurbitaceae is characterised by tendril bearing herbaceous plants with unisexual flowers and fleshy berry like fruits (Fig. 14.12). We are familiar with the gourds, melons, pumpkins and the cucumber which are commonly consumed in different parts of the country. It would be difficult to describe all these in detail because of space limitations. Fortunately, most of the plants of this family have similar characteristics (Fig. 14.13) and grow in the same kind of climatic and soil conditions although they may have originated in different parts of the world. The majority have spread to various tropical and subtropical regions where they are cultivated for the fruits. Besides being consumed as food, the fruits of cucurbits are also used for making some utensils for storage, containers, and musical instruments. The dry hard shells of the mature fruits are also used in many other ways. Sponges are made from the fibro-vascular network of the ripe fruits of *Luffa*. Seeds of many cucurbits are important constituents of confectionery and salted snacks.

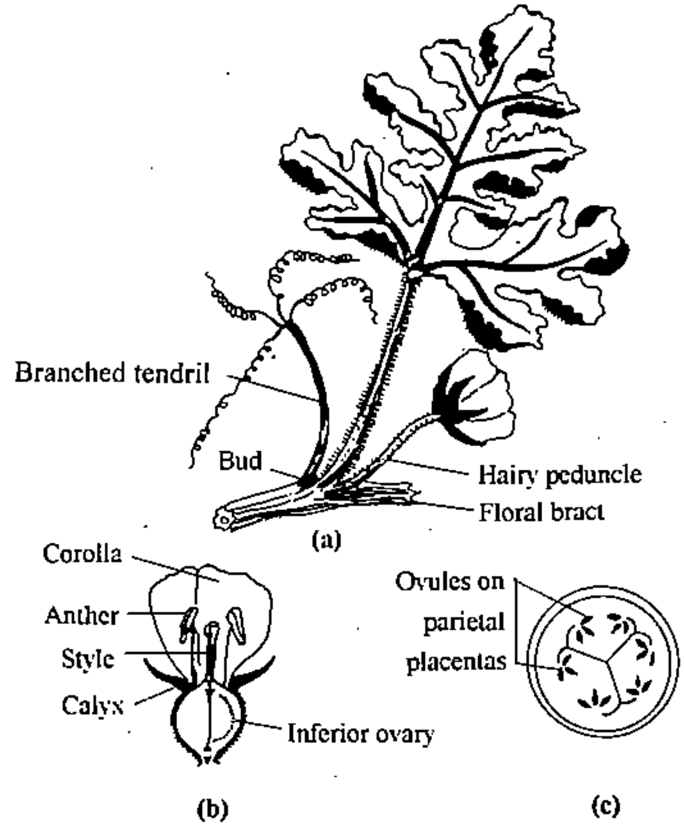

Fig. 14.12: Cucurbitaceae, a) Diagrammatic sketch of the general structural plan of the cucurbit leaf axil; tendril, bract, flower and bud. b) A longitudinal section of a hermaphrodite flower. c) A cross section of a young fruit.

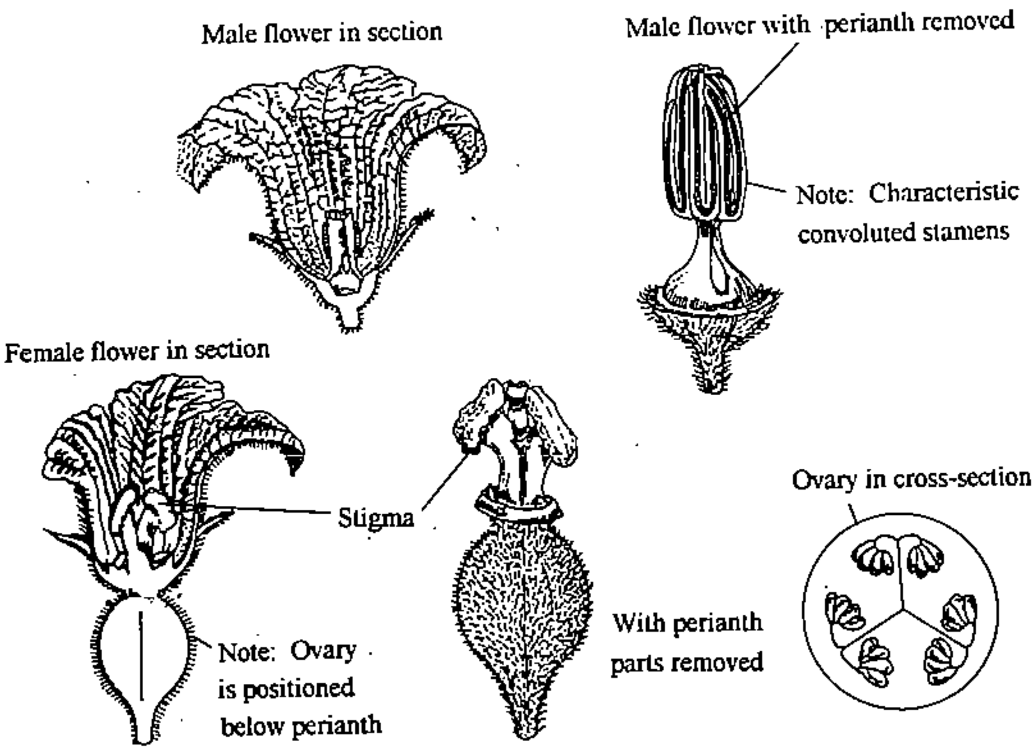

Fig. 14.13: Fruits are formed from inferior ovaries with the rind of the fruit a composite perianth of the ovary wall and lower parts of the calyx and corolla.

Some of the more important cucurbits grown as vegetable crops are listed here.

14.4.1.1 *Benincasa hispida* (Thunb) Logn.
(wax or white gourd)
Common name : Petha
n = 12

This plant originated in Java and is now cultivated throughout tropical Asia. The fruits are large, heavy spherical to oblong with a white waxy coating on the green rind. The white spongy flesh contains numerous flat seeds.

The young fruits are eaten as a vegetable. Ripe fruits are candied with sugar and made into a delicious sweet meat. The fruits are also used in religious ceremonies on auspicious occasions.

14.4.1.2 *Citrullus lanatus* var. *fistulosus* (Stocks) Duthie and Fuller.
(The squash melon)
Common name : Tinda
n = 11

This variety of the watermelon originated in India and is mostly cultivated in the northern parts of the country. The small rounded (green) fruits are cooked as a vegetable in a variety of ways.

14.4.1.3.a *Cucumis melo* Linn. var. *reticulatus* Ser.
(Musk Melon)
Common name : Kharbuza
n = 12

The musk melon. This has been described in detail in Unit 13.2.8. The fruits of some varieties are cooked and eaten as a vegetable.

14.4.1.3.b *Cucumis melo* Linn. var. *utilissimus* (Roxb.) Duthie & Fuller
(The long melon or snake cucumber)
Common name : Kakri
n = 12

This is a native of India and is cultivated for local consumption in different states. The young fruits are eaten raw as a salad.

14.4.1.4 *Cucumis sativus* Linn.
(The Cucumber)
Common name : Khira
n = 7

It originated in northern India and has now spread throughout the world. The shape, size and colour of the fruit vary considerably in different varieties.

The fruits are eaten as a salad vegetable.

14.4.1.5 *Cucurbita maxima* Duch. ex Linn.
(The Pumpkin or winter squash)
Common name : Sitaphal
n = 12

This originated in South America (Peru) and has now spread to many parts of the world.

The fruit is variable with a soft or hard rind which may be dull or brightly coloured. The flesh is of various shades of yellow. The seeds are plump and usually smooth.

Bristles are present on the stem and leaves of the plant.

The mature fruits are cooked as a vegetable.

14.4.1.6 *Cucurbita moschata* (Duch. ex Lam) Duch. ex Poir
(The Pumpkin)
Common name : Mitha Kaddu
n = 12

This species was widely distributed in North and South America and it may have been first domesticated in Central America or Mexico. It is now grown in the tropical regions of the world. This species is very similar to *Cucurbita maxima* and is distinguished by the absence of bristles from the stem and leaves.

The fruit is cooked as a vegetable and a sweet confection is also made from the fruit.

14.4.1.7 *Cucurbita pepo* Linn.
(The marrow or Summer Squash)
Common name : Vilaiti Kaddu, Kumra
n = 20

This species originated in North America and is now widely distributed. It can tolerate cooler climates, while *C. moschata* tolerates warmer climates. It is similiar to the other species but can be differentiated by its sharply angular, grooved, hard peduncles and small sized fruits. It is not as popular as the other two species.

The fruits are consumed as a cooked vegetable.

14.4.1.8 *Lagenaria siceraria* (Molina) Standl.
(The bottle gourd)
Common name : Lauki
n = 11

The bottle gourd has been known in both the Old and the New World since ancient times. It may have originated in Africa or India (Old World) or in Mexico or Peru (New World). It is now widely spread throughout the tropics.

The young fruits are cooked as a vegetable while the older mature fruits are allowed to dry on the plant itself. These form a hard shell in various shapes and sizes. They are used as containers (bottles) or made into domestic utensils such as bowls, ladles, spoons, etc.

14.4.1.9 *Luffa acutangula* (Linn.) Roxb.
The Angled Loofa
(Ridged or ribbed sponge gourd)
Common name : Kali torai
n = 13

This species originated in North-West India and is widely cultivated in our country. Unlike most other cucurbits, this grows well in low-humid tropics. The fruits are club shaped, angled and 10-ribbed.

The young tender fruits are cooked as a vegetable.

14.4.1.10 *Luffa cylindrica* (Linn.) M.J. Roem.
The smooth Loofa
(Smooth Sponge gourd)
Common name : Ghia torai
n = 13

It may have originated in India and is widely cultivated in the tropical regions of the world.

The fruit is nearly cylindrical with light stripes, but it is not ribbed or angled.

The young fruits are cooked as a vegetable. Mature fruits are allowed to dry on the plant, so that the fibro-vascular network develops completely. This is used as a bath sponge or for other purposes.

14.4.1.11 *Momordica charantia* Linn.
(The Bitter gourd)
Common name : Karela
n = 11

Although its actual centre of origin has not been determined, the bitter gourd originated in the Old World. It is now widespread throughout the tropics.

The pendulous fruits are long, fusiform, ribbed and with numerous tubercles. The young fruits are eaten as a vegetable. The bitterness is reduced by seeping the cut fruit in salt water before cooking. The bitter principle is believed to help diabetics in reducing the blood-sugar levels. It may be sliced and added to curries or samber etc.

14.4.1.12 *Trichosanthes anguina* Linn.
(The snake gourd)
Common name : Chachinda
n = 22

It has been known, in the wild state from India to Australia. It is cultivated in India, the far East and in the West Indies.

The fruits are slender, long, tapering, greenish-white. The interior is hollow and contains a few thick brownish sculptured seeds.

The young fruits are eaten as a vegetable.

14.4.1.13 *Tricosanthes dioica* Roxb.
(The pointed gourd)
Common name: Parwal
n = 11

This originated in India and is also cultivated in South East Asia.

The fruits are smaller when compared to the snake gourd. They are more sharply pointed and spindle shaped. The fruits are compact and contain numerous seeds.

The young fruits are cooked as a vegetable.

14.4.2 Solanaceous Vegetables

The family Solanaceae represents one of the most economically important families which provides vegetable from fruits. These fruit crops are not only botanically related but their cultural requirements are also same. They are grown as annuals, in warm season. Besides these the potato has been described in section 14.2.1. Typically, the seeds are first sown in nurseries and the seedlings transplanted later into the field when about 15 cm. high.

14.4.3 Tomato

Botanical name: *Lycopersicon esculentum* Mill.
Family : Solanaceae
Common name: Tamatar
n = 12

14.4.3.1 Origin and distribution : The tomato originated in the Peru-Ecuador area of Latin America. It was known in many parts of tropical America in the Pre-Columbian times and reached the Old World in the 15th century. Tomatoes are now cultivated throughout the world. The major production countries in the order of importance are the United States followed by China, Turkey, Italy, India, Egypt, Spain, Iran, Greece, Mexico, Russian Federation, Uzbekistan, Ukraine, the United Kingdom, Chile, Romania and United Arab Emirates. Morocco and Portugal are other important producers.

14.4.3.2 Cultivation : Tomatoes can be cultivated under a variety of climatic conditions. This is a warm season crop. Long sunny periods with light evenly distributed rainfall are very good. Very wet weather and low sunshine enhance vegetative growth thus reducing fruit formation. In tropical areas, 3 crops can be grown in a single year under irrigation. In the temperate regions, tomatoes are cultivated under controlled glasshouse conditions. Special cultivars have been developed to allow mechanical harvesting of the fruits.

Tomatoes grow best in rich, fertile loamy soils. Loose texture of the soil is very important for proper growth.

The crop is grown from seed. The seeds have to be freed completely from the fruit pulp because this contains a germination inhibitor. Seedings are raised in nurseries and then transplanted to the fields. Organic manuring greatly promotes the crop. Tomatoes can also be very successfully cultivated in soil-less cultures using hydroponics.

14.4.3.3 Botany : The tomato plant is a very variable herb. It grows as a perennial in the wild state but is cultivated as an annual. The seedling has a strong taproot, but this is damaged during transplanting and a dense fibrous adventitious root system develops. The weak stem is profusely branched, first in a monopodial manner, but later in a sympodial manner. The branches may be erect or trailing. Small capitate, reddish-yellow glandular hairs and long pointed trichomes cover the stem, petioles and young leaves.

The leaves are spirally arranged, showing a 2/5 phyllotaxy. The inflorescence is terminal, but because of the sympodial branching, the flowers appear to arise in clusters opposite to, or sometimes between the leaves (Fig. 14.14).

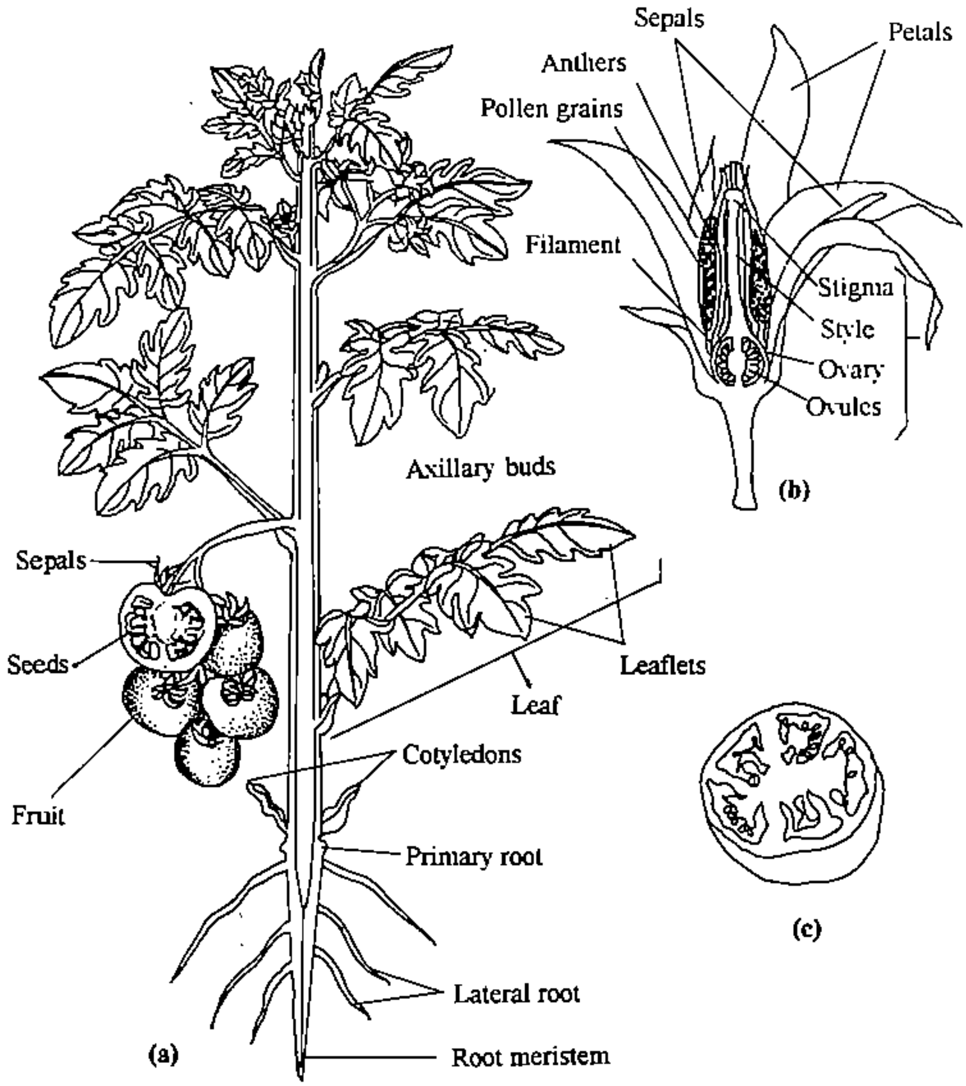

Fig. 14.14: ***Lycopersicon esculentum*****. a) A tomato plant b) the flower c) Fruit in C.S.**

The fruit is a fleshy berry. It is hairy when young, but becomes glabrous and shiny when mature. The shape, size and colour of the fruit varies in the numerous cultivars. The unripe fruit is green while the ripe fruit is usually red or yellow. The red colour of the fruit is due to the development of two pigments, carotene and lycopersicin (or lycopene) in the developing fruit. The relative amount of these pigments determines the actual colour of the ripe fruits. In the yellow fruited varieties, lycopersicin does not develop. The fruit contains numerous small light brown seeds.

14.4.3.4 Uses : The tomato is a very important vegetable crop and ranks second only to potato. It is the most important canned or processed vegetable due to its special nutritive value. The fruit is a rich source of minerals and vitamins A and C. The fruits are eaten raw as salad or are cooked. They are an important constituent of curries. Tomatoes are also used for making soups, sauces and ketchups. Processing of tomatoes into paste, puree and soups has now become an important industry. Tomato seeds (obtained from the pulp and residues) contain a semidrying oil. This is edible and used as a salad oil, or in the manufacture of margarine and soap.

14.4.4 The Brinjal or the Eggplant or Aubergine

Botanical name: ***Solanum melongena*** **Linn.**
Family.: Solanaceae
Common name : Baigun
n = 12

14.4.4.1 Origin and distribution : The brinjal plant originated in India. It is believed that this was first cultivated as a vegetable crop in the north east where wild plants of many types occur even today. Germplasm collections of the brinjal have been made by the National Bureau of Plant Genetic Resources from many parts of India to study the biodiversity of this vegetable crop. From India, this plant spread to other parts of the world. Brinjal is cultivated in the tropics, subtropics and warm temperate regions. It is an important crop in Japan, Turkey, Italy, Egypt, Iraq, besides India and South East Asia.

14.4.4.2 Cultivation : The agro-climatic requirements for cultivating the brinjal are very similiar or practically the same as for tomato. It however requires a longer growing season for the fruits to mature. This is a warm season crop and does not tolerate frost. It is a hardy plant and can be grown on different kinds of soils. The crop grows best on well-drained loamy soils. The seeds are germinated in nurseries and the seedlings are transplanted. The crop is labour intensive. The fruit is harvested when it attains a good size and colour. Fruit set can be increased by using chemical growth regulators when flowering begins. The seeds may be treated with the growth regulators before sowing.

14.4.4.3 Botany : In its wild state, the brinjal plant is a perennial, but it is cultivated as an annual. It has a strong, deep penetrating taproot system supporting the erect branching herb. The plant grows 0.5 to 1.5 m in height with spines and a grey tomentum on all parts. The stem is much branched and spreading (Fig. 14.15 a).

There are different types of flowers in brinjal on the basis of the length of the style. Only flowers having long or medium sized styles set fruit. The fruit is a large berry varying in shape, size and colour. It is smooth, shiny and firm fleshed. The fruit is a large, smooth, glossy, firm-fleshed, pendant berry (up to 15 cm long). Usually ovoid, oblong or obovoid (Fig. 14.15), ranging from white or yellow to deep purple or black, or even striped. Numerous small light brown seeds are embedded in the flesh of the fruit.

14.4.4.4 Uses : Fresh brinjal fruits are rich in minerals and vitamin B. They are cooked as a vegetable in a wide variety of ways. Small fruited varieties can be sliced and fried or cooked. Large fruited varieties can be roasted also. Slices of brinjal can also be deep fried after coating them with a batter of gram flour to provide a tasty snack.

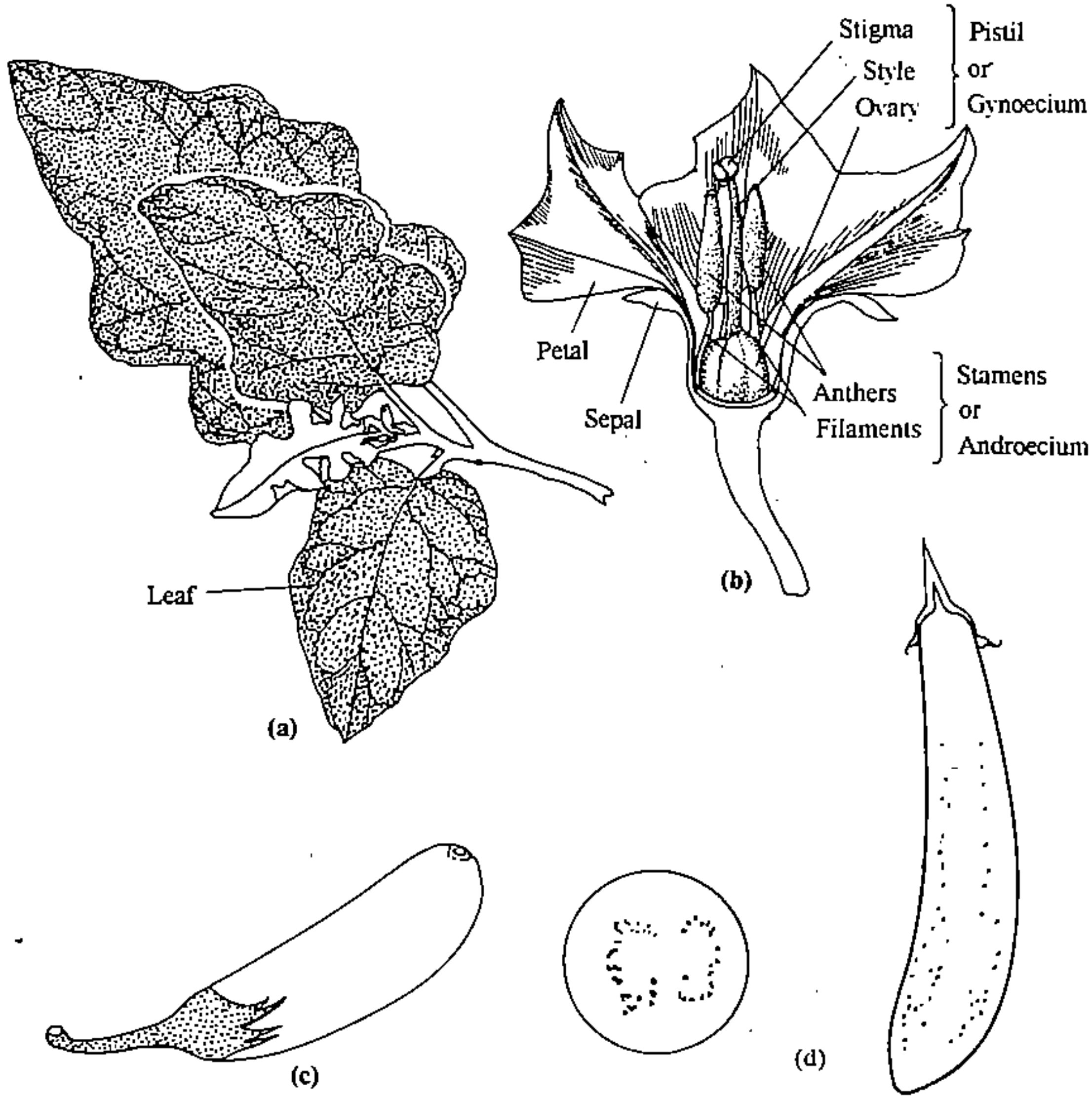

Fig. 14.15: *Solanum melongena.* a) twig of brinjal b) Flower c) fruit d) C.S. & L.S. of fruits.

14.4.5 Chillies

Botanical name : *Capsicum annuum* Linn.
***Capsicum frutescens* Linn.**
Family : Solanaceae
Common name : Mirch
n = 12

There are various kinds of chillies commonly used as vegetables, or as a spice or condiment for flavouring and seasoning food, either fresh or dried, whole or powdered. Those used as vegetable are called red or sweet peppers, bell pepper, capsicum, green-pepper, pimento, while the pungent varieties are referred to as capsicum-pepper, cayenne-pepper, chilli-pepper, long pepper and red-pepper. Some botanists recognise only one species, *Capsicum frutescens* (synonym *C. annuum*) with different varieties. The plants show distinct characteristics and are also considered to be different species of the same genus. Thus *Capsicum frutescens* Linn. and *C. annuum* Linn. are now recognised as distinct species which are widely cultivated throughout the world. There are also other species which are cultivated only in South America. Plants of *Capsicum annuum* are annual herbs bearing solitary fruits in leaf axils while those of *C. frutescens* are perennial and bear two or more fruits in groups in the leaf axils. The fruits of *C. annuum* are of various shapes and sizes as well as of different colour. They are mild in their pungency. The fruits of *C. frutescens* are small, conical, red or yellow and more pungent. The two species also do not interbreed easily, and when crossed, the hybrids are sterile. Both species are cultivated and *C. annuum* has numerous varieties.

Also study the Unit 17 Spices of Blocks III B.

14.4.5.1 Origin and distribution : The genus *Capsicum* originated in the New World and many wild species exist in America. Cultivated capsicums have been known since ancient times in Peru. There are also evidences of these peppers being cultivated in Mexico in pre-columbian times. This region also has a great diversity of cultivated *C. annuum* and no wild plants are known. The genus *Capsicum* spread to the Old World when Columbus took back the fruits to Spain after 1492. Interestingly, 50 years later, by 1542, three distinct cultivated races of *C. annuum* were recognised in India. Today India is the biggest producer of chillies. Other countries where this crop is grown include Thailand, Indonesia, Japan, Mexico, Uganda, Kenya, Nigeria and Sudan. Besides these areas, chillies are also grown in eastern and Southern Europe and Southern United States. Large quantities of chillies are imported by Sri Lanka, USA and Malaya.

In India, the crop is grown in all parts of the country. About 75% of the entire crop is produced in 4 states namely Andhra Pradesh, Maharashtra, Karnataka and Tamilnadu. Other states where chilli is cultivated are Madhya Pradesh, Punjab and Bihar.

14.4.5.2 Cultivation : Chillies are grown in tropical and subtropical regions and require a warm humid climate. They do not tolerate frost. Water-logging can result in defoliation and rotting of the plant. Prolonged rain fall leads to poor fruit set and rotting of the fruit.

The crop can be grown in different kinds of soils which are well-drained and well-aerated. Light loamy soil rich in calcium is best for cultivating the crop.

The seeds are germinated in nurseries and the seedlings are transplanted. Organic manures promote good growth of the plants. Harvesting of the fruits is determined by the purpose for which the crop is cultivated. They may be harvested when green and fully grown or when they are red and fully ripe.

14.4.5.3 Botany : *Capsicum annuum* is a variable herb which may become very large and shrub-like. Larger plants are sometimes woody at the base. The plant is grown as an annual and attains a height of 0.5 - 1.5 m. The strong taproot of the seedling is generally damaged during transplantation and numerous laterals develop. The fruit is an indehiscent berry containing many seeds. The shape, size and colour of the fruit varies considerably in different varieties (Fig. 14.16).

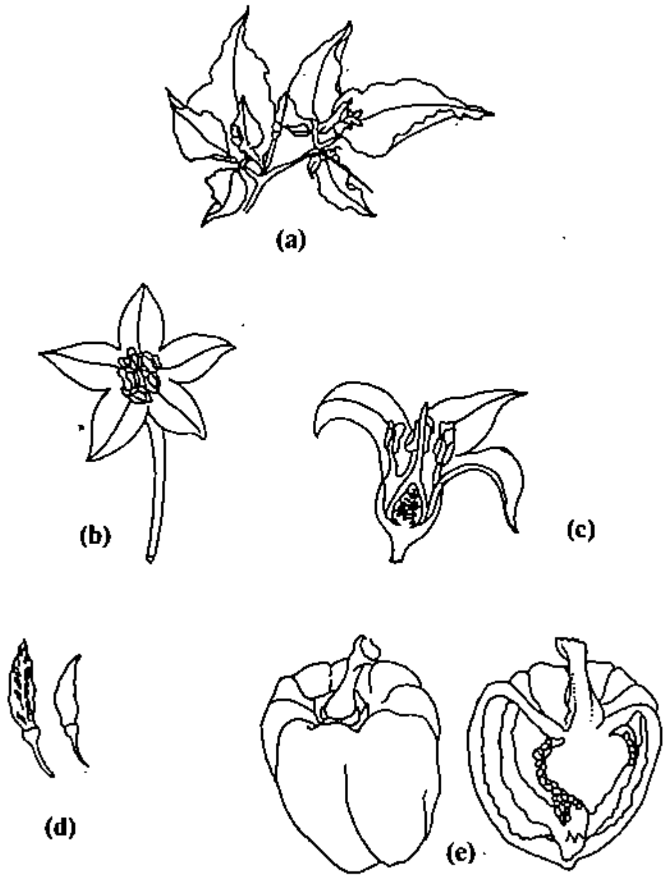

Fig. 14.16: a) flowering shoot of *C. frutescens* b) flower c) flower in L.S. d) fruit & fruit in L.S. e) *C. annuum* fruit & fruit in L.S. a-d, *C; frutescens* e; *C; annuum*)

14.4.5.4 Uses : Mildly pungent varieties with large fruits are eaten as a vegetable and in salads. The large unripe dark green berries of *C. annuum* var. *grossum* (called Simla mirch in N. India) are used as a vegetable. They may be cooked after slicing or whole with different kinds of stuffings. They are also added as "toppings" on pizzas. Other varieties are eaten raw or pickled or even added to flavour food.

When the fruits are allowed to ripen on the plant itself, they become red. These are dried and powdered. This is called Cayenne pepper and it is used for seasoning of curry powder alongwith other spices.

The pungency of these peppers is due to an alkaloid called capsaicin which is present in the placentae. The red colour is due to a pigment called capsanthin. Chillies also contain large amounts of vitamin C. Vitamin A and minerals are also present in the fruits.

14.4.6 Okra or Lady's finger

Botanical name : ***Abelmoschus esculentus*** **(Linn.) Moench**
Family : Malvaceae
Common name : Bhindi
n = 12

14.4.6.1 Origin and distribution : The okra plant originated in tropical Africa and wild plants can be found along the river Nile in Egypt and Ethiopia. It has now spread widely throughout the world and the crop is grown for local consumption. It is also cultivated as a vegetable crop in the subtropics and in the warm parts of the temperate regions. The okra is cultivated throughout India in different months in different states.

14.4.6.2 Cultivation : The okra is a warm season vegetable crop. The crop can be cultivated in any type of soil, but it grows best in well-manured loams. Young fruits are harvested after 2-3 months. The crop continues to produce fruits for 2-3 months usually on every second or third day.

14.4.6.3 Botany : The lady's finger plant is an erect annual herb, 1-2 m. tall. The entire plant is covered with epidermal hairs. The stems are green or sometimes tinged red.

The flowers are solitary and axillary with short peduncles. They have the typical organisation of the family Malvaceae. There is an epicalyx made up of 8-10 narrow bracteoles which usually fall off before the fruit matures. The calyx splits longitudinally as the flower opens. It falls off with the petals after anthesis. The fruit is a pyramidal oblong capsule. It is longitudinally furrowed and tapers to a beak-like end (Fig. 14.7). It may be glabrous or hirsute. The mature capsule splits (dehisces) longitudinally. The seeds are dark green to dark brown, rounded and tuberculate.

14.4.6.4 Uses : Fresh young fruits are consumed as a vegetable. They contain vitamins A,B and C, as well as minerals especially iodine. They are cooked in various ways after slicing or splitting them. They may also be deep fried. Mucilage can also be obtained from the stem. It is used industrially in the manufacture of jaggery (Gur) in India. It is also used in sizing paper in China. Fibre of inferior quality is obtained from the stem and very large mature fruits. This is used in the manufacture of paper and textiles. The ripe seeds contain an edible oil.

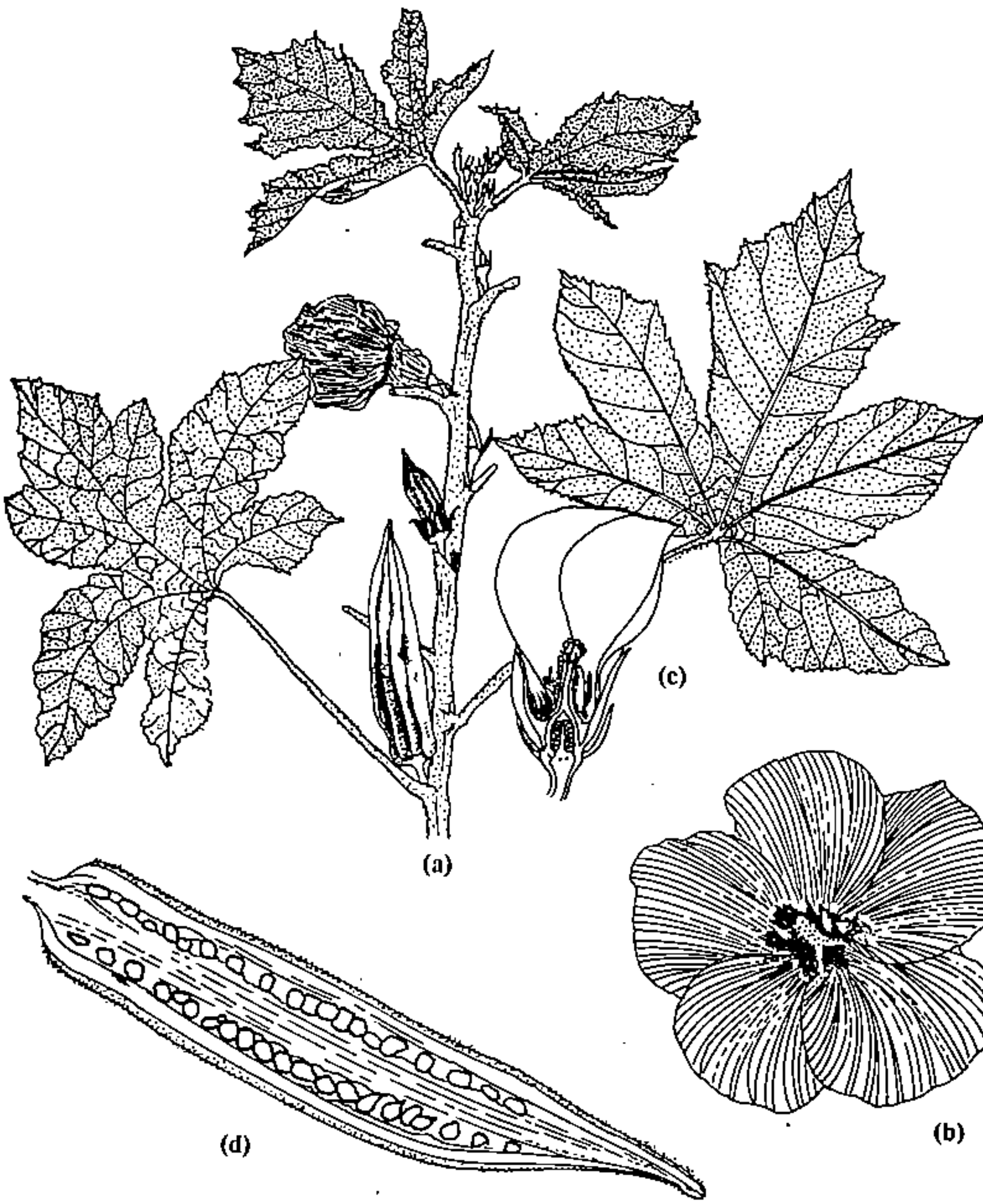

Fig. 14.17: ***Abelmoschus esculentus.*** **a) A flowering and fruiting branch b) flower c) flower in L.S. d) fruit in L.S.**

SAQ 3

1. Name six cucurbitaceous plants used as vegetables which originated in India.

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2. Name four fruit and seed vegetables which originated in the new world.

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3. Indicate whether the following statements are true (T) or false (F).

   a) The bright red colour of chillies and tomatoes is due to anthocyanin pigments. [ ]

   b) An alkaloid is responsible for the pungency of chillies. [ ]

   c) The deep purple colour of the brinjal is due to the presence of iodine in the fruit. [ ]

   d) The mucilage in the fruit of Lady's finger provides the flavour to this vegetable [ ]

   e) All fruit vegetables are produced from flowers having a superior ovary. [ ]

14.5 SUMMARY

- Information about different vegetables has been provided to you in this Unit. Different parts of the plant provide nutritious food for mankind and these vegetables are important in many ways. Many plants used as vegetables have been cultivated since ancient times and this information has helped us to know about the origin and distribution of these crops. It is possible to group these plants on the basis of their origin, their botanical classification, morphological nature of the part used, and other features. From this knowledge, it has been possible to know about some common properties of different vegetables.

- Detailed information on some of the more well-known vegetables has been provided. The vegetables have been grouped into three categories on the basis of the morphological nature of the edible part. In each case, the data have been presented to enrich your knowledge about the origin and distribution, the cultivation, botanical aspects and uses of the plants. The botanical name and the family to which the plant belongs has also been provided.

The following Table summarises some important information you have obtained

Tablel 4.1 : Vegetables

Botanical name	Family	Common English Name	Common Hindi Name	Part Used	Botanical Characteristics
Solanum tuberosum	Solanaceae	Potato or Irish Potato	Alu	Specialised underground stem called tuber	herbaceous plant with underground stolons bearing tubers: rich source steam called of starch, vitamins and minerals tuber -
Ipomoea batatas	Convolvulaceae	Sweet Potato	Shakar Kandi	Adventitious tuberous roots	Vine-like herbaceous plants with adventitious tuberous roots, rich source of starch, sugar, proteins, vitamins and minerals.
Manihot esculenta	Euphorbiaceae	Cassava or Manioc	Shakar Kanda	Adventitious swollen tuberous roots	Shrub with latex in all parts of plant, 5-10 large tubers, starch and tuberous roots hydrocyanic acid present -
Allium cepa	Alliaceae	Onion	Piyaz	Bulb with concentrically arranged fleshy leaf bases	Herbaceous bulbaceous plant; food stored in concentric layers of fleshy leaf bases; enzymatic changes due to injury or cutting of onion result in the characteristic odor and pungent flavour.
Allium sativum	Alliaceae	Garlic	Lahsun	Bulb with numerous small bulblets	Herbaceous bulbaceous plant; food stored in thickened. storage leaf which bulblets forms the 'bulblet'; pungent smell due to allicin formed from alliin.
Beta vulgaris var. *vulgaris*	Chenopodiaceae	Beetroot or Gardenbeet	Chukander	Swollen root with hypocotyl	Herbaceous plant showing anamolous var. *vulgaris* secondary growth producing the large beetroot; large amounts of betacyanin pigments and sugar present -
Beta vulgaris var. *rapa*	-do-	Sugarbeet	-do-		Large amounts of sugar, no pigments -
Beta vulgaris var. *bengalensis*	-do-	Beet greens or Indian Spinach	Palak	Young leaves used as vegetable in place of true Spinach	Herbaceous plant with a "head", of var. leaves; leaf sheaths contain some pigments, leaves contain minerals and vitamin A. The flowers are bisexual while in *Spinacea oleracea* they are unisexual.
Daucas carota	Apiaceae	Carrot	Gajar	Root	Herbaceous plant with conical taproot rich in carotenes, vitamins, sugar and minerals.
Brassica oleracea var. *capitata*	Brassicaceae	Cabbage	Bandgobhi or Pattagobhi	Leaves	Herbaceous plant with thick fleshy over-lapping leaves *capitata* forming a compact "head" Leaves are a rich source of minerals and vitamins.
Lactuca sativa	Asteraceae	Lettuce	Salad	Leaves	Annual glabrous herb with a compact radical rosette of leaves forming the lettuce head. Leaves are a rich source of minerals and vitamins -
Spinacea oleracea	Chenopodiaceae	Spinach	Palak	Leaves	This plant shows a superficial resemblance to Beet greens or Indian Spinach (*Beta vulgaris* var. *bengalensis*). It differs in its foliage and floral structure. The flowers are unisexual. The leaves are a rich source of minerals, vitamins and carotene.

Botanical name	Family	Common English Name	Common Hindi Name	Part Used	Botanical Characteristics
Benincasa hispida	Cucurbitaceae	Wax gourd or White gourd	Petha	Fruit	All cucurbitaceous plants are herbaceous tendrillar climbers or runners. They have unisexual flowers and fleshy berry like fruits. The shape. size and colour of the fruits vary considerably.
Citrullus lanatus var. *fistulosus*	-do-	Squash melon	Tinda	Fruit	
Cucumis melo var. *utilissimus*	-do-	Long melon or Snake cucumber	Kakri	Fruit	
Cucumis sativus	-do-	Cucumber	Khira	Fruit	
Cucurbita maxima	-do	Pumpkin or Winter Squash	Sitaphal	Fruit	
Cucurbita moschata	Cucurbitaceae	Pumpkin	Mitha Kaddu	Fruit	
Cucurbita pepo	-do-	The marrow or Summer Squash	Vilaiti Kaddu	Fruit	
Lagenaria siceraria	-do-	Bottle gourd	Lauki or Ghia Kaddu	Fruit	
Luffa acutangula	-do-	Angled Loofa	Kali Tori	Fruit	
Luffa cylindrica	-do-	Smooth Loofa, Vegetable sponge, Dishcloth gourd	Ghia Tori	Fruit	
Momordica charantia	-do-	Bitter gourd	Karela	Fruit	
Trichosanthes anguina	-do-	Snake gourd	Chachinda	Fruit	
Trichosanthes dioica	-do-	Pointed gourd	Parwal	Fruit	
Lycopersicon exculentum leves.	Solanaceae	Tomato	Tamatar	Fruit	Herbaceous plant with weak profusely branched stem and compound leaves. Fruit is a fleshy berry containing the pigments carotene and lycopersicin. They are rich in minerals and vitamins.

Botanical name	Family	Common English Name	Common Hindi Name	Part Used	Botanical Characteristics
Solanum melongena	-do-	Brinjal or Egg plant or Aubergine	Baigun	Fruit	Herbaceous plant becoming woody near base; large densely hairy leaves. Flowers purplish violet with distinct yelow stamens. Spines present on calyx which is persistent Fruit a berry rich in minerals and vitamins B.
Capsicum annuum *Capsicum fruitescens*	Solanaceae	Chillies	Mirch, Lal Mirch Simla Mirch	Fruit	Herbaceous plant with profusely branched stem; leaves variable, Simla Mirch flower solitary; fruit berry of variable shape, size, colour and flavour. An alkaloid capsaicin and a pigment capsanthin are present besides large amounts of vitamin C.Minerals and vitamin A are also present.
Abelmoschus esculentus	Malvaceae	Lady's finger Okra	Bhindi	Fruit	Erect annual herb becoming woody at base; leaves long petioled and palmately lobed. Flowers bright yellow with reddish spot near base of petals; fruit is a pyramidal oblong capsule containing seeds.

From the above Table and from your study of the material in this Unit, you have learnt that a large number of plants have been used by mankind as sources of vegetables for food. The majority are cultivated for local consumption, although some like the tomato are processed in different ways.

A large number of the plants are dicotylednous, but a few are monocotylednous. Garlic and onion are important monocotytednous vegetables. The families Solanaceae, and Cucurbitaceae have many plants which are consumed as vegetables. All these plants provide valuable vitamins and minerals in the diet and are thus important for healthy living.

14.6 TERMINAL QUESTIONS

1. Define the term vegetable and describe the different kinds of vegetables in botanical terms. Mention the important properties of vegetables in general.

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2. List the plants you have studied in which the fruit is used as a vegetable. Describe any two of these which are very popular in your region in detail. Mention the various uses of these fruits.

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3. Name the various underground plant parts serving as food storage organs. Mention the features by which you can differentiate a stem tuber from a root tuber. Describe one of these in detail under the headings: Origin and distribution; ecology; botany and uses.

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4. In what ways are leafy vegetables important in human diet? How are blanched leafy vegetables obtained? List the leafy vegetables popular in your region. Mention the important features of these

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14.7 ANSWERS

Self-Assessment Questions

SAQ 1

1.

Vegetable	Botanical Name	Family
a. Potato	*Solanum tuberosum*	Solanaceae
b. Sweet Potato	*Ipomoea batatas*	Convolvulaceae
c. Cassava	*Manihot esculenta*	Euphorbiaceae
d. Onion	*Allium cepa*	Alliaceae
e. Garlic	*Allium sativum*	Alliaceae
f. Gardenbeet	*Beta vulgaris* var. *vulgaris*	Chenopodiaceae
g. Carrot	*Daucas carota*	Apiaceae

2. a. The sweet potato, cassava, gardenbeet and carrot are specialised roots.

   b. i) Potato - Special underground branches called stolons bear branched outgrowths which are storage organs. These tubers have an anatomical organisation typical of a stem as described in 14.2.1.3.

   ii) Onion - The actual bulb consists of a short flattened disclike stem produced at the base of the plant. It increases in diameter as growth continues and gets surrounded by concentric layers of fleshy leaf bases.

   iii) Garlic - As in onion, the actual bulb consists of a flattened disc-like stem. This has a varying number of smaller bulbs or bulblets formed from the axillary buds of the young foliage leaves. Thus the bulb of garlic is a composite structure.

3. a) F b) T c) T

   d) F e) T f) F

4. a) Carotene

   b) sugar

   c) cassava

   d) sulphur

   e) starchy

5. a) Old World crops

   i) onion

   ii) garlic

   iii) Beetroot, sugarbeet

   iv) carrot

   b) New World crops

   i) potato

   ii) sweet potato

   iii) cassava

6 Refer to 14.1 - Introduction

SAQ 2

1.

Column I	Column II
Cabbage	Brassicaceae
Lettuce	Asteraceae
Spinach	Chenopodiaceae

2. i) Adequate amounts of minerals and vitamins are present

   ii) High water content and low energy value

   iii) Large surface area provides roughage in the diet. This is essential for the proper functioning of the alimentary canal.

3. See 14.3.2.2

4. a) T

   b) F

   c) F

   d) T

SAQ 3

1. a) *Citrullus lanatus* var. *fistulosus*

   b) *Cucumis melo* var. *utilissimus*

   c) *Cucumis sativus*

   d) *Luffa acutangula*

   e) *Luffa cylinderica*

   f) *Trichosanthes dioica*

2. a) *Cucurbita maxima*

   b) *Cucurbita moschata*

   c) *Cucurbita pepo*

   d) *Lycopersicon esculentum*

   e) *Capsicum annuum*

3. a) *Luffa acutangula* has club shaped, angled and 10 ribbed fruits; while *Luffa cylindrica* has nearly cylindrical fruits which are not ribbed or angled. They have light colour stripes.

b) *Cucurbita maxima* has bristles on the stem and leaves of the plant. These structures are absent in *Cucurbita moschata.*

c) *Capsicum annuum* is an annual herb with solitary fruits in the leaf axils. *C. frutescens* is perennial and produces 2 or more fruits in groups in the leaf axils.

4. a) F

   b) T

   c) F

   d) T

   e) F

Terminal Questions

1. The vegetables obtained from true botanical fruits show the following similarities with leafy vegetables.

   i) They contain large amounts of moisture.

   ii) They contain minerals and vitamins

   iii) They add necessary flavour and variety of food.

   iv) They are not very rich in proteins, fats and carbohydrates

   and Refer to the Introduction 14.1; SAQ 1 - 6.

2. Refer to 14.4 - Fruit and Seed vegetables. The list is provided in the summary also (14.5). Describe the two plants which are popular in your region as per the pattern followed in this unit.

3. Refer to 14.2 - vegetables obtained from roots and underground parts. The list is also provided in the summary (14.5). A stem tuber is a specialised tuberous outgrowth from an underground branch called the stolon. Anatomically this tuber shows the typical features of a stem. A root tuber is a swollen tuberous structure storing food. It is adventitious in its development and shows anatomical features of a root. Describe any one in detail as required in the question.

4. Refer to 14.3. Leafy vegetables.

Their importance has been listed in the answer to SAQ 2,4

Blanching of leafy vegetables is a common cultural practice. The leaves or leaf stocks are covered with earth or wrapping paper to exclude light. This leads to non-development of chlorophyll so that the leaves become pale white. Prepare the list of popular leafy vegetables in your region and mention the important features of these.

UNIT 15 PLANT OILS AND FATS

Structure

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15.1 INTRODUCTION

Vegetable oils, fats and waxes, collectively termed as lipids are products of great commercial value. Next to the food grains, oilseeds constitute the second major category of agricultural produce in India. Therefore, they are of vital importance to the agricultural economy in the country. Oils, fats and waxes have been used since ancient times. Chinese and Hindus were known to extract vegetable oils since pre-historic times. The old Chinese oil presses were driven by man-power, while the primitive Indian extractor known as *ghani*, *chekku* or *kolhu* was driven by bullocks. Even today the *ghani* is used in the rural areas of India. This operates on the principle of pestle rotating in a mortar. Ancient Egyptians and Phoenicians, used vegetable oils for food and for anointing their bodies. Homer mentions oil as an aid to weaving and Pliny talks about hard and soft soaps and such mentions of oil, butter and ghee were innumerable in vedic times. Even today, these oils and fats are put to numerous uses.

Most of the oils and fats used for making margarine, cooking and salad oils, soaps, paints and other familiar products come from plants grown as crops in the temperate zones. In fact, only a few important oils are obtained from wild plant sources presently, and these are principally from the tropical palms. Vegetable fats and oils that were extensively used as fuels, lubricants, and in the manufacture of soaps and detergents have, of late, been largely replaced by petrochemical substitutes. Nevertheless, these are still important in the modern industrial world. More so, the economic value of plant oils will increase as the stocks of nonrenewable resources are exhausted. In this respect these oil and fat yielding plants are just as important as the food plants.

Objectives

After studying this unit you should be able to:

- relate the importance of vegetable oils and fats to human life;
- explain the chemical structure of plant fats and oils;
- classify the vegetable oils on the basis of their drying properties and uses;
- distinguish fatty oils from essential oils;
- describe the general methods of extraction and refining of vegetable oils; and
- prepare detailed accounts on the major oil producing crops of India.

15.2 OILS AND FATS FROM PLANTS

Like carbohydrates, fats and oils contain only carbon, hydrogen and oxygen but in different proportions, having a relatively low percentage of oxygen. Vegetable fats differ only slightly from oils in having fatty acid constituents that are more or less solid rather than liquid at room temperature. Thus a solid fat in an arctic climate could be an oil in a tropical one.

The general formula of fatty acids are:
$CH_2 - COOR_1$
|
$CH - COOR_2$
|
$CH_2 - COOR_3$
Where R_1, R_2, R_3 are carbon chains of different fatty acids.

15.2.1 Chemical Composition of Oils and Fats

Vegetable oils and fats are triglycerides of complex organic fatty acids which are synthesized from carbohydrates. Fatty acids are long hydrocarbon chains that carry a terminal carboxyl group which gives them the characteristics of a weak acid. Oils and fats are formed by the combination of fatty acids with glycerol through enzymatic action to give the triglycerides having ester linkages (see Fig. 15.1).

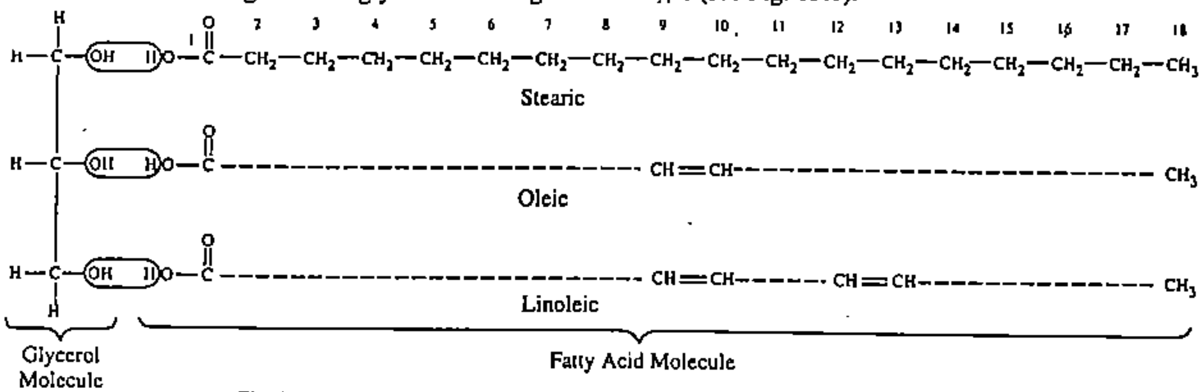

Fig. 15.1: An oil or fat molecule consists of three fatty acids joined to a glycerol molecule. These bonds are formed by the removal of a molecule of water, as was the case with polysaccharides. The figure shows three of the C_{18} acids combined as a molecule.

The glycerol forms a link with the carboxyl groups by the removal of a molecule of water, thus serving as a binder or carrier for fatty acids. The three fatty acid molecules that become linked to a given glycerol molecule may not be necessarily of the same kind. The ester linkages can be hydrolyzed by the enzyme *lipase*; thus the food reserve fat can eventually be converted back to glycerol and fatty acids. Some fatty acids like linoleic and linolenic (see Tables 15.1 & 15.2) cannot be synthesized by mammals and must be obtained from plant sources; they are therefore called **essential fatty acids.** Triglycerides are colourless and essentially tasteless. Therefore, the colour or taste of certain fats and oils is due to small amounts of sterols, lecithins and vitamins, present in them.

Table 15.1: Some naturally occurring fatty acids.

Common Name	World Distribution (in per cent)	Saturation	Symbol*	Melting Point (°C)
Lauric	4		12:0	44.2
Myristic	2	Saturated	14:0	53.9
Palmitic	11		16:0	63.1
Stearic	4		18:0	69.6
Oleic	24	Mono-unsaturated	18:1 (9¢)	13.4
Linoleic	34		18:2 (9¢, 12¢)	– 5
Linolenic	5	Polyunsaturated	18:3 (9¢, 12¢, 15¢)	– 11

*– The first figure indicates the number of carbon atoms in the fatty acid chain, and the second gives the number of unsaturated bond(s); the numbers in parentheses give their location. For example, 9¢ means between carbon atoms 9 and 10 and so on.

Fatty acids occur in straight, even-numbered chains (as they are synthesized from a two-carbon precursor). If every carbon in the chain bears two hydrogen atoms, the acid is said to be *saturated* (see Stearic acid in Fig. 15.1 and also Tables 15.1 & 15.2). The general formula for fatty acids of the saturated series is $C_nH_{2n+1}COOH$ (e.g., Lauric, Stearic, Myristic, Palmitic and Capric acid). Removal of hydrogen from specific adjacent carbon atoms in the chain produces double bonds, and the acid is thus *unsaturated* in terms of hydrogen. In most unsaturated fatty acids in plants, there is a double bond between carbon atoms 9 and 10; additional double bonds usually occur between C_{10} and the methyl terminal end of the chain. The major bulk of the plant fatty acids is unsaturated. The acids listed in Table 15.1 alone account for 94% of the world's commercial vegetable fats. In general, these acids are widely distributed in the form of lipid in all parts of the plants, but often Palmitic, Oleic and Linoleic acids predominate.

Table 15.2: Important fatty acids with empirical formulae (From Kochhar, 1986).

Saturated acids		Unsaturated acids	
Acid	*Empirical formula*	*Acid*	*Empirical formula*
Capric	$C_{10}H_{20}O_2$	Oleic	$C_{18}H_{34}O_2$
Lauric	$C_{12}H_{24}O_2$	Linoleic	$C_{18}H_{32}O$
Myristic	$C_{14}H_{28}O_2$	Linolenic	$C_{18}H_{30}O_2$
Palmitic	$C_{16}H_{32}O_2$	Ricinoleic	$C_{18}H_{34}O_3$
Stearic	$C_{18}H_{36}O_2$	Erucic	$C_{22}H_{42}O_2$

Most fats and oils are unstable and undergo changes when stored for relatively long periods, particularly at high temperatures and in the presence of air, giving rise to aldehydes and ketones that cause the **rancid** taste.

Oils, fats and waxes are very similar in their composition. Oils are liquids at room temperature whereas fats are solid or nearly solid. In general, the triglycerides of unsaturated fatty acids are liquids and triglycerides of saturated fatty acids with 12 or more carbon atoms are solids at ordinary temperatures. Coconut oil, palm oil, palm kernel oil and cocoa butter are examples of fats. Coconut oil, liquid in the tropical climate, is solid in temperate regions. Waxes are formed by the union of long chain alcohols (instead of glycerol) with fatty acid-molecules. They are found mostly as protective coverings on the surfaces of the leaves and stems, and greatly reduce the loss of water through transpiration. Waxes usually occur on the plant surfaces, and are very rarely found within living plant cells.

15.2.2 Vegetable and Essential Oils

Vegetable oils differ from essential or volatile oils in many respects:

1. they do not volatilise at room temperatures;
2. they cannot be distilled without being decomposed;
3. they leave a permanent greasy stain on paper;
4. being glycerides, they form soaps with alkali; and
5. they lack the strong taste and odour of essential oils and may become rancid on long exposure to air.

15.2.3 Classification of Vegetable Oils

The degree of saturation of the constituent fatty acids is an important characteristic of oils. The more double bonds there are, the more likely is the oil to oxidize as a waterproof film. Oils are often classified for their use according to their ability to oxidize into thin film, that is, as non-drying, semi-drying or drying oils.

Non-drying oils

These oils remain liquid at normal temperatures and are incapable of forming elastic films even after long exposure to air as they do not react with atmospheric oxygen. They are largely glycerides of saturated acids and oleic acid, with little or no linoleic and linolenic acids. The non-drying oils never undergo oxidation to form a film, hence are of no use in the paint, varnish or lacquer industry but are very useful in the manufacture of soaps, as lubricants and as food. These oils are found notably in the plants growing in the tropical regions. Groundnut, palm, olive, castor, rape and almond oils are examples of non-drying oils.

Semi-drying oils

These are intermediate between the drying and non-drying oils and are characterized by large amounts of linoleic and saturated acids but no linolenic acid. The semi-drying oils absorb atmospheric oxygen slowly, producing only a soft film after prolonged exposure to air and they never form a tough elastic film as is the case in drying oils. Oils such as cottonseed, sesame, sunflower, corn and croton are included in this category.

Drying oils

These oils are fairly rich in glycerides of the unsaturated fatty acids, particularly linoleic and linolenic with few oleic compounds. Such oils readily absorb oxygen on exposure to air and form a tough, elastic but resistant film. They are therefore, very important as solvents for pigments in the paint and varnish industries. Temperate plants like linseed, soyabean, tung, safflower and hemp-seed are important types of drying oils.

Box 15.1: Iodine number of various categories of fats.

Non-drying oils = The iodine number is less than 100.
Semi-drying oils = The iodine number is between 100-130.
Drying oils = The iodine number is more than 130.
The iodine number is the number of grammes of iodine or iodine compounds absorbed by 100 g of fat. The oils with higher iodine numbers readily absorb atmospheric oxygen and form a tough and durable film.

Although plant oils are frequently categorized by the relative degrees to which they dry to form a hard film, it is more useful to group them according to their primary use either for food or for industrial purposes:

a) oils used primarily for food – olive oil, rape oil, corn oil, soyabean (also written as soybean) oil, groundnut oil, cottonseed oil, safflower oil, sunflower oil and sesame oil.
b) oils used for both food and industrial purposes – palm oil.
c) oils used primarily for industrial purposes – castor oil, tung oil and linseed oil.

15.2.4 Extraction of Vegetable Oils

The fatty oils are insoluble in water and are located in the form of small insoluble droplets within the plant cells. Most oils are stored in seeds, most commonly in the endosperm and cotyledons, and almost exclusively in the embryo in most of the cereals. The vegetable oils may also be found in fruits, stems, tubers and foliage. Olive and palm oils are extracted from the fleshy pericarp of their respective fruits.

Methods of Obtaining Oils

The extraction of crude oils and fats from the oil-bearing plant cells involves any one of the following methods: rendering, mechanical pressure, and solvent extraction.

Rendering: It is chiefly used for recovering oils from animal fats but this method is sometimes employed in palm oil extraction in parts of Africa. The most common method is mechanical expression. Prior to extraction, twigs, leaves, stones and tramp material are removed by screening and passage over magnets. After cleaning, the seed coats (hulls) are removed with the help of machines and thereafter the kernels are reduced to thin flakes. This is followed by hot or cold expression, solvent or screw extraction and centrifugation.

Mechanical Expression: Pressure is applied to the oil bearing tissues to squeeze out the fat. This is accomplished either by hydraulic pressing or screw pressing. In the hydraulic press, the flaky material is usually placed in sacks or wrapped in strong cloth which holds back the residual mass as the oil strains through. In hot expression, the separated kernels are first cooked in steam to facilitate oil flow during extraction. In cold expression the kernels are directly crushed into a fine meal without any previous treatment. Hot expression is more common and as a result of pre-cooking, the oil is rendered more labile, giving a higher yield but the quality is relatively inferior.

Solvent Extraction: This method is quite effective but expensive. It is the only practical method for recovering oils from tissues having a relatively low proportion of oil. A number of solvents can be used, including gasoline, benzene, carbon disulphide, petroleum ether and chlorinated hydrocarbons. The solvent must have access to all oil bearing cells. The fatty oils are freed from the extracting solvents by distillation. The cake mass obtained during solvent extraction contains only one per cent or less of oil, compared to four to seven per cent in mechanical pressing.

Refining of Crude Vegetable Oil

The crude oils often contain impurities such as water, dirt, cellular material, free fatty acids and phosphatides, pigments, odiferous compounds such as aldehydes, ketones hydrocarbons and essential oils. Therefore, the oil is subjected to a refining process. The albuminoid fraction of the crude vegetable oils is removed through coagulation by heating. Free fatty acids are removed by agitation with sodium hydroxide. In some cases bleaching or deodorisation is also practised.

Keeping Quality of Oil Seeds, Vegetable Oils and Fats

Some seeds, if they are not bruised, can be stored for years without any change in the fat due to the presence of substances that tend to prevent auto-oxidation. The most common naturally occurring antioxidant is *vitamin E (tocopherol)*. Vegetable fats usually contain appreciable amounts of tocopherol, while animal fats are relatively lacking. In addition, other compounds are present that increase the activity of true antioxidants. These are referred to as *synergists*. Phosphatides function as antioxidants and may also enhance the activity of other antioxidants. *Sesamol* is an antioxidant contained only in sesame oil whereas *gossypol* is present in crude cottonseed oil. Both the antioxidant and synergists are sometimes partly or wholly removed from oils during refining process and such oils therefore tend to deteriorate and develop an unpleasant odour and flavour (this is due to the breakdown of glycerides into free fatty acids, aldehydes, ketones, etc. and is known as rancidity). In order to increase their stability, antioxidants must be added to refined oils. The hydrogenated fats are generally many times more stable than the oils from which they are produced, i.e., they are less likely to become rancid.

15.2.5 Hydrogenation of Oils

The process of converting oil containing unsaturated fatty glycerides into fats is known as *hydrogenation of oils*. Partial hydrogenation removes the double bond of the oil, making it more suitable for edible purposes, as well as improving the keeping qualities, taste, odour and melting point of the oil. The hydrogenated end product is known as *vanaspati ghee* in India and the oils commonly used in its preparation are groundnut, soyabean, cottonseed, sesame oil and many others. The hydrogenation process consists of the following steps:

1. Pre-hydrogenation includes following phases.
   a) Neutralisation – The oil to be hydrogenated is pumped into the neutraliser and agitated at high speed. Requisite amount of sodium hydroxide is added which neutralises the free fatty acids. The salts so formed appear as a scum on the oil surface and is cleared off. The oil is then pumped to the bleacher.
   b) Bleaching – The oil is bleached with Fuller's Earth at 90°C in the bleacher. The colouring matter is absorbed and the oil is filtered.
   c) Deodorising – The purpose of this operation is to eliminate objectionable odours and flavours caused by volatile constituents. The oil is heated and super-heated steam is pumped in, which vapourises the volatile constituents.
2. Hydrogenation – The bleached, deodorised oil is now sent to the convertor and hydrogenated under selected conditions of temperature and pressure. The oil is heated to about 77°C and agitated. Hydrogen gas is bubbled under pressure and the heated oil absorbs the hydrogen in the presence of finely divided nickel catalyst. The amount of hydrogen absorbed can be regulated, more hydrogen can be made to be absorbed, if fat with high melting point is desired. The hydrogenation is continued until a fat of the desired consistency is obtained. The hardened oil is removed and pumped through a filter press to remove the nickel.
3. Post-hydrogenation refining – To ensure high purity for preventing rancidity, the hydrogenated oil is processed in exactly the same way as described above and freed of any residual fatty acids or solid materials. The finished material is mixed with a small amount of colouring and flavouring matter and vitamins are added to increase its nutrient value. It is packed in containers and allowed to cool by refrigerated air so that the drop in temperature is 4.5°C per hour. This gives the product a granular, ghee-like appearance.

The degree of saturation is significant with regard to vegetable oils as foods, principally as cooking fats and oils, and margarines. Recently concern about excessive *level of saturated fatty acids in the diet has increased since it has become known that these are important along with cholesterol, in producing deposits that lead to hardening of the arteries. In this respect, now-a-days vegetable oils such as safflower, corn, soyabean and sunflower oils are preferred as edible oils as compared to saturated fats and animal fats.*

15.2.6 Uses of Vegetable Oils and Fats

They are mainly used as food, for industrial purposes and in pharmaceuticals. Some of the uses are listed below.

1. Many vegetable oils, for example, olive, groundnut, soyabean, corn and cottonseed are used as cooking oils and also in the manufacture of oleomargarine.
2. Vegetable oils and fats are highly concentrated reserves of energy. All fats have a high calorific value compared to that of carbohydrates and proteins. One gram of fat will supply approximately nine calories whereas a gram of carbohydrate or protein produces about four.
3. Oils and fats add flavour and variety to foods and make the meal palatable. They have a role in satiety value of food, i.e., they give feeling of satiation and delay the onset of hunger.
4. Fats act as solvents for the fat soluble vitamins such as vitamins A,D, E, and K.
5. The residue left after the extraction of oil, known as oil-cake, is often rich in proteins and is used as livestock feed. Some oil-cakes, e.g., castor, linseed and tung, however, contain toxic constituents that make them unsuitable for feeding purposes, but they may be used as nitrogenous fertilisers.
6. Oils and fats are employed in the manufacture of paints, varnishes and lacquers, and as components in linoleum and oil-cloth, soaps, detergents, candles, plastics, synthetic fibres, artificial leather, polishes, cosmetics and lubricants.
7. Fixed oils and fats such as castor and croton oils are used pharmaceutically for their soothing properties.

SAQ 1

1. Put a tick (✓) mark against the correct statement and a cross (X) against the wrong ones in the given boxes.

a) Linoleic and linolenic acids are called essential fatty acids as these cannot be synthesized by mammals and must be obtained from a plant source. ☐

b) Vegetable oils and fats are triglycerides of complex organic fatty acids. ☐

c) Most fats and oils are stable and do not give rancid taste on exposure to air and high temperature for long periods. ☐

d) The triglycerides of unsaturated fatty acids are solids whereas the triglycerides of saturated fatty acids are liquids at ordinary temperature. ☐

e) Vegetable oils do not volatilise at ordinary room temperature. ☐

f) The non-drying oils form an elastic film on exposure to air. ☐

g) Linseed oil is an example of semi-drying oil. ☐

h) The oils rich in glycerides of the unsaturated fatty acids particularly linoleic and linolenic are drying oils. ☐

i) Semi-drying oils are characterized by large amount of linoleic acid and saturated acids and no linolenic acid. ☐

j) Fatty acids are straight, odd or even numbered chains and if every carbon in the chain bears two hydrogen atoms the acid is unsaturated. ☐

15.3 SOURCES OF COMMONLY USED FATS AND OILS

15.3.1 Groundnut

Botanical Name: ***Arachis hypogaea***
Family: Fabaceae
Subfamily: Papilionoideae
Common names: Groundnut, Peanut, Monkey-nut, Mungphali
n = 20

Groundnuts are the second largest source of vegetable oils, the largest being the soyabean. The botanical name *Arachis hypogaea* is derived from Greek words, "Arachis" meaning a legume and "hypogaea" meaning below ground referring to ripening their fruits underground (geocarpic). A native of Brazil it became widely distributed throughout South America at an early date and in the sixteenth century Portuguese brought it to West Africa. Later it was introduced to China, Japan, India, Malaysia and Malagasy Republic. The botany of the plant and culture practices, have already been discussed in Unit-12, Legumes (Pulses). Here only the chemical composition and uses of groundnut oil are discussed.

Structure of Pod: The peg, after entering the soil, develops into a pod (Fig. 15.2). The fruit is a one-loculed pod. The shell of the pod consists of outer spongy layer, a middle fibrous and woody layer and an internal layer which lines the pod and becomes more or less papery. Each seed is composed of two cotyledons and is covered by thin papery seed coat. The cotyledons are creamy-white in colour. The number of kernels in the groundnut pod varies from one to five.

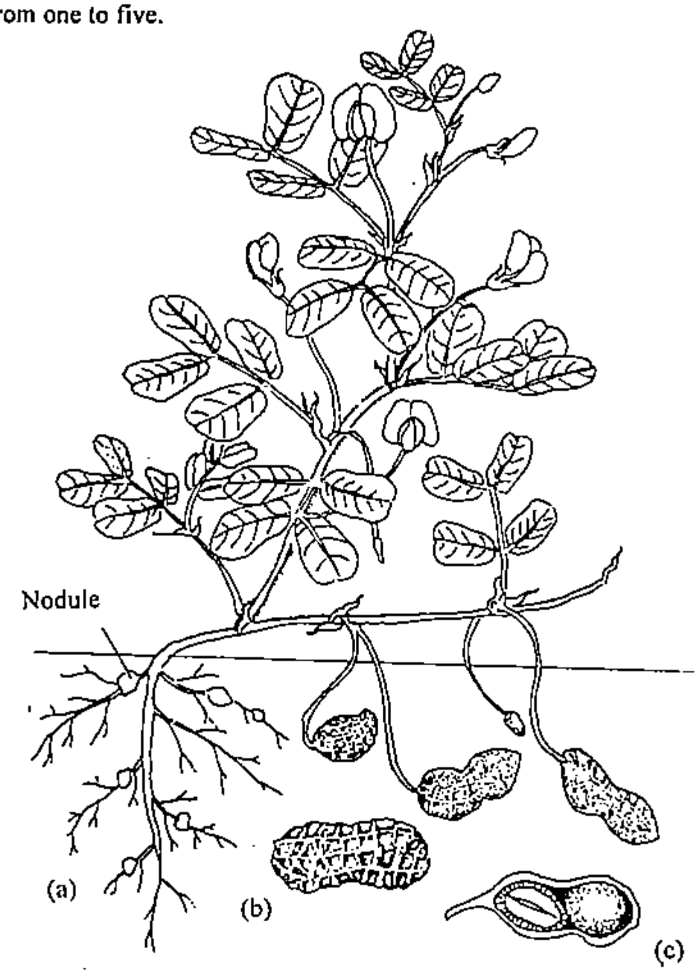

Fig. 15.2: Groundnut. a) Outline diagram of a plant showing its pods at various stages of development. b) A complete pod. c) A pod longitudinally cut to show two seeds (one cut longitudinally) in its locule. (Redrawn from Simpson & Ogarzaly, 1986).

Chemical Composition: Shelled nuts contain about 26 per cent protein and 45 per cent oil. The kernels are also rich sources of phosphorous, thiamine, riboflavin and niacin. Cold-pressed groundnut oil is golden yellow in colour and has a faint agreeable odour, while the hot-pressed oil has a reddish yellow tinge. The principal fatty acids are: oleic acid, 56 per cent; linolenic acid, 25 per cent; palmitic acid, 6-12 per cent; and a little each of stearic, arachidic and higher saturated acids.

Extraction of Oil: Prior to extraction of oil, the seeds are shelled and cleaned. The seeds contain 40-45 per cent oil. The oil is extracted by expellers or hydraulic press. India is the highest producer of groundnut oil.

Uses

1. The refined oil is a popular cooking medium and is used for making margarine, and peanut butter.
2. Peanut oil is often used in the manufacture of "vanaspati ghee" by hydrogenation.
3. The oil is also used for cooking sardines before packing them in olive oil.
4. The inferior grades of the oil are used for soap making, illuminants, lubricants and as a rubber substitute.
5. The residual cake meal is rich in nitrogen (7-9%) and is an important cattle-feed. The cake is used as a manure.
6. Medicinally, the oil is used as a laxative and emollient.

15.3.2 Mustard

Botanical name: *Brassica* spp.
Family: Brassicaceae
Common Names: Rape, Mustard, Sarson, Kali sarson, Toria, Rai, Sondha
n = 8,9,10,11

The genus *Brassica* includes over 150 species and several of them are the source of oil. Some commercially important sources are: Rape (or Colza) and Mustard. *Brassica* seeds have a very long history and find several references in the Bible and in the Greek and Roman writings. Sanskrit records of 3000 BC refer to mustard as an important spice. The plants are annual, biennial or rarely perennial herbs, mostly native to the north temperate parts of the old world, especially Mediterranean region. *Brassica* spp. are believed to have originated in three different centres: Europe, Central and Southern Asia, and China. The different species have spread to the subtropics and tropics as cold season crops. *Brassica* spp. are extensively cultivated in North America, Canada, U.K., Denmark, France, Germany, China, Japan and India. In India, they are cultivated in Punjab, Haryana, Uttar Pradesh, Bihar, Bengal and Assam.

The cultivated *Brassica* species may be divided into two distinct types: the vegetable types and oil seed types; the former comprising cabbage, cauliflower, broccoli and turnip. Those extensively cultivated for oil are: *Brassica napus* and *B. juncea* in China and Japan; *B. napus* and *B. praecox* in Europe and America; and *B. juncea* and *B. napus* in Russia and Mediterranean region.

In India, the principal oilseeds are *B. campestris* (Fig. 15.3) and *B. juncea*. *Eruca vesicaria* sub sp. *sativa* grown mainly in Punjab yields "jamba oil" (also see Table 15.3). Three distinct varieties have evolved from *B. campestris* in India; brown sarson, yellow sarson and toria, restricted to distinct eco-geographical regions. In Western Europe, *B. campestris* is also grown as an oilseed crop but the varieties are different from those cultivated in Southeast Asia.

Table 15.3: The common oil-yielding cruciferous crops grown in India.

Botanical name	Common name	Common Indian name
Brassica campestris var. "brown sarson"	Turnip rape	Brown sarson
B. campestris var. "yellow sarson"	Turnip rape	Yellow sarson
B. campestris var. "toria	Indian rape	Toria
B. juncea	Indian or brown mustard	Rai
B. nigra	Black or true mustard	Banarsi rai
Sinapis alba	White mustard	Ujli sarson
Eruca vesicaria sub sp. *sativa*	Rocket cress	Taramira

In Indian trade, three varieties of *Brassica* (*B. campestris* – brown sarson; *B. campestris* – yellow sarson; ***B. campestris* var. toria) are collectively known as Rape, while the rai (*B. juncea*) is known as mustard.** *Brassica nigra* and *Sinapis alba* are not much used for oil extraction in India but they are used in Europe and Canada.

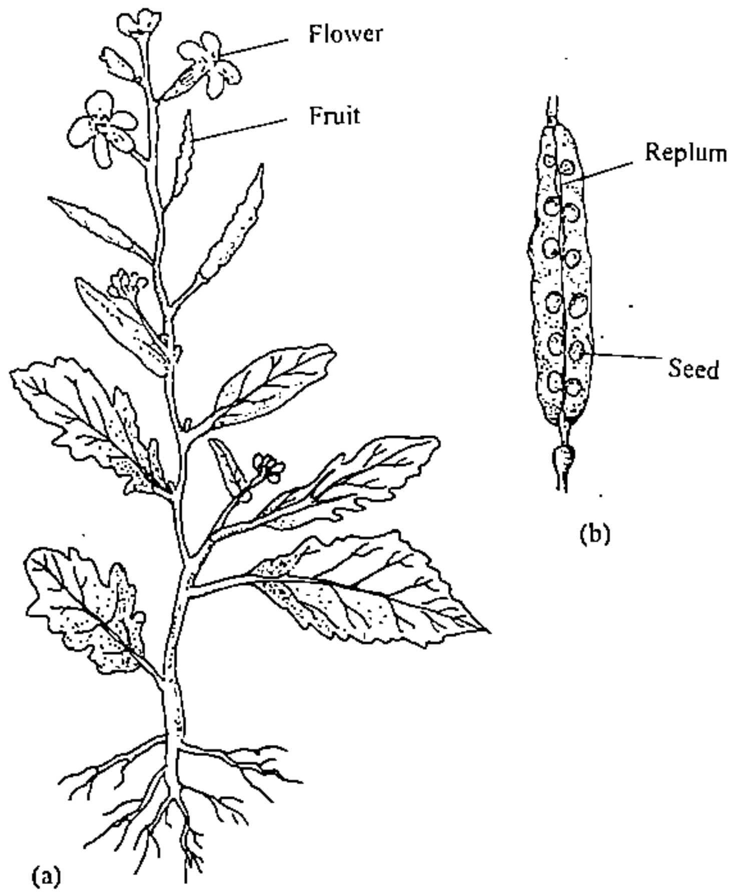

Fig. 15.3: Mustard (*Brassica campestris*). a) Outline diagram of a mustard plant showing flowers and fruits at various stages of development. b) A mature fruit cut in longitudinal section, showing replum and many seeds.

(i) Rape Seeds

(Yellow sarson, Brown sarson and Toria)

Of the different types of rape seeds, yellow sarson is probably the oldest and it is described in the old Indian medicinal books. Eastern Afghanistan together with the adjoining north-western India is one of the independent centres of origin of brown sarson. From the fact that brown sarson and toria resemble closely, it has been concluded that they have been introduced from the north-west into Punjab from where they have extended eastwards into India. Yellow sarson is commonly grown in the eastern parts of India where it exhibits diversity of forms in Uttar Pradesh and West Bengal. It is quite probable that its primary centre of origin is north-western India. In India rape seeds are grown in the states of Uttar Pradesh, Punjab, Assam, Bihar, Madhya Pradesh, Rajasthan, West Bengal and Orissa.

Rape plants are slender, erect, branched, annual herbs, generally covered with a waxy bloom. The height varies from 30-45 cm in some varieties of toria, to about 1.5 m in yellow sarson. The leaves are auricled, generally lyrate (pinnatipartite) and stem clasping. Inflorescence is corymbose raceme type. The flowers are small and variously coloured. Each flower has a typical cruciferous plan, i.e., with four free sepals, four free clawed petals, tetradynamous stamens and a bicarpellary, syncarpous, superior ovary, initially unilocular but later becoming bilocular due to the formation of a false septum known as replum (see Fig. 15.3 b). The fruit is a siliqua or silicula (a short and compressed pod), dehiscing from the base upwards with the seeds attached to the replum (Fig. 15.3). The seeds are small, spherical, yellow (yellow sarson) or finely rugose (brown sarson and toria), mucilagenous (brown sarson) or non-mucilagenous (yellow sarson and toria). Aleurone and endosperm are present beneath the seed coat.

The seeds of *Brassica* are known to possess a glycoside sinigrin or potassium myronate and *Sinapis alba* contains the glycoside sinalbin whose physiological activities are not clearly known, but on hydrolysis with the enzyme myrosin, they yield dextrose and essential oil mustard.

Sinapis alba (white mustard)

Sinalbin ($C_{30}H_{42}O_{15}N_2S_2$) + H_2O $\xrightarrow{\text{myrosin}}$ Acrinyl isothiocyanate(Sinalbin mustard oil) + dextrose + Sinalbin hydrogen sulphate

***Brassica nigra* (Black mustard)**

Sinigrin ($C_{10}H_{16}O_9NS_2K$) + H_2O $\xrightarrow{\text{myrosin}}$ Allyl isothiocyanate (volatile oil of mustard) + dextrose + Potassium hydrogen sulphate

Cultivation: Mustard is grown in India as a *rabi* crop. But toria is generally sown in September and is treated as zaid kharif (autumn crop). Sarson is usually sown in October-November. Medium or heavy loam soils are suitable for cultivation of rapes. These are sown as a mixed crop along with wheat, barley or gram. Toria is, however, chiefly sown as a pure crop. Brown sarson is grown as a pure crop in *barani* (rain fed) areas of Uttar Pradesh, Rajasthan and Punjab.

Harvesting: Yellow sarson varieties take 120-160 days and brown sarson 105-145 days to mature. Toria crop matures in 85-100 days. Toria is harvested when the pods begin to turn yellow and sarson is harvested when the plant has turned yellow. Harvesting is done by means of hand sickles. The plants are tied in bundles and stacked in the sun for a couple of days. Then these are threshed by beating with wooden mallets. The threshed grain is separated from the husk by winnowing, dried in the sun for a couple of days and then stored.

Oil content: The oil content of the seeds varies from 30 to 48 per cent depending upon the variety and the climatic conditions under which it is grown. The seeds contain about 20 per cent protein. All varieties are characterized by having high percentage of erucic acid, i.e., 40-45 per cent of total fatty acid. Oleic and linoleic acids represent about 47 per cent. The other saturated acids such as palmitic, stearic and lignoceric acid are present in very small quantities. The seeds contain a glucoside called sinigrin and potassium myronate. On hydrolysis by an enzyme *myrosinase* it yields dextrose allyl-isothiocyanate and potassium hydrogen sulphate. The pungency in the rape and mustard oil is due to the essential oil allyl-isothiocynate.

Uses

1. The whole seed and its oil are used as a condiment in the preparation of pickles and for flavouring curries and vegetables.
2. The oil extracted from rape is used almost entirely for edible purposes such as salads and cooking oils and in margarine.
3. It is also used as a lubricant, in the manufacture of greases, lubricants and for the manufacture of soft soaps.
4. The oil cake is used as a cattle feed and manure.

(ii) Mustard Seeds
(Indian mustard; Rai, Sarson rai)

Brassica juncea is one of the important oil seed crops in India. It is distinghished from sarson or toria by its petiolate, narrow based leaves which are not stem-clasping. Rai was originally introduced from China into north-eastern India. Mustard is cultivated in India, China, Pakistan and Japan. In India the chief mustard growing states are Uttar Pradesh, Punjab, Assam, Bihar, Madhya Pradesh, Rajasthan, West Bengal and Orissa.

The plants are herbaceous, annual with slender branched stems, 1-2 m high. The stem branches from the axils of the 4^{th} or 5^{th} leaf upwards. Leaves are lyrate, stalked and are about 15-30 cm long. The inflorescence is a corymbose raceme. Flowers are small, petals pale yellow, yellow or cream coloured. Stamens are tetradynamous and anthers introse. Ovary hypogynous, bicarpellary, syncarpous with a very large number of ovules, parietal placentation. The fruit is silqua 1.25-6.25 cm long, erect with short and stout beaks. Seeds are small, round, brown or dark brown and non-mucilaginous. The seeds show marked reticulation over the surface when examined under microscope. *B. juncea* is a self-fertile species.

Cultivation: Mustard may be cultivated as a pure crop or as a mixed crop with wheat, barley and gram. Mixed cropping is specially common in Uttar Pradesh. Mustard is grown in India as a *rabi* crop. Medium or heavy soils are best for the cultivation of mustard. When sown mixed, it receives the preparation and manuring of the main crop with which it is associated. The crop is usually sown from the middle of October to the beginning of November. In mixed cropping, the seeds are sown either in parallel rows 1.2-1.8 m apart alternating with the main crop or broadcast in the entire field. When sown as a pure crop the seed is generally sown by broadcast method (dispersing with hands).

Harvesting: The mustard crop comes to maturity in about 110-160 days. Harvesting of the crop goes on from February to March. The harvesting of the crop is done by means of hand sickles. The crop is made into bundles and stalked in the sun for few days. Threshing is very easily done as the pods easily shatter and give away the seeds. The threshed grain is separated from the husk by winnowing and then dried in sun and stored. The storage rooms should be completely free from humidity.

Extraction: Oil is extracted from the seeds in bullock operated ghanis (Kolhu) or power driven rotary ghanis, expellers and hydraulic press. In recent years solvent extraction methods are also employed.

Mustard seeds contain 30-42 per cent oil. Oil is a pale yellow liquid and does not form a solid film on exposure to air. Mustard seeds like seeds of other members of family Brassicaceae, contain a glucoside called sinigrin and potassium myronate. On hydrolysis with enzyme myrosinase it yields dextrose, essential oil – Allyl-isothiocyanate, and potassium hydrogen sulphate. The pungency in the mustard oil is due to this essential oil. The chief component of the fatty acids of the oil is *erucic acid*.

Like all other edible oils, rape and mustard oil are also adulterated. The commonly used adulterants are groundnut and linseed oil. Sometimes seeds of *Argemone* get inadvertently mixed during harvesting and mustard oil may contain a small percentage of *Argemone* oil also. Dropsy, a disease in human beings, is due to contamination of mustard with large quantities of argemone oil that contains a toxic alkaloid sanguinarine.

Uses

1. The chief use of mustard oil in India is for edible purposes.
2. Mustard seeds are used as a condiment in the preparation of pickles and for flavouring curries and vegetables.
3. Inferior grades of oil are used as illuminant and also as cutting oil.
4. The erucic acid fraction of the oil is used for lubricating jet engines and in the manufacture of plastics.
5. Mustard oil is employed to impart a soft and pliable texture to skins and hides during the tanning process. Animal skins contain in their cells a certain amount of fat which is removed during tanning.
6. The seeds are fed to the cattle as they are digestive and help in preventing diseases.
7. Mustard oil along with rock salt is used as a dental solution in the diseases of gum. It also forms an ingredient in Ayurvedic medicated oils used as an ointment, or for massage in many paralytic disease of the nervous system.
8. The leaves of young plants are consumed as a green leafy vegetable. This is also raised as a green fodder for cattle and occasionally as a green manure.
9. The oil cake is used as cattle feed and manure.
10. The essential oil of mustard is an extremely powerful irritant, causing severe blisters on the skin and, therefore is used as a counter irritant in highly dilute concentrations in medicines.

(iii) Taramira
(Rocket seed)

Taramira, botanical name *Eruca sativa* is a cold-weather oil seed crop in the drier areas of north west India, where it is commonly grown mixed with gram or barley. It is a herbaceous annual, 0.6-1.2 m tall. The stem is solid at the base but hollow above, branched and glabrous. The leaves are dark green or glabrous. The inflorescence is corymbose raceme. There are two types of flowers – long-styled and short-styled. The petals are distinctly clawed, greenish yellow with dark purple veins. Stamens-6, tetradynamous, ovary hypogynous, bilocular and has two rows of ovules in each locule. Fruit is a siliqua about 2.5 cm in length with a flat ensiform seedless beak and closely pressing to the stem. The seeds are ovoid, smooth, light and reddish-brown. The seeds have an irregular mucilaginous coating more thickly deposited near the micropyle.

Cultivation: Taramira is grown as pure or mixed crop in areas where the soil is light, the moisture supply is very low and the soil fertility is poor. As a matter of fact taramira is grown by the cultivators in areas where no other crop can be profitably grown. The crop is sown at any time between September and November.

Uses

1. Taramira oil is used as a burning oil in lamps in villages. The oil gives a more luminous and less sooty flame than *Brassica* oils.
2. The oil cake is used as cattle feed. Cattle fed on taramira are reported to be free from tick attacks.

15.3.3 Safflower

Botanical Name: ***Carthamus tinctorius***
Family: Asteraceae
Common Names: Safflower, Kusum
n = 12

Safflower (*Carthamus tinctorius*) is an annual, oil seed crop of India, United States and Mexico and also of minor importance in Australia, Spain, Portugal and Turkey. Two kinds of oil are obtained from safflower, one polyunsaturated, which is used in soft margarines, salad oils and surface coatings and the other monounsaturated, which is used primarily as a frying oil. Several countries of the Middle East grow this plant on a small scale basically for its dried flowers, which serve as a substitute for saffron.

The oldest evidence of safflower as cultivated plant comes from the archeological records in Egypt. There, in about 1600 B.C., safflower was grown for its flowers which showed the same variability in colour as may be found in that country now. The reddish-orange florets were sewn sideways on narrow strip of papyrus or cloth to form long garlands that were wrapped about the necks and bodies of mummies. Then, or at some later date, it was discovered that the orange or red flowers could serve as a source of dye to colour cloth. This suggests that man became interested in safflower when he first found plants with orange or red flowers. By the early nineteenth century, safflower had become one of the two most important plant sources of dye-stuffs, the other being "indigo". Its importance declined, when synthetic aniline dyes were developed. The dried flowers may still be purchased in the market, being sold as colouring agent for foods. The colouring pigment is carthamone, a chalcone derivative.

It is likely that safflower seed was used as a source of oil during the Roman period in Egypt, and perhaps earlier. The date of its first culture in India is not known, but it was probably also very early. Until the later part of the nineteenth century it was not tested as a potential oil crop in any other area. The species was first domesticated in the near east as a dye plant and subsequently very widely used for this purpose in the Old World subtropics. At an early stage it was locally converted into an oil seed. In cultivation over a huge area and for a long time, considerable diversity developed. Its centres of diversity (Knowles, 1969) with predominent types in each are:

1. Far East – late, spiny, tall, red-flowered.
2. India-Pakistan – early, very spiny, short, orange-flowered.
3. Middle East – late, spineless, tall, red-flowered.
4. Egypt – variable, usually large-headed.
5. Sudan – early, very spiny, yellow-coloured.
6. Ethiopia – late, very spiny, tall, red-flowered.
7. Europe (Mediterranean) – variable.

The plant is an annual herb (Fig. 15.4) that grows very rapidly. It is highly branched and grows to a height of about 30 cm – 1.2 m. Leaves are crowded near the base of the stem in the form of a rosette. These are usually arranged in a spiral manner and are borne at irregular intervals. The leaves occur very closely at the tips of the branches and form involucral bracts of the inflorescence. The leaves are entire, rigid, unarmed or spinuloseserrate. The inflorescence is formed at the tips of each branch of the plant. All the florets (flowers) are irregular and tubular (homogamous). Flowers are bisexual and orange red in colour. The fruit is an achene which is obovoid with pappus. The seed contains 24-36% drying oil.

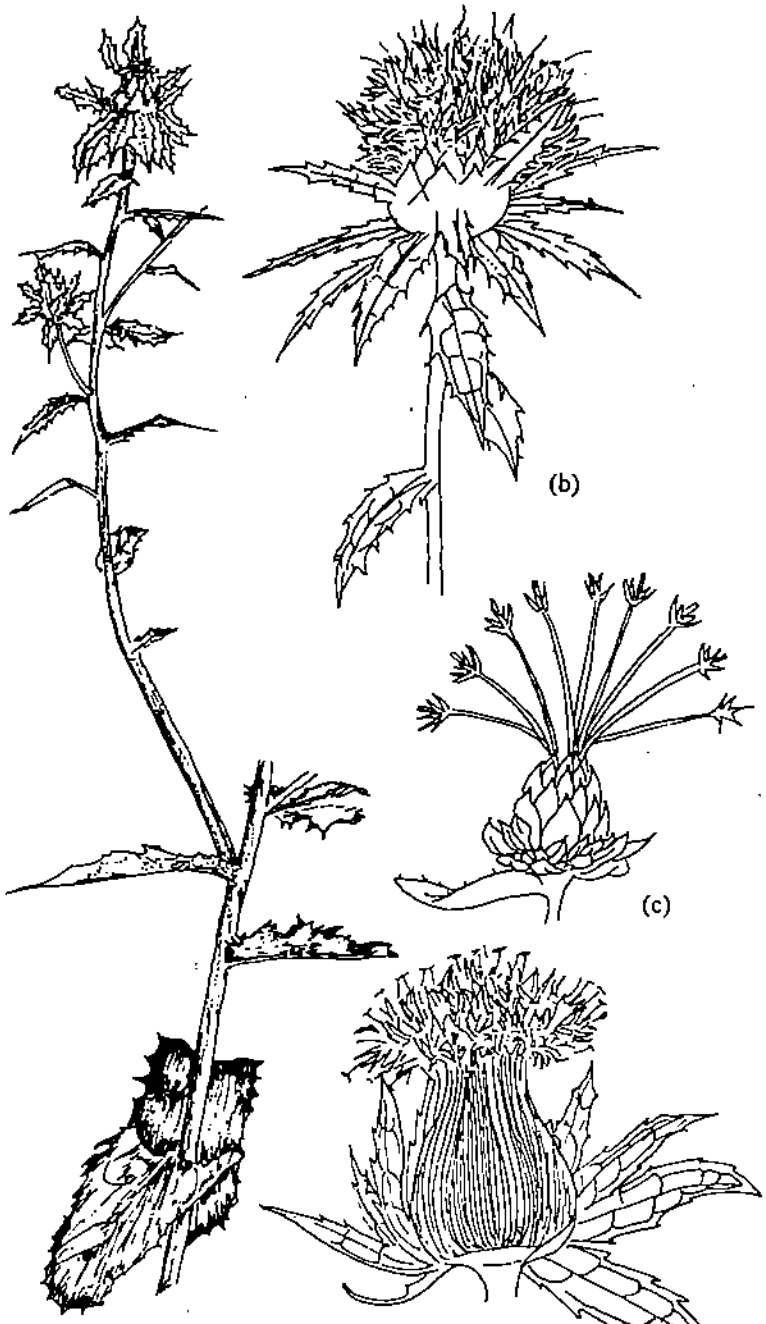

Fig. 15.4: Safflower (*Carthamus tinctorius*). a) A part of the plant showing inflorescence. b) A capitulum as seen in external view. c) A capitulum with most of its flowers removed. d) A capitulum in longitudinal section. [Redrawn from: a,b,d) Purseglove, 1988; c) Cobley & Steele, 1976].

Cultivation and Harvesting: In India, the herb is widely cultivated as an important oil seed crop in Andhra Pradesh, Maharashtra, Karnataka and Madhya Pradesh. It is a dry, winter crop on plains and is cultivated both as a rainfed as well as an irrigated crop. Being drought resistant it could be grown even on poor sandy soils as well as in regions having low rainfall. Black-cotton soils, loams and light alluvial soils are good for safflower cultivation. For the extraction of dye it is generally sown as a pure crop, but as an oilseed crop it is sown mixed with wheat, jowar, barley or gram.

Safflower is sown in October–November and harvested by February–March. Seeds are sown on the moist seed-beds in strips of one to three rows alternated with six to twelve rows of the main crop such as wheat or rabi jowar. In order to encourage branching, the tips are often nipped off when the plants are about two months old. This induces greater production of flowers and seeds.

The crop is harvested by uprooting the plants, generally early in the morning, when there is a dew on the crop. The labourers often cover their legs and hands with gunny cloth to protect themselves against the prickly spines. The plants are heaped for a few days and then threshed by beating with sticks. The seeds are then cleaned and winnowed. The trash consisting of stems and leaves, are used as a fuel or burnt in the field or sometimes removed to the manure pit for making compost.

Extraction of oil: Decorticated seeds give a better quality of oil, as well as oil cake. The oil is extracted by crushing seeds in a "ghani" (country oil press) or by hot dry distillation. Hydraulic presses, expellers, and solvent extraction methods are employed for the commercial production of safflower oil.

Chemical composition of oil: The fatty acids of the oil are: myristic acid, 1.5 per cent; stearic acid, 1 per cent; arachidic acid, 0.5 per cent; oleic acid, 33 per cent; and linoleic acid; 61 per cent. The oil content varies from 20-30 per cent.

Breeding: Cultivated safflower belongs to a group of closely related diploids (2n = 24) that extend from Turkey, Lebanon and Israel in the west to northeastern India in the east. Two successful wild species are *Carthamus flavescens*, which is self-incompatible, and *C. oxyacantha*, both self-compatible and incompatible. The development of the crop has been severely handicapped by insects, many of them adapted to survival on other composites, including the wild safflower species. Most serious among them is the safflower fly (*Acanthiophilus helianthi*). The safflower of the Deccan region of India shows little damage from the pest, apparently because alternate hosts are not abundant or the crop is ready so early that it escapes damage.

In breeding programmes, much effort has been devoted to the development of disease resistant varieties. Cultivars have been bred with resistance to wilt caused by *Fusarium oxysporum*, *F. carthami*, and *Verticillium albo-atrum* and rust caused by *Puccinia carthami*. The major objectives of all breeding programmes are to raise disease resistant varieties and develop varieties with higher oil content, with levels exceeding 50% both by reducing the hull and by raising the oil at the expense of protein.

Uses

Safflower oil may be variously used.

1. A golden-yellow coloured oil is produced by cold-pressing which is used for cooking purposes.
2. Safflower oil may be refined, bleached and hydrogenated to produce an edible oil.
3. Its good drying property makes it a useful raw material in the manufacture of paints, varnishes and linoleum.
4. It is also used for illumination purposes and for soap manufacture.
5. It is used for adulterating ghee and sesame oil.
6. Charred safflower oil is used for healing sores and in rheumatism related problems.
7. The protein rich oil cake is used as a cattle feed.

15.3.4 Coconut

Botanical name: ***Cocos nucifera***
Family: Arecaceae
Common names: Coconut, Narial
n = 16

The coconut palm (Fig. 15.5) is one of the most important sources of vegetable oil in the world and is known as a wonder plant or the tree of heaven – *Kalpaviriksha* yielding many products. Practically all parts of the plant are useful in one way or the other but it is the dried kernel (copra) which is of prime importance.

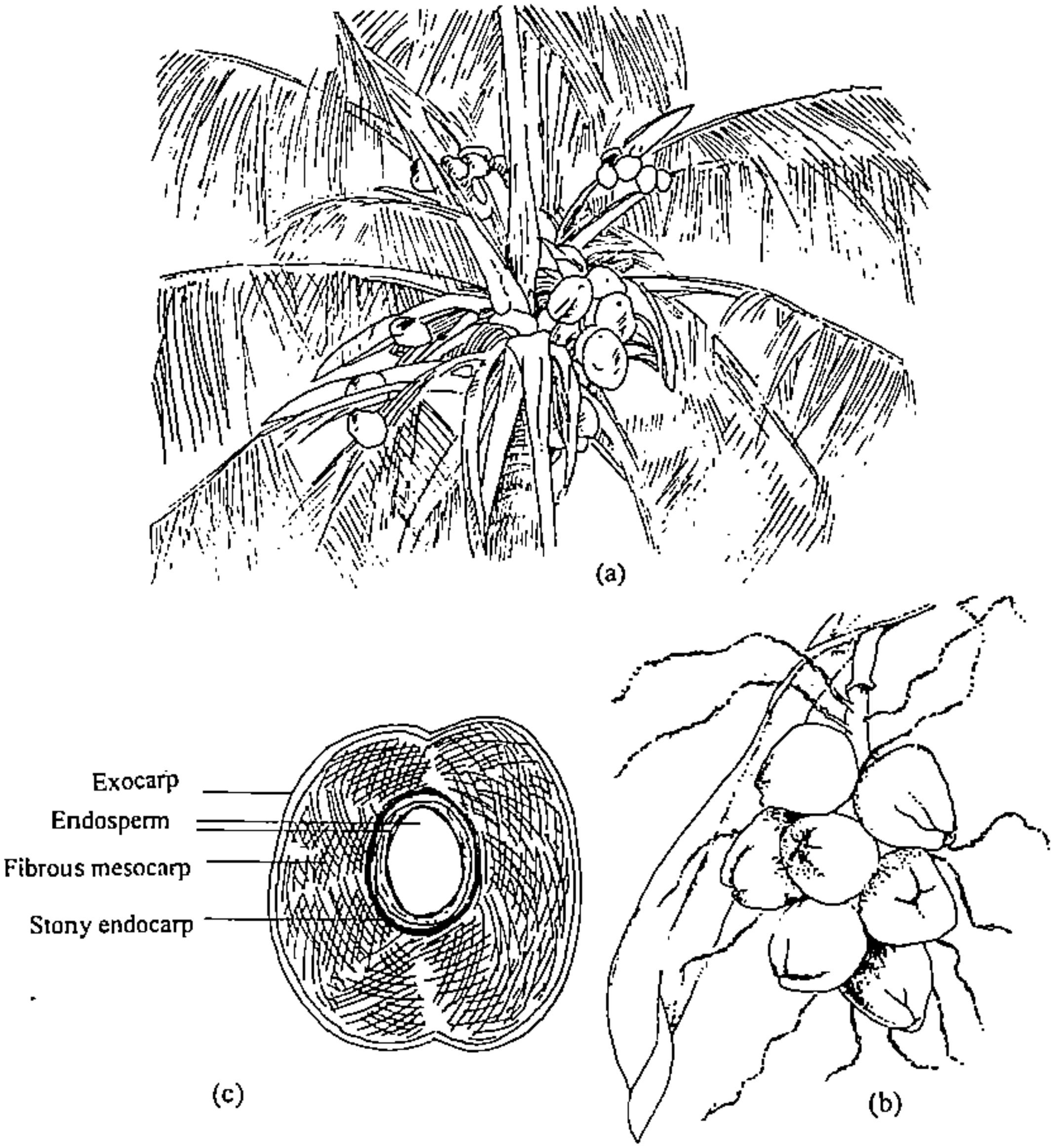

Fig. 15.5 : Coconut (*Cocos nucifera*) : a) The crown portion of the tree magnified showing fruits amongst the leaves. b) A fruiting twig. c) Outline diagram of the fruit cut in longisection.

Extraction of Oil: For copra production, fully ripe fruits (11 to 12 months old) should be harvested to obtain the optimum amount of better quality oil. The "copra" is the dried meat (endosperm) of the coconut. Nuts for coir production are picked when 10 months old and drinking nuts are harvested earlier, usually at about 7 months. The fruits are dehusked with the help of an upright steel bayonet fixed on a wooden post. The husked nuts are spilt across the middle, usually with a sharp blow from the cutlass. The endosperm is removed and dried either in the sun or in artificial heat. The essential requirements of copra drying is to bring down the moisture content of the wet meat from 50 per cent to 5-6 per cent. Good quality copra contains 60-65 per cent oil and 3-5 per cent moisture. The dried meat is now scrapped off and throughly ground. In rural areas, copra is crushed in the "chekku". On a commercial scale, power driven "chekku" or rotary mills, expellers and hydraulic presses are used for crushing. In the modern industrial units, solvent extraction plants are linked with the expellers or hydraulic presses for the optimum recovery of residual oil from the copra cake. In India, the yield of oil varies from 58-60 per cent from "chekku", 62-63 per cent from rotaries and 63-65 per cent from expellers.

Refining of Oil: Coconut oil received from the milling process contains free fatty acids and various impurities and is therefore refined before consumption. The refining is done by treatment with alkali (caustic soda) solution which neutralises the free fatty acids. The soap formed during the process is removed by washing with hot water and the moisture subsequently removed by heating the oil under vacuum. The oil is finally deodorized and decolourized by treating it with a mixture of Fuller's Earth and activated carbon and blowing superheated steam. The resulting oil is water white and odourless and is fit for human consumption.

Chemical Composition of Oil: The oil content of copra varies from 55-65 per cent. The main fatty acid constituents of coconut oil are lauric, 44-51 per cent; myristic, 13.1-18.5 per cent; palmitic, 7.5-10.5 per cent; capric, 4.5-9.7 per cent; stearic, 1.0-3.2 per cent; arachidic, 0-1.5 per cent; oleic 5.0-8.2 per cent, and linoleic 1.0-2.6 per cent. The latter two unsaturated fatty acids constitute only 9.0 per cent of the total fatty acid content. Coconut oil is a white to yellowish solid fat at temperatures below 24°C. At higher temperatures it melts to give a colourless or pale brownish yellow oil.

Uses

Coconut oil is one of the most important vegetable fats and is used in various ways. Some of the uses are listed below.

1. Refined coconut oil is edible and extensively used as a cooking medium in South India. It is also used for making margarines, candy bars and confectioneries.
2. The oil is also employed for anointing the body and for illumination.
3. Coconut oil is one of the most popular hair oils. It forms the base oil for various cosmetic preparations such as soaps, shaving creams, shampoos, and face creams.
4. It may be hydrogenated to form 'Vanaspati Ghee'.
5. Due to higher content of lauric and myristic acids, the oil has a very high saponification value and is used in the preparation of bath soaps. The soap obtained from coconut oil lathers freely in hard and salt water.
6. The oil cake is an excellent cattle feed.

15.3.5 Cotton

Botanical name: ***Gossypium*** **spp.**
Family: Malvaceae
Common names: Cotton, Kapas
n = 13

Cotton seed oil is derived from the seeds of various species of *Gossypium* that are grown primarily for their fibres. The cotton plant has been discussed in detail in Unit-20. In this unit we shall concentrate mainly on its seed as a source of oil.

Cotton seed (Fig. 15.6), as it comes out of the gin, consists of three main parts : (a) the fuzz or "linters", forming a thick coating of short fibres which give the seed a whitish or greyish colour; (b) the testa or "hull", a tough covering constituting nearly 35-40 per cent of the whole seed, and (c) the embryo with a long radicle and convoluted cotyledons, invested by a thin papery membrane (perisperm). The seeds, after the removal of the fuzz, are dark brown or nearly black, pointed and ovoid. The hilum and micropyle are at the pointed end of the seed, while the point of attachment of the stalk is at the other end towards one side.

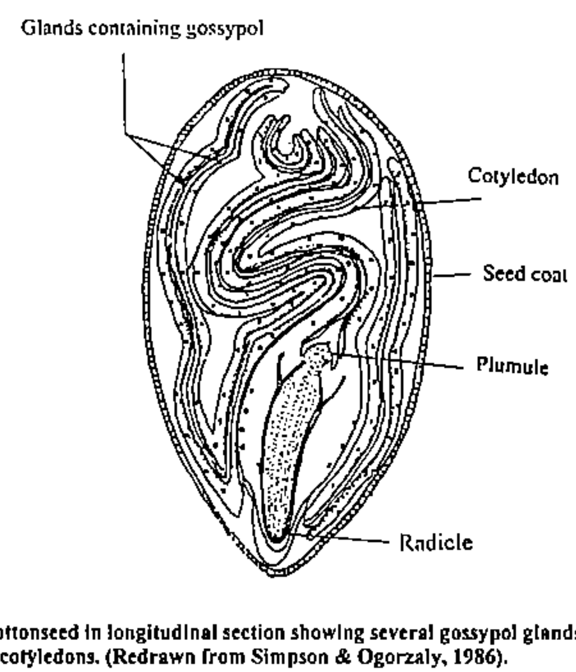

Fig. 15.6: A cottonseed in longitudinal section showing several gossypol glands. Note the intricate folds of the cotyledons. (Redrawn from Simpson & Ogorzaly, 1986).

The raphe is indicated by a slight ridge along the seed. The speckled appearance of the kernel is due to numerous tiny dark coloured pigment glands containing gossypol (1-2 per cent) – a polyphenolic substance that is toxic to pigs and chickens but not to cattle. In addition, the glands also contain gossypurpurin, gossyfulvin and gossycaerulin. Fortunately, most of the gossypol found in glanded cultivars of cotton is rendered harmless during processing as it combines with proteins to form substances which cannot be assimilated. Efforts are being made to produce cotton varieties having little or no gossypol.

Extraction of oil: The seeds after being thoroughly cleaned and freed from linters and impurities are crushed, heated and subjected to hydraulic pressure or expellers for oil extraction. The oil is led off to settling tanks where the impurities settle down, and the pure refined oil is drawn off.

Chemical composition of oil: The oil and protein contents of the seeds vary with the variety and agro-climatic conditions. The average oil content of Indian cultivated cotton is 18.5 per cent. The fatty acid compostion of cottonseed oil is: linoleic acid, 40-55 per cent; palmitic acid, 20-25 per cent; oleic acid, 18.3 per cent; stearic acid, 2-7 per cent and a small proportion of myristic and arachidic acids. Cottonseed oil also contains 0.9 per cent tocopherol (Vitamin E) known for its antioxidant effect, which helps to maintain the quality of the oil.

Uses

1. The pure refined oil is a valuable cooking medium and is used for making margarine, and is used as salad oil.
2. Low grade oil is used in the manufacture of soaps, lubricants, sulphonated oils and protective coatings.
3. The press foots (meal), obtained as a by-product during the refining of cottonseed oil, finds use in various industries such as soap, washing powder, oil-cloth, artificial leather, insulating material, tar, putty, glycerine and many others.
4. The cottonseed cake is used as a fertilizer and a cattle feed. In India, the whole seed is also fed to dairy cattle.
5. Pharmaceutically, cottonseed oil is used as an emollient. The refined cottonseed oil is used as a solvent for the preparation of steroid hormone injection.

15.2.6 Soyabean

Botanical Name: ***Glycine max***
Family: Fabaceae
Subfamily: Papilionoideae
Common Names: Soybean, Soyabean, Bhat, Ramkurthi
n = 20

Ancient Chinese literature reveals that the soyabean (Fig. 15.7) was extensively cultivated and it was highly valued as food. The first written record of the plant is contained in Chinese writings dating back to 2800 B.C. in which it is mentioned as one of the five principal and sacred crops. It was an important food plant in China, Manchuria, Korea and Japan since early times. It was carried to Europe by French Missionaries in 1740. Soyabeans were first brought to the United States in 1804 but failed to receive any recognition. It is only relatively recently that it has become widespread and its potential has been recognised. At present it ranks high among the leguminous crops in its nutritional value owing to high protein content (43 per cent). It has about 20 per cent oil. So numerous are the uses of the Soyabean that it is called as "wonder bean".

Soyabean has also been discussed in detail earlier in Unit-12, Legumes (Pulses). In this unit we will discuss the chemical composition of seeds, extraction of oil and uses of Soyabean oil.

Chemical Composition of Seed: The soyabean is an oleaginous seed, containing lipids, proteins, carbohydrates and minerals. Black-seeded varieties are richest in proteins and have a low percentage of oil. Yellow-seeded forms, on the other hand, have a higher oil content but are low in proteins. The soyabean oil in the crude form consists of 90-95 per cent fatty acid, glycerides and minor components of phosphatides, sterols, tocopherols and pigments. The fatty acid constituents of oil are oleic acid, 23-34 per cent; linoleic acid, 52-60 per cent; palmitic acid, 7-14 per cent; stearic acid, 2-6 per cent; linolenic acid, 3.0 per cent and higher saturated acids up to 2.0 per cent. Soyabean contains the glycosides genistin and diadzin and saponins. The chief form of protein is a globulin (glycinine) accounting for nearly 80-90 per cent. Besides this, another globulin (phaseolin) and an albumen (legumelin) are also present. The seeds are also a rich source of calcium, iron and vitamins, especially of the B-complex type. Other minerals present are phosphorus, potassium, copper and traces of sodium, magnesium, sulphur, chlorine, iodine, manganese, zinc and aluminium.

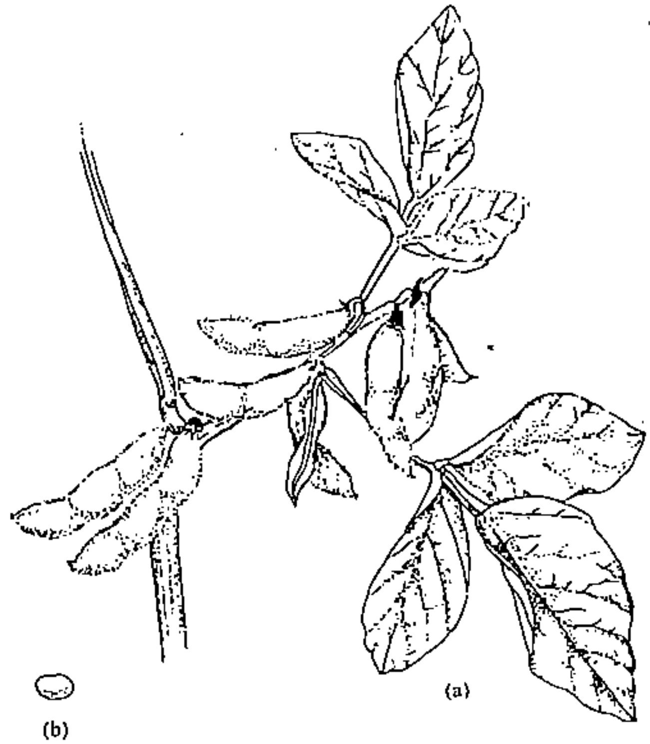

Fig. 15.7: Soyabean (*Glycine max*). a) A twig with pods. b) A seed. (Redrawn from Langer & Hill, 1991).

Extraction of oil: Soyabean oil is obtained by expression or by solvent extraction. The oil varies in colour from yellow to dark amber, depending upon the process employed and the type of seeds processed. It has a characteristic beany odour and flavour which can be eliminated by refining and deodorization.

Uses

1. The refined oil is used for edible purposes, particularly as a cooking oil, salad oil and for the manufacture of margarine.
2. It is also employed for packing sardines, tuna and other kinds of fish.
3. It finds wider application in the manufacture of soaps, glycerine, printing inks, greases, lubricants, resins, insecticides, disinfectants and leather dressings.
4. The oil is used extensively with drying oils in the paint, varnish and enamel industries.
5. Soy lecithen, an important by-product of the oil industry, is used in the food industry as an emulsifier and also in the cosmetic, pharmaceutical, paint and plastic industries.
6. Soya meal, the residue left after the extraction of oil, is a very rich protein feed for cattle, pigs and poultry.

15.2.7 Sunflower

Botanical Name: ***Helianthus annuus***
Family: Asteraceae
Common Name: Surajmukhi
n = 17

Sunflower is ranked fourth in the world among sources of vegetable oil, following Soyabean, groundnut and cottonseed oil. The commercial sunflower of today is believed to have originated in Peru or Mexico. It was introduced into Europe by the Spaniards in the sixteenth century. After its introduction to Spain, it spread to Bavaria in 1625, to

Europe in 1787 and then to Hungary, Russia and other parts of Europe. The largest producers of sunflower seeds are the Russia, Argentina, Rumania, USA and Turkey. In India, the value of sunflower as an oil-yielding plant has been lately recognised. It is grown mainly in Karnataka and Maharashtra. It is also cultivated in Andhra Pradesh, Tamil Nadu and Uttar Pradesh.

The plant is a coarse, tall, annual (see Fig. 15.8). It has a woody stem which is covered with rough hairs. It is of 0.6 to 4.5 m in height. Large, ovate or cordate, dark green coloured leaves are borne in alternate manner. The inflorescence is a capitulum or head which is usually terminal. There are two kinds of florets – tubular disc florets and ligulate ray florets in the inflorescence. The former are hermaphrodite and latter pistillate. The ovary is inferior with a single ovule. The flower heads are strongly adapted for insect pollination. The fruit is a single-seeded achene with pappus for air dispersal.

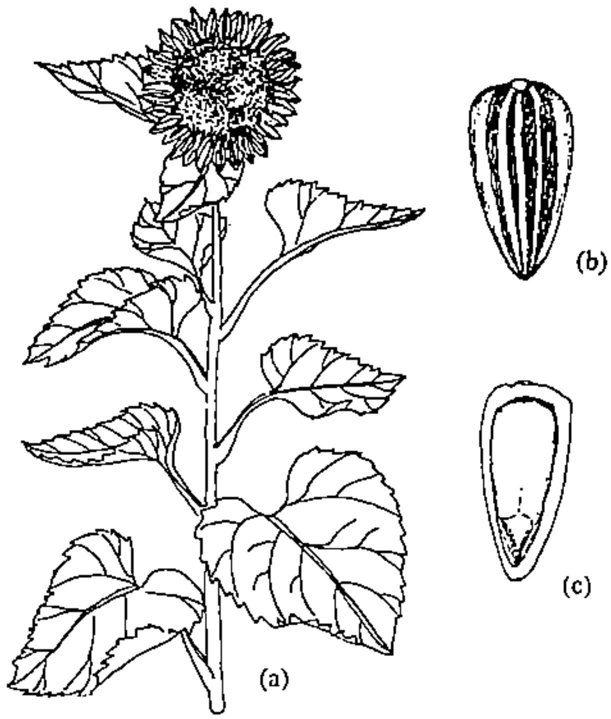

Fig. 15.8: Sunflower (*Helianthus annuus*). a) A flowering shoot showing a single large flower. b) and c) Seed in surface view and in longitudinal section, respectively.

Cultivation and Harvesting: Sunflower crop can be grown on any type of soil, alkaline to sandy types, but acidic soils are not suitable. It is cultivated as rainfed or irrigated crop, as a mixed crop or pure crop. The crop likes humus and this can be best supplied by rotted dung or compost. NPK fertilizer is also applied to the soil before sowing the seed. Green manure is also applied. The seeds are sowed in rows with multi row drills. Hand sowing can be done after making holes in the ground with shallow drills.

It is possible to grow three sunflower crops a year with an average yield of 20 to 25 quintals per hectare per season. On account of its day neutrality, sunflower crop can be adjusted in any crop rotation and may be helpful in solving the problem of non-utilisation of land in off-seasons.

When the crop is mature, the stalks are cut about 7.5 cm above the ground and then they are field dried. Under good drying conditions the heads rapidly lose moisture. Hand threshing is practiced with small crops. The seeds are dried on airy floors and winnowed.

Chemical Composition of Oil: The seeds contain 55-60 per cent of linoleic acid and 25-30 per cent of oleic acid. In cool temperate climates the seeds contain 70 per cent linoleic acid and 15 per cent oleic acid, while in hot tropics the linoleic acid is as little as 20 per cent and oleic acid is as much as 65 per cent. The semidrying oil is usually 32-45 per cent. The oil is extracted by hot or cold expression.

Refined first grade sunflower oil, freshly obtained, is pale yellow, with pleasant odour and flavour. The second pressings usually retained for manufacturing purposes are of a darker colour.

Uses

1. It is a very good salad oil. It is used in margarines and in the manufacture of butter substitute.
2. Its low fat content makes it an ideal cooking medium especially for heart patients, as it does not increase the cholesterol level in blood.
3. Sunflower oil may be used as a substitute for groundnut oil in the manufacture of "vanaspati ghee".
4. It has many commercial uses, such as in the manufacture of fine paints, soaps and cosmetics. As an oil for paint it is valuable as it dries in about 26 hours whereas linseed takes 34 hours to dry.
5. The seeds are a good poultry food, particularly for the egg-laying birds in winter.
6. The oil cake is used as a cattle feed.

15.3.8 Linseed

Botanical Name: ***Linum usitatissimum***
Family: Linaceae
Common Names: Alsi, Flax
n = 15

Linseed is one of the earliest plants to have been under cultivation for the extraction of fibres. The plant also yields oil of commercial importance. It is grown widely in many parts of the world, both in tropical and temperate zones. The crop is grown in hot dry regions mainly for oil production, and in temperate regions for high grade fibre. The varieties grown for fibre are usually different from those for oilseed production.

Two main geographical groups corresponding to the oldest areas of cultivation and the centres of diversity may be recognized. Linseed has been cultivated since antiquity in the Mediterranean coastal lands, Asia minor, Egypt, Algeria, Spain, Italy and Greece. In all these areas only fibre flaxes are cultivated. The second group comprises South-west Asia including Afghanistan and India; only oil types are grown in these areas. In Asia minor and South Russia, transitional forms are cultivated for both fibre and oil. Presently, the linseed crop is cultivated in India, Pakistan, China, Japan, Australia, Argentina, Canada and the United States of America. The leading linseed producing states in India are Madhya Pradesh, Uttar Pradesh, Maharashtra, Rajasthan, Bihar, West Bengal and Orissa.

The plants are annual, herbaceous, with cylindrical erect stem, simple below, 0.6-1.2 m tall, often solitary corymbosely branched above (Fig. 15.9 a); leaves narrow, linear or lanceolate without stipular glands, flower 2.5 cm in diameter, in broad cymes; sepals ovate, acuminate; petals blue; styles free, stigmas linear-clavate. The fruit (Fig. 15.9 b) is a small, indehiscent, globular, multi-chambered capsule with a persistent calyx, developing from a pentacarpellary ovary. It possesses 10 locules, each with one seed. The seeds are oval or lenticular in outline, 4-6 mm long by 2 to 3 mm wide, and have distinct obliquely pointed end where the hilum and micropyle are located in a slight depression. The seeds are characteristically smooth and flattened with a shining yellow to reddish brown testa and possess a distinct raphe line along one edge. The testa produces a large amount of mucilage when wetted. The endosperm is scanty and surrounds the thick cotyledons.

Cultivation: In India, flax is a winter crop and flourishes equally well in both the peninsular region of the South and the alluvial soils of the North. In general, a lighter soil where the rainfall is heavy, and a heavier soil where drier conditions prevail, suits the flax plant very well. It is mainly a rain-fed crop and requires average rainfall ranging from 75-175 cm in a year. Flax is primarily a winter (*rabi*) crop all over India. Its normal time of sowing differs from region to region. In the Peninsular India, it is generally sown early in October, whereas in the North in the gangetic alluvium it is generally sown in November. Linseed is grown as a mixed crop with gram, wheat, barley and mustard. There is a general belief that flax is an exhaustive crop and therefore, raising flax after flax is not often practised as the land is said to become flax-sick. So crop rotation practices with jowar, arhar, til, coriander, wheat, gram and cotton are followed. Varieties grown for seeds are shorter and more branching and spaced farther apart to encourage added branching, thereby increase seed production.

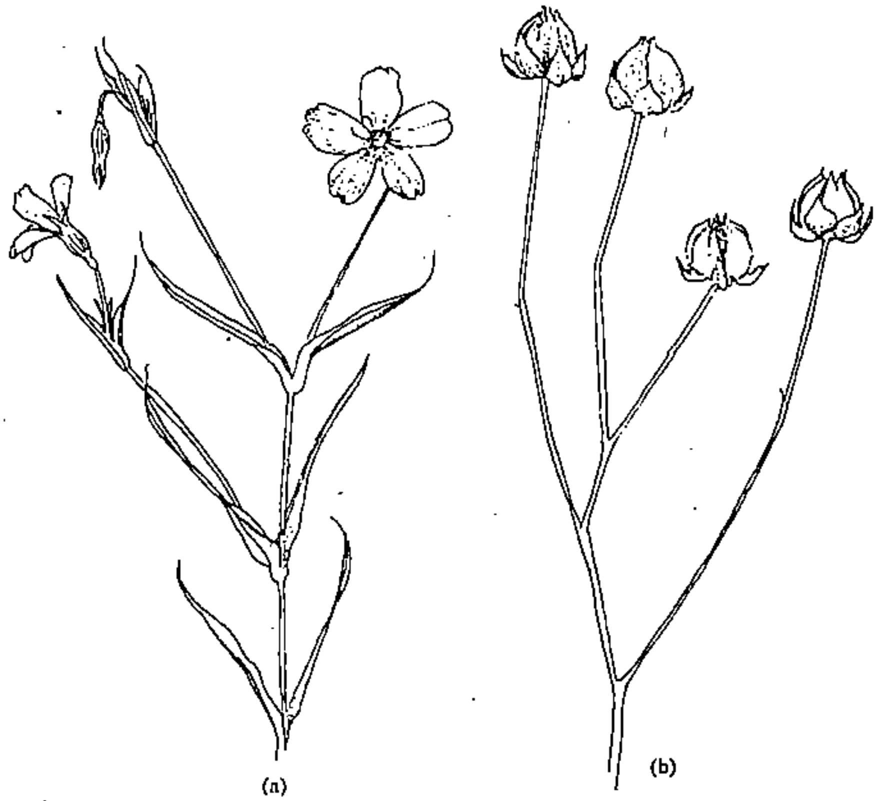

Fig. 15.9: Linseed (*Linum usitatissimum*). a) A twig showing leaves and flowers. b) A part of inflorescence showing capsules (From Langer & Hill, 1991).

Harvesting: The linseed crop matures in about six to seven months. In India, the crop is harvested generally in February and March in two ways, viz., either by cutting the plants close to the ground with sickle or by uprooting the plants by hand. For oil-seed purposes the first method is employed and for fibre purposes the latter method is followed. After harvesting, the crop is allowed to dry in the field for a few days and then threshed under bullock's feet or with wooden mallets or by simple peddle-operated machines or stone rollers. The separation of the seed from the chaff is easily carried by exposing the threshed material to the blowing winds, when the seeds fall down and the chaff (bhusa) is blown away to a distance before it settles down. A hand-winnowing machine can also be utilized in separating the seeds from the chaff.

Extraction of the oil: The oil is contained in the cells of the two large cotyledons in the form of yellowish globules intermixed with aleurone grains. The oil content of the seed is between 33 and 43 per cent. The oil extraction is carried out mostly by bullock-driven ghanis (Kolhu) which are not useful in extracting all the oil available and as such a large part of the oil is left in the cake. In recent years power driven rotary *ghanis*, hydraulic presses and expellers are used for oil extraction. Both cold and hot expression methods are used for the extraction of oil. In general before crushing, the seeds are rolled into meal and cooked in a steam jacketed trough.

Chemical Composition of the Oil: The oil content of the seed varies according to the variety of linseed and climatic conditions under which the crop has been raised. If protected from air and light, the oil has a good keeping quality. On exposure to air, however, it is converted into an elastic solid known as linoxyn. Linseed oil is a yellowish brown liquid, characterised by the presence of a high percentage of linolenic acid (30-60 per cent). Other fatty acids are stearic and palmitic (6-16 per cent), oleic (13-36 per cent), linoleic (10-25 per cent), and traces of myristic and arachidic acid. Crude linseed oil yields 0.25 per cent phosphatides consisting of lecithin and cephalin.

Uses

1. It is principally used in the paint and varnish industry as it is a drying oil. A mixture of lac: linseed oil: red lead in the proportion 80:160:12 gives the most satisfactory lac-linseed-oil varnish.
2. It is also used in the manufacture of linoleum, oil-cloth, printing and lithographic inks and soft soaps.
3. The oil is employed in the preparation of lubricants, greases and polishes.
4. Raw linseed oil is used in pharmaceuticals as an emollient, expectorant and diuretic. Because of the hydrophilic property of mucilagenous substance in the seed coat, the whole seed is used as a laxative as it draws fluid from body tissue with which it is in contact. The extracted mucilage is often used in the cosmetics and pharmaceutical industries as a demulcent.
5. Linseed oil mixed with limewater is applied to burns.
6. Oil cake is used as a good organic manure. It can be mixed with other inorganic manures for increasing the fertility of soil.
7. Oil cake is palatable, protein rich (30 per cent) and used as a cattle feed. It has slightly laxative action. But this possesses some poisonous properties, so only small quantities are fed to cattle. The poisonous effect of the seed is due to the presence of a cyanogenetic glycoside, phaseolunatin (linamarin). Cattle poisoning is caused by the hydrocyanic acid or prussic acid which is released by the activity of the enzyme linase on linamarin. Hot pressed linseed cake is harmless as the linamarin fraction is not hydrolysed to HCN owing to the denaturation of the enzyme linase during cooking.
8. Quite often the raw linseed oil is heated to 90-105°C in the presence of driers such as the salts of certain metals like lead, manganese, cobalt and zinc. Boiled oils dry at a faster rate and form a smooth and lustrous film and are preferred for most industrial uses, e.g., in the paint, lacquer and varnish industry.

15.3.9 Olive

Botanical Name: ***Olea europaea***
Family: Oleaceae
Common Name: Jaitun
n = 23

Olive oil is obtained from the fruits of the common olive tree, *Olea europaea*, of which there are now hundreds of cultivars, some developed exclusively for oil extraction. It is cultivated mainly in the Mediterranean countries with Spain, Italy, Greece and Portugal as the leading countries. Olive is cultivated to some extent in Northern India. *O. europaea* is a narrow-leaved xerophytic tree, usually attaining a height of 15.0-18.5 m. The fruit is one-seeded. The colour of the fruit is green at first and then changes through blue, purple and red then to black. The mesocarp or pulp is oily and encloses an elongated brown seed, often referred to as a "store".

The olive tree grows only in regions with a warm and dry summer and a mild winter. Temperatures below −10°C are fatal for the tree. For good flowering and fruiting a mean temperature of 10°C or lower (chilling) is considered necessary for nearly two months. The tree will grow but not fruit in the tropics. Typically, olives are grown in semi-arid regions and prefer light, deep soils, thriving best on calcareous sandy loams. Lands adjacent to the Mediterranean sea are ideal locations for olive cultivation. The olive tree is propagated by means of cuttings or grafting. The tree begins to bear fruits after six years and productivity declines after fifty years. For green olives. the fruits are picked by hand when straw-coloured and for ripe olives they are gathered when they turn black. For oil extraction harvesting is being done with mechanical shakers.

Extraction of Oil: The oil content of the fruit is between 25 to 60 per cent and the fruit pulp (mesocarp) contains at least 75 per cent. The kernels, on the other hand, have 12-28 per cent oil. The fruit being pulpy, the oil is squeezed from the pulp, either by hand or mechanically. Manual extraction yields the finest grade of oil which is golden yellow in colour, clear and limpid whereas the inferior grades have a greenish tinge and a tangy odour. Maximum yield of oil is obtained from fully ripe olives. In the milling operation most commonly used kernels are not separated from the pulp. Several expressions are made, the first pressing yielding the more valuable "virgin oil" is suitable for use without refining.

Chemical Composition of Oil: The fatty acid components of olive oil are: oleic acid, 65-86 per cent; palmitic acid, 7-20 per cent; linolenic acid, 5-15 per cent; myristic acid, 0-1 per cent and stearic acid, 0.3 per cent.

Uses

1. Olive oil is the most important non-drying oil. Its value as an important food oil is due to its keeping property, as it becomes sour only on long and continuous exposure to air. It is an important cooking medium in European countries and is used as salad oil, in canning sardines and in medicines.
2. The inferior grade oil is used for soap making and as a lubricant.
3. The residual oil meal is an important cattle feed and is used as a substitute for humus in soil.

15.3.10 Castor

Botanical name: *Ricinus communis*
Family: Euphorbiaceae
Common names: Erand, Arand
n = 10

Castor (Fig. 15.10) is an important oil crop. The oil is considered to be one of the best lubricants for high speed aero-engines. Its unique chemical properties make it suitable for a wide variety of uses and make it an oil of great industrial importance. The finest quality is used for medicinal purposes.

Castor is widely grown in tropical and sub-tropical regions, usually as an annual crop. The most important producers are Brazil, India and China. The United States of America is the largest importer, followed by France and the United Kingdom. Its cultivation has recently been taken up in the USA and some East-European countries. In India, Gujarat is the major castor producing state followed by Andhra Pradesh, Karnataka, Orissa, Tamil Nadu and Rajasthan.

The genus *Ricinus* is monotypic. Its four important subspecies are: *persicus, chinensis, africanus* and *zanzibarinus*. The first is considered to be the most productive and has no caruncle; *chinensis* has a small caruncle and the last two have large ones. *Ricinus* is now pantropical in distribution and its weedy or escaped forms abound. Early records of the use of the crop come from Egypt and India (in the great Sanskrit medical work, the *Suşruta Ayurveda*). It is thus presumably of ancient domestication and in Europe was reported to have been cultivated in the middle of the thirteenth century. The oil came into use for medicinal purposes in the eighteenth century but the small quantities of oil and seeds then required for European medicine were mostly obtained from Jamaica and India.

It is a tall, glabrous, perennial plant, often attaining tree-like proportions (9-12m), having well marked nodes and prominent leaf scars. Recently annual dwarf strains have been developed that grow to a height of only 1 to 2 m and complete their growth cycle in 150-180 days and these varieties are of much significance in modern farming. The leaves are large, green or reddish, palmately-lobed, serrated and borne in more or less alternate manner (Fig. 15.10 a). The castor plant is usually monoecious; the female flowers are produced in the upper part of panicle, whereas the male flowers develop in the lower part. Occasionally both types of flowers are interspersed along the entire length of the inflorescence. The capsular fruits (Fig. 15.10 b, c) may be spiny or smooth that split at maturity into three one-seeded cocci. Castor seeds (Fig. 15.10 d) exhibit a great variation in size and colour, and resembles a tick or beetle in having a mottled testa which encloses a thin integument, the tegmen. The hilum is almost concealed under the caruncle which is an integumentary proliferation at the micropylar end. The raphe is very prominent.

Cultivation: The plant if grown on a field scale, requires about 280 days from seeding to seed setting, but if it is grown in gardens or backyards of houses where there is a constant supply of water, the plant lives for a number of years. The crop thrives best where temperatures are fairly high throughout the growing season, i.e., between 20° and 30°C. Castor can withstand dry arid climate. In India, castor is grown under very varied conditions of soil and climate. It is raised on the poorest *chalka* (sandy) soil of the Telengana area of Andhra Pradesh and also on the rich alluvial soils of Uttar Pradesh. It is grown from sea level up to an elevation of 1500 – 2100 m but cannot tolerate frost, heavy rainfall and water logging. It is usually raised as a rainfed crop in regions with a rainfall between 60 and 90 cm but can grow well under 50 cm of rainfall also.

Harvesting and Extraction of Oil: Castor beans (seed) are harvested either mechanically or manually before the seeds reach full maturity. The seeds are decorticated with the help of specially designed hullers, the seed coats contributing up to 25 per cent of the weight of the seed. The kernels on expression yield about two-thirds of fixed oil or nearly 50 per cent of the total weight of the seed. The finest quality of almost colourless castor oil for medicinal and aeroengine lubrication purposes is produced by crushing the kernels at cold temperature. The once-expressed cake may be pressed again either hot, or solvent extracted with heptane, benzene or trichlorethylene to give inferior grades of oil. Castor seed cake contains at least three toxic substances : (a) *ricin*, an extremely poisonous substance present in large amounts; (b) *ricinine*, a slightly toxic alkaloid, and (c) an *allergen*, a protein polysaccharide. Ricin acts as a blood coagulant.

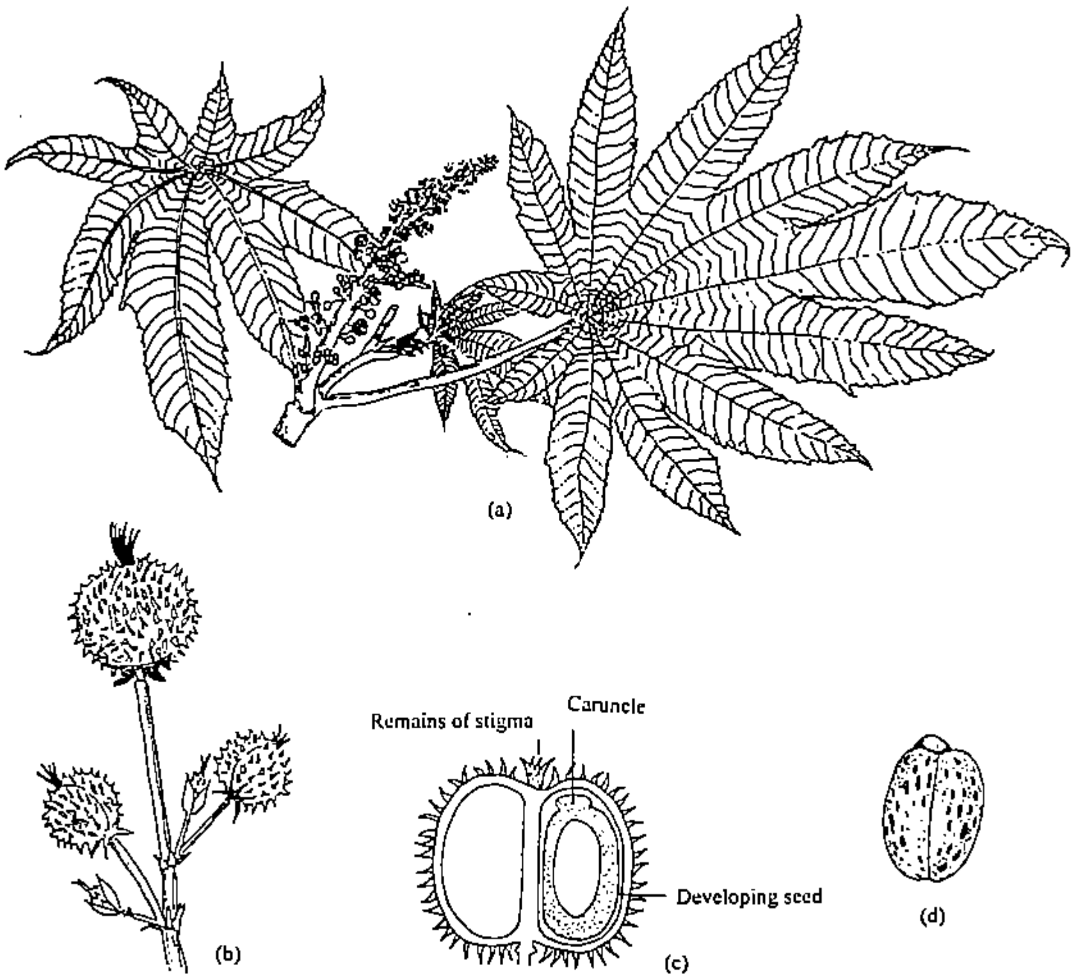

Fig. 15.10: Castor (*Ricinus communis*). a) A portion of shoot showing leaves and a young inflorescence. b) A part of the inflorescence showing female flowers and young fruits. c) Outline diagram of a young fruit in longitudinal section. d) Seed in front view [Redrawn from: a,d) Purseglove 1988; b,c) Cobley & Steele, 1976].

Chemical Composition of the Oil: Castor oil is nearly colourless or very pale greenish yellow viscous liquid. The fatty acid composition of castor oil is ricinoleic acid, 91-95 per cent; linoleic acid, 4.5 per cent; palmitic and stearic acids, 1.2 per cent and a negligible amount of oleic acid. The presence of ricinoleic acid to the extent of above 90 per cent imparts to the oil certain distinctive properties, such as high acetyl or hydroxyl value; high specific gravity, refractive index and viscosity; low saponification value, miscibility with ethyl alcohol, and near insolubility in petroleum ether.

Uses

1. Dehydrated castor oil – a product obtained as a result of heating, is a good drying oil and is used for paints, varnishes and other protective coverings. It is used in white surface finishes of refrigerators, in the manufacture of high quality varnishes, cover print varnishes, synthetic lithographic varnishes, in the printing ink industry, linoleum and oil cloth manufacture. It is an important raw material in the manufacture of various chemicals, e.g., sebacic acid and undecylenic acid used for the production of plasticisers and nylon fibres.
2. Heating castor oil at 450° C leads to pyrolytic decomposition as a result of which heptaldehyde and undecylenic acid are obtained. The former is used in the manufacture of various perfumes, i.e., violet, ionone, liliac. The latter is also used in perfumery and also finds wide use as a bactericide and fungicide.
3. Hydrogenated castor oil is used in lithium-based lubricating greases, in polishes and plastics and as a shellac blend.
4. Castor oil is widely used in India, as a solid contact lubricant in railway engine and locomotive bearings. Hydraulic brake fluid contains a large proportion of castor oil.
5. Fine quality castor oil is used for aeroengine lubrication.
6. Castor oil is also used in the manufacture of transparent soaps, and in toothpastes due to their strong bactericidal action.
7. Sulphonated castor oil is used in cotton dyeing and printing and also in the leather industry.
8. Castor oil is used in pharmacy as a strong laxative.
9. Ricinoleic acid finds use as an ingredient in chemical contraceptives where it functions by lowering the surface tension so that the sperms are disrupted.
10. Amides from castor oil yield on pyrolysis undecylamides used in fly sprays and insecticides.
11. Castor oil is used as an illuminating agent in rural areas.
12. The residue or cake meal is rich in protein, carbohydrates and minerals like phosphorus, calcium, potassium, magnesium and iron. Due to the presence of ricin, a blood coagulant, the cake is not used as a livestock feed, but is used chiefly as a fertiliser. However, of late, methods have been developed to detoxicate the meal.

15.3.11 Sesame

Botanical name: ***Sesamum indicum***
Family: Pedaliaceae
Common name: Til
n = 13

Sesame has been claimed to be one of the most ancient oil seeds known to man. It is an annual crop that matures in 70-140 days, but mostly around 105 days. The oil content of the seed is high (45-60 per cent) and is valued for high quality and stability and is used mostly for culinary purposes. The oil, seed and even leaves have several medicinal and other desirable properties.

Sesame has been under cultivation in the Mediterranean region, Africa, India and the far east. The origin of the plant is not known with certainty. There are numerous archaeological, prehistorical or literary references to sesame from the Middle East, Eygpt and India. The presence of nearly two-thirds of *Sesamum* species in tropical Africa suggests Africa as its possible primary centre and India as the secondary centre. Nearly 80 per cent of the production of sesame is from India, China, Sudan, Mexico, Burma, Ethiopia and Venezuela. The major exporting countries are Sudan, Mexico and Nigeria. The largest sesame acreage in the world is in India and the major supply comes from the states of Orissa, Uttar Pradesh, Rajasthan, West Bengal, Maharashtra, Madhya Pradesh, Gujarat, Tamil Nadu and Karnataka.

The plant is an erect, bushy annual, up to 2.0m in height with a longitudinally furrowed and densely hairy stem. The leaves are sessile or petiolate, entire, lobed or partite (Fig. 15.11). The lower leaves are broad and often lobed, whereas the upper leaves are more or less lanceolate. The bell-shaped (Fig. 15.11 a, b) white, pink or mauve flowers are borne singly or in groups of two or three in leaf axils.These are shortly pedicellate, calyx persistent or deciduous; Pedicels usually short with nectarial glands at the base; Corolla foxglove-like, obliquely campanulate; ovary 2-celled with numerous ovules; capsule hairy, oblong or ovoid, upright, deeply grooved with short triangular beaks (Fig. 15.11

a,c). The fruits dehisce by splitting along the dorsal sutures of each carpel. Two types of fruits have been recognised, one developing from a bicarpellate (four-loculed) gynoecium and the other arising from a quadricarpellate (eight loculed) gynoecium. In the latter case the fruits are usually developed singly. Seeds numerous and compressed, somewhat pear-shaped, ranging from pure white to brown or black in colour with a smooth or rough surface, enclosing an embryo with prominent cotyledons. The endosperm is found as a thin layer around the embryo.

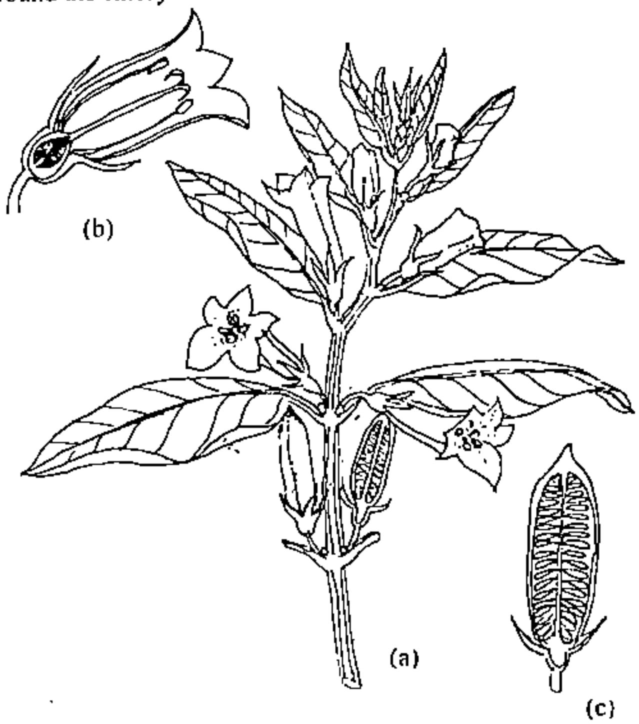

Fig. 15.11 : Sesame (*Sesamum indicum*). a) A twig with flowers and fruits. b and c) A flower and fruit in longisection respectively. (Redrawn from : Simpson & Ogorzally, 1986).

Cultivation: Sesame is a crop of the hot dry tropics, usually grown in areas with an annual rainfall of 50 to 110 cm. Heavy rainfall and high humidity damage the plant but it is drought resistant. The seeds fail to germinate when the soil temperature is below 21°C, but extremely hot weather (above 40°C) often leads to poor fruit set. In India, it is cultivated both as *rabi* as well as *kharif* crop and is grown alone or as a mixed crop along with bajra, millets, pulses and castor. It prefers light to sandy soil (kharif) or moisture containing medium, heavy, alluvial or black soil (rabi).

Harvesting: The crop is harvested before the plants are completely dry because this prevents shattering of capsules. The proper time for harvesting is when the lowermost capsules begin to turn yellow, but before they open. The crop is cut close to the ground with hand sickles. The stems are tied in bundles and stacked upside down over mats or threshing floor for about a week for the seed to ripen. The seeds fall as they ripen and also when the heads are shaken. Threshing can also be carried out by beating with sticks.

Extraction of Oil: Sesame seeds are rich in oil (50 per cent) and protein (20-25 per cent). The oil can be extracted simply by pounding the seeds in a wooden mortar after which the oil is removed by floatation process with hot water. In India sesame oil is obtained by using *ghani* which is drawn by bullocks or *chekku* or hydraulic press. Direct solvent extraction methods are used for extracting the oil on a commercial basis. The seeds on extraction by cold pressure, yield the commercially important *gingelly oil*. The finest quality of oil is obtained from white or yellowish seeds, whereas the dark coloured seeds of red, brown or black types yield a high per centage of fixed oil.

Sesame oil is pale yellow in colour, nearly odourless with a bland taste. It is insoluble is water, slightly soluble in alcohol and completely soluble in chloroform and ether. Like many other vegetable oils it lacks vitamin A, but is rich in vitamin E. The most useful property of this oil is its high stability so that, unlike other fats, rancidity does not spoil flavour and vitamins existing in the foods cooked in this oil.

Chemical Composition of the Oil: The sesame oil contains about 85 per cent of unsaturated acids. The fatty acid composition of the oil is: oleic acid, 37-50 per cent; linoleic acid, 37-47 per cent; palmitic acid, 7-9 per cent and stearic acid, 4-5 per cent. The oil contains two minor constituents that are not found in other fixed oils namely *sesamin* (0.5-1.0 per cent) and *sesamolin* (0.3-0.5 per cent). On hydrolysis the latter yields sesamol, a powerful antioxidant. In addition to sesamin and sesamolin the oil also contains phytosterol and tocopherol.

Uses

1. In India, sesame seeds are an important ingredient in a variety of sweetmeats and confections such as "rewari" and "gazak".
2. The sesame oil is used in the manufacturing of cooking fats, margarine and salad oil.
3. The finer grades of oil are edible and used as a cooking medium.
4. In European countries it is used as a substitute for olive oil.
5. In the U.S.A. and European countries, seeds are used as a garnish for bread rolls and baking products, often scattered on the tops of cakes, pastries and bread.
6. The seeds may be eaten fried or mixed with sugar.
7. The seeds are used by Hindus in their religious rituals.
8. The lower grades of oil are used in the manufacture of soap, rubber substitutes, in paint industries and also as a lubricant and illuminant.
9. In India the oil forms the basis of most of the scented oils used in perfume.
10. Sesame oil is highly prized in medicine as a carrier or suspending agent for antibiotics, vitamins and steroid hormones and also in insecticide preparations.
11. The oil cake is an excellent protein supplement for dairy cattle, poultry and pigs. The cake is also quite rich in calcium, phosphorous and niacin.

SAQ 2

i) Fill in the blank spaces with appropriate words.

a) The .... contains two minor constituents sesamin and sesamolin that are not found in other fixed oils.

b) Castor oil cake contains three toxic substances namely: (i) ...., (ii) ....and, (iii) ....

c) .... and .... both yield fibres and vegetable oils of commercial importance (write botanical names).

d) The kernel of cotton seed has speckled appearance due to numerous tiny dark coloured pigment glands containing ....

e) Sometimes the seeds of .... are mixed with *Brassica* seeds as an adulterant which causes epidemic dropsy in human beings due to the presence of an alkaloid sanguinarine.

ii) Give Botanical names of five fatty oils yielding plants in India.

....

....

iii) Briefly classify the vegetable oils.

....

....

....

iv) What do you mean by the term hydrogenation?

....

....

....

v) Why the castor oil cake is not used as a cattle feed?

....

....

15.4 SUMMARY

In this unit you have studied that:

- Vegetable fats and oils, also called fixed oils, are triglycerides of organic fatty acids. Fats are solid or semisolid at ordinary temperatures, whereas oils are usually in a liquid state.
- In modern industrial units, the vegetable oil is extracted from plant material by hydraulic or screw presses or solvent extraction systems, but throughout the tropics there are many local, simple methods of extraction. The residue remaining after oil extraction (oil cake) is usually rich in protein and is therefore used in the manufacture of animal food, and also as a fertilizer.
- Although oil has been extracted from the seeds of many species, there are only about twelve major oil crops which are mainly cultivated in the tropics. Oils used mainly as cooking and salad oils and in margarine manufacture include those from the sunflower (*Helianthus annus*), maize or corn (*Zea mays*) groundnut (*Arachis hypogaea*), Soyabean (*Glycine max*), olive (*Olea europaea*) and sesame (*Sesamum indicum*). Rape seed oil (*Brassica campestris*) is also used in margarine manufacture and in industry as a lubricant. Castor oil (*Ricinus communis*), in addition to its medicinal properties, is largely used in the preparation of paints, enamels, soap and lubricants. Linseed oil (*Linum usitatissimum*) is the most important of the drying oils and is used in the manufacture of paints and varnishes. Cottonseed oil (*Gossypium* spp) is a by-product of commercial cotton production for fibre and is used in foodstuffs: The dried kernel or copra of coconut (*Cocos nucifera*) is one of the major sources of vegetable oil in the world trade. Fruit of the West African Oil palm yields two oils: palm oil from the mesocarp and palm kernel oil from the kernel. Both are used in food and soap manufacture.

15.5 TERMINAL QUESTIONS

1. Give the method of extraction, properties and economic uses of the following:
   (a) Groundnut oil, (b) Linseed oil, and (c) Castor oil.

   ....

   ....

   ....

2. Name five important oil plants of India and write a detailed account of any two. You may use a separate sheet for writing answer.

   ....

   ....

   ....

   ....

3. List the chief fatty oil-yielding crops of India. Classify the oils on the basis of their drying properties and mention their uses.

   ....

   ....

   ....

4. What are vegetable oils and fats? Give a brief account of the botany, cultivation, extraction and uses of important vegetable oils produced in India.

   ....

   ....

   ....

5. Name two oil-yielding plants of India. How oil is extracted. Describe the uses of vegetable oils.

....

....

....

....

6. Mention the plants of following families which yield vegetable oil. How oil is obtained from these plants and what are their commercial uses?
   (a) Asteraceae, (b) Arecaceae, (c) Malvaceae, and (d) Euphorbiaceae

....

....

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....

7. Distinguish between:
   (a) Oils and fats
   (b) Essential oils and vegetable oils
   (c) Drying and non-drying oils.

....

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....

....

8. 'The groundnut fruits develop underground but the flowers are aerial', comment on this statement.

....

....

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....

15.6 ANSWERS

Self-assessment Questions

1. a. (✓), b (✓), c. (×), d. (×), e (✓), f (×), g (×), h (✓), i (✓), j. (×),

2. i) (a) Sesame oil, (b) ricin, ricinine, allergen
   (c) *Linum usitatissimum, Cocos nucifera,* (d) gossypol,
   (e) *Argemone*

   ii) *Arachis hypogaea, Carthamus tinctorius, Sesamum indicum, Ricinus communis, Brassica campestris.*

   iii) Refer to Subsection 15.2.3.

   iv) The process of converting oils, containing unsaturated fatty glycosides into fats, is known as hydrogenation of oils. Hydrogenation removes the double bonds of the oil, making it more suitable for edible purposes as well as improving its keeping quality, taste and odour.

v) The castor oil cake is not used as a cattle feed due to the presence of ricin, an extremely poisonous substance, which acts as blood coagulant.

Terminal Questions

1. a) See subsection 15.3.1
   b) See subsection 15.3.8
   c) See subsection 15.3.10

2. Refer to Section 15.3

3. See Sections 15.2 and 15.3

4. See Sections 15.2 and 15.3

5. Write any two examples. You may refer to section 15.3.

6. Refer to section 15.3

7. See Section 15.2

8. See subsection 15.3.1

UNIT 16 SUGAR AND STARCHES

Structure

16.1 Introduction
Objectives
16.2 Sugar
16.2.1 Sugarcane
16.3 Starches
16.3.1 Potato
16.3.2 Cassava
16.4 Summary
16.5 Terminal Questions
16.6 Answers

16.1 INTRODUCTION

Sugar and starches, the two common forms of carbohydrates, constitute a group of organic compounds containing carbon, hydrogen and oxygen generally, in the ratios of 1:2:1. The comparatively high percentage of oxygen makes carbohydrates a less efficient source of energy than fats and oils. They may be roughly divided into monosaccharides, oligosaccharides and polysaccharides. Monosaccharides are the least complex of the carbohydrates having a general formula $C_nH_{2n}O_n$. They cannot be hydrolysed further into simple carbohydrates and are the building blocks of the more complex oligo- and polysaccharides. Of all plant monosaccharides, glucose and fructose are the most common. Oligosaccharides are composed of two or more molecules of monosaccharides joined together by glycoside linkages and they yield simple sugars on hydrolysis. Sucrose (the condensation product of a fructose and glucose unit) and maltose or malt sugar (the condensation product of two glucose molecules) are two common examples of disaccharides. Polysaccharides are complex molecules of high molecular weight composed of a large number of repeating monosaccharide units held together by glucoside linkages. They have lost all their sugar properties. Their general formula is $(C_nH_{2n-2}O_{n-1})_x$. They can be broken down into their constituent sugars by hydrolysis. Starch and cellulose are the two most abundant polysaccharides in plants.

The carbohydrates are reserve food supply of not only plants but animals too. They are the most valuable products of the plant world and constitute a necessary food component for man. Carbohydrates make up the bulk of the dry weight of plants. Although they are of many kinds, various sugars, starches and cellulose predominate. The sugars are water soluble but starches and cellulose are insoluble in water. Cellulose cannot be digested by man but can be decomposed by microorganisms. The common sugar and starch yielding crops are listed in the following table (16.1).

Table 16.1: Sugar and Starch Crops.

Common name	Scientific name	Family
Plants yielding sugar		
Sugarcane	*Saccharum officinarum*	Poaceae
Sugarbeet	*Beta vulgaris*	Chenopodiaceae
Barley	*Hordeum vulgare*	Poaceae
Sweet sorghum, Sorgo	*Sorghum bicolor*	Poaceae
Wild date palm	*Phoenix sylvestris*	Arecaceae
Toddy palm, Sago palm	*Caryota urens*	Arecaceae
Coconut palm	*Cocos nucifera*	Arecaceae
Plants yielding starch		
Potato	*Solanum tuberosum*	Solanaceae
Cassava	*Manihot esculenta*	Euphorbiaceae
Queensland arrowroot	*Canna edulis*	Cannaceae
Taro	*Colocasia esculenta*	Araceae
Giant taro	*Alocasia macrorrhiza*	Araceae

Contd...

East Indian arrowroot	*Curcuma angustifolia*	Zingiberaceae
Greater Asiatic Yam	*Dioscorea alata*	Dioscoreaceae
White Guinea Yam	*D. rotundata*	Dioscoreaceae
Yellow Guinea Yam	*D. cayenensis*	Dioscoreaceae
Air potato	*D. bulbifera*	Dioscoreaceae
Cush-cush, Yampee	*D. trifida*	Dioscoreaceae
Sago palm	*Caryota urens*	Arecaceae
Sago palm, Queen sago	*Cycas circinalis*	Cycadaceae
Japanese sago palm	*C. revoluta*	Cycadaceae
Maize	*Zea mays*	Poaceae
Wheat	*Triticum species*	Poaceae
Rice	*Oryza sativa*	Poaceae

Objectives

After reading this unit, you should be able to:

- explain the process of formation of sugars, and their functions in plants;
- prepare a list of the main sugar-yielding plants of the world;
- describe the methods of cultivation of sugarcane;
- describe the morphological nature of the plant parts yielding sugar;
- explain the method of extraction of sugar and discuss its uses;
- explain the formation of by-products generated during sugar production and discuss their uses;
- summarise methods of improvement of sugar crop;
- explain the formation and storage of starch;
- identify main plant sources of starch;
- identify various types of starch grains;
- describe the morphological nature of the plants, and their parts that yield starch;
- describe the methods of cultivation of potato and cassava; and
- relate the importance and uses of starch to humans.

16.2 SUGAR

The name 'sugar' comes from the Sanskrit word "sarkara" meaning gravel and refers to the crude sugar. The human tongue knows only four basic tastes - sweet, sour, salt and bitter. Our "sweet tooth" has therefore always played a major part in making food attractive, so the sugar bearing plants are of great interest to us. It would be difficult to imagine our lives without sugars both as a source of energy and as a sweetening agent. Honey was the first sweetening material of our ancestors and, in order to have a steady supply at hand, man domesticated the bee and thus began apiculture. Sugar was a rare commodity in Europe until the Middle Ages and was used only by the aristocratic society. However, by the end of the fifteenth century, sugar had replaced honey as sweetener and became a cheap and common food for all people in the nineteenth and twentieth centuries.

All green plants are capable of synthesising sugars through their photosynthetic activity and it commonly occurs in small amounts in many plant species (see Fig. 16.1). Mostly the sugar produced is so scanty that little is accumulated while most of it is used during metabolism of the plant. The sugarcane plant is amongst the most efficient convertors of solar energy, carbon dioxide and water into energy giving food. Besides sugarcane, sugars are stored in large quantities in sugarbeet, carrots – roots; maize, sorghum and sugar maple – stems; number of palms – chiefly in their inflorescences; onion – bulb, and in many fruits.

Sugar is not only an essential food but is also an important preservative for several food products. The world's major supply of sugar at present comes from the culms of sugarcane (*Saccharum officinarum*) and smaller proportion from roots of sugarbeet (*Beta vulgaris*). The former is essentially a tropical plant while the latter is confined to subtropical and temperate climatic conditions. Sugarbeet has proved successful in Europe and forms the main source of sugar. It is second to sugarcane as the major source of the world's sugar supply. A small proportion is obtained from sugar maple (*Acer saccharum*); sugar palm (*Arenga pinnata*); palmyra palm (*Borassus flabellifer*); toddy palm (*Caryota urens*); coconut palm (*Cocos nucifera*); wild date palm (*Phoenix sylvestris*) and *Sorghum vulgare* var. *saccharatum*.

Sugarcane, an important source of sugar in tropics, is discussed in this unit.

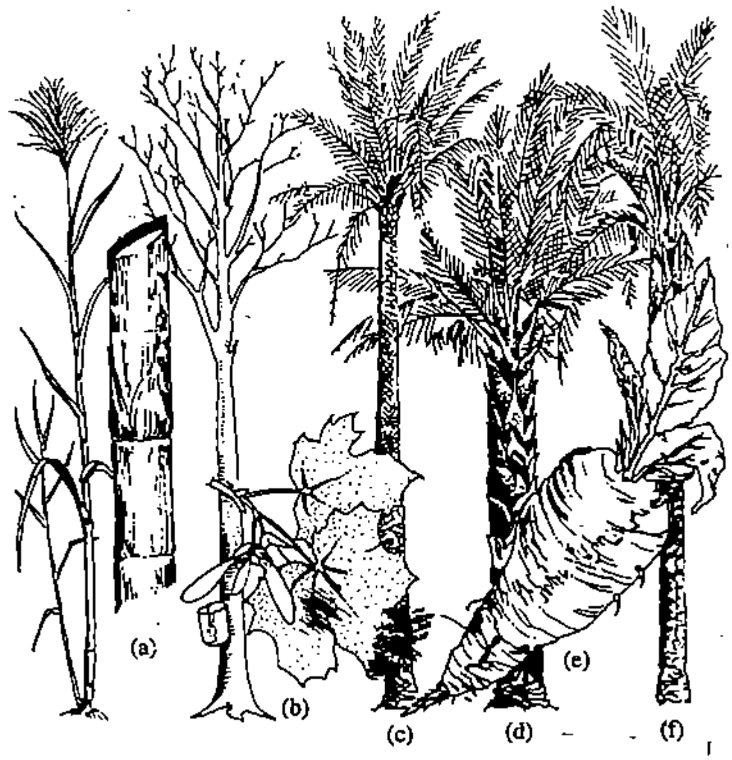

Fig. 16.1 : Common sugar and starch crops. a) Sugarcane, b) Sugar maple, c) Wild date palm, d) Sugar palm, e) Sugarbeet, f) Sago palm.

16.2.1 SUGARCANE

Botanical name: ***Saccharum officinarum***
Family: Poaceae
Vernacular name: Ganna
n = 6,8,10

Sugarcane, the primary source of sugar, is tropical by origin and is cultivated in all the warm countries. India, Cuba, Pakistan and Brazil are the major producers of sugar. There are significant productions also in the southern USA, the West Indies, several central and south American countries, Mexico, Egypt, Java, China, Taiwan, Philippines, South Africa and Australia. Cuba, also known as the 'world's sugar bowl', is the largest producer of sugarcane. Sugarcane is believed to have originated in the South Pacific, probably New Guinea and it spread throughout most of the southeast Asia.

In India sugarcane is known to have been cultivated since prehistoric times and became an important crop by the end of the fourth century B.C. During the invasion of India (327 B.C.) Alexander's army found the local people obtaining "honey" from a grass-like substance without the aid of bees. These grasses were in fact the plants yielding a sugary juice and they have been identified as belonging to genus *Saccharum*. The method of growing cane and making sugar then diffused towards East to Indo-China and West to Arabian countries and Europe. Sugarcane was being cultivated in China before the first century B.C. It reached Persia (now Iran) in the beginning of 6^{th} century A.D. Columbus is credited with having introduced it into the New World from the Canary Islands. By the 17^{th} century this plant was well distributed in the whole world.

In India sugarcane occupies about 2½ million hectares of cultivated land, and is cultivated practically in every state, with Uttar Pradesh well in the lead, followed by Tamil Nadu, Maharashtra, Andhra Pradesh, Karnataka, Haryana, Punjab, Bihar, Orissa, Gujarat and Rajasthan. This crop requires fertile soil, long growing period, plenty of water throughout the year, rainfall atleast 200-225 cm and between temperature range of 16-

50°C and average temperature of 26°C. It requires a short, dry season during later stages when sugar is being stored in the stem.

Origin

Cultivated sugarcane has two geographic centres of origin:

1) South Pacific islands particularly New Guinea, where there is maximum diversity of the genus *Saccharum*. Most botanists are of the opinion that cultivated sugarcane originated in this region and spread eastwards and finally became established as an important crop in several countries of South East Asia.
2) The second centre is Northern India. The tall large barrelled tropical species *S. officinarum* probably originated from *S. robustum* in New Guinea. As it migrated outwards it became modified to the new natural habitat with species of related *Erianthus maximus* or *Sclerostachya fusca*. The north Indian sugarcane *S. sinense* (Chinese or Japanese cane) and *S. barberi* (Indian canes) are believed to have originated in North India by natural hybridization between migrating form of *S. officinarum* the *S. spontaneum* (wild cane). The last two species also occur in the wild state (also see Fig. 16.2).

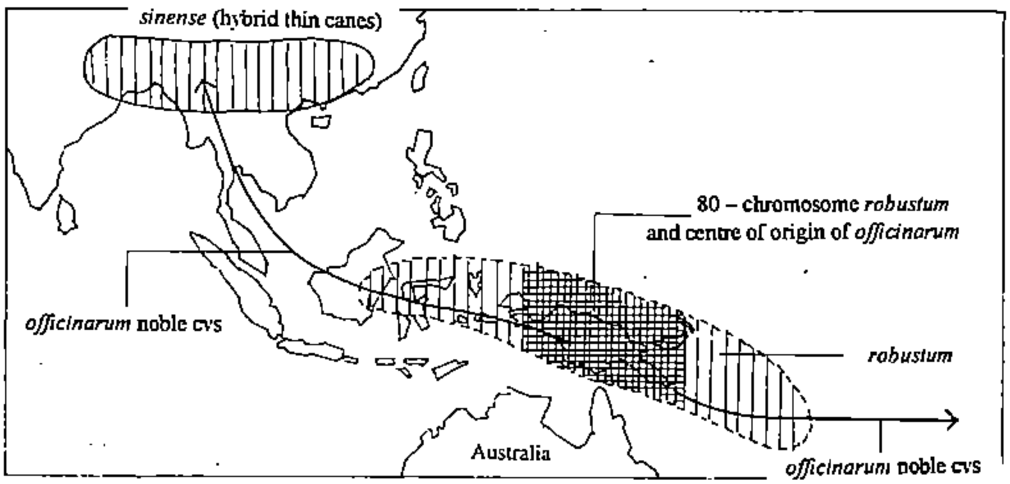

Fig. 16.2 : Map showing evolutionary geography of sugarcane.

Systematics of *Saccharum*

Five species of *Saccharum*, namely *S. officinarum*, *S. barberi*, *S. sinense*, *S. spontaneum* and *S. robustum*, have been recognised. These are indigenous to the old world and are polyploid or aneuploid. These five species are building blocks for all breeding work because they intercross and hybridize easily. Today most of the cultivated sugarcane are interspecific hybrids. The programme of producing these hybrids is known as "*Nobilisation*". The chief characters of these species are as follows:

S. officinarum (2n=80) Noble or thick cane. It is soft, thick-stemmed, large barrelled with a low fibre and high sucrose content. Although this species is an important source of sugar, it cannot be grown satisfactorily in most areas because it is susceptible to almost all the serious diseases reported on the crop.

S. barberi (2n=82 to 124) Indian cane. The species appears to be intermediate between the wild and the noble canes. In general, these varieties are hard, small barrelled with higher fibre content, a vigorous root system and have a good amount of juice. They have become prominent because of immunity to sereh.

S. sinense (2n=116 to 118) Chinese or Japanese canes. These are hard and small-barrelled. It has a great vigour, has wide adaptability and matures early. It stands light frost and drought and can be cultivated in north India. Though its sugar content is less the canes are fairly resistant to root rot and sereh and a few are also resistant to mosaic disease.

S. spontaneum (2n=40 to 128) wild cane. It is a vigorous, thin, grassy form, often with pithy stalks, virtually devoid of sucrose. It has a deep penetrating root system, and is resistant to drought and immune to sereh, mosaic and root rot. It is very widely used in breeding work.

S. robustum (2n=80) wild cane. This species includes tallest canes, has great vigour and wide adaptability. It has high fibre but low sugar content and is disease resistant. This species is exceedingly valuable in the cane breeding programme.

SAQ 1

(i) Give botanical names of three sugar-yielding plants.

....

....

....

(ii) Name the plants in which sugar is stored in stem, root, bulb and inflorescence.

....

....

(iii) Which Indian states are leading producers of cane sugar?

....

(iv) Which are the centres of origin of cultivated sugarcane?

....

....

(v) Give the botanical names of: (a) Noble cane, (b) Indian cane, and (c) Wild cane.

....

....

....

Morphology

Sugarcane is a perennial rhizomatous giant grass with a thick solid aerial stem, 3 to 8 m tall and usually 3.8 to 6.0 cm in diameter. It grows in clumps (stands). The colour of the cane ranges from almost white through yellow to deep green, purple red or violet. The stem is jointed, the joints being shorter at the base, gradually increasing both in length and thickness upward until a maximum is reached beyond which they become progressively smaller and finally terminate in an inflorescence.

A cane joint consists of five conspicuous parts:

i) A node – the area where the leaf sheath is attached to the stem;
ii) The root band composed of several minute translucent dots – the root initials or root primordia;
iii) The intercalary meristem, a narrow meristematic zone just above the root band, which is responsible for the growth of the internode;
iv) The internode - a barrel shaped structure covered with a fairly thick waxy bloom; and
v) The lateral buds placed alternately on opposite sides of the stem and protected from damage by the leaf sheath that forms a tight covering around the internode (Fig. 16.3).

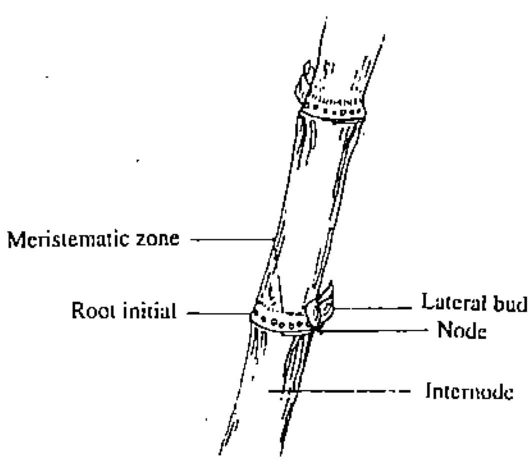

Fig. 16.3: Outline diagram of a piece of cane stalk consisting of two complete joints and part of two adjacent joints.

Anatomically, the outer part of the stem (rind) is composed of several layers of thick walled lignified cells that provide protection to the underlying cells. Internally, it consists of soft light-coloured tissue (pith) in which are embedded numerous fibro-vascular bundles. The parenchyma cells surrounding them contain a high percentage of juice, which amounts to about 85-88 per cent of the total weight of the fresh cane juice. The sucrose content of the juice varies from 12 to 17 per cent. The leaves are attached alternately in two rows on either side of the stem at the nodes and are built upon a typical graminaceous plan. The leaf blade is a long, thin, flat structure with a finely serrate margin, usually 2.5-10 cm wide and 0.9-1.5 m or more in length, and often clothed with hairs which inflict painful skin puncture (Fig. 16.4).

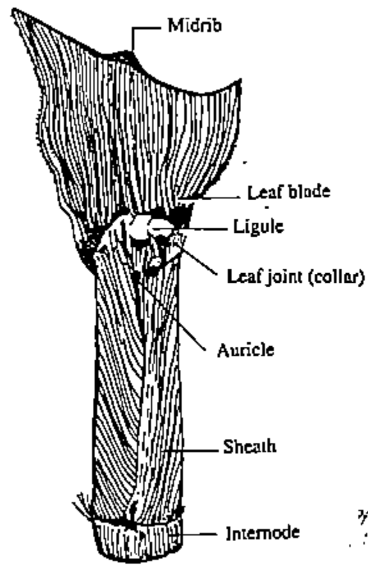

Fig. 16.4: Outline diagram showing serrate leaf margin (only a part of leaf shown here).

The light silvery tan coloured inflorescence, commonly referred to as a 'tassel' or an arrow, is an open feathery or woolly panicle, about 0.3 - 0.6 m in length and is produced only in the left-over or experimental plants (Fig. 16.5). Both spikelets are surrounded at the base by a ring of long silky hairs which impart a characteristic silky appearance to the inflorescence. The leaf sheath immediately surrounding the inflorescence is quite long (0.6 - 0.9 m), while the blade is quite short and is known as the flag. The structure plan of both the spikelets is similar, each having a pair of glumes that enclose both the florets, the lower flower being represented by only a sterile lemma. The lemma is, however, missing in the upper flower of *S. officinarum* (but is present in *S. spontaneum* and its hybrids) whereas the palea is a small, thin, narrow structure. The lemma of the lower flower, nevertheless, strongly enfolds the palea of the upper fertile flower. Two lodicules, three stamens and a centrally placed gynoecium with two styles ending in feathery stigmas are present (Fig. 16.6). The fruit is caryopsis. The seeds retain their viability for a very short time.

Chemical Composition

The millable cane contains 50-60% of the total dry matter of the whole plant, the tops and trash are about 30-40% and the roots and stubble is about 10%. The chemical composition is affected by age, environment and culture conditions. The leafy tops have a high percentage of reducing sugars and a low percentage of recoverable sucrose except when ripened under ideal conditions. The amount of sucrose, $C_{12}H_{22}O_{11}$ in the stem increases with maturity and is usually highest near the base, but changes occur with the degree of ripeness. The 26% organic matter consists of 9-16% of fibre and the rest is mainly sugars. The juice 85-88% of the total weight of cane is essentially water and sucrose, with some glucose and fructose and small quantities of mineral salts and nitrogenous substances. The total solids in the juice, is usually 20-22% of which 80-95% is sucrose, depending on the ripeness of cane. The overall recovery of raw sugar per 100 tons of millable cane is usually 9-13 tons. Efficient modern factories recover about 87% of the total sucrose originally present in the cane at the point of entry of factory.

Final raw molasses contains about 20% water, 35% sucrose , and 14% reducing sugars. Bagasse contains 25-55% water, 42-47% fibre, and 2.3-3.0% sucrose.

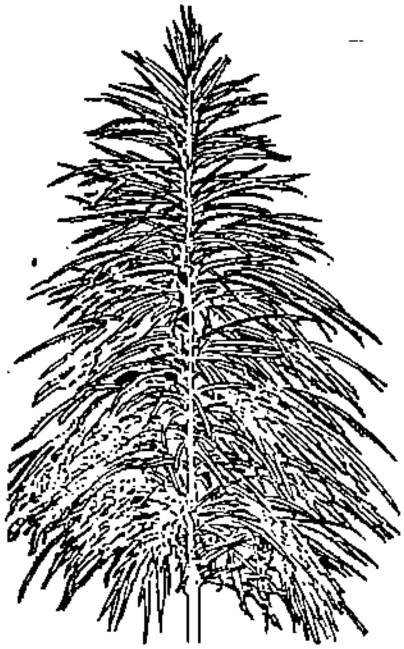

Fig. 16.5 : An inflorescence of sugarcane.

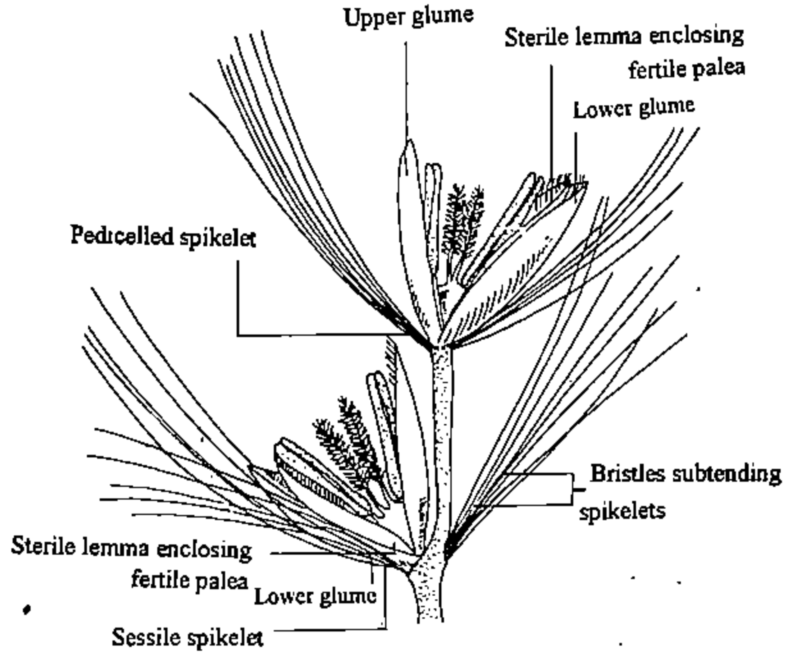

Fig. 16.6 : Sugarcane. A part of inflorescence showing paired spikelets. (From Cobley & Steele, 1976).

Propagation

Sugarcane is propagated vegetatively by stem cuttings of three to five joints termed 'seed cane' or 'seed pieces' or by ratooning, in which the dormant buds on the portion of the cane left underground after harvesting, sprout in two or three weeks time, producing a new crop – commonly known as "stubble" or "ratoon crop" (Fig. 16.7). The yield, however, almost always declines slowly with successive ratoon crops. Fields are usually cleared every three to four years and replanted with fresh cuttings.

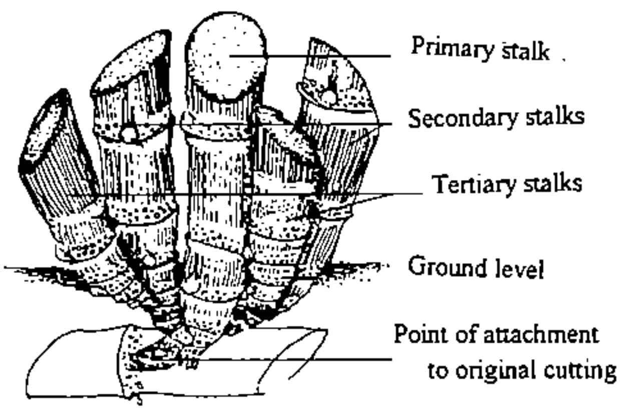

Fig. 16.7: Underground portion of a cane cutting (stool) bearing primary, secondary and tertiary stalks.

The cuttings are usually taken from plant canes 8-12 months old or ratoons of 6-8 months. Care is taken that they should be free from disease and pests. Setts are best taken from the upper third of the cane. The stem cuttings used for planting may be sections with two or more buds or eyes, usually three. They may be planted at an angle of 45° or laid horizontally in the base of furrows. Two cuttings are sometimes placed side by side. For rapid multiplication, one joint bearing a single pregerminated bud is used. The setts are often treated with organo-mercurial compounds before planting. For successful sprouting a well prepared seedbed, which is moist at the time of planting is required and planting is usually done early in the wet season.

The first crop after planting, known as the plant crop, takes 9-24 months to mature depending on local conditions. In most of the tropics it is usually planted during the rainy season to mature 15-16 months later. In other countires it occupies the land for 2 years. After harvesting the stubbles are left to produce 2-4 or more ratoon crops, each taking about a year to mature, after which the field is cleared and new plant crop is planted.

Sometimes a fallow period is left before replanting. The period of the plant and ratoon crop before replanting is known as the **crop cycle**. About 30-40% of the crop is ratooned.

Harvesting

Sugarcane is harvested when it reaches the stage of maturity as at this time it is with the highest sucrose content. Tests for ripeness are usually made on random samples taken over the whole field at intervals of 7-10 days. This can be done by cutting the whole cane or by examining the juice with a hand refractrometer from the central internodes of the upper and lower thirds of standing canes. Experience, visual observation and the field history also help in assessing ripeness. Modern cane evaluation is based on the sucrose content at the time of delivery to the factory. In most tropical countries the crop is ready to harvest in 14-18 months in **plant crop** and at 12 months in **ratoon** or **stubble crop**. It is usual to harvest first the ratoon crops which are due to be ploughed out, followed by the plant crop and lastly ratoons which will be again ratooned.

In most countries, the cane is cut by hand using cutlasses (machete). The crop is cut close to the ground. It is also harvested by gigantic cutting machines in modern plantation. They are then stripped of the dried leaves and sent to factories for processing without any loss of time. The cut cane soon begins to deteriorate (the sugar being labile undergoes inversion into glucose and fructose) but the effect on milling and recovery is negligible during the first 48 hours.

SAQ 2

(i) What is ratoon crop?

....

....

(ii) Which is the right stage of harvesting the sugarcane and how it is tested?

....

....

Manufacture of Sugar

The white crystalline sugar from cane is manufactured as follows:

1. **Extraction of Juice:** The ideal material for processing is clear, ripe cane, free from trash, tops and foreign material. The freshly cut cane stalks are shredded into small pieces with the help of crushers and then passed through heavy, grooved steel rollers to squeeze out the juice. Several successive expressions are required to ensure complete extraction of the juice. After each expression, the cane is moistened by sprays of water to facilitate a complete recovery. The material left behind is called "bagasse". The expressed juice is a turbid, dark greyish sweet fluid full of impurities such as organic acids, minerals, proteins, colloidal colouring matter, gums, pieces of cane and other extraneous material.

2. **Purification of Juice:** The juice is first strained to remove the insoluble and suspended particles and is then subjected to defacation, carbonation and sulphitation, to remove completely the dissolved non-sugars. During defacation the juice is heated with measured amount of lime to remove free organic acids and phosphates as insoluble calcium salts. The proteins and colloidal colouring matter are removed from the solution as a thick scum appearing on the surface. The precipitated calcium salts and the scum are removed by filteration through canvas. The filtered juice is then led to tanks where it is allowed to come in contact with carbon dioxide (carbonation), a process which removes excess lime as calcium carbonate and also brings about decomposition of calcium sucrate into soluble black sugar. During *sulphitation* the filtered carbonated juice is treated with sulphur dioxide to complete the neutralisation of lime and the decomposition of calcium sucrate.

3. **Concentration and crystallisation:** The purified juice is now led to evaporators where it is boiled under reduced pressure until it becomes a thick syrup. Partial vacuum boiling also prevents darkening and decomposition of sugar. The concentrated raw syrup is finally boiled in a vacuum pan to the point of

crystallisation to produce a thick sticky mass (massecuite) in which a part of the sugar is thrown out in the form of crystals. This dark brown mixture of sucrose crystals and mother liquor (molasses) is next stirred in open tanks, or crystallisers until it crystallises. Finally the massecuite is led into centrifugal machines, an operation during which the molasses passes through the screen and the crude sugar is retained in the basket from where it can be removed after a quick washing with water. The molasses still contain some crystallisable sugar and is mixed with the raw syrup and boiled. This is repeated three or four times to remove as much sugar as possible. The centrifugal raw sugar is reddish brown or somewhat greyish in colour and contains about 96 per cent sucrose. It is usually exported in this form, further refining being done in the importing country.

4. **Refining and Drying of Crystals:** The raw sugar is redissolved in hot water and the suspended impurities removed by adding diatomaceous earth. The solution is decolourised to a colourless sparkling liquid by treating with carbon black. The clear syrup, after vacuum concentration, is centrifuged so that pure sparkling white crystals of sugar separate out. The crystals are then dried in large rotary driers in the presence of strong current of hot air. The dried granulated sugar crystals are now passed across inclined vibrating screens to be graded according to size and are shipped for export after packaging.

In India and other parts of Asia, a considerable amount of juice is evaporated over an open fire in a large shallow iron pan with flaring sides. When the boiling syrup reaches a temperature of 118-120°C, the thick semi-solid mass is quickly transferred to wooden troughs or moulds where it solidifies on cooling. It is known as "gur" in India, "jaggery" in Africa, and "panela" in Latin America, technically it is non-centrifugal sugar.

SAQ 3

Fill in the blank spaces with appropriate words.

(i) The dry fibrous residue left behind after extraction of juice from sugarcane stem is called ....

(ii) During .... the extracted juice is heated with measured amount of lime to remove free organic acids and phosphate as insoluble calcium salt.

(iii) .... is an important by-product of sugar industry widely used for making alcoholic drinks.

(iv) The concentrated syrup formed after sulphitation, which is passed on to the crystallizing tank is known as ....

Economic Importance

1. Sugarcane is a very important source of sugar, which is an important source of energy in the human diet.
2. Large quantities of sugar are used in the manufacture of alcoholic beverages, soft drinks, confectionery, ice-creams and chocolates, and in canning industry.
3. Cereal manufacturers use sugar as a sweetening agent.
4. It is used in hair tonics, explosives, photographic supplies and medicines.
5. It helps in the tanning of leather, the silvering of mirrors and making adhesives.
6. Molasses, an important by-product of the cane sugar industry, is widely used as a livestock feed, for making alcoholic drinks such as rum and for the manufacture of a host of chemicals, including industrial alcohol, vinegar, glycerol, lactic and citric acids. It contains about 35% sucrose and 15% reducing sugars. It is this 50% of fermentable sugar which gives it its principal value as an industrial raw material. Rum is produced by the fermentation of molasses by the yeast *Saccharomyces cerevisiae* followed by distillation. Molasses are also used for manufacture of dry ice. Acetone and butanol are produced by fermentation of molasses with *Clostridium* bacteria.
7. Cane wax, after extraction with solvents, is used in manufacturing polishes, cosmetics and paper coating.
8. The filter cake is used as a fertiliser because of its high calcium, nitrogen and phosphorus content.
9. Thick noble (relatively soft, with a high juice and sugar content and low in fibre) canes are chewed.
10. Bagasse is burnt as boiler fuel, used as a mulch for plants and as a litter or bedding for poultry and livestock. It is also used in the manufacture of paper, insulating

fibreboard, cardboard, plastics and furfural. The furfural is important in oil refining and nylon industries.

Breeding of Sugarcane (Improvement)

Sugarcane has been subjected to elaborate breeding work, and the hybrid canes produced have been selected for disease resistance, faster growth, lack of branching and higher sucrose yield. The Dutch installed a sugar experiment station in Java as early as 1885 and one of the varieties of canes produced there is among the world's best. The British set up a similar station at Coimbatore in India and another in Barbados, and the improved canes produced at these stations are also widely planted.

It was in 1888 that Soltwedel in Java, and Harrison and Bovell independently discovered the viability of sugarcane seeds. This discovery came at a time when diseases were threatening the cane growing regions and it marked the beginning of a new phase in sugarcane breeding. During the first few years, the breeding programme was confined to selection, but was soon followed by intervarietal and interspecific **hybridization.** Crosses were made between varieties of *Saccharum officinarum* and other species such as *S. barberi* and *S. sinense* to produce resistant varieties. The reason for crossing noble canes with the wild types was to produce hybrids that combine the best features of both the parents, i.e., thick, soft, long barrelled cane and high sucrose content of *S. officinarum* as well as the deep penetrating root system, vigour, drought and disease resistance of the wild parents – *S. spontaneum* and *S. robustum*. The first generation progeny is intermediate between these two parents and is commercially unsuitable for sugar production as the stems are often thin, pithy and contain little sugar but have some of the vigour and disease resistance characters. The back cross of F_1 hybrids with noble varieties greatly improves the productive quality of the canes without diluting the favourable attributes of the wild parent hybridization with noble canes (*S. officinarum*) to upgrade the sugar content is known as '*nobilisation*'. The key event in cane breeding was the production in 1921 in Java of the greatest cane of all, P.O.J. 2878, the first of the so-called nobilized canes, now generally outclassed, but present in nearly every modern pedigree. These canes are all essentially derivatives of *Saccharum spontaneum* backcrossed to noble types (Fig. 16.8). The genetical explanation of this additive effect, i.e., the increase in sugar content in the hybrid, was given by Bremer in 1922. *Saccharum officinarum* transmits its somatic chromosome number (2n) to hybrid offspring when pollinated by any of the forms of *S. spontaneum, S. barberi* and *S. sinense*, but behaves normally in transmitting only the gametic (reduced haploid) number in intraspecific crosses or when pollinated by *S. robustum*. For example, in crosses of *S. officinarum* ($n = 40$) as the female parent with *S. spontaneum* ($n = 56$) as the pollinator, the hybrid instead of having the normal diploid chromosome number ($40 + 56$), will contain $40 + 40 + 56 = 136$ chromosomes. If this male fertile F_1 hybrid ($n = 68$) is back-crossed with the *S. officinarum* type ($n = 40$) as the maternal parent, the new hybrid will have $40 + 40 + 68$ or $2n = 148$ chromosomes. Clones of this back-cross do not result in a further increase of chromosomes when *S. officinarum* is used as the male parent.

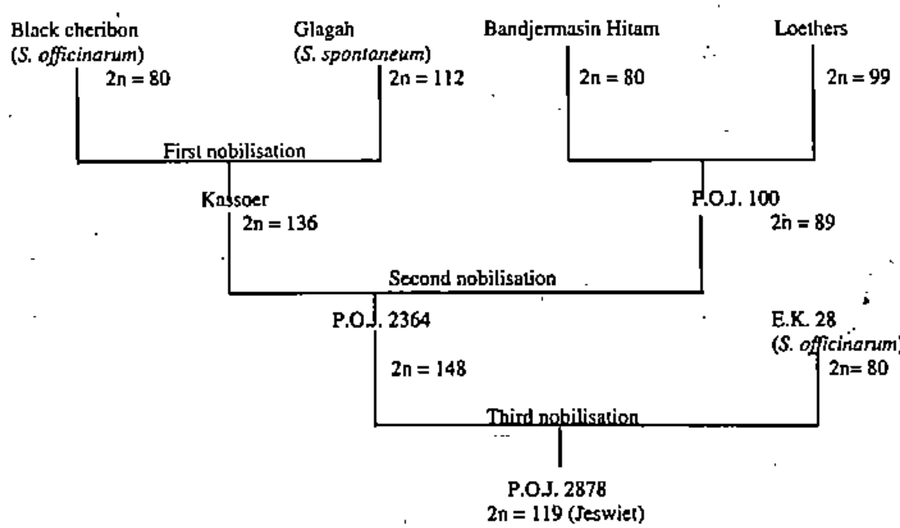

Fig. 16.8: Parentage of P.O.J. 2878.

SAQ 4

Give the chromosome number of F_1 generation of the following crosses :

(i) *S. officinarum* (n = 40) (Female parent) X *S. spontaneum* (n = 56) (Male parent)
↓
F_1 ☐

(ii) *S. officinarum* (n = 40) (Female parent) X *S. officinarum* (n = 40) (Male parent)
↓
F_1 ☐

(iii) *S. officinarum* (n = 40) (Female parent) X *S. robustum* (n = 40) (Male parent)
↓
F_1 ☐

(iv) *S. officinarum* (n = 40) (Female parent) X F_1 male fertile hybrid from cross No. 1
↓
F_1 ☐

Through 'nobilisation' and other similar processes, a large number of new varieties have been evolved in India, Australia, U.S.A, Hawaii and many islands in the Eastern and Western Hemispheres. The improvement of crop needs constant evolution of new improved varieties. In our country, this work had been undertaken by **The Sugarcane Breeding Institute** at **Coimbtore in Tamil Nadu**. It is engaged in this work since its inception in 1912. Of the sugarcane grown in India about 90% varieties come from this Institute which has contributed immensely in the increase in the total yield in the country. Some of the high yielding varieties include – CO.11, CO.413, CO.622, CO.712, CO.658, B.14, H.M. 320; some of the disease resistant varieties are – CO.331, CO.213, CO.349 and some popularly cultivated varieties are CO.513, CO.527, and CO.421.

The Indian Institute of Sugarcane Research, Lucknow and National Institute of Sugar Technology at Kanpur, conduct research in varietal improvement and also impart know-how about sugarcane and sugar industry. The Sugarcane Breeding Institute, Coimbatore, carries out main research in the country.

The sugarcane, like wheat and rice, is an outstanding example of international cooperation and transfer of biological technology in agriculture. The high yielding and disease resistant sugarcane clones evolved at various breeding stations have diffused widely all over the world and have entered into the parentage of strains adaptable to local agroclimatic conditions.

16.3 STARCHES

Carbohydrates are stored primarily as starch, which occurs as grains (up to 150 μ in size) inside plastids where the enzymes for their synthesis occur. In chloroplast, the glucose formed as a result of photosynthesis, is converted into starch. In the parenchyma cells of roots and other storage organs, as well as in many seedlings, the translocated sucrose is synthesized into starch in leucoplasts or amyloplasts which may remain in this form for months before being hydrolyzed by amylase. Each leucoplast produces only one starch grain, so that the grain appears to be free in the cytoplasm. Starch is composed of α-d glucose residues of two different kinds - amylose and amylopectin (Fig.16.9). Amylose is a long molecule (200-1000 glucose units) that forms an unbranched helix. It is soluble in hot water and is therefore the kind of starch used commercially as 'soluble starch' (e.g., for starching clothes). Amylopectin is a shorter molecule (containing 40-60 units) but forms a highly branched helix. It makes up 70-

80% of the starch in most grains and legumes (almost 100% in corn and 30% in peas). Starch molecules, perhaps because of their helical nature, tend to cluster in granules. Starch is deposited in concentric layers in grains and there are characteristic patterns for different species (Fig. 16.10). It is thus possible to check such commercial products as corn and potato starch for adulterants.

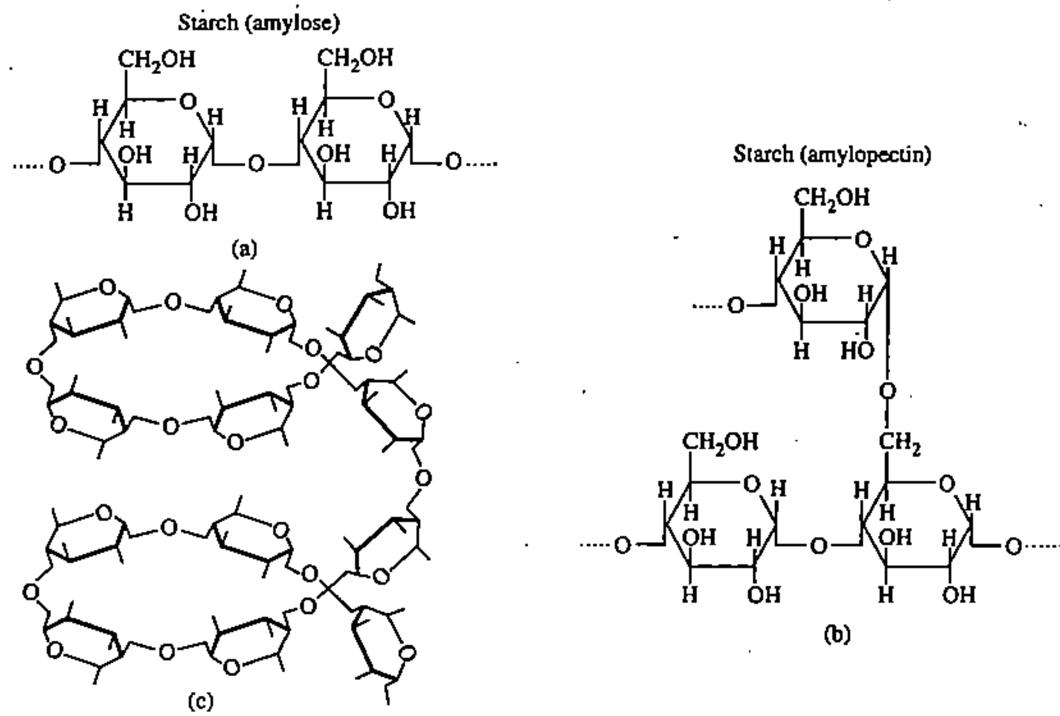

Fig. 16.9 : a) A single molecule of amylose contains 1000 or more glucose units in a long unbranched chain. b) Amylopectin is made up of 40 to 60 glucose units arranged in shorter, branched chains. c) Starch molecules tend to form a helix and then aggregate into granules.

Starch is found in most green plants as the chief food reserve. Typically it is stored in seeds, stems, leaves and roots of plants in the form of starch grains differing in size, shape and other microscopic details. Starch grains are either eccentric (potato, bean and arrowroot) or concentric (wheat, maize). In some cases, however, they may be joined together to form compound starch grains as in rice (Fig. 16.10). They stain characteristically bluish-black with a solution of Iodine Potassium Iodine.

Cereals are the basic source of our starchy foods. All important civilizations were founded on the basis of one or other of the cereal grains. But potato (*Solanum tuberosum*), sweet potato (*Ipomoea batatas*), yam (*Dioscorea alata*), cassava (*Manihot esculenta*), banana (*Musa sapientum*) are still important constituents of the diet of many people living in regions not well-suited to growing cereals. Although not closely related, these plants have much in common. All are tropical in origin with potato coming from the highlands, while others are lowland species. They are propagated vegetatively. They are valuable source of carbohydrate (energy food), although all are deficient in proteins and a diet consisting almost exclusively of any of them can lead to serious diseases.

For commercial purposes, starch is obtained from the stem tubers of potato (*Solanum tuberosum*), the root tubers of cassava (*Manihot esculenta*) and the rhizomes of arrowroot (*Maranta arundinacea*). In this unit potato and cassava are discussed in detail and some important commercial starches are described.

SAQ 5

(i) Fill in the blank spaces with appropriate words:

a) Starch is composed of α-d glucose residue of two different kinds .... and ....

b) Amylose is a long molecule that forms an .... helix.

c) Starch grains of potato are ...., however in .... they may be joined together to form compound starch grains.

d) Starch grains stain .... with Iodine Potassium Iodide solution.

e) .... are the basic source of our starchy food.

f) Starch is obtained commercially from the .... of potato and from the .... of cassava.

(ii) Name three non-cereal starch producing plants.

....

....

....

....

....

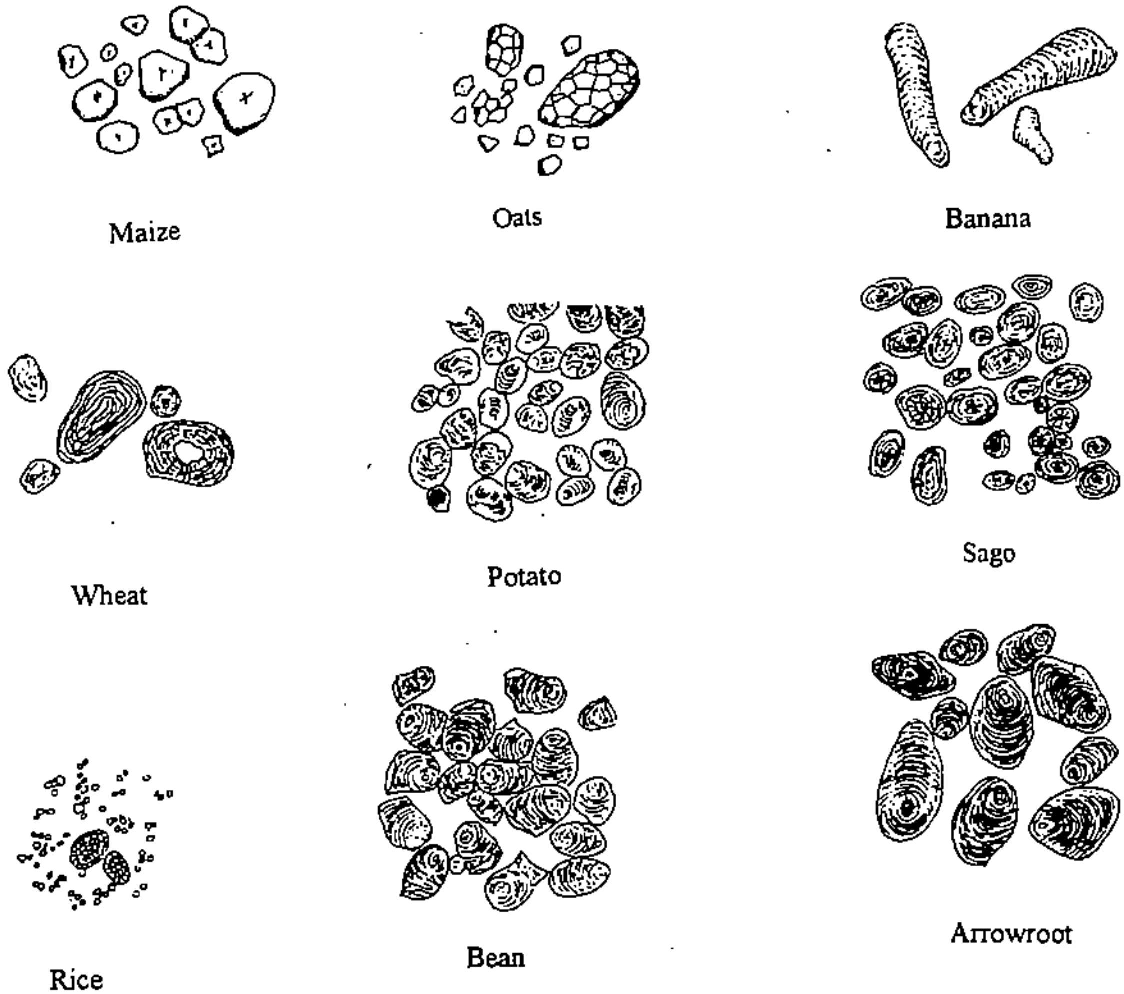

Fig. 16.10: Starch grains from different plants showing their characteristic patterns for each species.

16.3.1 POTATO

Botanical name : ***Solanum tuberosum***
Family : Solanaceae
Vernacular name : Alu
n = 24

The common potato (*Solanum tuberosum*) belongs to Solanaceae. Various wild *Solanum* species produce small potato-like tubers, which from time immemorial have been grubbed from the ground by the Indians. One or more of these was domesticated in the Andes Mountains of Bolivia and Peru, certainly prior to 2000 A.D., to become the cultivated *S. tuberosum*. The diploid chromosome complement in *Solanum* is 24 with *S. tuberosum* (2n = 48), being an autotetraploid.

The potato was presumably first seen by an European in 1537, when the Spanish landed in what in now known as Columbia. New world explorers and monks became familiar with it in the decades that followed and it was brought back to Europe by 1570. It was cultivated throughout the continent before 1600, and in Ireland by 1663. The cultivated potato is said to have been first introduced in North America in 1621. Not until 1700 however was the potato extensively planted. One reason for its sudden prominence in Europe during the 1700s was that reigning sovereigns recognizing its food potential compelled the people by royal edict to plant it (Germany, 1744; Sweden, 1764). In Ireland (the Irish were perhaps the first to recognize the potential of potato as a staple food and started to grow it as a crop by the middle of seventeenth century) especially, the potato was adopted as a mainstay food on which the Irish peasants survived until 1845-46, when the 'potato blight' (a fungal disease caused by *Phytophthora infestans*) swept across Europe, blackening the leaves of the plant and causing the tubers to rot. The failure of the so-called 'Irish potato' to support the Irish people produced one of the worst famines in the history of the Western World, followed by an unparalleled migration. Death and emigration to America reduced the population of Ireland. One might speculate that the Irish introduction stemmed from one narrow genetic source and had the great genetic variability of the potato in its South American homeland been available, the famine might have been avoided and the course of history would have been different. Even before the Irish immigrants came to the United States, introduction of the potato into New England from Ireland had given it the appellation "Irish" potato. It is sometimes referred to as "white potato" to distinguish it from "sweet potato" (member of a different family).

There have been two views regarding the origin of cultivated potatoes: (1) that they might have arisen directly from an ancestral form of *Solanum stenotomum* by a process of simple chromosomal duplication; or (2) they might have arisen as a spontaneous amphidiploid hybrid between the more ancient diploid *S. stenotomum* and the diploid weed *S. sparsipilum*.

In India, the major potato producing states are Uttar Pradesh, West Bengal, Punjab, Gujarat, Madhya Pradesh and Tamil Nadu. In the hilly tracts, the potato is grown as a summer crop, while in the plains it is a winter crop.

The food value of potato varies depending on the variety, growth conditions, storage and handling. Analyses have indicated its composition to be 70-81 per cent water, 8-28 per cent starch, and 1-3 per cent protein (most cultivars have around 5 per cent Kjeldahl nitrogen perhaps half of it not in protein form), 2-3 % fibres, and 0.1% fat and with varying amino acid composition with traces of minerals (potassium, phosphorus, iron and magnesium) and other food elements.

Tuberization is not favoured by high temperature. Therefore, potato is grown only in colder months of subtropical climate. The best environment is a cool, moist climate with a mean annual temperature between 15°C and 21°C and a rich, friable, porous, well drained, acidic, light soil. Long day conditions along with high nitrogen content of the soil favours the heavy growth of plant whereas short days and deficiency of nitrogen favour early tuberization. Crop is usually grown by tubers free from disease, that are either planted whole or cut into sections or sets. Large seed potatoes are cut into several sections, each having at least one bud or eye. Ideally, they should be cut at right angle to the main axis to eliminate apical dominance. Tubers need a dormancy period of about 3 months but some varieties need 7 months of dormancy (*Solanum tuberosum*). Green potatoes contain a poisonous glycoside, solanin, which in high concentrations may cause sickness and even death in both humans and livestock. This compound is also present in potato sprouts.

Morphology

It is an erect, branching more or less spreading, tuber-bearing plant about 60-90 cm in height. Though a perennial plant, it is treated as an annual under cultivation. The aerial part of the stem is erect in the early stages of growth but later it becomes more spreading. Except for the nodes the aerial stem is hollow and weak. The underground portion of stem is more or less rounded and solid, sending forth horizontal branches (stolons) that arise from the axillary buds. Adventitious roots are produced in groups of 3-4 at the nodes of main underground stem as well as stolons (Fig. 16.11).

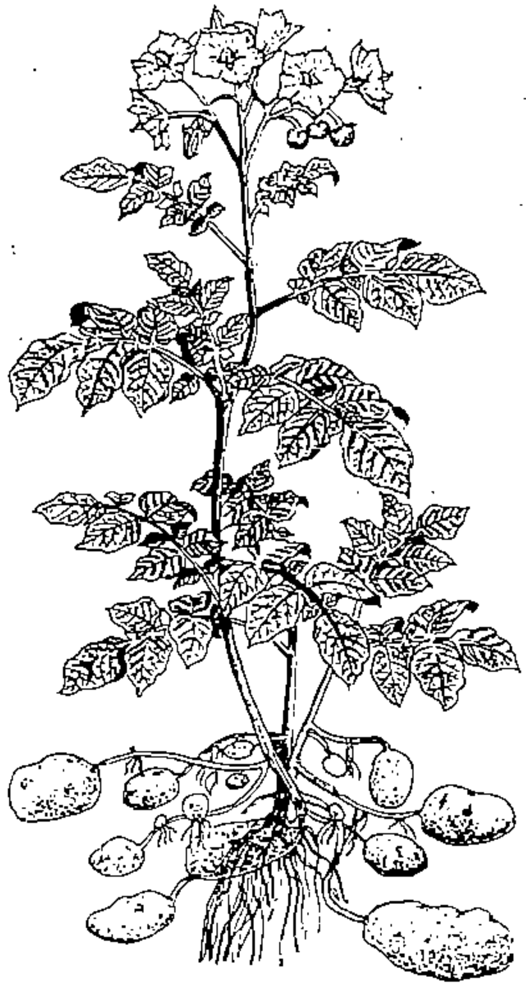

Fig. 16.11 : A potato plant.

The first few leaves developing from the "seed" piece are usually simple but subsequent ones are compound, and irregularly imparipinnate. Each leaf has one terminal leaflet, 2-4 pairs of large lateral primary oval leaflets with entire or serrate margins and small secondary leaflets (folioles) interspersed between primary leaflets (Fig. 16.11). The leaflets are more or less opposite and are densely hairy when young but at maturity the hairs are confined to the midribs and lateral veins. The leaves are spirally arranged on the main stem with two small basal leaf-like stipules clasping the main stem.

The tuber is the short, greatly enlarged apical portion of the stolon (Fig. 16.12), full of stored food. Morphologically it is a shortened, thickened stem bearing buds or eyes in the axils of scale-like leaves which are soon shed, bearing a rudimentary leaf scar (eyebrow) or ridge. The eyes may be shallow, medium or deep, the eyebrow being well marked (semi-circular) towards the heel or the attached end where the tuber is attached to the stolon. Each eye consists of a rudimentary leaf scar and cluster of at least three buds lying in a slight depression, representing a lateral branch with under-developed internodes. The eyes are arranged spirally around the tuber and are more crowded towards the apical or rose end of the tuber than the heel or basal end (Fig. 16.13). The size, shape and colour of the tubers vary greatly. The skin may be smooth or rough.

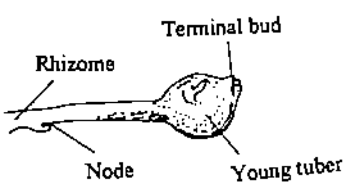

Fig. 16.12: An early stage in development of a tuber.

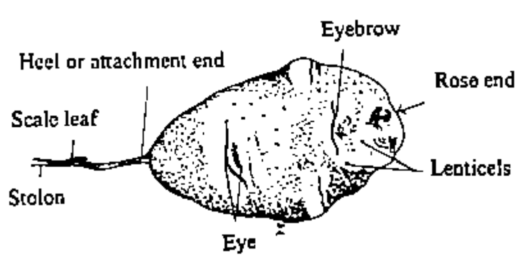

Fig. 16.13: A potato tuber to show its external features.

Anatomically tuber is a typical stem consisting of periderm, cortex, vascular cylinder (consisting of patches of outer phloem and a ring of distinct xylem bundles), the outer medulla representing the inner phloem and the inner medulla or pith with parenchyma (Fig. 16.14).

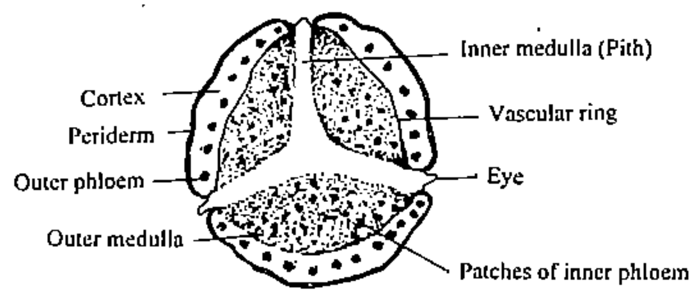

Fig. 16.14: Outline diagram of a potato tuber in cross-section.

The phloem elements both outer and inner are in numerous groups. The internal phloem is rich in parenchyma and appears to be the principal storage tissue of the tuber. The periderm and xylem bundles contain little storage parenchyma. The thin corky periderm forms the outer protective layer (the skin) which can be easily peeled off. The skin is pitted with lenticels. The greater part of proteins, minerals, tannins, crystals and pigments (in coloured varieties) is localized in the outer layers of the cortex. Deep peeling of potatoes should always be avoided as it removes the valuable nutritional ingredients. The starch in the tuber cells swells upon cooking and consequently bursts the thin cell walls.

Flowers may or may not be produced, depending upon the variety; wherever produced these are white, yellow or purple, borne in terminal clusters, consisting of five fused sepals, five fused petals, five epipetalous stamens and bicarpellate gynoecium. The fruits are spherical (berry), green when immature, and yellow, purple or black when mature.

Methods of Breeding

Introduction, hybridization and selection constitute the main ways of potato breeding. Hybridization is the principal method used in which intervarietal crosses are made between commercial varieties to combine desirable characters. Such a cross may be a dihybrid or a multihybrid one, involving several varieties. Since potato is a vegetatively propagated crop, commercial varieties are heterozygous; clonal selection is usually practised in F_1 generation after hybridization. Main breeding work is done in long day summers in Shimla (**Central Potato Research Institute**) and the crop is grown as a short day winter crop in plains. However, selections are difficult to make in varieties adapted to the conditions in plains. For this crosses are made at Shimla and F_1 seeds are sent to regional stations at Patna and Jalandhar, where they are grown and selections are made during short-day conditions.

Of the various desirable qualities of tuber mention may be made of keeping quality, size, shape, colour, texture, skin thickness and nutritive value of tubers.

Now a days older varieties are being replaced by new varieties such as Kufri Kissan, Kufri Kundan, Kufri Sindoori, Kufri Chandramukhi, Kufri Chamtkar, and Kufri Alankar. Most recent are Kufri Bahar, Kufri Badshah, Kufri Jyoti and Kufri Lalima.

Economic Importance and Uses

1. Potatoes are consumed, as a fresh vegetable, in the daily diet in a variety of ways – boiled, steamed, fried, baked or roasted.
2. A number of delicacies like cutlets, "papar" are prepared.
3. They are processed into many products such as potato chips or crisps, dehydrated mashed potatoes, potato flour, frozen French fries and canned potatoes.
4. Fresh potatoes are important source of Vitamins B and C.
5. Potato flour (up to 4%) can be mixed with wheat flour for bread making.
6. Potato starch is also used for preparing adhesives.
7. Potato starch or 'Farina' is largely used in laundries and is suitable for sizing paper.
8. Industrial alcohol is prepared in enormous quantities from potato starch which is converted into sugars and are then fermented by yeast for production of alcohol.

9. Potato is a good substrate for the growth of microorganisms. The liquor from boiled potatoes has long been used as a nutrient medium in experimental work.
10. 'Vodka', Russian alcohol beverage is prepared by fermentation of cooked potatoes.

SAQ 6

(i) Give names of major potato producing states in India.

....

....

(ii) Potato could be grown only during the colder months of subtropical climate. Comment.

....

....

(iii) Why are the green potatoes harmful?

....

....

....

(iv) Name three varieties of potato cultivated in India.

....

....

(v) Name the place and institute where improvement work on potato is being carried out in India.

....

....

16.3.2 CASSAVA

Botanical name : *Manihot esculenta*
Family : Euphorbiaceae
Vernacular name : Manioc, mandioca, yuca, tapioca and sagu
n = 18

Cassava is a species of the tropical lowlands. It adapts to poor soil and casual cultivation, and has consequently become a staple food in many of the poor and developing parts of the world. It is a perennial shrub which produces a high yield of tuberous roots in one to three years after planting. It produces exceptional carbohydrate yields, much higher than those of maize or rice. Cassava is the sixth most important staple food in the world today. It is the second in importance only to the sweet potato as a root crop throughout the tropics. It is grown in every tropical country and over 200 different varieties of the plant are known. It can be grown easily from stem cuttings. The root tubers can be left in the ground until required without serious deterioration. Root tubers are eaten after steaming or boiling.

Cassava is a native of Brazil (S. America). This crop does not withstand severe cold and that is why it does not flower well in cold conditions of north India. It can however withstand heavy rainfall. This plant was introduced in Travancore (Southern Kerala) in India long ago by colonizers either the Portuguese, the Dutch or the Spanish. It is an important crop of Kerela and also forms staple food crop of West coast districts for many people. It is now being introduced in Tamil Nadu, Andhra Pradesh, Gujarat, Assam and Maharashtra.

Well-drained garden loam soil is best suited for this crop. Planting material consists of short stem cuttings, obtained after harvesting the previous crop. Portions taken are comparatively young and are stuck either flat or upright but in a slanting position into the soil just before the rainy season. It is often intercropped with other food crops but may also be planted as a pure stand. Sprouting takes about in a week's time. When properly grown not more than three branches are allowed per plant, which attains a height of about

2.5-3 m. For good root growth plant should be chopped and not allowed to grow more than 1.8 m in height. Mature roots are about 7-10 cm in diameter and 30-45 cm in length and weigh 1-2 kg. Some of the giant roots may weigh as much as 10 kg. In rare cases each plant produces about 4-5 good sized roots.

Morphology

It is a short-lived shrub with latex in all its parts. Tubers develop as swellings on adventitious roots, a short distance from stem by the process of secondary thickening (Fig. 16.15). Their number, shape, size and length at which they penetrate the ground, colour of outer cork and internal tissue vary greatly. These consist of: (a) outer skin or periderm; the cork layers may be rough or smooth, white, light-to dark brown, pink or red; (b) thin rind or cortex, usually white but may be tinged pink or brown; and (c) core or pith mainly consisting of parenchymatous cells rich in medium-sized starch grains with stellate hilum, few vascular bundles and latex tubes, usually white but may be yellow or red tinged. This is the edible portion. In addition to tubers, fibrous, adventitious roots develop horizontally and vertically. Old tubers become lignified.

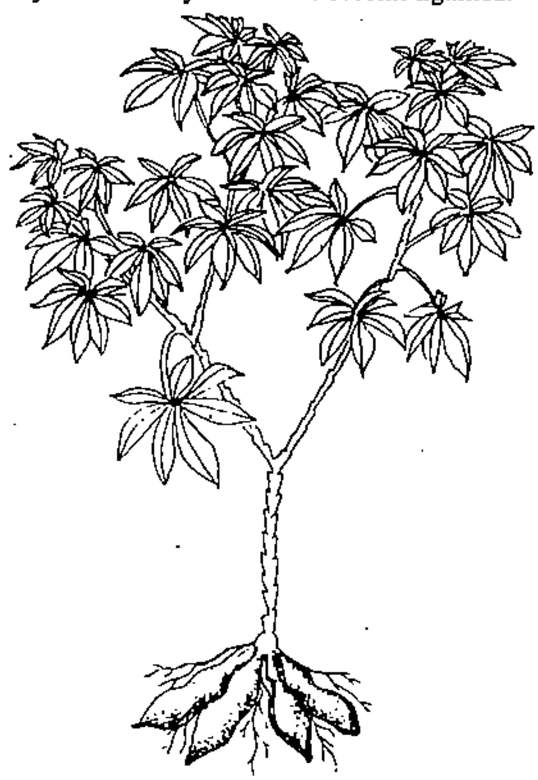

Fig. 16.15: Cassava plant showing roots and leaves with palmately-divided lobes.

Stems vary greatly in height and branching habits. Branches are usually glabrous, slender with leaves towards apex and with prominent leaf scars below. The colour of periderm and leaf scars ranges from silvery-grey to greenish-yellow, pale or dark brown streaked with purple.

Leaves are sprially arranged, large, palmate, and are variable both in the size and the colour. Petioles are usually longer than lamina. The lamina is deeply palmate with 3-9 lobes, usually 5-7. Lobes ovate-lanceolate, entire margin, base narrowed, tip acuminate, glabrous above, occasionally slightly hairly beneath veins, stipules usually with 3-5 lanceolate lobes, deciduous. Petiole and midrib green to deep red. Lamina may be tinged red, green and yellow variegated forms also occur.

Flowers are borne in axillary racemes near the end of branches. These are unisexual with male and female flowers in the same inflorescence and female near the base.

The flowers are very small. The calyx lobes are coloured and the corolla is absent. The male flowers have ten stamens in two whorls of five each. The gynoecium in the female flower is tricarpellary, trilocular with one ovule per locule. The fruit is 1.5 cm long globular capsule with six longitudinal, and 3-celled wings.

Endocarp woody splitting explosively on ripening 3-5 months after pollination and ejecting seeds. Seeds are ellipsoid, grey mottled with dark blotches and pronounced caruncle.

Cultivation

The plant is cultivated in hot climates. It grows very easily and does not require much labour. Stem cuttings of few inches in length are sown in holes dug at intervals of 1 meter. Different varieties take different time to mature. Some varieties produce mature tubers within six months to a year while others take 18 months to 2 years to mature. Secondary growth occurs in the adventitious roots to form tubers. Tubers have a starch content of about 30 per cent. Older tubers are not edible due to lignification of cells. The tubers, variable in size, are very elongated and cylindrical structures attaining a length of 60-90 cm, and develop in a cluster around the base of the stem in well grown plants. They may be surrounded by a mass of normal fibrous roots. These are usually harvested after 8 months but large and better quality yields can be obtained after a period of 16 months or more. The left-over roots continue to produce new stems so that the plant remains perennial.

The cultivars of cassava are vaguely grouped as "bitter" or "sweet" having respectively high or low concentration of a cyanogenic glycoside. Sweet cassavas require no special treatment before consumption, but bitter varieties are shredded, squeezed, cooked, and treated in other ways to rid them of the poisonous juice or to reduce its toxicity. There is no clear cut demarcation between these two groups, as the glycoside content varies with individual plants and cultivars. In sweet varieties it tends to concentrate in the skin and in bitter it tends to concentrate in skin and cortex of tuber. In sweet varieties the main storage region is relatively free of glycoside.

Central Tuber Crops Research Institute (CTCRI) was established in 1963 at Trivandrum. It maintains tuberous crop collection from our country and from outside. It has about 1300 collections of cassava of which 250 varieties are from outside country. Attempt is made to obtain good varieties of cassava, resistant to mosaic disease and those that give higher yield. As a result of intervarietal hybridization, hybrid and superior quality forms have been isolated; of these are H-97, H-165 and H-226. The variety H-97 possesses high starch content. Some tetraploids have been developed which have registered average protein value of 3.9% as compared to 1.8% in diploids. Attempts are made to increase protein value of high yielding varieties.

Economic uses

Cassava is used in a number of ways.

1. The whole root may be boiled, it has a sticky heavy consistency, and of itself is rather tasteless. It is used as vegetable (after boiling) like potatoes or sweet potato.
2. It is shredded, then heated and dried, to make a meal known as *farinha* (in Brazil), eaten alone if need be, or mixed with other food and sauce.
3. Tapioca is prepared by grating the peeled roots, the mass soaked in water for several days, kneaded, strained, dried, and then heated to partly hydrolyze the starch to sugar and gel. It swells up into lumps and these lumps and starch are known as Topioca pearls. Tapioca is used for puddings, biscuits and confectionery.
4. These are also used by cutting thin slices after removing rind which are boiled moderately then dried and stored. These chips can be eaten like potato chips or ground into meal and eaten like porridge.
5. Cassava also has several industrial uses and its starch in some form or the other is a marketable commodity in general world trade. Starch is used in the preparation of adhesives for laundry, for paper sizing and as a source of sugars, alcohol and acetone.
6. In lowland tropical South America, the beer is still prepared by chewing the roots; by salivation the starch is converted into sugars, followed by fermentation by wild yeasts.
7. In Africa, the leaves are used as a pot-herb, since they may contain up to 30% proteins. Their wider use might help prevent malnutrition among people who subsist mainly on cassava.
8. Tapioca flour is prepared by a special process. The tubers are peeled, washed and grated or ground. The compressed pulp is then separated from latex and the juice extracted by squeezing the mass in a bag. The starch comes out like a stream of milk and impurities remain inside the cloth bag. Squeezing/kneading is continued with fresh changes of water till starch stops coming and only water comes out. A smooth

layer of starch settles at bottom and clear water is decanted off. Wet starch is first dried in sun and then on a hot plate.

9. The starch is used as animal fodder.
10. The juice of bitter varieties is used to produce "cassareep" which is used in preparing sauces. The juice is fermented into alcoholic beverages.

Types of commercial starches:

1. **Arrowroot starch:** The tuber of several tropical plants such as West Indian arrowroot (*Maranta arundinaceae*), Florida arrowroot (*Zamia floridana*), Queensland arrowroot (*Canna edulis*), and East Indian arrowroot (*Curcuma angustifolia*) yield arrowroot starch. The tubers are peeled, washed and crushed and the pulp is passed through perforated cylinders, where a stream of water carries the starch into settling tanks. Arrowroot starch is easily digested and is used for preparing broth for children. It also finds some use in laundries.
2. **Corn starch:** It is obtained from the grains of maize (*Zea mays*). The grains are soaked in warm water containing small amounts of sulphurous acid, which prevents fermentation and helps to loosen the grains. They are then ground, preventing injury to the embryos, passed through germ separators, then ground finely and washed in perforated cylinders to remove the bran. The resulting milky fluid is made to flow over inclined tables, where the starch grains settle down. It is collected, dried and readied for marketing.
3. **Cassava starch:** The starch obtained from cassava (*Manihot esculeuta*) is used as sizing material in many industries.
4. **Potato starch:** It is obtained from tubers of potato (*Solanum tuberosum*). Starch is obtained from the culls which are washed, pulped and passed through sieves to remove the fibrous matter. Sedimentation, followed by centrifuging removes the solid starch, which is dried and made ready for marketing. Potato starch finds great use in the textile industry and is an important source of glucose, dextrin and industrial alcohol.
5. **Rice starch:** It is obtained from the grains of rice (*Oryza sativa*). The broken or imperfect grains of rice are utilized for extracting the starch. The grains are softened by treating with caustic soda and are washed, ground and filtered through fine sieves. To the filtrate, alkali is added, so that the starch settles down as sediment, which is removed, washed and dried. Rice starch is mainly used for laundry work.
6. **Sago starch:** It is obtained from sago palm (*Metaxylon sagu*). The pith of the stem of the sago palm is the source of the commercial sago starch. This tall, tropical palm stores up starch within the stem just before flowering, after which the trees are cut down and the starchy pith is removed. By the process of grinding, mixing with water, straining through a coarse sieve and sedimentation, the starch is freed, washed and dried to yield the end product known as *sago flour*. The sago flour is made into a paste and rubbed through a sieve, to form granules which are dried in the sun or ovens to form hard shiny grains, commercially known as *pearl sago*. Sago starch and pearl sago are valuable sources of edible starch.
7. **Wheat starch:** It is obtained from the grains of bread wheat (*Triticum aestivum*). This is the oldest commercial source of starch, and is extracted by partial fermentation of the grain. Wheat starch is used exclusively in the textile industry.

SAQ 7

(i) Cassava (*Manihot esculenta*) is a member of the family .... and its other common names are ....

(ii) Cassava is a native of .... and was introduced in .... in India by Portuguese colonisers.

(iii) Cassava is cultivated in .... climate, whereas potato requires low temperatures for ....

(iv) The cultivars of cassava are grouped as .... and .... on the basis of concentration of a cyanogenic glycoside.

(v) The full form of CTCRI is ....

16.4 SUMMARY

In this unit you have studied that:

- Sugars are the primary products of photosynthesis, of which the major portion is utilized for the various metabolic processes of the plant itself. Sugar is a carbohydrate chemically composed of carbon, hydrogen and oxygen in the ratio of 1:2:1. It is one of the best natural sources of energy for man.
- The common sugar yielding plants are : sugarcane (*Saccharum officinarum*), sugar-beet (*Beta vulgaris*), maple (*Acer saccharum*) and palms (*Phoneix sylvestris, Caryota urens, Arenga pinnata, Borassus flabellifer, Cocos nucifera*).
- The cane sugar is obtained from sugarcane. It is an extensively cultivated plant. Sugarcane is propagated by cuttings of three to five joints termed "seed cane" or "seed pieces" preferably from the joints of the upper region of the mother plant, or by "ratooning" in which the dormant buds on the portion of the cane left underground after harvesting sprout in two or three weeks time, producing a new crop known as "stubble" or "ratoon crop".
- Harvesting is accomplished by cutting the stems as close to the ground as possible, for the lower end of the cane is richest in juice content. Soon after harvesting the sugarcane is brought to the factories for extraction. The clear and dark coloured juice is concentrated to a density that causes sugar to crystallize out from the thick syrup (massecuite).
- Sugar has been used as a sweetener since time immemorial and is variously used as a sweetening agent in the preparation of sweets and drinks. It is extensively used in food preservation. It is also used in the preparation of oxalic acid and octa-acetate.
- Improved varieties of sugarcane which are disease resistant and high yielding are obtained through elaborate breeding work involving selection, intervarietal and interspecific hybridisation and nobilisation.
- Starch is the chief type of reserve food material of all green plants. It is complex carbohydrate present in the form of grains (inside plastids) and stored within thin-walled cells. The cereal crops such as rice, maize, and wheat and underground tubers such as potato, arrowroot, sweet potato, cassava are the chief sources of starch.
- Starch grains differ in size, shape and other microscopic details. They are either eccentric or concentric or may be joined together to form compound starch grains.
- Starch is used as a sizing agent in the paper industry. In calico printing it serves as mordant. It is also used in laundry, medicines, toilet preparations and binding materials.
- The common potato is an important source of starch. In India the major potato producing states are Uttar Pradesh, West Bengal, Punjab, Gujarat, Madhya Pradesh and Tamil Nadu. In the hilly areas it is grown as a summer crop while in plains it is a winter crop. The potato tuber is anatomically a stem, with external buds (eyes) that sprout into new plant. Sections of potato with a bud are used to vegetatively propagate and maintain potato varieties, since sexual reproduction would be slower to yield and would risk changes due to genetic segregation.
- Hybridization is the principal method of potato breeding in which intervarietal crosses are made between commercial varieties to bring desirable characters.
- Cassava is another important starch producing root crop. This plant is a native of Brazil and is being cultivated in many states of India. The Cassava plant produces several swollen roots that resemble sweet potato. The palmate leaves are characteristic of the genus. The roots contain about 30% starch found chiefly in the voluminous pith. The cultivars of Cassava are grouped as bitter or sweet having respectively high or low concentration of a cyanogenic glycoside. Sweet varieties require no special treatment before consumption but bitter varieties are shredded, squeezed and cooked to reduce its toxicity and then consumed.

16.5 TERMINAL QUESTIONS

1. Write short notes on:
   a) Nobilisation of sugarcane
   b) By-products of sugar industry
   c) Bagasse

d) Molasses

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2. What is cane sugar? Write an account of the process of commercial production of cane sugar.

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3. Draw a labelled sketch of nodal and internodal region of sugarcane stem.

4. Write briefly on advantages of vegetative propagation of sugarcane.

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5. Name the:
   (a) Regions of present day cultivation of sugarcane.
   (b) Research Institutes along with their locations where improvement work in sugarcane is being carried out in India.
   (c) Indian states which are the leading producers of cane sugar.

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6. Give the botanical names, families and morphological nature of plant parts yielding commercial starch.

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7. Draw a labelled sketch of a potato tuber and label its parts.

8. Write short notes on:
   (a) By-products of starch and their uses.
   (b) Potato famine and Irish emigration.
   (c) *Manihot esculenta.*

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9. 'Nation's dependence on a single crop is not free from risks'. Discuss this with reference to potato.

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10. Describe the methods of cultivation and uses of potato or cassava.

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16.6 ANSWERS

Self-Assessment Questions

1. (i) Sugarcane – *Saccharum officinarum*
   Sugarbeet – *Beta valgaris*
   Sugar Maple – *Acer saccharum*

   (ii) Stem – Sorghum, Sugarcane, Sugar maple
   Root – Sugarbeet, Carrot
   Bulb – Onion
   Inflorescence – Palms

   (iii) Uttar Pardesh, Tamil Nadu, Maharashtra, Andhra Pradesh, Punjab, Harayana and Bihar

   (iv) Cultivated sugarcane has two geographic centres of origin:
   (a) South Pacific Islands (New Guinea); and
   (b) Northern India

   (v) Noble cane – *Saccharum officinarum*
   Indian cane – *Saccharum barberi*
   Wild cane – *Saccharum spontaneum*

2. (i) After harvesting, some portions of cane are left underground. The dormant buds present on these canes sprout in 2-3 weeks time, producing a new crop known as "stubble" or "ratoon crop".
   (ii) The right stage of harvesting the sugarcane is, when it reaches maturity and is with highest sugar content. Tests for ripeness are made on random samples taken at an interval of 7-10 days. This can be tested by cutting whole cane or by examining the juice with refractrometer from the central internode of the upper and lower thirds of standing canes.

3. (i) bagasse, (ii) defacation, (iii) Molasses, (iv) massecuite

4. (i) 40+40+56 = 136 chromosomes
   (ii) 40+40 = 80 chromosomes
   (iii) 40+40 = 80 chromosomes
   (iv) 40+40+68 = 148 chromosomes

5. (i) (a) amylose; amylopectin; (b) unbranched; (c) eccentric, rice; (d) bluish-black; (e) Cereals; and (f) stem tubers; root tubers

   (ii) Potato – *Solanum tuberosum*
   Sweet Potato – *Ipomoea batatas*
   Cassava – *Manihot esculenta*

6. (i) Uttar Pradesh, West Bengal, Punjab, Gujarat, Madhya Pradesh and Tamil Nadu.
   (ii) The potato could be grown only in colder months of subtropical climate as tuberization is not favoured by high temperature. The best environment is a cool moist climate.
   (iii) Green potatoes contain a poisonous glycoside solanin, which in high concentrations may cause sickness and even death in both humans and livestocks.
   (iv) Kufri Kissan, Kufri Kundan, Kufri Sindoori
   (v) Central Potato Research Institute, Shimla.

7. (i) Euphorbiaceae; Mandioca, Yuca, Tapioca, Sagu
   (ii) Brazil; Tranvancore (South Kerala)
   (iii) hot; tuberization
   (iv) bitter; sweet
   (v) Central Tuber Crop Research Institute.

Terminal Questions

1. (a) **Nobilisation of sugarcane** : To improve the varieties of sugarcane, the crosses were made between noble canes (*Saccharum officinarum*) and wild canes (*S. spontaneum* and *S. robustum*). The reason for crossing was to produce hybrids that combine the best features of both the parents, i.e., thick, soft, long-barelled cane and high sugar content of *S. officinarum* and the deep penetrating root system, drought and disease resistance of wild parent. The first generation progeny is intermediate between these two parents and is commercially unsuitable for sugar production as the stems are often thin, pithy and contain little sugar but have some of the vigour and disease resistance characters. The back-cross of F_1 hybrids with noble varieties greatly improves the productive quality of the cane without diluting the favourable attributes of the wild parent. This hybridization with noble canes (*S. officinarum*) to upgrade the sugar content is known as "nobilisation".

   (b) The important by-products obtained from the sugar industry are as follows:
   1. **Bagasse** : After extraction of juice, the dry fibrous residue left over is known as bagasse. It is used as a fuel for mills, in the manufacture of fibre board, card board, insulation board and in paper making. Bagasse is also used as a mulch for plants and as a litter or bedding for poultry and livestock.
   2. **Molasses** : The liquor left after the crystallization of sugar is known as molasses and is an important by-product of the sugarcane industry. It is widely used as a livestock feed, for making alcoholic drinks such as rum . and for the manufacture of a host of chemicals, industrial alcohol, vinegar,

glycerol, lactic and citric acid. It contains about 50% of fermentable sugar (35% sucrose and 15% reducing sugar) which gives it, its principal value as an industrial raw material. Rum is produced by the fermentation of molasses by the yeast *Saccharomyces cerevisae* followed by distillation. Acetone and butanol are produced by fermentation of molasses with *Clostridium* bacteria. Molasses are also used for manufacture of dry ice.

(c) See Bagasse in the above answer.

(d) See Molasses in the above answer.

2. Refer to Section 16.2, 'Manufacture of Sugar'.

3. See Figure 16.3.

4. Most of the cultivated varieties of sugarcane are interspecific hybrids and are propagated vegetatively by stem cuttings of three to five joints termed as "seed cane" or "seed pieces". The advantage of vegetative propagation are: (a) by "ratooning" two or three more crops are obtained before another "seed cane" planting becomes necessary. (b) Since the seeds retain their viability for a very short time, propagation by vegetative means helps overcome this problem. (c) The crop raised by vegetative means mature early. The cuttings are usually taken from plant canes 8-12 months old or ratoons 6-8 months whereas the first crop after planting, known as the plant crop takes 15-24 months to mature but ratoon crops takes about 1 year to mature.

5. (a) India, Cuba, Pakistan and Brazil are major producers.
   (b) i) Sugarcane Breeding Institute, Coimbatore (Tamil Nadu)
   ii) Indian Institute of Sugarcane Research, Lucknow (U.P.)
   iii) National Institute of Sugar Technology, Kanpur (U.P.)
   (c) Uttar Pradesh, Maharashtra, Tamil Nadu, Andhra Pradesh, Karnataka, Haryana, Punjab, Bihar, Orissa, Gujarat and Rajasthan.

6.

Name	Botanical Name	Family	Plant Part
Corn starch	*Zea mays*	Poaceae	Fruit
Wheat starch	*Triticum vulgare*	Poaceae	Fruit
Potato starch	*Solanum tuberosum*	Solanaceae	Tubers (stem)
Rice starch	*Oryza sativa*	Poaceae	Fruit
Arrowroot starch	*Maranta arundinacea*	Marantaceae	Roots
Sago starch	*Metroxylon sagu*	Arecaceae	Stems
Cassava starch	*Manihot esculenta*	Euphorbiaceae	Root tubers

7. See Fig. 16.13.

8. a) See Section 16.3.
   b) See Subsection 16.3.1.
   c) See Subsection 16.3.2.

9. Refer Subsection 16.3.1.

10. See Section 16.3.

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Uttar Pradesh
Rajarshi Tandon Open University

UGBY -02
PLANT DIVERSITY-II

Block

3B

ECONOMIC BOTANY

UNIT 17 **Spices**	**5**
UNIT 18 **Beverages**	**31**
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3B ECONOMIC BOTANY

Apart from the basic need of food, needs such as shelter, clothing and a host of other essentials are still derived mainly from plants. In this block we are going to discuss some such essentials namely spices and condiments; beverages; drugs; essential oils; woods; fibres; cork and rubber – all are obtained from plants.

Spices are primarily used for imparting a pleasant taste to the food. They give an agreeable flavour and aroma to the tasteless food, and are widely used particularly in the tropics. They also stimulate the appetite and increase the flow of gastric juices. In Unit-17, ginger, turmeric, cinnamon, saffron, clove, capsicum, pepper, coriander, fennel, mustard, cardamom, nutmeg and mace are described with reference to their origin, distribution, morphology, cultivation and uses.

In addition to water that is one of the prime requirements of human life, a large number of people world-over are accustomed to liquids like tea, coffee and cocoa. These are the most widely consumed, non-alcoholic beverages of plant origin. Their twin properties of stimulation of nervous system, and prevention of fatigue are the reasons for their widespread use, and often addiction! Unit-18, entitled "Beverages" deals with the above mentioned three beverages, with particular reference to their distribution, agro-climatic conditions, salient morphological and anatomical features, cultivation, harvesting and processing methods, common adulterants and their uses.

The Unit-19, titled as "Medicinal and Aromatic Plants" is about another sphere of valuable plant derivatives. Plants are not merely the providers of a variety of nutrients – that are essentially required in building and maintaining our body, but they also help in keeping it healthy. Presently, a large number of plants are used for making medicines. Not only that, several important drugs that were first discovered in plants and were found useful in curing various diseases, are now synthesized in chemical laboratories all over the world. Also, the search of new medicinal plants continues, to take on the emerging challenges to our health. Out of the very long list of medicinal plants, we have chosen a few examples for study in this unit, to give you an idea of their use in a wide range of health afflictions.

Another section of the unit is devoted to "fumitory and masticatory materials obtained from plants". These are the substances that have been consumed for hundreds of years largely for pleasure and for feelings of exhilaration. The last section of the unit deals with a few indigenous examples of essential-oil yielding plants. These have been variously used, for instance, to improve the taste of foods, for preservation of food and to adorn the body. These are highly volatile, aromatic organic substances that differ both in their physical and chemical properties from the vegetable oils and fats that have been discussed earlier, in Unit-15.

The title of the next unit, that is, "Wood, Fibre and Related Products" speaks itself about the contents of this unit. In this unit too, we continue our exploration and discussion on various kinds of valuable products of plant origin, that are closely associated to us in our day to day living. Wood, cork, rubber, and various kinds of fibres are the focal points of discussion in this unit. These commodities are of great commercial value and are therefore, important in the world-trade. In this unit we have also included diverse applications of these products in our lives.

We hope a study of these units sets your thought process in motion for the judicious use and management of these highly versatile natural resources, that can be renewed year after year and for generations!

UNIT 17 SPICES

Structure

17.1 Introduction
Objectives
17.2 Spices and Condiments
17.3 Importance of Spices
17.4 Spices Obtained from Underground Parts: Rhizome
17.4.1 Ginger
17.4.2 Turmeric
17.5 Spices Obtained from the Bark
17.5.1 Cinnamon
17.6 Spices Obtained from Flower Buds or Flowers
17.6.1 Saffron
17.6.2 Clove
17.7 Spices Obtained from Fruits
17.7.1 Capsicum/ Chillies
17.7.2 Pepper
17.7.3 Coriander
17.7.4 Fennel
17.8 Spices Obtained from Seeds
17.8.1 Mustard
17.8.2 Cardamom
17.8.3 Nutmeg and Mace
17.9 Summary
17.10 Terminal Questions
17.11 Answers

17.1 INTRODUCTION

The story of spices is one of the most spicy chapters in the history of the plant kingdom. Historically, spices have been responsible for the rise and fall of empires and the great sea voyages to explore the distant corners of the globe. Infact, spices have played an important role in shaping the course of history; they have been connected with adventure, conquests, exploration and exploitation around the world. In the latter half of the fifteenth century, both Portugal and Spain explored sea routes to the spice islands (Moluccas). Christopher Columbus sailed west from Spain in 1492, hoping to reach the spice islands ahead of the Portuguese, but he failed in his primary mission. Instead, he discovered the America and also helped in the discovery of two of the three important New World spices, all spice (*Pimenta officinalis*) and red pepper (*Capsicum* spp.). The third important New World spice is vanilla (*Vanilla planifolia*). In early part of the eighteenth century spices were smuggled away and planted around the world, especially in the West Indies. Now a days, substantial plantations are grown in America. However, the vast majority of spices are still obtained from the wetter parts of the tropics, chiefly Asia.

In India, the major spices produced are pepper, cardamom, ginger, turmeric and chillies. Black pepper is one of the most important Indian spices, and is known as the 'King of Spices' or it is called black gold of India. While next comes cardamom called the 'Queen of Spices' through which India earns a lot of foreign exchange. Some other important spices grown in India include ajowan, aniseed, caraway, celery, coriander, cumin, dill, fennel, fennugreek, garlic, onion, saffron and vanilla. Spices are grown mainly in Kerala, Karnataka, Tamil Nadu, Andhra Pradesh, Maharashtra, Orissa, Rajasthan and Bihar.

India produces 2.5 million tonnes of spices and exports about 450,000 tonnes.

In this unit we will describe in detail some of the importat spices which are commonly used in Indian cooking.

Objectives

After studying this Unit you should be able to:

- Differentiate between the terms spices, condiments and herbs,
- describe the importance of spices in our life,
- know the system of classification of spices,

- state the botanical, common and vernacular names of the plants, their chromosome numbers, families, parts of the plant used as spices,
- name the place of origin of the spice, its distribution in the world with special reference to Indian states,
- give a description of the plants that produce the spices,
- enumerate the uses of various spices,
- identify some common adulterants of spices.

17.2 SPICES AND CONDIMENTS

According to the International Organization for Standardization (ISO) there is no marked distinction between **spices** and **condiments**. The term **spice** is used for aromatic plant products or mixtures thereof, either as whole or in ground form. It is rather loosely applied to an assortment of dried barks, roots, seeds, fruits and flower parts. Spices which impart aroma, flavour and piquancy (tangy or sharp distinctive flavour) to foods are generally tropical in origin.

Most of the chemical compounds responsible for the distinctive tastes and smells of spices and condiments are known as **essential oils.**

Condiments on the other hand are spices that are usually added to food after cooking. In contrast, when the aromatic vegetable product comes from a temperate plant, it is considered as a culinary herb (non-woody), as in case of bay leaves, coriander, fennel, mustard, etc.

17.3 IMPORTANCE OF SPICES

Most of the chemicals responsible for the distinctive tastes and smells of herbs, spices and condiments are compounds known as essential oils (volatile oils). These volatile oils are usually terpenes and are found in specialized plant cells, glands or vessels that occur in any or all parts of a plant. In some instances these essential oils are produced by plants to attract animals that may serve as pollinators or fruit dispensers. The importance of spices in our life is as follows:

i) Serve as appetizers, therefore they are also termed as 'food adjuncts' or 'accessories',
ii) Add a tang and flavour to insipid or bland food,
iii) Increase the secretion of saliva rich in ptyalin which facilitates food digestion,
iv) Possess anti-oxidant properties,
v) Are used as preservatives in pickles and chutneys,
vi) Possess strong anti-microbial and antibiotic activities,
vii) have medicinal value,
viii) Act as mouth freshner, cleans the oral cavity from adhesion and bacteria, also protects the mucous against thermic, mechanical and chemical irritation,
ix) Impart flavour to beverages, and
x) Ingredient of some cosmetics

In India, the records indicate that herbs/ spices have been in use for treating diseases since ancient times. **Charaka Samhita** – the most important work on Ayurvedic system of medicine deals with 700 herbs. Today in the world, there is renewed interest in herbs/spices as alternative medicines.

There are about 70 spices grown in different parts of the world. Spices can be grouped according to (i) different systems of classification such as botanical analogies (similarity between unlike plants) or families, (ii) economic importance (major and minor spices), (iii) similarity in methods of cultivation, (iv) similarity in plant parts used as spice such as root, rhizome, bark, bud, flower, fruit, seed and leaves.

In this Unit the classification and description of the twelve spices is based on similarity in plant parts from which they have originated : rhizome (ginger and turmeric), bark (cinnamon), bud (clove), flower-stigma (saffron), fruit (capsicum, pepper, fennel and coriander), seeds (mustard, cardamom, nutmeg and mace).

17.4 SPICES OBTAINED FROM UNDERGROUND PARTS: RHIZOME

There are several spices which are obtained from underground parts of plants (rhizome) such as galangal (*Alpinia officinarum*), ginger (*Zingiber officinale*), sarsaparilla (*Smilax* spp.), and turmeric (*Curcuma longa*). In this section we will describe ginger and turmeric. Ginger is used in both fresh and dried forms whereas turmeric is mostly dried and powdered. Both of these have medicinal value, especially in Ayurvedic preparations.

17.4.1 Ginger

Botanical name: ***Zingiber officinale***
Family: Zingiberaceae
Common name: Adrak
n = 11

Origin: Ginger is indigenous to south-east Asia.

Distribution: It is now cultivated in several parts of the world; the most important regions are India, Jamaica, Sierra Leone and Australia. India is the world's largest producer and exporter of ginger, and 70 per cent of the total production comes from Kerala. It is also cultivated in West Bengal, Orissa, Karnataka, Madhya Pradesh and Gujarat.

Morphology: The ginger plant is an erect perennial herb. It has a thick hard, laterally compressed, often palmately branched rhizome (hands). It is covered with small scale leaves and fine fibrous roots (Figure 17.1). Minute sacs containing essential oil and resin are distributed through out the rhizome, but mainly in the epidermal tissue. The characteristic aroma of ginger is due to a volatile oil (ginger oil), and its pungency is due to a non-volatile oleoresin (gingerin).

In 1672 Elihu Yale joined the British East India Company as a clerk and from the fortune he made in the spice trade, becam the foundation of Yale University in the United States.

The leafy shoots arise annually. They are erect, 60-90 cm. tall, and are closely invested by the sheathing leaf bases. The leaves are alternate, linear-lanceolate and about 5-20 cm long (Fig.17.1).

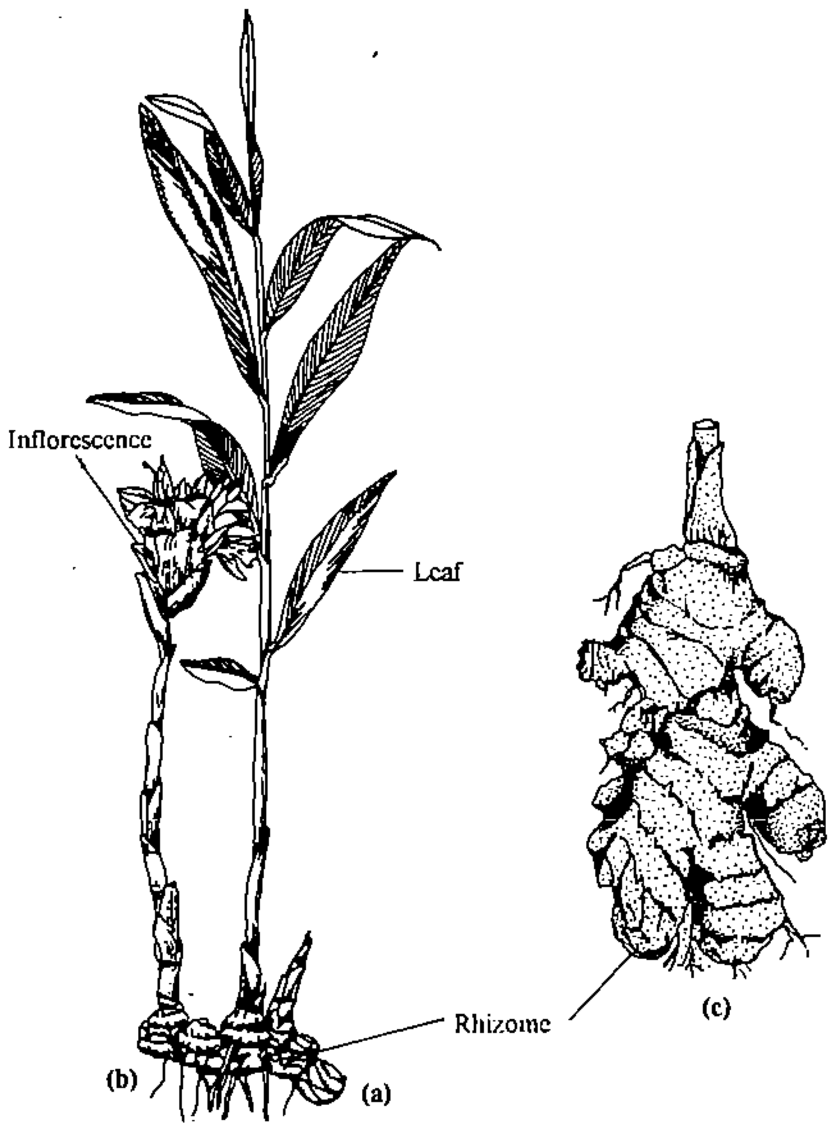

Fig. 17.1: ***Zingiber officinale.*** **Ginger. a) Plant with rhizome. b) Inflorescence. c) Close up of rhizome.**

Cultivation: The plant grows best in warm tropical climate and can grow in the region from sea level to 1500 m. The plant is propagated commercially by portions of the rhizome, 2.5 to 5 cm. long, with at least one viable bud. Ginger is a soil exhausting crop, requiring heavy fertilization. Sandy, clayey or lateritic loams are best suited for crop. It is usually grown on small holdings.

The crop is harvested in stages. For green ginger, the tender rhizomes, which are needed for pickling, are ready for harvesting from the fifth month. But for mature or brown rhizome, harvesting is done 9-10 months after planting when the leaves begin to turn yellow. The rhizomes are pale yellow, faintly orange or yellow-orange in colour externally and greenish yellow inside. It requires curing after harvesting and appears in market in two forms:

1. **Dried or cured ginger -** It is produced by various methods in different countries. Two important grades of dried ginger are recognised in the spice trade (a) scraped or peeled ginger (uncoated ginger), and (b) unscraped or coated ginger. The finest quality of Jamaica ginger is carefully scraped and dried in the sun for five to six days. Scraped Jamaica ginger is light buff in colour with a very delicate aroma and flavour. In some countries, the rhizomes are plunged into boiling water for a few minutes (scalded) and are dried in the sun with or without peeling. Liming has been found to improve the colour and appearance and the spice is protected from mildew and other pests. The rhizomes are sometimes bleached by sulphur fumes.

2. **Green ginger -** It is prepared by boiling the tender, fleshy peeled rhizomes in water, after which they are boiled and sold in sugar syrup. Crystallised ginger is produced in the same way, but is dried and dusted with sugar. Much of the preserved and crystallised ginger is now exported from Hongkong. Chinese ginger with a low pungency and aroma is used for this purpose.

Uses

i) **In Food Preparations:** It is widely used for culinary purposes in the preparation of ginger bread, biscuits, cakes, puddings, soups and pickles.
ii) **Recovery of starch and manufacturing soft drinks from exhausted ginger (after recovery of volatile oil):** Starch can be obtained from ginger residue after the recovery of oleoresin. Likewise, vitaminised effervescent or plain ginger powder can be obtained from the exhausted ginger.
iii) **Alcoholic Beverages:** Ginger is also used for flavouring beverages, such as ginger beer, ginger ale and ginger wine.
iv) **In Medicine:** According to the Ayurvedic system of medicine, ginger is considered to be a stimulant and carminative (helps in the expulsion of gas in the stomach).
v) **Ginger oil:** It is used (a) as a flavourant in non-alcoholic beverages, confectionery and pickles, (b) in pharmaceutical industry as a carminative, rubefacient (causing redness, as of the skin), in gastritis and dyspepsia (indigestion), and (c) in perfumery as it imparts a distinctive smell of the oriental type.

17.4.2 Turmeric

Botanical name: ***Curcuma longa*** **L. syn.** ***C. domestica*** **Val.**
Family: Zingiberaceae
Common name: Haldi
2n = 62, 63, 64

Origin: Turmeric is indigenous to southern Asia. It is not known in a wild state with certainty but has become naturalized in some areas in drier parts of eastern Java. The cultigen is a sterile triploid which does not fruit. It seems to have arisen by continued selection and cultivation by vegetative propagation from unknown wild ancestors, of which *Curcuma aromatica*, a wild diploid (2n = 42) in India, may have been one parent.

In India, about 150000 t. of cured turmeric is produced annually, of which about 92 per cent is consumed in India and rest is exported.

Distribution: Turmeric is cultivated extensively in India, Sri Lanka, Indonesia, China, Taiwan, Indochina, Peru, Haiti and Jamaica. India is by far the largest producer in the world. The main turmeric growing states are Andhra Pradesh, Maharashtra, Orissa, Tamil Nadu, Karnataka and Kerala and in northeast in Khasi and Jaintia hills.

Morphology: Turmeric is a perennial herb up to 1 m tall with a short stem bearing a tuft of 6-10 leaves, surrounded by bladeless sheaths; the leaf sheaths form a pseudostem.

The main thickened bulb i.e. rhizome "bulb" has a number of cylindrical primary, secondary and even tertiary rhizomes (fingers). The rhizome, is short, thick, blunt, rounded and coarser than ginger (Fig. 17.2). It branches at right angles and bears fibrous adventitious roots. It has a closely ringed, corky epidermis and a bright orange core with a distinctive smell and taste.

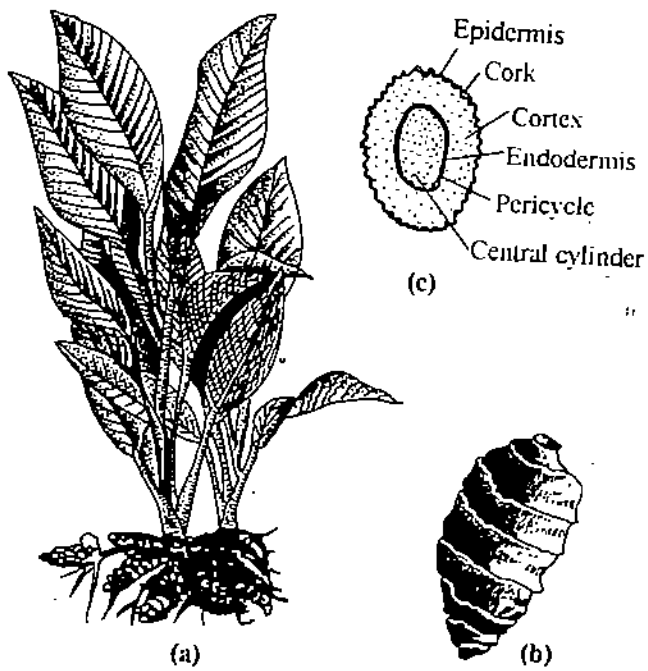

Fig. 17.2: Turmeric. a) Plant; plant with rhizome. b) Only rhizome. c) Cross section of the finger.

Cultivation: The plant is propagated vegetatively. The rhizome or finger with one or two buds is used as 'seed' for planting. It is often grown on ridges and thrives best in hot, moist tropical climate in well drained soil.

A number of varieties in India are distinguished by the names of the localities in which they are grown Those with hard, bright-coloured rhizomes are preferred for dyeing Larger, softer, more aromatic, an light-coloured rhizomes produce the best spice. Madras turmeric is highly esteemed in the market.

The crop is harvested nine to ten months after planting when the lower leaves develop a yellow colour. The main rhizome along with finger-like off-shoots is carefully dug out and the fibrous roots are cut-off. Green turmeric has to be cured and processed before it is marketed. Curing consists of boiling the rhizomes in water over a slow fire until they become soft. A few leaves of turmeric are usually added to the water in a cooking vessel. The cooked rhizomes are dried in the sun for about a week. Finally they are polished by rotating them in polishing drums. The resultant product is graded into 'fingers', 'rounds' and 'splits', fingers fetching a higher premium in the spice trade. Cured and finished turmeric is deep yellow to orange-yellow and has a distinctive pungent flavour.

Uses

i) **As a Flavourant:** In most of the Asiatic countries turmeric is used as a food adjunct in many vegetable, meat and fish preparations. Turmeric is an antioxidant because of the phenolic character of curcuma. This also increases the keeping quality of the spice. Its aromatic oil content imparts flavour and colour. It is an important part of curry powder. It acts as an appetiser and helps in digestion.

ii) **As a dye:** Turmeric has a colouring matter called curcumin, which imparts a yellowish shade in an acid bath. It is used for dyeing wool, silk and cotton. It is also used in paint and varnish industry. Turmeric paper is used for testing alkalinity.

iii) **In Medicine:** In the Indian system of medicine turmeric occupies an important place as an ingredient in the preparation of medicinal oil, ointments and poultices. It is useful in curing periodic attacks of hysteria and convulsions, intestinal disorders, anemia (turmeric is rich in iron), measles, asthma, cough and cold, sprains, boils, skin disorders and sore eyes. Burnt turmeric used as toothpaste relieves dental troubles.

Turmeric has a musky odour due to the presence of essential oils (5-6 per cent), of which main constituents are d-a-phellandrene, d-sabinene, cineol, borneol, zingiberene and sesquiterpenes. The yellow colour is due to curcumin.

iv) **In Cosmetic industry:** Because of its healing and antiseptic properties, turmeric is used in the preparation of kumkum, creams and lotions.

17.5 SPICES OBTAINED FROM BARK

Cinnamon and cassia are the only two spices that comes from bark. Chinese cassia comes from *Cinnamomum cassia*. Indian cassia comes of *Cinnamomum tamala*. It's leaves (tejpat) are also used extensively in North India as a spice, while true cinnamon or dalchini comes from bark of *Cinnamomum zeylanicum* which is frequently used as a spice in India. We will describe it in detail.

17.5.1 Cinnamon

Botanical name: *Cinnamomum zeylanicum* Breyn
Family: Lauraceae
Common name: Dalchini
2n = 24

Origin: Cinnamon is indigenous to Sri Lanka. In India this tree is grown in Kerala and forests of Western ghats.

In India, cinnamon is grown on the west coast. In Anjarakkandi, Cannonore district, Kerala, there is a 248 acre Randa Tarra cinnamon plantation – One of the biggest and perhaps the oldest plantation in Asia.

Distribution: The quality of cinnamon depends, among other factors on the region where it is grown. Sri Lankan cinnamon and cinnamon from the Seychelles Islands are considered to be among the best. The other producers are China, Malaysia and Indonesia. It is also, to some extent cultivated, in Kenya, Tanzania, the West Indies and South America.

Morphology: *Cinnamomum zeylanicum* is an evergreen tree. It reaches a height of 9-12m (sometimes up to 18m) in its native habitats Sri Lanka and South India. It is usually grown as a 'cut back' bush under cultivation. Both bark and leaves are strongly aromatic. The leaves are large (12.7 - 17.5 cm in length) leathery, bluntly pointed, glossy, dark greenish above and dull grey greenish below with three or five prominent ribs.

The flowers are in lax axillary and terminal panicles at the end of twigs (Fig. 17.3 a). The flowers are small (Fig. 17.3 b), with foetid smell. The fruit is purplish or black, fleshy, 1-seeded, ovoid with enlarged calyx at base (Fig. 17.3 c).

Cultivation: Plants are generally raised from seeds, but can also be propagated from cuttings. The cinnamon plant grows best in sheltered situations from almost sea level up to an elevation of about 1000 m. where average rainfall is 200-250 cm. and mean temperature about 27°C. A hot and moist or humid climate is considered ideal for its cultivation. Two to three years after planting, the plants are cut back or 'coppiced' to induce the formation of new shoots from the suckers which, in due course, are pruned to leave six to eight plants per bush.

The first crop of cinnamon is obtained some two years later when the plants have reached a height of 2-2.5 m. The plants are cut close to the ground following the monsoon rainfall as it facilitates the peeling of the bark.

Headache produced by exposure to cold air is readily cured by applying a paste of finely powdered cinnamon mixed in water on the temples and forehead.

Two longitudinal slits are made lengthwise in the severed shoots and the bark is peeled off in one meter lengths with the help of specially designed tools. The bark lengths are then firmly tied together in bundles and left for 24 hours to 'ferment'. The corky outer layer of the bark is then carefully scraped off and allowed to dry which makes it contract and curl inwards in the form of hollow tube-like structure the quills of commerce (Fig. 17.3 c). Good quills should be about 1 cm. wide and 4 mm. thick.

The bark contain 0.5-1.5 per cent essential oil. Its chief constituent is cinnamic aldehyde (60-75 per cent). Cinnamon leaf oil contains 70-95 per cent eugenol.

Uses

i) **As a flavouring agent:** Dried cinnamon leaves and inner bark are used for flavouring cakes and sweets and in curry powder. Cinnamon bark oil is also used for flavouring confectionery and liquors.

ii) **Medicinal:** Cinnamon is an effective remedy for common cold. It checks nausea, vomiting and diarrhoea. It stimulates digestion.
Cinnamon leaves are useful in relieving flatulence and in increasing secretion and discharge of urine. It also prevents nervous tension. It is used in pharmaceutical soaps and dental preparations.

(iii) **In perfume industry:** Both cinnamon bark and leaves are used in the preparation of incense, and perfumes. Leaf oil (it has 70-95 per cent eugenol) is generally preferred to clove oil for the synthesis of vanillin.

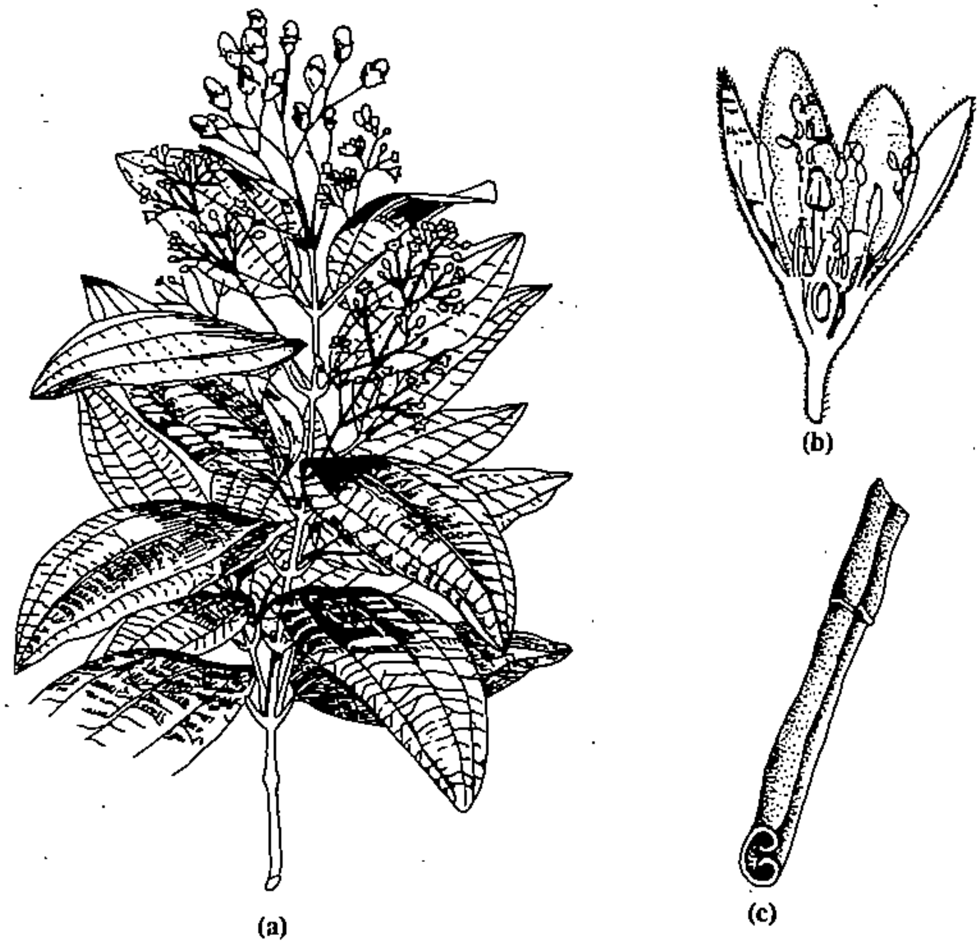

Fig. 17.3: *Cinnamomum zeylanicum*. a) Flowering shoot. b) Flower in longitudinal section. c) Quills.

Box 17.1: I.S.O. Officially recognises the following species:

		Botanical names	Popular names
A.	(i)	*Cinnamomum zeylanicum*	Cinnamon
	(ii)	*C. tamala* (Buch - Ham.) T. Nees and Eberm.	Tejpat or Indian *Cassia Lignea*
	(iii)	*C. obtusifolium*	Tejpat
B.	(i)	*C. aromaticum* C.G. Nees or *C. Cassia*	Cassia China or Cassia
	(ii)	*C. burmannii* Blume *Cassia vera*	Batavia Cassia or Java Cassia or Padang cinnamon
	(iii)	*C. laureirii*	Saigon cassia

SAQ 1

Fill in the blanks using appropriate words:

1. Columbus helped in the discovery of two important New World spices, ... and ....
2. Most of the chemicals responsible for the characteristic flavour and odour of herbs, spices and condiments are compounds known as ....
3. Ginger plant has a oleoresin known as ....
4. Turmeric is indigenous to ....
5. .... has a colouring matter called curcumin, which imparts a yellowish shade in an acid bath.

17.6 SPICES OBTAINED FROM FLOWER BUDS OR FLOWERS

Several spices are obtained from flowers or flower buds such as capers from *Capparis spinosa*, cloves from *Eugenia caryophyllata*, and saffron from *Crocus sativus*. We are going to describe in detail saffron (the costliest spice) and clove, these are commonly used in Indian cooking.

17.6.1 Saffron

Botanical name: ***Crocus sativus*** **Linn.**
Family: Iridaceae
Common name: Kesar/Zafran
n = 12

Origin: The saffron plant is probably a native of southern Europe and Asia Minor.

Distribution: Saffron is cultivated in Spain, Turkey, France, Italy, Greece, Austria, England, Iran, China and India. In India, saffron cultivation is mostly confined to Pampore (altitude 1700 m) in Kashmir and the Kishtwar region in Jammu. Experimental cultivation of saffron has been successful in nurseries at Doonda (Uttarkashi), Joshimath (Chamoli), Bisar (Pithoragarh) and Bharsar (Pauri Garhwal) in the Uttar Pradesh hills.

Box 17.2 : Saffron cultivation

> The Central Council for Research in Ayurveda and Siddha (CCRAS) has succeeded in cultivating five tons of saffron over 2,000 hectares of land at Ranikhet and Chamoli in the hill areas of Western Uttar Pradesh. This is for the first time that it has been grown on such a scale anywhere outside the Kashmir valley.

Morphology: Saffron plant is a low-growing perennial herb (15- 25 cm high). It has a globular, underground corm (a solid bulb-like part of the stem, usually subterranean) and bears six or more radical, narrow, linear leaves (Figure 17.4). The bluish or violet flowers are borne singly.

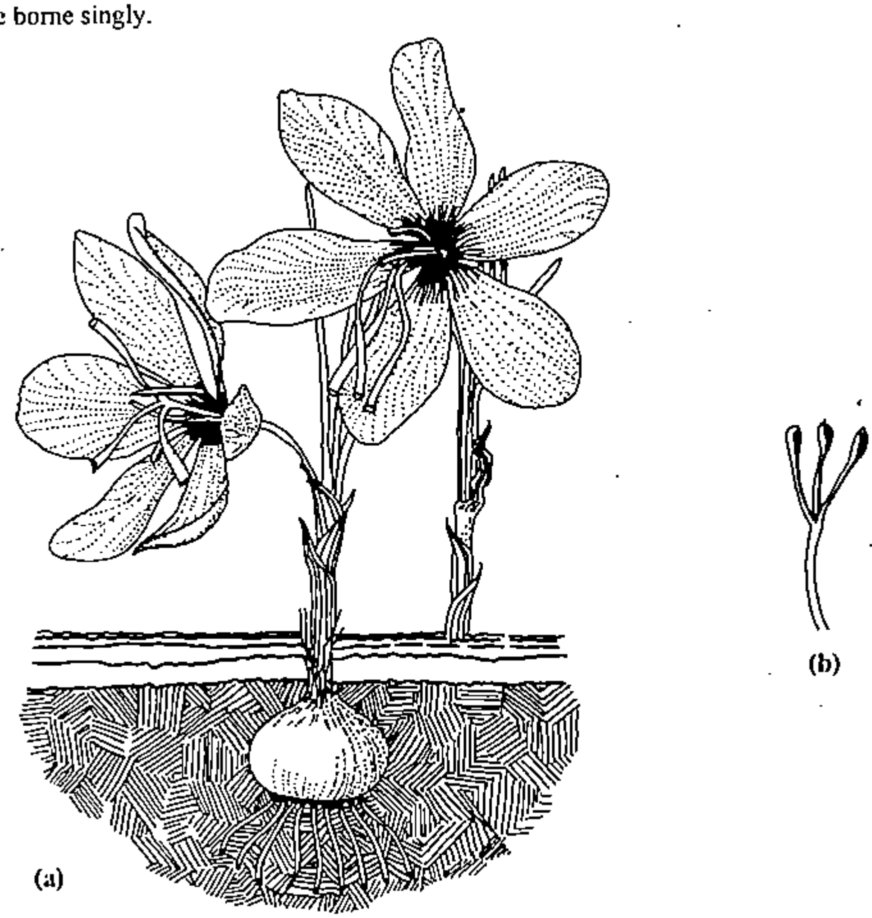

Fig. 17.4: a) *Crocus sativus* plant with a corm. b) Tripartite funnel shaped stigmas.

The value of saffron depends mainly on the method used for drying the stigmas. The process is known as 'drying' in India or 'toasting' in Spain. The spice sold in the market is a loosely matted mass of dark, reddish-brown flattened stigmas. It has a characteristic aromatic odour due to the presence of an essential oil, safronal, and a bitter taste because of glucoside picrocrocin. It contains a reddish yellow pigment a glycoside crocin, and is also a rich source of riboflavin. Nearly 154,000 flowers or 210,000 stigmas are required for a kilogram of dried spice. It is indeed, the world's most expensive spice.

Cultivation: Saffron plants are propagated vegetatively by planting young cormlets. The warm or subtropical climate in cold region is needed for cultivation of this spice. The flowering period in India begins during middle or late October and lasts until first or second week of November. Stigmas are hand picked every day as flowers open. They are dried in the sun or by artificial heat. After complete drying, the saffron is packed immediately, preferably in tin container. The finest quality of saffron, 'Shahi Zafran' is obtained from the red tips of the stigmas. The remaining part of the stigma constitutes the inferior grade saffron.

Uses

(i) **As a flavouring and dyeing agent:** Saffron is used for colouring and flavouring butter, cheese and confectionery. It is used in exotic dishes particularly Indian sweets, Spanish rice specialities and French fish preparations.

(ii) **In medicine:** (a) Saffron is an important ingredient of the Ayurvedic and Unani systems of medicine in India. It is used in fevers and enlargement of the liver and spleen. It strengthens the functioning of stomach and counter - acts spasmodic disorders. It is also reported to give strength to the heart and brain.

  b) It is also used for colouring other medicines.
  c) Saffron 'bulbs' are toxic to young animals and overdose of stigmas has a narcotic effect.

Saffron is an ingredient of many continental dishes, particularly the famous Indian dishes such as 'Pullao' are flavoured and coloured with saffron.

Saffron oil obtained from the distillation of dried stigma is the most expensive of the essences and the characteristic odour is due to safronal.

17.6.2 Clove

Botanical name: *Eugenia caryophyllus* **(Spreng) Bullock & Harrison Syn.** *Syzygium aromaticum* **(Merrill & Perry),** *Eugenia caryophyllata Thumb*
Family: Myrtaceae
Common name: Laung/Lavang
n = 11

Origin: The clove tree is believed to be indigenous to the Moluccas or spice Islands - a group of volcanic islands in Eastern Indonesia.

Distribution: The biggest clove producing region in the world today is Zanzibar, followed by Pemba, Madagascar and Indonesia. It is also grown in Malaysia, Sri Lanka, India and Haiti. In India the lavang is cultivated in the Nilgiris, Tenbasi hills and Kanyakumari district in Tamil Nadu and Kottayam and Quilon districts in Kerala.

Morphology: The name 'clove' is derived from the French word 'le clou' meaning nail (Fig. 17.5). Each flower bud consists of a peduncle (hypanthium), four distinct triangular calyx lobes, four crimson unopened petals surrounding numerous stamens and a central columnar style. The hypanthium represents the enlargement of the receptacle. The bicarpellary inferior ovary is enclosed by a more or less fleshy receptacle. The hypanthium is a small angular peduncle, flattened at the base. It has numerous oil glands that impart a characteristic aromatic odour. The leaves, unripe fruit and broken clove including the stalk are all aromatic and yield essential oil.

The clove tree is a rich source of essential oil with 16 per cent in clove buds, 2 per cent in leaves and 4-6 per cent in stem. The clove oil contains 80-92 per cent eugenol.

Cultivation: *Eugenia caryophyllus* is a small symmetrical evergreen tree (12 – 15 m in height). Crimson red flowers are produced in clusters of three in wild growing plants, but under cultivation the trees are not allowed to bloom. The flower buds are hand picked when they are dull red and then sun dried on a mat or in a kiln. Good quality cloves are bold, plump, rough but not wrinkled. The clove tree thrives best in deep volcanic, loamy soil, and requires a warm humid climate. Clove is propagated by seeds, which are usually planted in shaded nurseries and then transplanted into the field.

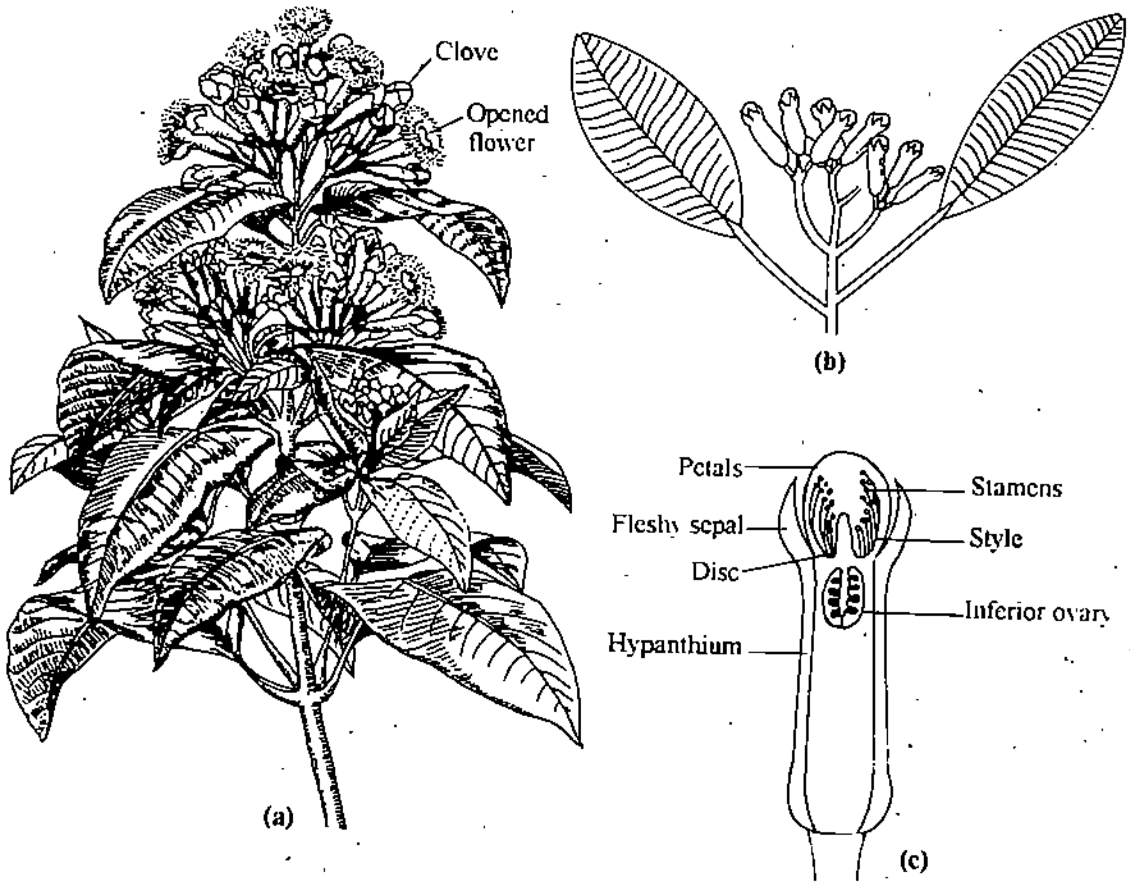

Fig. 17.5: *Eugenia caryophyllus.* a) Flowering branch. b) Two simple leaves and part of inflorescence. c) L.S. of bud.

Uses

(i) **As a culinary spice:** Clove is very aromatic and has a fine flavour. It is used for flavouring both sweet and savoury dishes. Whole as well as ground cloves are used in confectionery, pickles and preserves.

(ii) **In cigarettes & betelnut chew:** In Java, clove is used in the preparation of a special brand of cigarettes. It is one of the ingredients of betelnut chew because of its stimulating and warming qualities.

(iii) **In Medicine:** Clove is used to cure flatulence and dyspepsia. Clove oil has antiseptic, analgesic and antibiotic properties, and is a must at every dentists shelf. It is an ingredient of many tooth pastes and mouth washes.

(iv) **As a clearing agent:** Clove oil is used as a clearing agent in histological work.

(v) **In perfume industry:** The clove oil contains, eugenol which is extensively utilized in perfumes, and in scenting soaps and bath salts. It is also used in the preparation of artificial vanilla.

SAQ 2

1. Write whether the following statements are right or wrong. Put ✓ or × sign in the given bracket.

i) *Cinnamomum zeylanicum* is usually grown as a 'cut back' bush under cultivation. [ ]

ii) The leaf oil of *Cinnamomum* contians 20-30 per cent of eugenol. [ ]

iii) The value of saffron depends mainly upon the method by which the stigmas are dried. [ ]

iv) The aromatic saffron odour is due to the presence of safronal and bitter taste due to eugenol. [ ]

v) In clove the hypanthium represents the enlargement of the receptacle. [ ]

vi) Clove oil is used as a clearing agent in histological work. [ ]

17.7 SPICES OBTAINED FROM FRUITS

There are several spices which are obtained from fruits such as Allspice from *Pimenta officinalis*, capsicum or chillies from different species of *Capsicum*, pepper from *Piper nigrum*, vanilla from *Vanilla planifolia*, caraway from *Carum carvi*, coriander from *Coriandrum sativum*, cumin from *Cuminum cyminum*, dill from *Anethum graveolens* (Indian dill, *A. sowa*), and fennel from *Foeniculum vulgare*. Here we are going to describe in detail capsicum, pepper (king of spices), coriander and fennel.

During 1996-97, India produced 9.45 lakh tonnes of chillies (dry) over an area of 9.565 lakh hectares spread over 23 states.

17.7.1 Capsicum/Chillies

Botanical name: *Capsicum annuum* Linn. *C. frutescens* Linn
Family: Solanaceae
Common name: Mirch
n = 12

Origin: Capsicum or red pepper is America's most important contribution to the spices. Chillies are indigenous to the American tropics and subtropics and the West Indies. Its remains have been found in Mexican caves dating back to 7000 B.C.

Distribution: *C. annuum* is most widely grown all over the world. *C. frutescens* is cultivated mainly in the tropics. India is the world's largest exporter of chillies. In India chillies are grown practically throughout the country but major producing states are Andhra Pradesh, Maharashtra, Karnataka and Tamil Nadu.

Pungency of chillies is due to a crystalline substance capsaicin, concentrated mainly in the placental region, where the seeds are attached to the spongy central portion. Vitamins A and E (tocopherol) are also reported from it. Colouring matter in ripe fruits consists of compounds such as, capsanthin, a and b cartoenes, xanthophylls etc.

Morphology: *C. annuum* - All cultivars are annuals with a short growing season (Fig.17.6). Flowers are borne singly in the leaf axils. Ripe fruits (berries) are reddish, yellowish or brownish. Fruits may be 30 cms long but some varieties have small fruits. These may be erect or pendant. Fruits are hollow and fleshy, rich in vitamin C, and are not very pungent. *C. frutescens* - Plants are short lived perennials. Flowers are in clusters of 2 or more in the leaf axils. Fruits are bright red. They are generally small (2 -3 cm long), erect, conical, usually thin-fleshed and pungent. Vitamin C content is lower than in *C. annuum*.

Cultivation: The capsicum is grown as an annual, warm season crop because it is unable to withstand frost. The seeds are first sown in nurseries and the seedlings transplanted later into the field when about 15 cm. high.

Most of the berries used are of milder cultivars belonging to *C. annuum* var. *grossum* (L.) Sendt. These unripe dark green berries of sweet pepper (known as simla mirch in India) are consumed as vegetable.

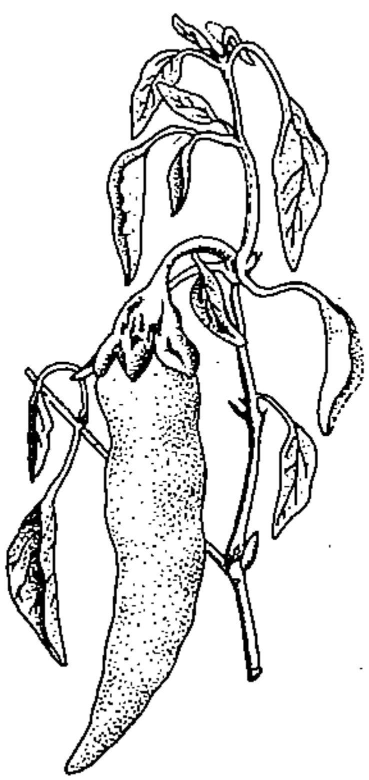

Fig. 17.6: A fruiting branch of *Capsicum frutescens*.

Uses

(i) **As a flavourant and colourant:** Paprika (Spanish pimento, is the mild or non pungent variety of chilli), Kashmiri mirch and red chillies are used both as spice and condiment for flavouring food preparations, sauces, pickles, etc.

(ii) **Role in human physiology:** Chillies, being rich in Vitamins C and A, are a good vitamin supplement in addition to their being an appetizer. The green chillies are more nutritious than ripe, dried chillies as most of the vitamins are lost during drying. The chillies stimulate the taste buds and increase the flow of saliva which contains the enzyme 'amylase'. This helps in the digestion of starchy or cereal foods into glucose.

(iii) **Medicinal properties:** Capsicum preparations are used as counter-irritants in lumbago, neuralgia and rheumatic disorders. It is carminative but if taken in excess, it may cause gastro-enteritis. According to some experiments conducted at Cancer Research Institute, Chennai (Madras), green chillies are reported to suppress cancer.

17.7.2 Pepper (King of Spices)

Botanical name: ***Piper nigrum* Linn.**
Family: Piperaceae
Common name: Kali mirch
n = 26

Origin: *Piper nigrum* is indigenous to the damp forests of the Malabar coast of southwestern India.

Distribution: It is now cultivated in the tropics of both Eastern and Western Hemispheres. It is produced mainly in India, Thailand, Malaysia, Brazil, Sri Lanka and Indonesia. In India, Kerala alone contributes about 96 per cent to India's total pepper production. Pepper is also grown in Karnataka and Tamil Nadu.

Morphology: The plant is a perennial vine, reaching a length of 9 m or more in the wild state but is kept low (4 m high) under cultivation for easy harvesting. The vine shows dimorphic branching:

(i) **Orthotropic vegetative climbing shoots** - These have swollen nodes from which arise numerous adventitious roots, leaves and axillary buds. The roots help the plant to cling to tree trunks and other supports.

(ii) **Lateral plagiotropic fruiting branches** - These develop from the axillary buds and have no roots.

The leaves are alternate, ovate, dark green, shining above and pale green below, with sharp pointed tips. The inflorescence (3-25 cm long), with up to 150 flowers, is borne opposite leaves on plagiotropic branches. Flowers are unisexual or hermaphrodite. Fruits are sessile globose drupes. During the course of ripening the fruit changes from green to bright red and eventually yellow. In dried fruits, its black mesocarp is pulpy. Seeds (3-4 mm in diameter) have a minute embryo and little endosperm; most of it is occupied by perisperm (Fig. 17.7 d).

Black pepper is obtained from unripe fruits after drying, whereas white pepper is prepared from greyish white rounded seeds obtained from nearly ripe fruits. Green pepper is obtained from semi mature tender greenish spikes.

Pepper contains alkaloids piperine and piperidine. The pungency of the pepper is because of an oleoresin fraction which is abundant in the mesocarp. The characteristic aroma of pepper is due to the presence of a volatile oil, chiefly present in the cells of the pericarp. Some hybrids have been evolved at Pepper Research Station, Panniyur, Kerala.

Cultivation: The pepper vine thrives best in a moist, hot climate and partial shade. A rich friable loam with high humus content and good drainage is necessary for a good crop. Propagation is done through stem cuttings which are taken generally from the upper portion of young and viable branches. Generally two or three cuttings are planted adjacent to each support. The vine is supported on bamboo or wooden poles, concrete pillars or trained on to the trees such as mango, coconut or arecanut. When plants are only 0.6 m. tall, their tips are removed to facilitate the development of lateral buds thus plant becomes shrubby. The vine are pruned from time to time so that they are kept low. It takes three to seven years for the vine to reach full bearing. The crop ripens five to six months after flowering.

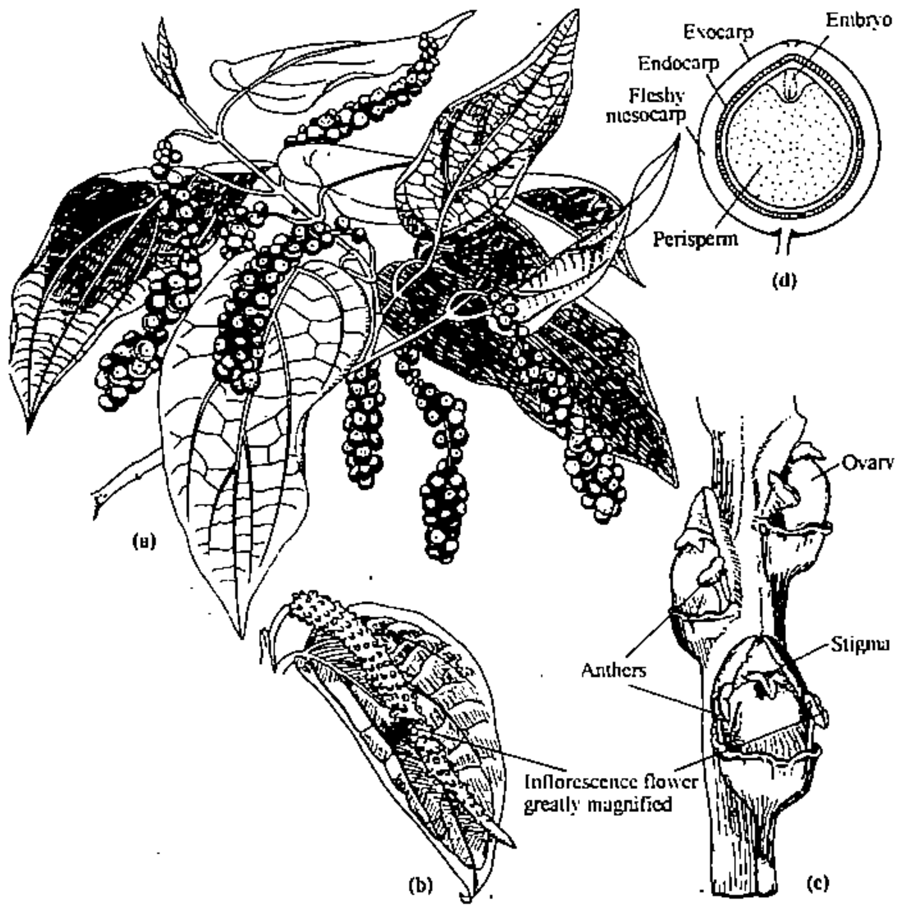

Fig. 17.7: *Piper nigrum*. a) Fruiting branch. b) Hermaphrodite inflorescence. c) Female flower showing stamen. d) Male fruit in Transverse section.

Harvesting: Two main grades of pepper are recognized in spice trade; black pepper and white pepper. For black pepper the berries or the fruits are picked when they are not fully mature and are still green or, sometimes, when only a few spikes are red. They are piled in heaps and left in the sun to dry. The berries may also be dried artificially in smoke houses. As they dry, the pericarp becomes tough and wrinkled and develops a dark brown or black colour owing to natural fermentation. Sometimes the freshly harvested unripe spikes are dipped in boiling water to hasten blackening and drying.

On the other hand, white pepper is produced from semi ripened berries that are greenish yellow or nearly red. After picking, the berries are packed in sacks and soaked in running water for about eight to ten days to loosen the skin. They are then trodden with bare feet to rub off the outer hull. The greyish white seeds so left are thoroughly washed with water and then they are dried in sun. Now-a-days, however, white pepper is mostly prepared from black pepper with the help of decorticating machines and is, therefore, less pungent.

Box 17.3: Pepper Cultivation

The total production of black pepper in India is nearly 50,000 tonnes with an area of 1.58 lakh hectares. The new high production technology evolved by the National Research Centre for Spices, Calicut, aims at doubling the total yield of this important spice by the turn of the century so that India could capture at least 50 per cent of the world export market.

Uses

(i) **As a flavourant** - Black pepper is an essential ingredient of many ground spice formulae and seasonings. White pepper commands a higher market price because in products such as mayonnaise black specks of black pepper are not liked. It is used in confectionery and in the preparation of beverages.

(ii) **In Medicine** - The Aryans considered it as a powerful remedy for various disorders such as dyspepsia, malaria, delirium, and tremors.

(iii) **As a preservative** - It is used as a preservative for curries and other perishable foods. **The Egyptians used it for embalming.**

(iv) **As an insecticide** - It is stated to be more toxic than pyrethrum against houseflies. The Dutch and the French are known to use it as an insect - repellant and moth killer.

(v) **Oil of pepper** -It is a valuable adjunct in the flavourings of meats, soups, sauces, beverages and liquor. It is also used in perfumery and medicine industry.

(vi) **Pepper byproducts** - A patent has been taken out by Central Food Technological Research Institute (CFTRI), Mysore for the preparation of a flavouring substance named 'Pepper-sal' from waste black pepper (rejections) and common salt. Pepper-sal is used as a flavouring agent for salads, drinks and meat dishes.

(vii) **Pepper hulls** - Pepper hulls or shells removed during the preparation of white pepper are sold separately as a light to brownish powder with a very pungent odour and taste. It is used for flavouring tinned foods. Pepper hulls, being rich in volatile oil can also be used as a source of pepper oil.

The characteristic aroma of pepper is due to the presence of a volatile oil (chiefly present in the cells of the pericarp). The pungency in the fruit is due to non-volatile oleoresin fraction and various alkaloids. Piperine is the chief alkaloid about.

17.7.3 Coriander

Botanical name: *Coriandrum sativum* L.
Family: Apiaceae (Umbelliferae)
Common name: Dhaniya
n = 11

Origin: Coriander is indigenous to the Mediterranean region.

Distribution: It is extensively cultivated in Russia, Central Europe, India, Turkey, Morocco, Argentina and the U.S.A. In India, coriander is grown in almost all states but mainly in Andhra Pradesh, Maharashtra, Tamil Nadu, Punjab, Uttar Pradesh, Himachal Pradesh, Assam and Madhya Pradesh.

Morphology: Apiaceae (Umbelliferae) is one of the most important families which provides several culinary herbs that give rich aroma to the food. Almost the entire family is confined to the temperate regions of world. A few of them are cultivated in the tropics wherever climatic conditions are favourable.

The important flavouring spices are anise, caraway, coriander, cumin, dill and fennel - all of which grow in the Mediterranean countries. Of all the above mentioned spices, caraway can be grown as far as in Iceland in the north and survives well.

Coriander is an annual herb (30-70 cm high) with dimorphic leaves. The lower leaves are broad with shallowly round-toothed margins, while upper leaves are finely dissected into linear lobes (Fig. 17.8).

Flowers are small, white or pinkish in compound terminal umbels. The fruit is 2-seeded with an unpleasant smell of bed bugs when unripe, but later becomes pleasantly aromatic due to the presence of coriander oils, the chief constituent of which is **coriandrol**. Of all volatile oils derived from the umbelliferous fruits, coriander oil is more stable and retains the sweet and agreeable odour for long. The coriander fruit is a typical schizocarp which is nearly globular and yellowish brown and bears the remnants of the calyx and stylopodium at its apex. The ridges of the fruit are indistinct and the fibrovascular layer runs all along the dorsal surface. The two mericarps are attached to an undivided carpophore (Fig. 17.8 d). The pericarp has no vittae on the dorsal side but usually a pair of vittae is present on the commissural side.

Box 17.4: Some Umbelliferae Spices.

The family Umbelliferae provides many culinary herbs because of their aromatic fruits. Apart from coriander the other two important spices *Carum carvi* L. (caraway) and *Cuminum cyminum* L. (cumin) are widely used for culinary purpose. Caraway seeds are used in flavouring bread, biscuits, cakes, cheese, apple sauce and cookies. Its seed oil is used in flavouring sausages, meat, canned goods, perfumes, mouth freshner preparations and liquors (Kuimmels). Its seeds act as mild stomachic and carminative. In India cumin is an important ingredient in curry powder and mainly for flavouring soups, sausages, pickles, cheese, meat dishes, bread and cakes. The cumin seeds are used as a stimulant, carminative and stomachic. The residue, left after extraction of volatile oil, can be used as cattle feed. Another spice *Trachyspermum ammi* (L.) (ajowan or Bishops weed) and *Ferula assafoetida* (*asafetida*) are also widely used in Indian cuisine.

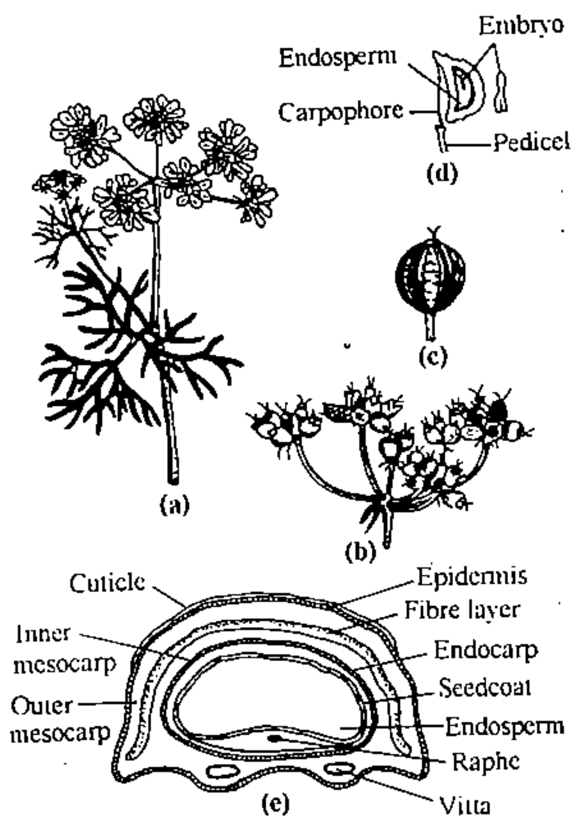

Fig. 17.8: *Coriandrum sativum*. (a) A branch bearing finely dissected compound leaves and umbel with actinomorphic and zygomorphic flowers. (b) Fruiting branch with involucral bracts and involucel bractlets. (c) A single fruit. (d) Mericarp cut longitudinally and (e) Mericarp in transverse section.

Uses

(i) **As a flavourant** - The coriander leaves because of their strong aroma are used for garnishing curries, sausages and chutneys. They are used for flavouring curries, soups and curd. The fruits are an important constituent of curry powders. In some western countries gin is flavoured with coriander.

(ii) **In Medicine** - Coriander seeds are considered to be carminative, diuretic, stomachic, antibilious and aphrodisiac. Coriander oil is used to mask offensive odours in pharmaceutical preparations.

(iii) **In Perfumery** - Oil of coriander seeds is valuable in perfumes; its soft, pleasant, slightly spicy note blends into perfumes with an oriental character. It harmonises well with jasmine.

17.7.4 Fennel

Botanical name: ***Foeniculum vulgare*** **Mill.**
Family: Apiaceae (Umbelliferae)
Common name: Saunf
n = 11

Origin: Fennel is a native of Southern Europe and the Mediterranean region.

Distribution: Bitter fennel *F. vulgare* var *vulgare* is now extensively cultivated in Russia, India, Romania, Hungary, Italy, Germany, France, Japan, Argentina and *F. vulgare* var. *dulce* (Mill) Thellung is grown only in France, Italy and Macedonia. In India, fennel is grown as a winter crop in Maharashtra, Gujarat and Karnataka. To a small extent it is also cultivated in Uttar Pradesh, Punjab, Haryana and Rajasthan.

Morphology: The fennel plant is a tall, aromatic perennial herb. All parts of the plant are aromatic. Leaves are pinnate, dissected four to five times, on long petioles; these are used as pot herb. The inflorescence is a compound umbel of yellowish flowers.

The fruits are oblong-oval or elliptical, greenish or yellowish brown with a long pedicel and a short stylopodium (a nectar-secreting, disclike enlargement at the base of the style, Figure 17.9). The two mericarps (one seeded sections) are attached to a divided carpophore (a modified extension of the pedicel). The pericarp usually contains four dorsal and two commissural vittae (oil tube, Figure 17.9).

Bitter fennel oil contains 6 per cent fenchone and 70 per cent anethole. Sweet fennel oil has up to 90 per cent anethole, but fenchone is absent.

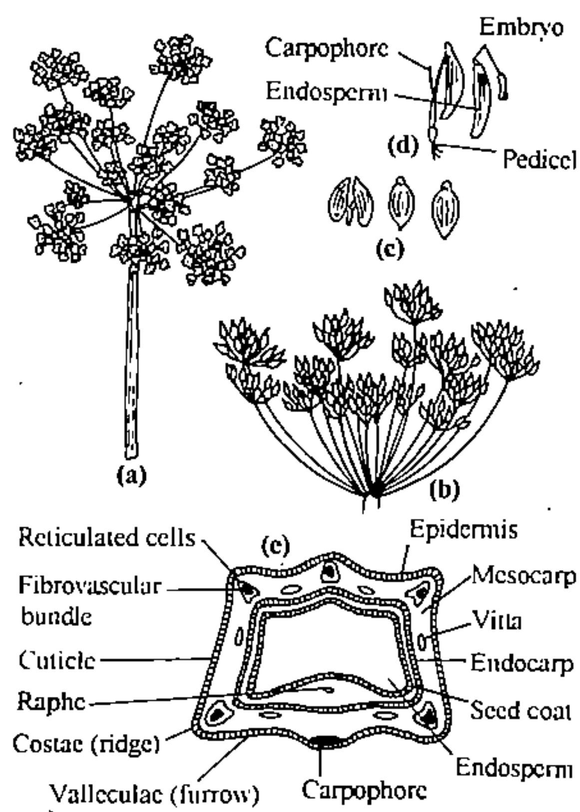

Fig. 17.9: ***Foeniculum vulgare.*** **a) A compound umbel (without involucral bract and involucel bractlet) having long primary pedicels or rays but with much shorter secondary rays. b) A fruiting umbel. c) Schizocarpic fruits whole and split showing branched carpophore (note the persistent stylopodium). d) Longitudinal section of mericarp, the carpophore is branched and the embryo is situated somewhere just below the stylopodium end and e) Median cross section of the mericarp.**

(i) **As a flavourant** - Dried fennel is an important ingredient of curry powders and is often used for flavouring soups, sauces, pickles, confectionery and liquors. The leaves are used for flavouring sauces and for garnishing.

(ii) **As a vegetable** - The thickened leaf stalks of fennel are blanched and used as a vegetable.

(iii) **In medicine** - Pharmacologically, fennel oil is used as a stimulant and carminative. It may be given in small doses to help children digest carbohydrates. Chewing fennel after meals prevents foul breath, indigestion and vomiting.

(iv) **In perfumery** - The oil of fennel is used in the manufacture of soaps and perfumes.

(v) **As a cattle feed** - The residual mass left after the distillation of fruits forms a valuable cattle feed.

SAQ 3

Match the botanical names given in **column A** with their respective fruits listed in **column B.**

	Column A	Column B
1.	*Foeniculum vulgare*	a) Berries
2.	*Piper nigrum*	b) Drupe
3.	*Coriandrum sativum*	c) Schizocarp
4.	*Brassica* sp.	d) Schizocarp
5.	*Capsicum annuum*	e) Siliqua

17.8 SPICES OBTAINED FROM SEEDS

Seeds from a large number of plants are used as spice, eg. mustard from *Brassica*, cardamom from *Elettaria cardamomum*, fenugreek from *Trigonella foenum - graecum*, and nutmeg and mace from *Myristica fragrans*. We are going to describe mustard, cardamom, nutmeg and mace.

17.8.1 Mustard

Brassica contributes many spices of considerable economic importance. There are about 150 species which are annual, biennial or, rarely perennial herbs. In India the principal oilseed crops are *B. campestris* and *B. juncea*. *Eruca vesicaria* sub sp. *sativa* another cruciferous plant, is a minor oil seed crop, grown mainly in Punjab and yield jamba oil. From *B. campestris* three distinct varieties viz. brown sarson, yellow sarson and toria have been evolved and they are restricted to distinct eco-geographical regions.

India has the largest acreage and production of rape and mustard in the world. The chief producer of rapeseed is U.P which alone contribute 60 per cent of total production. Other state are Punjab, Rajasthan, Madhya Pradesh and Assam.

Table 17.1: Mustard

Botanical name (common name) and Chromosome no.	Indian common name	Origin	Distribution
1. *Brassica alba* (Linn) Boiss or *B. hirta* or *Sinapsis alba* Linn (White mustard) n = 12	Safed rai	Mediterranean region	Russia Canada Denmark United Kingdom
2. *B. campestris* Linn. var. dichotoma n = 10 var. glauca syn var. toria Duthie & Fuller	Kali sarson Pili sarson (Yellow sarson) Toria	Mediterranean region	China Pakistan and India
3. *B. juncea* (Linn) Czern. & Coss. (Indian or brown mustard)	Rai	Africa	Africa, Europe to China, Japan,
4. *B. nigra* (Linn) Koch (True or black mustard)	Banarsi rai	Eurasia	Russia Europe

Family: Brassicaceae (Cruciferae)

The flowers show a typical cruciferous plan, i.e. with four free sepals, four free clawed petals, tetradynamous stamens and a bicarpellary, syncarpous, superior ovary, initially unilocular but later becoming bilocular due to the formation of a false septum (replum).

Morphology: Mustard plants are slender, erect, branched annual herbs about 0.6-1.5 m tall. They are generally covered by a waxy coating termed 'bloom'. The leaves are auricled (ear-shaped), and generally lyrate (Fig. 17.10) (pinnatifid, but with an enlarged terminal lobe and smaller lower lobes).

The seeds are small, spherical, yellowish- brown or black. The seeds possess a glycoside sinigrin or potassium myronate (sinalbin in *B. alba*). Both are virtually without physiological activity, but on hydrolysis with enzyme myrosin they yield dextrose and essential oil of mustard.

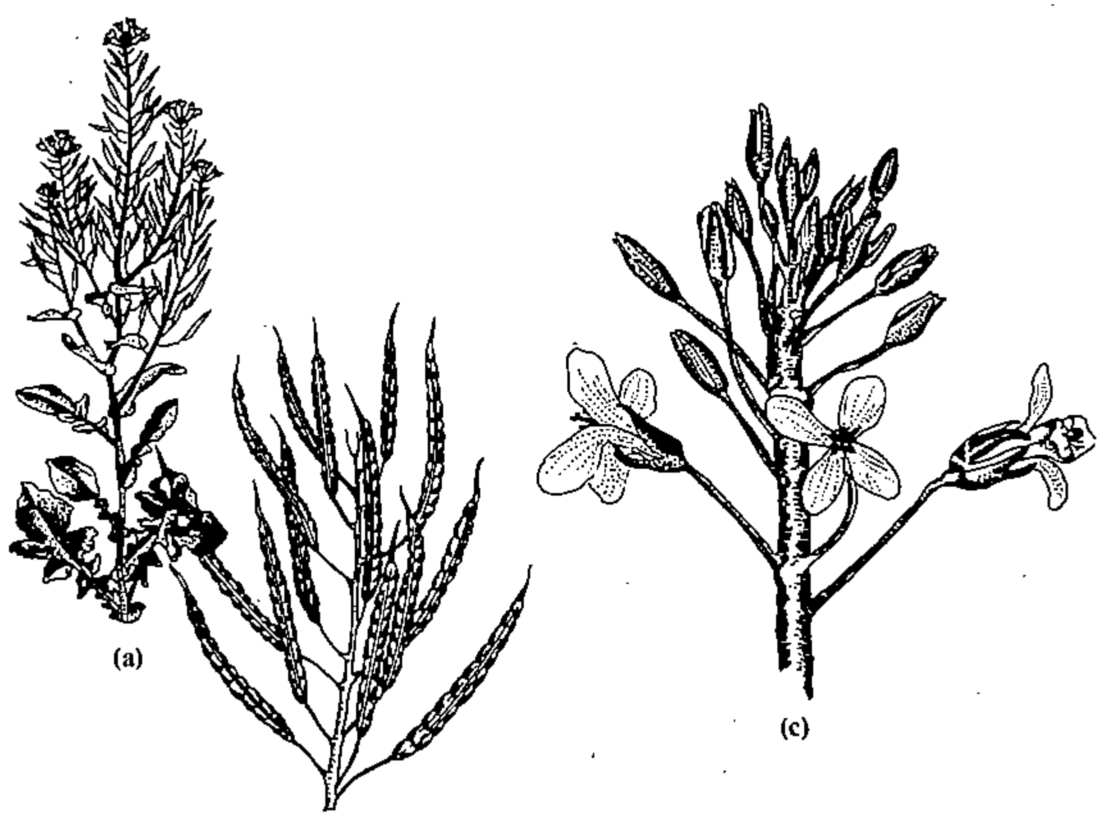

Fig.17.10: *Brassica* sp. a) Plant; with basal leaf. b) Pod. c) Flower.

Uses

(i) **As a flavourant** - mustard seeds, particularly rai are used as a condiment in the preparation of pickles and for flavouring curries and vegetables. The oil extracted from seeds is used as cooking oil and for salads and in margarine.

(ii) **As an illuminant** - inferior grades of mustard oil are used as an illuminant.

(iii) **As lubricant** - The erucic acid fraction of the oil is used for lubricating jet engines and in the manufacture of plastics. It imparts a soft and pliable texture to skins and hides during the tanning process. In India the oil is used for anointing the body.

(iv) **As a livestock feed** - The oil cake forms a livestock feed in India.

(v) **As a fertilizer** - In Japan, India and Europe the oilcake serves as fertilizer also. *B. hirta* is, sometimes, grown for green manure.

(vi) **In preservation** - Of all the spices, condiments and herbs studied with respect to their effect on yeast fermentation in wines, etc., mustard flour is prime in its preservative properties, being followed in order of efficacy by cloves and cinnamon.

17.8.2 Cardamom (Queen of Spices)

Botanical name: *Elettaria cardamomum* (L.) Maton
Family: Zingiberaceae
Common name: Chhoti elaichi
n = 24

Origin: The genus *Elettaria* is indigenous to India and Sri Lanka where it grows wild in the tropical rain forests including Indo-Malayan region.

A monotypic genus represented by *E. cardamomum*, is distributed in the tropical Indo-Malayan region.

Distribution: Besides India and Sri Lanka, Guatemala and Thailand are the other major producers of cardamom. It is also grown on a small scale in Laos, Vietnam, Cambodia, Costa Rica, El Salvador and Tanzania. In India, cultivation of cardamom is restricted to the states of Kerala, Karnataka and Tamil Nadu. Kottayam in Kerala and Coorg and Hassan in Karnataka are important districts where cardamom is grown.

E. cardamomum var. *major* Thw. is the 'wild' cardamom of Sri Lanka and the southern half of the Western Ghats.

Morphology: The cardamom plant is robust, about 3 m. herbaceous perennial. It has an underground branched rhizome; it gives off several erect leafy shoots. The leaves are two ranked on opposite sides of the stem and in the same plane (distichous). Flowers are borne in panicles. They are white or pale green with a central lip streaked with violet. The cardamon fruit is a trilocular capsule. It is creamy- white, oblong-ovoid (about 8-15 mm long) and shortly beaked. The pericarp is fibrous, papery and longitudinally wrinkled (Fig. 17.11).

E. cardamomum var. *cardamomum* (syn. var. minor Watt. Var. *minuscula* Burkill) include most of the cultivated races grown in India.

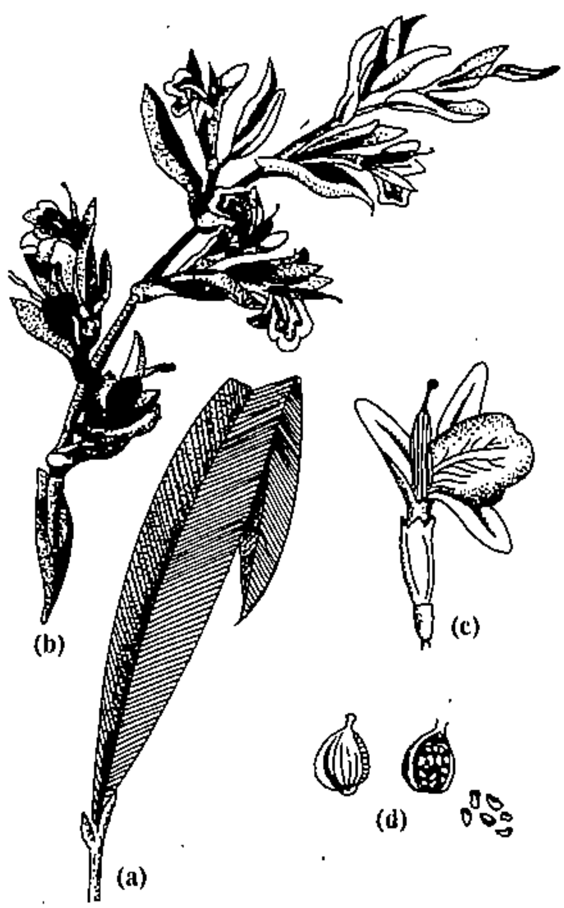

Fig. 17.11: *Elettaria cardamomum*. a) A leaf. b) The panicle with axillary cincinni, usually two to three flowered. c) A flower with tubular bracteole and calyx and obovate labellum with streaks radiating from the centre. d) Capsules and seeds.

In each fruit there are 15-20 seeds. They are aromatic, about 3 mm long, brownish, angled, wrinkled, and are held together by a loosely attached papery structure - the aril. The seed has a bulky white starchy perisperm and a small embryo (Fig. 17.12).

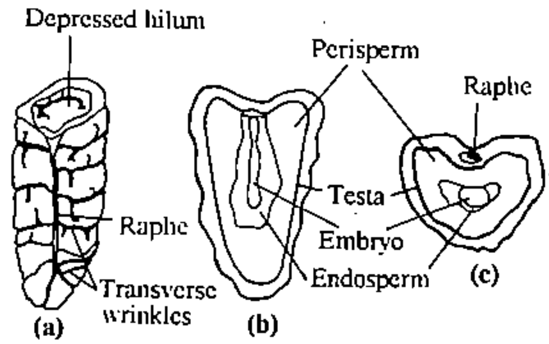

Fig. 17.12: Cardamom seeds. (a) Surface view. (b) Longitudinal section and (c) Transverse section.

Cultivation: The cardamom is strictly a tropical crop from the hilly regions. The plants are propagated by the segmentation of rhizomes or by seeds. The fruits are harvested just before they are fully ripe to prevent their dehiscence during drying. They are either dried in sun or in a drying shed. Sometimes the fruits are bleached with sulphur fumes to improve the colour of the outer skin. Husked fruits retain their aromatic odour for a long time. The seeds have a pleasing aroma and a characteristic warm, slightly pungent taste. This pleasant aroma is due to the presence of a volatile oil (2-3%). The chief components of the essential oil (cardamom oil) are cineol, terpineol, turpinene, sabinene and limonene.

Box: 17.5: Cardamomum varieties.

E. cardamomum exhibits considerable variation under cultivation and the naming of commercial types after the places of production has led to confusion regarding the identity of the varieties. Two varieties based on the size of the fruits are recognized. They are (i) *E. cardamomum* var. *major* Thw. comprising the 'wild' indigenous cardamom of Ceylon or Greater oblong cardamom or long cardamom and (ii) *E. cardamomum* var. *minor* Watt (syn. *E. cardamomum* var. *minuscula Burkill*) comprising all the cultivated races particularly those included under the names Malabar and Mysore. Cardamom var. *major* is the more primitive variety from which the cultivated var. *minor* is derived. The latter is commonly grown in India. It includes a large number of races differing in size of the plant, the nature of the leaf surface and the characters of flowering panicles and fruit capsules. All the varieties and races are interfertile and the observed variations are probably due to natural crossing.

Large Cardamoms

Botanical Name: *Aframomum amomum*

Hindi Name: Bari elaichi

Uses

(i) **As a flavourant and masticatory:** Cardamom seeds, whole or in powdered form, are used in the preparation of curry powder, pickles, confectionery, coffee, liquors and tobacco. Cardamom fruit is chewed after meals or often included in 'pan' preparations. It is distilled to yield cardamom oil. In Saudi Arabia, cardamom is the most popular spice.

(ii) **In medicine:** It acts as a powerful aromatic stimulant, carminative, stomachic and diuretic. It is said that eating a cardamom once daily with a tablespoon of honey improves eye-sight, strengthens the nervous system and keeps one healthy. Powdered seeds of cardamom boiled with tea-water imparts a very pleasant aroma to the tea and helps to overcome exhaustion due to over-work, depression, etc.

SAQ 4

Make a list of spices that are obtained from seeds and describe any one in detail.

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17.8.3 Nutmeg and Mace

Botanical name: ***Myristica fragrans*** **Houtt**
Family: Myristicaceae
Common name: Jayaphal
n = 21

Myristica fragrans yields two spices, nutmeg and mace, nutmeg is the dried kernel from the seed, whereas mace is the dried reticulated aril.

Origin: It is a native of the Moluccas Islands, also known as spice Islands.

Distribution: At present, around 60% of the world's production of nutmeg and mace comes from Indonesia, especially the islands of Sianew, Singhales, Ternate, Java, Sumatra, Northern Celabes and Banda. Other chief producers are Grenada in the West Indies, Malaysia and Sri Lanka. In India, nutmeg trees are grown on a small scale in Tamil Nadu (Nilgiris, Burliar, Coimbatore) Kanyakumari and Madurai districts, Kerala, Assam etc.

Morphology: *Myristica fragrans* is a handsome, aromatic evergreen tree with a height of 9-12 meter under cultivation. The trees are usually dioecious. The fruits look rather like large apricots and are orange yellow in colour. At maturity, the pericarp or 'husk' splits along the grooves into two halves, exposing the beautiful, brilliant scarlet, somewhat tough, leathery, net like protective covering - the aril. On complete drying of the glossy brown oily seed, the seed kernel separates from lustrous hard shell - like testa with a rattling sound. The seeds are broadly oval, brown or greyish brown and reticulately furrowed. The cut surface presents a lustrous but marbled appearence with the lighter - coloured endosperm marked by many dark brown veins (perisperm). The essential oil of nutmeg is present in these veins (Fig. 17.13).

Cultivation: The trees are propagated from fresh seeds. The seed may be planted in nurseries or baskets and transplanted to the field when about 15 cm tall. The nutmeg tree is dioecious but you cannot distinguish the sexes until it flowers that too after six years of planting. To get maximum production of nutmegs from plantations, it is considered necessary to maintain a ratio of one male tree for 10 to 12 females. The trees thrive well in sheltered valleys, in a hot moist climate. Nutmeg trees need a friable, well-drained sandy soil, which is rich in humus and well distributed rainfall (200 - 250 mm per annum), and temperature of 25 - 33°C for good growth. It can also tolerate the waterlogging or drying out of the soil.

Nutmeg trees usually start fruiting in sixth year and remain productive for 50 years or more. The fruits ripen in six month after flowering. In Grenada there are two main production peaks, January to April, and September to October. But fruits are produced all round the year. Harvesting is done with a long, two pronged pole equipped with a basket when the fruits burst open on the tree. Fruits and seeds which have fallen on the ground are also collected. The average annual yield per tree is 1200 nutmegs and sometimes up to 4000.

A record yield of 20000 fruits per tree annually has been reported.

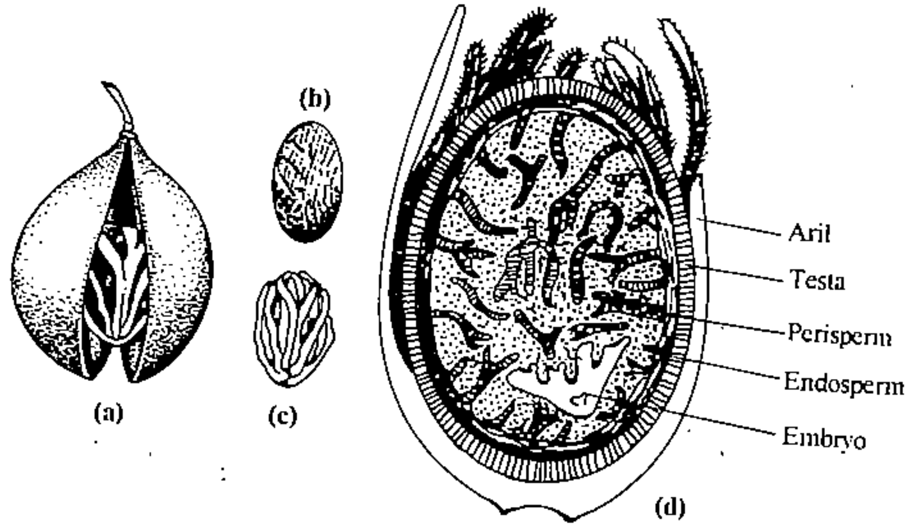

Fig. 17.13: a) A *Myristica fragrans* fruit cut open to show nutmeg and mace in position. b) Seed. c) Nutmeg seed 'aril' contact. d) L.S. of nutmeg seed.

After the husk splits open, the fruit is picked, the pericarp removed, and the mace stripped from the shell, flattened, and dried. It turns a yellowish brown. The seeds are dried and the shell cracked off. The yellowish red aril has the most delicate flavour of all spices. It has a fragrant aromatic odour. Dried mace may be fumigated with carbon disulphide or methyl bromide to increase its longevity. The nutmeg seeds are dried separately either in sun or over smouldering fires until the kernel rattles in the shell. The shell is broken either by a wooden mallet or in specially designed cracking machines. The dried kernels constitute the commercial nutmeg. Quite often the kernels are limed to increase their storage life.

The seeds yield a fixed oil and nutmeg butter; these contain myristicin which is narcotic and poisonous, so that nutmeg and mace should be used sparingly.

Uses

i) **As a Flavourant:** (a) Nutmeg and mace are used mainly as mild spices. The granular product obtained after grinding nutmeg seeds is used for flavouring sweet dishes especially milk dishes, pies, sauces, meat and vegetable dishes and beverages.
(b) Mace imparts a delicate flavour to pastries, cakes, biscuits, sauces, ketchups, and meat and fish dishes.

ii) **As a Perfume:** The fixed oil of nutmeg is employed in the manufacture of soaps, perfumes and ointments.

iii) **As medicine:** i) Nutmeg is said to have stimulative, carminative and aphrodisiac properties. ii) Large dosages are said to have a powerful narcotic effect, producing hallucinations and stupor.

iv) **In Cosmetic Industry:** Oil of nutmeg is also used for scenting soaps, tobacco and dental creams.

17.9 SUMMARY

In this unit you have learnt that:

- There is no clear cut difference between 'spices' and 'condiments'. The word spice is rather loosely applied to an assortment of dried barks, roots, seeds, fruits and flower parts, used for their characteristic flavours and scents. Condiments are spices that are usually added to food after cooking.
- Spices are generally tropical in origin; in contrast, when the aromatic vegetable product comes from a temperate plant it is considered as a herb (non-woody).
- Most of the chemicals responsible for the characteristic tastes and smells of herbs, spices and condiments are compounds known as essential oils. They are found in specialized plant cells, glands or vessels that can occur in any or all parts of a plant.
- There are about 70 spices grown in different parts of the world. Classification of spices is based on botanical analogies (similarity between unlike plants) or families, economic importance, similarity in methods of cultivation or similarity in plant parts.
- Table summarizes some of the important aspects of spices and condiments.

- Simple tests for detection of some of the common adulterants found in spices are given in Table 17.2.

Table 17.2: Some commonly used spices and their adulterant.

Old World Spices

S. No.	Botanical Name	Common name	Hindi Name	Family	Part of the plant used as spice	Adulterants	Uses
1.	*Zingiber officinale* Linn.	Ginger	Adrak	Zingiberaceae	Rhizome	Extraneous matter, Calcium oxide, colour matter and insect infection	i) As a flavourant in food preparation ii) In medicine iii) In beverages & perfumery
2.	*Curcuma longa* Linn.	Turmeric	Haldi	Zingiberaceae	Rhizome	Lead chromate and metanil yellow	i) As a flavourant ii) As a dye iii) In medicine iv) In cosmetic industry
3.	*Cinnamomum zeylanicum* Breyn.	Cinnamon	Dalchini	Lauraceae	Dried inner bark	Foreign vegetable matter or artificial colour	i) As a flavourant ii) In medicine iii) In perfume industry
4.	*Crocus sativus* Linn.	Saffron	Kesar	Iridaceae	Dried stigmas	Floral waste of saffron, floral parts of *Calendula* spp., *Carthamus tinctorius*, corn silks and coloured wax	i) As a flavourant ii) As a dye iii) In medicine iv) Saffron oil and essence
5.	*Eugenia caryophyllus* (Sprengal) Bullok & Harrison	Clove	Laung	Myrtaceae	Dried unopened flower buds	Extraneous matter and artificial colour	i) As a flavourant ii) In cigarettes & betelnut chew iii) In medicine (dentistry) iv) As a clearing agent in histological work v) In perfume industry
6.	*Piper nigrum* Linn.	Pepper	Kali mirch	Piperaceae	Fruits (drupe)	Extraneous matter, artificial colour, dust, seeds of *Carica papaya*	i) As a flavourant ii) In medicine iii) As an insecticide iv) Oil of pepper used in perfumes v) In preparation of pepper sal
7.	*Foeniculum vulgare* Mill	Fennel	Saunf	Apiaceae	Dried ripe fruits (schizocarp)	Extraneous matter, stone, insect damaged matter, artificial colour	i) As a flavourant ii) In medicine iii) In perfumery iv) As a cattle feed
8.	*Coriandrum sativum* Linn.	Coriander	Dhaniya	Apiaceae	Dried ripe fruits (schizocarp)	Extraneous matter, edible seeds of fruits other than coriander	i) As a flavourant ii) In medicine iii) In perfumery
9.	*Brassica* spp.	Mustard	Sarson	Brassicaceae	Seed	Extraneous matter, edible food grain, oil seed eg. seed of *Argemone, mexicana* Linn. Oil	i) As a flavournt ii) As an illuninant (oil) iii) As a lubricant iv) As a livestock feed v) As a fertilizer vi) In preservation
10.	*Elettaria cardamomum* (Linn.) Maton	Cardmom	Chhothi Elaichi	Zingiberaceae	Dried seeds from fruits (Capsule)	Extraneous matter, artificial colour	i) As a flavourant ii) As a masticatory iii) In medicine
11.	*Myristica fragrans* Houtt.	Nutmeg	Jayaphal	Myristicaceae	Fruit and aril	Extraneous matter, artificial colour	As medicine in cosmetic industry As flavourant

New World Spice

12.	*Capsicum annum* Linn. *C. frutescens* Linn.	Capsicum	Mirch	Solanaceae	Green or dried fruits (berry or capsule)	Extraneous matter, artificial colour, excess ash	i) As a flavourant & colourant ii) Role in human physiology iii) In medicine

17.10 TERMINAL QUESTIONS

1.

1. Cinnamon spice is obtained from .... of the evergreen tree.

2. Saffron is obtained from .... It belongs to family ....
3. Spice islands are a group of volcanic islands in ....
4. The ripened fruit is a purplish ...., known as 'mother of cloves' and is not important in the spice trade.
5. .... is useful in both dentistry and histology.
6. The spice from *Capsicum annuum* is obtained from ....
7. King of spices .... is a native of South West India.

2. Match the botanical names in column A with their families listed in the column B.

	Column A		Column B
1.	*Brassica nigra*	a)	Zingiberaceae
2.	*Capsicum frutescens*	b)	Apiaceae
3.	*Zingiber officinale*	c)	Piperceae
4.	*Foeniculum vulgare*	d)	Myrtaceae
5.	*Elettaria cardamomum*	e)	Solanaceae
6.	*Cinnamomum zeylanicum*	f)	Apiaceae
7.	*Piper nigrum*	g)	Lauraceae
8.	*Cariandrum sativum*	h)	Brassicaceae
9.	*Eugenia caryophyllus*	i)	Iridaceae
10.	*Crocus sativus*	j)	Zingiberaceae

3. Make a comprehensive list of spices with the botanical and common names, and the plant part used as spice.

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4. Give reasons why saffron is the most expensive spice.

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5. Which are the two grades of pepper and how are they harvested?

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6. Which of the two spices are important medicinally important and why?

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17.11 ANSWERS

Self Assessment Questions

1. 1. allspice, capsicum.
   2. essential oils
   3. gingerin
   4. Southern Asia
   5. Turmeric

2. 1 – T; 2 – F; 3 – T; 4 – F; 5 – T; 6 - T

3. 1 – c; 2 – b; 3 – d; 4 – e: 5 – a.

Terminal Questions

1. 1. bark
   2. trifid stigmas, Iridaceae
   3. Eastern Indonesia
   4. drupe
   5. *Eugenia caryophyllus*
   6. fruits
   7. *Piper nigrum*

2. 1. h
   2. e
   3. a, j
   4. b, f
   5. a, j
   6. g
   7. c

8. b, f
9. d
10. i

3. Make a list of spices which you have studied in the unit. You can also include other spices which are not described in the unit.

4. Please refer to section 17.6.1.

5. Please see harvesting of pepper where two types of main grade of pepper are described.

6. Write two spices which in your view are more important than others also support your answer why these two are more important.

UNIT 18 BEVERAGES

Structure

18.1 Introduction
  Objectives
18.2 Tea
18.3 Coffee
18.4 Cocoa
18.5 Summary
18.6 Terminal Questions
18.7 Answers

18.1 INTRODUCTION

Fresh tea is sterile, and is the second most consumed liquid world-wide after water. Coffee is second in importance only to petroleum and its by-products, in terms of annual trade value in the international market. Beverages (excluding soft drinks) can be grouped into two heads: (i) alcoholic, and (ii) non-alcoholic (as shown in Table 18.1).

The drinking of tea, coffee and chocolate has become an important part of our lives; these three beverages like some others (Table 18.1) are stimulants because they contain a chemical primarily caffeine (Table 18.2) and its relatives. These chemicals cause physiological reactions in our body. Five minutes after drinking coffee, the caffeine in it reaches the blood stream. As it circulates throughout the body, it stimulates the heart, increases stomach acidity and urine output, and causes a rise in metabolic rate. After a tiring day when we drink one of these beverages we feel stimulated or alert because of the presence of caffeine in it. Caffeine mimics the same feelings which are produced when the body releases adrenaline. If these beverages are consumed in excess, for example 10 cups of coffee (equivalent to one gram of caffeine) it can cause anxiety, headache, dizziness, insomnia, heart palpitation, and even mild delirium. Heavy tea or coffee drinkers can develop a tolerance to caffeine and can even suffer withdrawal symptoms if they quit their habit. In this unit we will discuss the above mentioned three beverages in detail.

Objectives

After studying this unit, you should be able to:

- differentiate between alcoholic and non-alcoholic beverages;
- discuss the importance of the presence of caffeine in tea, coffee and cocoa;
- prepare detailed accounts on tea, coffee and cocoa;
- differentiate between China and Assam tea;
- explain the processing methods for the preparation of various kinds of teas;
- explain the difference between Arabian, Robusta and Liberian coffee;
- appreciate the difference between raw, roasted, powdered, instant, and decaffeinated coffee; and
- identify the adulterants of tea, coffee and cocoa products.

18.2 TEA

Botanical name: ***Camellia sinensis***
Family: Theaceae (Ternstroemiaceae)
Common names: Cha, Chai
n = 15

Origin and distribution

Southeast China, foothills of the Himalayas of Myanmar and Assam are considered the areas of origin of tea. Presently the most important tea producing areas lie within a restricted region, from 8°S (in Java) to 35°N (in Japan) and from 80°E to 140°E, this includes China, Japan, Taiwan, Sumatra, Sri Lanka and India. The major tea growing areas in India are Assam, West Bengal, Kerala, Karnataka, Tamil Nadu, Tripura, and Himachal Pradesh.

Table 18.1 : The common beverages

Beverages

- **Alcoholic (Depressants)**
  - Fermented (alcohol is formed by the fermentation of sugar)
    - Wines — Fruit juices, mainly from grapes, 7-16% alcohol
    - Beers — Cereal starch mainly from barley, flavoured with hops (*Humulus lupulus*) 3-8% alcohol
    - Cider — Juice of apple
    - Perry — Juice of pear
    - Palm wine — Juice of palm inflorescence
    - Chicha — Maize kernels
  - Distilled (alcohol obtained by successive distillation of fermented liquors)
    - Whisky — Fermented mash of cereals and potatoes
    - Brandy — Fermented juice of various fruits especially grapes
    - Rum — From sugarcane juice or molasses
    - Gin — Fermented malt of barley and rye (flavoured with the 'berries' of common junipers, coriander and other spices)
- **Non-alcoholic (Stimulants)**
  - Tea — leaves
  - Coffee — seeds
  - Cocoa — seeds and pulp
  - Mate or Paraguay tea — leaves of *Ilex paraguariensis,*
  - Guarana — seeds of Amazonian climber - *Paullinia cupana,*
  - Cola — powdered seeds of *Cola nitida*
  - Khat — leaves and buds of a north-east African plant *Catha*
  - Yoco — bark of S. American tree *Paullinia yoco*

(Tea, Coffee, Cocoa: Strictly tropical crops)

Table: 18.2: Amounts of caffeine in commonly consumed beverages. (From Simpson & Conner-Ogorzaly, 1986)

Beverage	Caffeine (mg)
Coffee	
5 – oz cup, drip method	146
5 – oz cup, percolator method	110
5 – oz cup, instant	53
5 – oz cup, decaffeinated	2
Tea	
5 – oz cup, brewed (1 min)	9 – 33
5 – oz cup, brewed (3-5 min)	20 – 50
12 – oz cup, canned	22 – 36
Cacao and chocolate	
6 oz, made with canned milk powder	10
1 oz, milk chocolate	06
1 oz (1 square) baking chocolate	35
Soft drinks	
12 oz Pepsi, regular	37
12 oz Coca Cola	34

Fig. 18.1: A flowering twig of tea (From Kochhar, 1998).

Morphology

Tea plant (Fig. 18.1) is an evergreen or semi-evergreen woody shrub (9-15 m); the bushes are constantly pruned to encourage maximum leaf production and are also kept at plucking height. After about 10 years the bushes are often cut back to ground level allowing suckers to replace the old bushes. Leaves are alternate, generally elliptic to lanceolate with toothed margins (5-30 cm long); the undersurface of young leaves is covered with soft hairs that vanish with age. The old leaves become leathery. The characteristic fragrance and aroma of the leaves is due to the presence of numerous oil glands. See Fig. 18.2 for leaf anatomy. Flowers are white or pinkish with yellow centre, and are borne in leaf axils either singly or in groups of 2-4, from July to October. Fruit is a 3-celled woody capsule, each compartment of which contains a brown seed (about 1.25 cm in diameter). Fruit takes 9-12 months to mature, and dehisces by splitting from apex into three valves.

The cultivated tea is generally grouped in two major types:

(a) China tea (*C. sinensis* var. sinensis)
(b) Assam tea (*C. sinensis* var. assamica). Also see Table 18.3. In addition some hybrid tea varieties are also cultivated outside China, Japan and Assam.

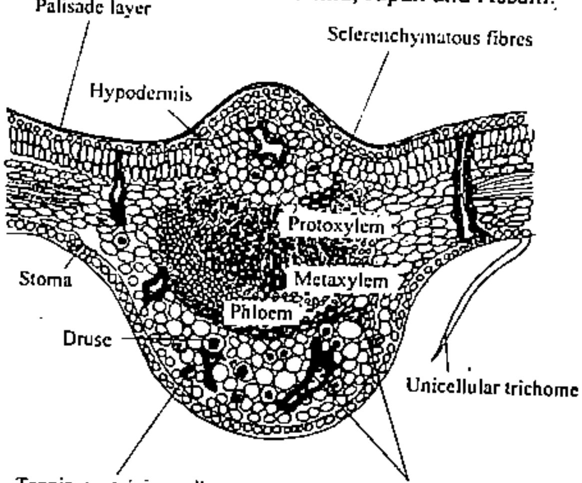

Fig. 18.2: A V.S. through a tea leaf. Vascular bundle is arc-shaped in the mid rib region. Stomata and thick-walled uni-celled, hairs are present on lower surface. Druses are scattered throughout the mesophyll. Idioblasts often spread from lower to upper epidermis. Tannin cells are distributed throughout. The marginal serrations of each leaf terminates into a small conical gland that breaks off easily, and is often not seen in mature leaves.

Table 18.3 : Difference between Assam and China teas.

Assam tea	China tea
1. Quick growing	1. Slow growing
2. Tree single-stemmed, 6.1-18.3 m in height	2. Bushes multi-stemmed, 1.2-2.7 m in height
3. Leaves large (15-30 cm long) held horizontally or pointing slightly downward, pale green with glossy and bullate upper surface	3. Leaves small (4-7 cm long), narrow, dark greenish with a dull flat surface
4. Flowers borne in clusters of 2 to 4	4. Flowers borne singly
5. Crop yield more	5. Crop yield less
6. Economic life up to 40 years	6. Economic life of at least 100 years
7. Richer in caffeine and polyphenolic compounds	

In India a large number of promising triploid lines of tea have been produced by crossing tetraploid stocks with diploid clones.

Agroclimatic conditions

About 150 cm per annum rainfall that is well distributed throughout the year, and temperature between 21-32°C is required for vigorous growth. It grows best in deep, well-drained, acid soils (pH between 4.0-5.0), rich in humus. It does not grow in alkaline soils. Tea is tolerant of high levels (17,000 ppm) of aluminium. In some instances the accumulation of aluminium has been found to even cause aluminium toxicity in tea leaves. Aluminium is also a diagnostic characteristic for determining good tea soil, where it plays a regulatory role in the uptake of ions of manganese, or is associated with phosphorous uptake. Because tea is a leaf crop, nitrogenous manuring should be provided to neutralize the drain on nitrogen brought about by the regular removal of leaves. Application of ammonium sulphate consistently gives a good crop, because it maintains soil acidity, which is necessary for tea to flourish and it also imparts resistance to red rust caused by an alga (*Cephaleuros parasiticus*). Tea develops more vigorously under light shade than in exposed situations. The shade trees are planted 12-15 m apart and the most commonly used species are *Albizia chinensis*, *A. procera*, *A. stipulata*, *Dalbergia assamica*, *Derris robusta*, *Gliricidia sepium*, and *Erythrina* species. In addition to providing shade, they supply some of the essential plant nutrients and their roots ventilate the soil.

Propagation

Tea is usually propagated by seeds sown in nurseries. The viability of the seed is short and therefore it should be sown within a few days of gathering. Seeds germinate soon and the seedlings when nearly 30 cm tall are planted in the field. Vegetative propagation is by single internode cuttings taken immediately above the leaf and axillary bud. Plant is kept bushy through regular pruning. After about 10 years the bushes are often cut back to ground level allowing suckers to replace the old bush. Harvesting or plucking involves removing the young tender shoots, i.e., the terminal bud and two or three of the youngest leaves (Fig. 18.3). Plucking is done generally when trees are 4 years old. A single bush can be plucked about once a week.

Fig. 18.3: The plucking of tea leaves. The terminal bud and the first two leaves of the young shoot are plucked for preparing finer grades of tea.

Processing

The type of processing of the leaves depends on the final type of tea desired. Commercially, tea is of three basic types: black, green, and oolong tea. The oolong tea is made from a particular variety of tea (*Camellia sinensis* var. *chemisa*). Also see Table 18.4. The fresh leaves after picking are lightly packed in baskets to prevent bruising and heating, and are immediately sent to the processing units (Fig. 18.4 a – i).

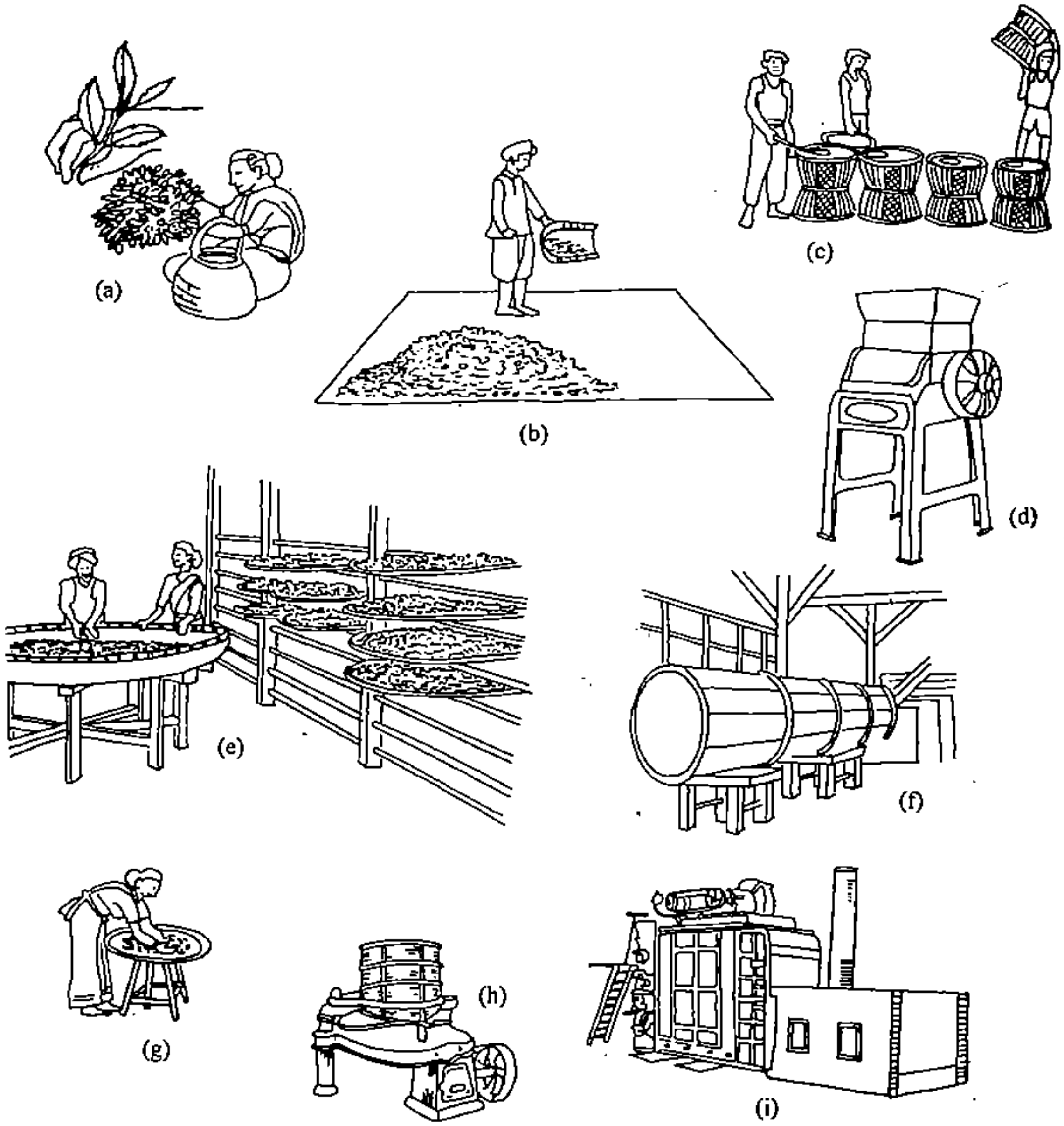

Fig. 18.4: The basic steps involved in the processing of tea. a) Harvesting of tea (also Fig. 18.3). b) Withering and fermention of tea. c) Drying leaves in bamboo baskets over charcoal, this way is common in China. d) A tea cutter. e) Withering and fermenting tea on wicker trays, a method commonly used in the orient. f) Drums are also employed for accomplishing withering. g) Hand-rolling in black tea production. h) Rolling of teas also done by machines, one such early rolling machine is shown in the figure. i) A power tea dryer. (From Simpson & Conner-Ogorzaly 1986).

Table 18.4 : Difference between Black, Green and Oolong tea.

Black tea	Green tea	Oolong tea
Four-fifth of the world's tea is processed into black tea. 1. It is fermented (this causes alteration of various chemical constituents of the leaf)	About 1/5 of the tea drunk world wide is the green tea. 1. It is unfermented.	2% of the tea drunk is oolong tea. 1. It is semi-fermented. (Contd.)

2. It involves 6 main operations: i) Withering ii) Rolling iii) Fermentation iv) Drying or firing v) Cleaning process vi) Grading This is also known as orthodox method of tea processing.	2. It involves 3 main operations: i) Heating or steaming ii) Rolling iii) Drying	2. It involves 4 steps: i) Withering ii) Light fermentation iii) Rolling iv) Drying
i) **Withering** – is done in open sheds or in special sheds equipped with controlled heating and ventilating facilities. The leaves are spread thinly over withering racks, arranged one above the other horizontally, and allowed to remain there for 12 to 18 hours at 30°C to let them loose the excessive moisture. Moisture content is reduced to 50-60% from 75-80%. Sometimes, heated air is forced over these racks if the atmosphere around is humid. The leaf slowly and evenly becomes soft and flaccid like soft leather and is ready for rolling.	i) The leaves are generally plucked without stalk and are heated in an iron pan, i.e., pan fired (as in China) or steamed (as in Japan), instead of natural withering. Steaming makes the leaves pliable for rolling and protect the leaves against fermentation and blackening. This process inactivates the enzymes polyphenol oxidase and thus prevents the oxidation of polyphenols.	i) The leaves are slightly withered before panning; during this process a slight fermentation is allowed.
ii) **Rolling** – imparts the characteristic twist to the leaf, breaks the leaf cells, exposes the juices to the air for fermentation to set in. After half-an-hour of rolling the leaf is removed in aluminium trolleys to a sifter and ball breaker. This machine consists of a long and flat metal sheet with perforations, fixed on a frame which makes reciprocating motion; as a result the broken leaf and fine particles fall below and the rest is taken out after sieving to be rolled for the second time with increased pressure. The leaf which is still green and quite flaccid is removed to the fermenting room.	ii) The leaf is rolled and dried more or less in a similar way to black tea.	ii) Rolled and dried like black tea.
iii) **Fermentation** – The temperature (24-27°C), and relative humidity (RH-90%) are controlled in the	iii) Fermentation between rolling and drying is eliminated. No oxidation of polyphenols is allowed.	(Contd.)

rolled leaves are spread on tiles of aluminium or even glass sheets for oxidation. During fermentation, the tannin (polyphenols) in tea are partly oxidised and the leaves change colour and turn bright coppery-red. As a general rule, the **shorter** the fermentation, the more pungent would be the liquor obtained; and the **longer** the fermentation, the softer the liquor and deeper the colour.		
iv) **Drying or firing** – is done to arrest further oxidation of the leaf and to reduce moisture content to 3-5%. Careful regulation of temperature is essential as excessive heat will scorch the leaves while lack of it will result in incomplete drying. A current of hot (90-100°C) air is passed for 20-25 minutes in specially constructed ovens.	Drying retains the greenish colour of the leaf due to the absence of fermentation. Tea obtained by Iron pan firing is of better quality.	
v) **Cleaning process** – Tea is now cleaned and sorted with the help of rotating or vibrating screens.	Polishing is done with soapstone or French chalk to improve colour.	
vi) **Grading** – There are essentially three grades of Indian tea: leaf, broken waste left, and dust (smallest particle's) . excluding tuft and stalk, which after sorting and grading is called 'fluff', it contains 3.5% caffeine and can be used for the extraction of caffeine. After grading tea is packed in tea-chests lined with tin or aluminium foil and paper.	The tannin and caffeine content in green tea is higher than in black tea.	
It is produced mainly in India and Sri Lanka.	Most teas made in China and Japan are of this type. A small quantity of green tea is also manufactured in North India but mainly for sale in Afghanistan, Iran .. and in America.	There is a special market for Oolong tea in America and is exclusively manufactured in southern China and Taiwan.

In each of these main classes, the tea is further classified, according to size, and final grades which generally bear fancy names (Table 18.5).

Table 18.5 Different Grades of Tea.

Grade	Category	Content
Leaf	Orange Pekoe (O.P.) Pekoe (P.) Pekoe Souchong (P.S.)	Bud, first leaf and softer parts of the stalk. The buds are absent. Bold and round leaf with pale liquors.
Broken	Broken Orange Pekoe (B.O.P.) Broken Pekoe (B.P.) Broken Pekoe Souchong (B.P.S.)	Contain tips or bud leaf. Tips are absent. Leaves are little large than B.P., lighter in the cup.
Dusts	Fannings or Pekoe (F. or P.) Fannings (F.)	These are smaller than B.P., are quick in brewing. The smallest particles excluding 'fluff' and 'stalk', blended with smaller sized leaves or broken grades.

Cuppage from orthodox tea is 200 cups a kilogram of tea leaves.

Legg-cut teas : It is manufactured mainly in the Dooars, Terai and in some Cachar gardens of North East India. This process eliminates withering, which is often difficult in these humid areas. As the non-withered leaf is difficult to roll, the leaf is cut into small strips by using a chaff-cutter, also known as Legg-cutter, after which these teas take their name. After being cut, the leaf is lightly rolled and allowed to ferment for a short time before being thoroughly 'fired'. Although the tea is slightly brownish and stalky in appearance, it is still in demand because of its quick brewing and fine liquoring qualities.

Brick tea : It is prepared from left-over or waste, left after the preparation of black and green teas. It may consist of leaf, stalks and even twigs or mainly coarse tea dust. The bulk is softened with steam and then compressed into blocks or bricks. This type of tea is mostly consumed in Tibet and China.

Leppet-so or Miang : It is pickled tea. In Myanmar, Thailand and China the boiled or steamed green leaves of tea are preserved in pits. They are used more as pickles or vegetables than as beverages.

C.T.C. Tea : Besides the 'orthodox' method of tea processing, a variation was introduced in the process of manufacturing tea especially in north India. The variation consists of the use of a machine named 'crushing, tearing and curling machine' (C.T.C in short). The machine consists of parallel stainless steel rollers revolving inward at different speeds. The rollers are about 1 meter long, 15 cm in diameter and are grooved concentrically and spirally. The concentric grooves of one roller are made to inter-mesh with those of the other to varying degrees. The leaf after withering is lightly rolled without pressure. Then the fine leaves are separated and the coarse leaves are fed into this machine 2,3,or even 4 times. The leaves fed between the rollers gets 'mangled'. The time required to pass the leaves through the machine is very short (only a few minutes), therefore the time spent in the rolling room is considerably reduced and this in turn, reduces the whole manufacturing time. The cuppage from C.T.C. tea is 500-1000 cups a kilogram of tea leaves.

Chemical Composition

The main constituents which give tea its distinctive character as a beverage are *polyphenols* (these are derivatives of gallic acid and catechin, but not tannins). These polyphenols are oxidized by enzyme action during maceration and fermentation to produce ortho-quinones; and these ortho-quinones are changed into:
(i) theaflavins or TF (which is related to brightness of the infusion), and
(ii) thearubigins or TR (responsible for body and strength of tea). Ideal fermentation produces a proper balance of TFs and TRs and these are partially extracted in brewing tea (also see Fig. 18.5).

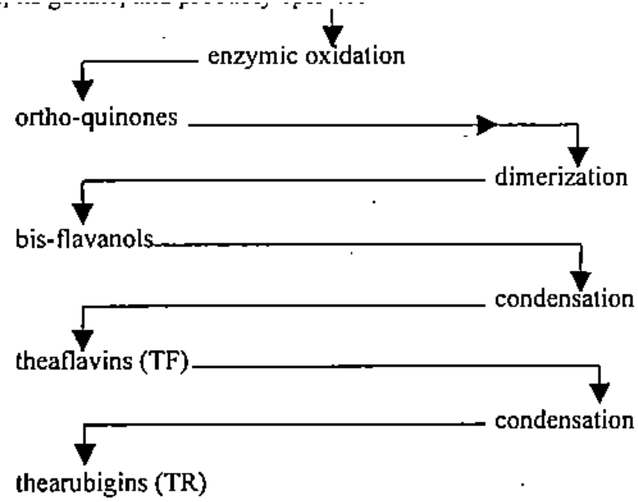

Fig. 18.5: Biochemical changes during Black Tea preparation which are partially extracted while brewing tea (From Eden, 1976).

The tea leaf contains tea polyphenols and an enzyme, polyphenol oxidase. Upon harvest of the tea leaves, these are withered. If the product is pan heated or steamed, the polyphenol oxidase is inhibited. During the subsequent drying of the macerated leaves, the product obtained is *green tea*. On the other hand initial rolling permits ultimate contact between the enzyme and the polyphenols which are oxidized. A short period of oxidation, about 30 minutes yields oolong tea, and a longer exposure of tea polyphenols to the enzyme for 90 – 200 minutes produces black tea.

In addition, the alkaloid fraction caffeine (or theine) is responsible for the stimulating and refreshing effect; a small amount of the allied alkaloid theophylline is also present.

The most important aromatic components are the essential oils (theol) which give the characteristic aroma and flavour to the tea.

Fresh plucked tea leaves contain:

Water	75-80% (dry weight percentage)
Polyphenols	25-28%
Protein	20%
Caffeine	2.5-4.5%
Crude fibre	27%
Carbohydrates	4%
Pectin	6%
Sugars	12 kinds
Organic compounds	6 types

Fresh manufactured tea contains: (i) about 3 per cent moisture, (ii) about 2.5-4.5 per cent caffeine (twice as much of that of roasted coffee beans - 1.0-2.0 per cent), (iii) the polyphenols concentration is reduced to 12 per cent from 28 per cent, and (iv) several B-complex vitamins and Nicotinic acid.

Tea bags are manufactured from leaf fibres of *Musa textiles* (Musaceae).

A cup of tea contains on an average a little under a gram of caffeine and about two grams of polyphenols and provides four calories. When milk is added to tea, polyphenols are fixed by the casein in milk, thus robbing it of practically all its astringency. The sugar added to the tea merely adds to the value of the drink as a food. A tablespoon of milk and a lump of sugar to a cup of tea gives 40 calories. In green tea most of the polyphenols are present in the original form. Green tea does not have as much aroma and flavour as black tea, since fermentation is omitted.

Box 18.1: Boston Tea Party

Americans of European descent were primarily tea drinkers. They were so used to their tea that they became angry when the British declared that they had to pay a tax on tea which was brought to their colonies. To show their resentment, the colonists staged the famous Boston Tea Party (December 16, 1773) during which they dumped 342 chests of tea of the British East India Tea Company's cargo into Boston Harbor.

Uses

1. Tea has been used as a beverage for 2000-3000 years.
2. Caffeine is manufactured from tea waste.
3. The popular concept that tea is a health promoting beverage has been greatly strengthened by detailed research in humans and in animal models as regards the

types of human cancer.

Box 18.2: Tea in India at a glance. (From Jain, 1995)

Area under tea cultivation	:	4.25 lakh hectares
Average yield	:	1752 kgs per hectare
Production	:	744 million kgs
Domestic consumption	:	580 million kgs
Export earnings	:	Rs 900 crores
India's share in world production	:	31 per cent in 1992
India's share in world export	:	29 per cent in 1992
Tea first discovered	:	By the Chinese Emperor Shen Nung in 2737 B.C.
First discovered in Assam	:	By Major Bruce in 1823
First exports to Britain	:	8 Chests in 1838 from tea grown by tribals
Research Centres	:	- Tocklai Experimental Station, Jorhat, Assam; - Tea Research Institute of UPASI, Cinchona, Coimbatore, and Tamil Nadu; - CSIR Complex, Palampur

SAQ 1

(i) Why is tea plant often pruned?

....

....

....

(ii) Describe the morphology of tea leaves.

....

....

....

(iii) Differentiate between Assam and China tea.

....

....

....

(iv) Tea bags are manufactured from leaf fibres of which plant?

....

....

18.3 COFFEE

Botanical name: ***Coffea*** **spp;** ***C. arabica*** **(Arabic coffee)**
C. canephora **(Robusta or Congo Coffee)**
C. liberica **(Liberian coffee)**
Family: Rubiaceae
Common name: Coffee
n = 11

Origin and distribution

Ethiopia, Africa and most probably the province of Kaffa in Ethiopia are believed to be the areas of origin of coffee. There are two botanical varieties of *Coffea arabica* from which 90 per cent of the world's production is obtained.

1. *C. arabica* var. *arabica* (syn. var. *typica*) is considered to be the primitive form.
2. *C. arabica* var. *bourbon* is native to Ethiopia. It gives higher yields than var. *arabica* under favourable conditions and has replaced the latter in Brazil.

C. canephora (Robusta coffee) and *C. liberica* (Liberian coffee) are used to produce about 9 and 1 per cent respectively of the world's crop. Table 18.6 tabulates the diagnostic features of the Arabian, Robusta and Liberian types of coffee.

It is cultivated 20° North and South of the equator. Annual global production of coffee is over six million tonnes. Brazil is the largest producer of coffee (27.2% of the world's total production). Columbia accounts for 12% of the world's total production. It also grows in Cote Divoire. The headquarters of International Coffee Organisation (ICO) established in 1963, are in London, UK.

In India coffee is grown in Karnataka, Kerala and Tamil Nadu, besides the Northern Eastern States, Andhra Pradesh and Orissa. India contributes 3.5 per cent of the world production (2.23 lakh tonnes in 1995-96 and was ranked sixth among the producing countries; the production in 1997-98 was 2.41 lakh tonnes. The Central Coffee Research Institute (CCRI) is in Chikmaglur, Andhra Pradesh.

Table 18.6: Differences between Arabian, Robusta and Liberian coffee.

Arabian coffee	Robusta coffee	Liberian coffee
1. Plants are less hardy than the other two	1. Plants are more hardy than the Arabian coffee	1. Plants are more hardy than Arabian coffee
2. Produce less fruits per tree	2. Produce more fruits per tree	2. Produce more fruits per tree
3. It is a self compatible polyploid (2n = 44)	3. It is a self incompatible diploid (2n = 22)	3. It is a self incompatible diploid (2n = 22)
4. Better flavour than the other two.	4. Its bitter flavour is preferred in some parts of Africa. It is used in blended coffees or to make decaffeinated or instant coffee where the taste is disguised or changed.	4. Most bitter of the three and is used mainly as a filler in mixtures with other coffees.

At one time, Ceylon was the leading producer of coffee in the Indian Ocean and its economy depended heavily on this crop, but the entire plantations were devastated within a few years in the nineteenth century (1880) when one of the plant plagues 'leaf spot' or 'coffee rust' caused by the fungus *Hemileia vastatrix* swept through the island. Sri Lanka's shattered economy was saved by the reestablishment of tea plantations.

A remarkable new dwarf species of *Coffee* has been reported in 1997 from Lower Guinea (tropical Africa). *C. magnistipula* is peculiar in having adventitious roots on the stem and very large stipules which with the leaf-bases form debris-collecting cups. This adaptation presumably allows extra uptake of water and nutrients.

Morphology

It is an evergreen shrub or a small tree (4.5-9.0 m height) but is kept low by pruning. Pruning has other advantages as well as it: (a) produces robust and well balanced framework, (b) promotes the periodic rejuvenation of fruiting branches, and (c) protects from wind and excessive sunlight. The leaves (Fig. 18.6) are ovate-elliptic, opposite, glabrous and glossy with undulate margins acuminate tips and inter-petiolar stipules. The flowers (Fig. 18.6) are star-like, snow white and smell delicately like jasmine flowers. These occur in dense axillary clusters, and are produced in flushes, 3 to 4 times a year. Flowers are short-lived, remain open in the morning and fade by mid-day. The Fruit (Fig. 18.6) is a drupe (1.5 cm long). It is greenish turning crimson red at maturity, i.e., about 6 to 9 months after flowering. The drupe has 3 distinct regions: exocarp or epicarp is the outer thin deep crimson skin; mesocarp is yellowish mucilaginous or fleshly; and endocarp is hard,cartilaginous and parchment like, enclosing two (occasionally only one), ellipsoidal or oval seeds often called coffee beans. Coffee seeds or beans have: an outer delicate seed coat called silver skin; and the bulk of the seed is composed of a curiously folded corneous endosperm enclosing a very small embryo (Fig. 18.6 g).

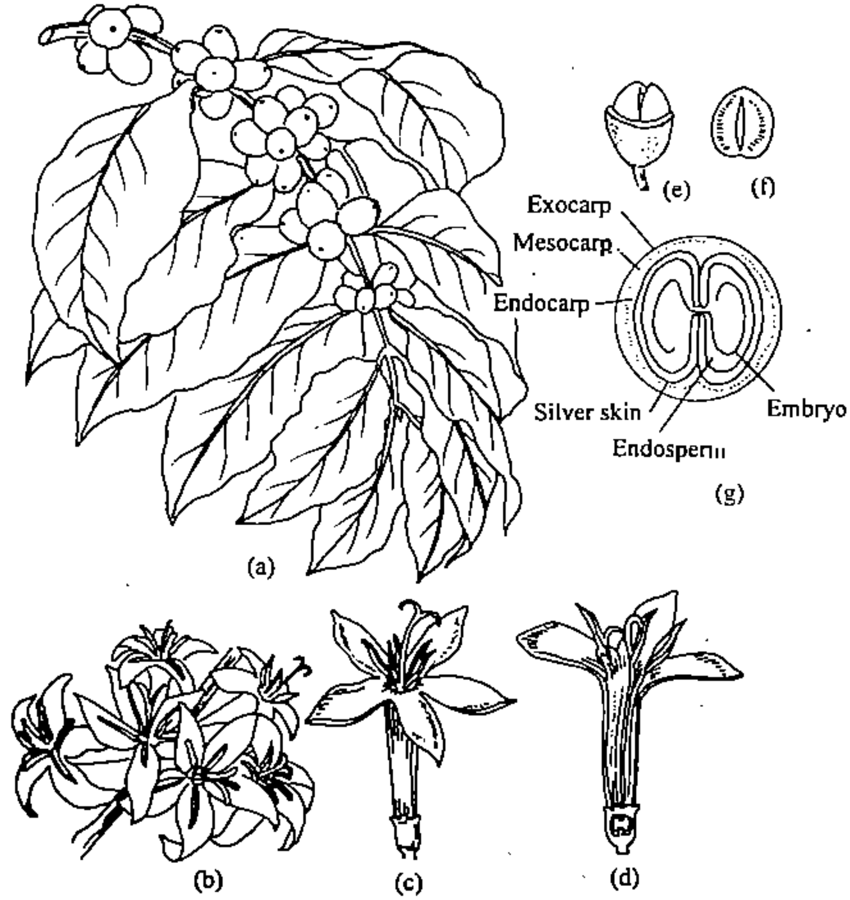

Fig. 18.6: a) A twig of coffee laden with cluster of berries in leaf axils. b) A cluster of coffee flowers. c) A flower. d) Same in longisection. e) A berry, with its top portion cut to show two seeds. f) The ventral (flat side) of the seed. g) A berry in cross section showing its component parts. (Redrawn from Simpson & Conner-Ogorzaly, 1986).

Agroclimatic conditions

C. arabica grows well in cooler and less humid climate of mountainous regions from 600-1700 m. *C. canephora* and *C. liberica* grow better in warm humid low-lands. For healthy growth, plants require an evenly distributed rainfall of over 150 cm per annum; it must have subsoil moisture all the year. Napier grass seems to conserve subsoil moisture in East Africa where the rainfall is below 125 cm per annum. Mulching is also useful in low rainfall areas to increase yield. Average temperature should be around 20°C. Coffee is a soil exhausting crop and grows best on deep, slightly acidic, well drained fertile loams of lateritic or volcanic origin. The 'terra roxa' soils (red soils rich in iron and potassium) of Brazil are famed for coffee growing. Earlier coffee plants were grown in shade (Brazil and Hawaii) but there is a growing tendency to eliminate shade. Without shade a substantially higher level of fertilizer application is necessary especially nitrogen. Usually ammonium sulfate is applied which has an acidifying influence on the soil; shortages of individual elements are more quickly noticeable than under shade tree. In highlands, shade has a favourable effect, because it moderates the temperature fluctuations between day and night. In regions with slight rainfall or long dry spell, coffee cannot be cultivated with shade trees, as these would use too much water. The lack of shade can in part be compensated for by a thick layer of mulch (more uniform and lower soil temperature). The optimal pH value is 6-6.5. The quality of coffee is influenced by the growing conditions.

Cultivation

Coffee is largely propagated by seeds. *C. canephora* and hybrids are mostly or exclusively propagated vegetatively; usually single-node cuttings of unripe wood is used for this purpose. Coffee seeds remain viable for only 2 months, and up to 4 months with storage in moistened charcoal powder. About 8-weeks after sowing the seedlings are transplanted from the seed-beds into nursery beds, or better into plastic bags. The seedlings are planted (about 2 m apart) in the open, after the development of 6 pairs of leaves and before the appearance of the first side shoot. Fruits are borne when the plant is 3-5 years old. Often coffee is intercropped with bananas or figs for extra economic benefits. In Tamil Nadu it is grown along with *Piper nigrum*. Coffee trees may live for 50 years or more, but are generally productive only for about 25 years.

Harvesting

Although coffee trees come into bearing 3-5 years after planting, full bearing generally takes place after 6-8 years. The fruits mature (7-9 months after flowering) over a period of several weeks; picking of ripe red berries at intervals of 10-14 days is necessary.

Processing

Coffee berries are processed by anyone of the following methods:

1. **Dry method** is an older method of processing coffee and is practised in Africa and Near East and also in other coffee producing countries where water is scarce. Gathered fruits, also called berries, along with twigs and other extraneous material are spread out in thin layers in the open sun or in hot air driers for 15-25 days. Fruits are turned over to permit uniform and thorough drying. Thereafter they are put in bags and stored in warehouses.

2. **Wet method** fruits are pulped as soon as possible after picking and not longer than 24 hours or they begin to ferment. This method includes the following steps (see Fig. 18.7): Fruits or berries are placed in large tanks filled with water. The well developed fruits sink to the bottom. Thereafter, such ripe fruits are subjected to pulping, fermenting, drying, hulling, polishing, grading and roasting.

   i) **Pulping** – brought about by pulping machines which remove the exocarp and part of the fleshy mesocarp. The remainder pulp adhering to the parchment coat of the beans is separated by controlled fermentation.

   ii) **Fermentation** – is carried out by enzymes, yeasts and bacteria, that remove the mucilage adhering to the endocarp. This process usually takes 12-24 hours. Fermentation may be hastened by adding enzyme preparations or 2 per cent $NaOH$.

   iii) **Drying** – depulped fruits are dried to a moisture content of about 12 per cent either by exposing to sun or by hot air driers. At this stage the beans (seeds with endocarp) are bluish green and shrink within the parchment shell that appears like a silver skin. The greenish coffee can be stored for a long time.

   iv) **Hulling** – removes the seed parchment (endocarp) and also the seed coat or pellicle or testa (silver skin), exposing the coffee seeds.

   v) **Polishing** – improves the sheen on the surface of the beans (seeds) and also removes the vestiges of seed coat and parchment.

   vi) **Grading** – defective beans are sometimes picked out by hand; at this stage the beans may be bagged and shipped for export.

   vii) **Roasting** – polished coffee beans are roasted in coffee roasting machines for 5 min.at a temperature of 200-260°C. The seeds become deep brown, porous and crumbly and there is partial sugar caramelization. The beans lose 14-23 per cent of their weight but they increase in size by 30-100 per cent. They also develop the characteristic coffee aroma and flavour (is due to essential oil – caffeol and the mercaptans present in the roasted beans). Raw coffee does not have the flavour or taste associated with coffee. During roasting the main stimulating constituent caffeine is freed from the tannin complex 'caffeotannic acid' and it is reduced by half. Also see Table 18.7.

   viii) **Grinding** – roasted beans are rapidly cooled in vats and are ready for grinding.

   ix) **Packing** – is done in impervious containers under vacuum or in an atmosphere of inert gas. Powdered coffee loses its aromatic quality and turns rancid if it is not immediately put in hermetically sealed containers. Caffeine is present in ground coffee to the extent of 0.75 to 1.5 per cent.

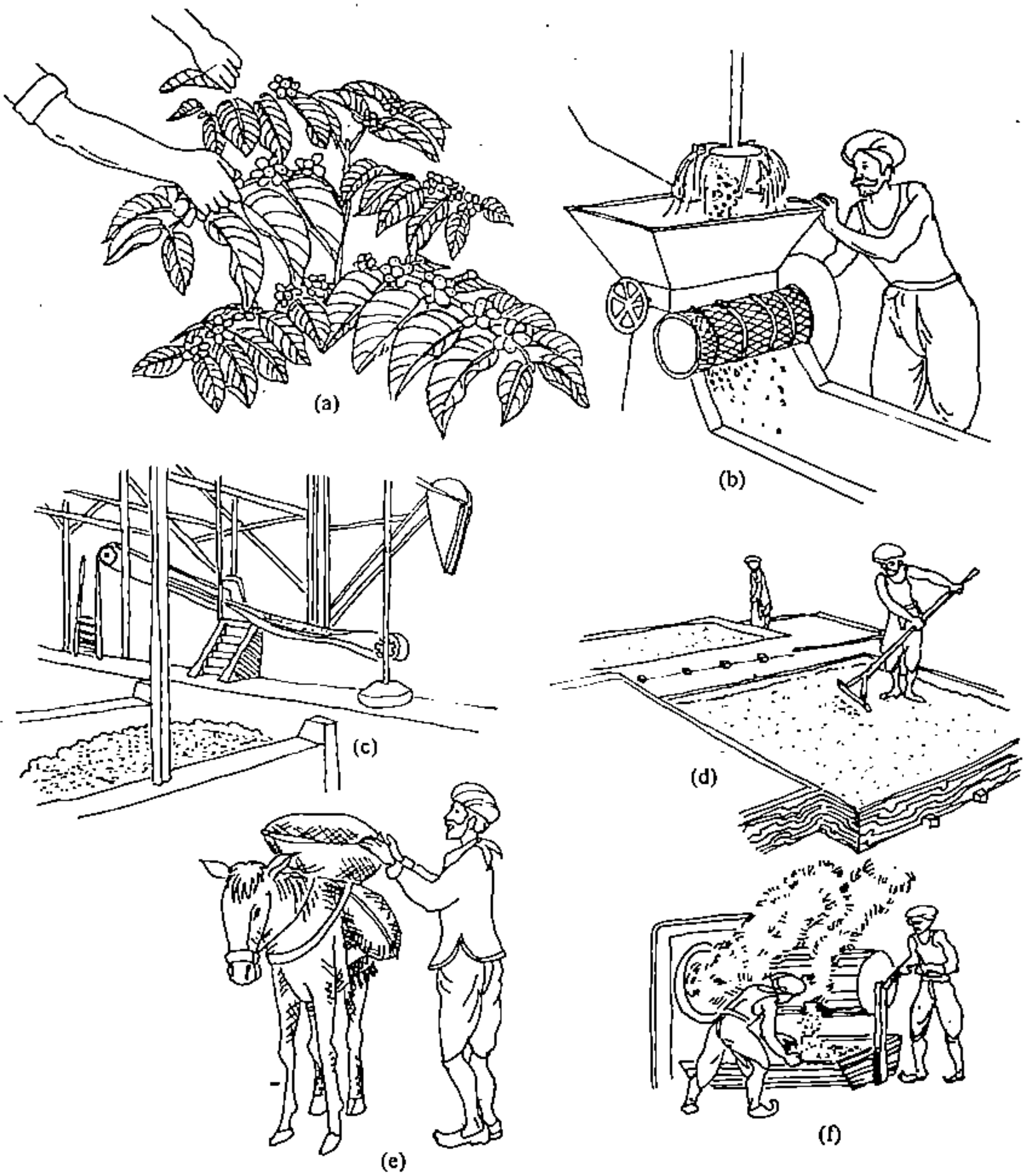

Fig. 18.7: Diagrammatic representation of steps in the processing of coffee. a) The ripe or the red berries are hand-picked. b) These are washed with water and are subjected to fermentation. c), d) The beans are dried after removing their pericarps. e) The green beans can be transported to the market. f) A simple roaster machine for roasting beans. Modern machines have automatic tumblers (From Simpson & Conner-Ogorzaly, 1986).

Instant coffee

This is obtained by vapourising a strong infusion of coffee in vacuum or by the freeze drying technique. Beans of *C. canephora* are generally used in making instant coffee.

Coffee Flavours

The flavour of coffee depends upon the following:

(a) location,
(b) type of variety,
(c) degree of ripeness of the seed,
(d) method of curing and drying,
(e) practice of roasting, and also
(f) the extent and type of substitutes used.

Professional coffee tasters like tea tasters blend together, in appropriate proportions coffees from different locations, to produce a particular flavour.

Caffeine-free (decaffeinated) coffee

It is obtained by removing the caffeine from unroasted greenish coffee beans with any of the following methods: (a) using organic solvent, (b) water extraction, or (c) steam extraction.

a) **Solvent method**

Beans are presoftened with steam and are extracted with an organic solvent such as methylene chloride. The solvent is then drawn off the beans and any remaining traces left in the coffee are evaporated by steam or heat during the roasting process. The caffeine is removed from the solvent with water. About 20 kg. (44 lb) of caffeine is recovered from each ton of processed coffee.

b) **Water extraction method**

Green beans are percolated with water, that is saturated with all of the water-soluble compounds in coffee except caffeine. The caffeine is then removed from the extraction water with organic solvents and purified. In this method no toxic organic solvents actually come into contact with the coffee. This is a costlier method.

c) **Steam extraction method**

The procedure is a well guarded secret.

Table 18.7: Average composition of raw and roasted coffee beans (From Kochhar, 1998).

Constituents	Raw (per cent)	Roasted (per cent)
Ash	3.97	5.17
Fats	11.42	8.30
Moisture	8.26	0.36
Sugars	8.18	1.84
Gluten	10.68	12.03
Caffeine	1.10	1.06
Cellulose	42.36	44.96
Extractive matter	14.03	26.28

Uses

1. In Arabia, an alcoholic drink is prepared from the dried coffee pulp.
2. 'Coffelite' – a type of plastic material with good insulating properties can be made from coffee beans.
3. The residues from coffee processing are used as fertilizer and mulch.
4. In India the residue is also used as fuel and animal fodder.
5. In Ethiopia, drinks are prepared from dried leaves, and dried and roasted berries.
6. In Indonesia and Malaysia, a tea is made from the coffee leaves.
7. Coffee has a stimulating effect on the central nervous and vascular system.
8. It is also a diuretic and aids in digestion by stimulating the flow of digestive juices and increasing intestinal peristalsis.
9. A cup of coffee contains about 3 times more caffeine as much as a cup of tea.

Adulterants of Coffee

Roasted peas, beans, cereal grains and roasted tamarind seeds are its common adulterants. Many times use of flavour enhancers like chocolate, liqueurs, orange or almond extract and vanilla, is also made. The most common coffee additive is chicory (*Cichorium intybus*, Asteraceae) root, which can be considered an adulterant or a flavour enhancer.

SAQ 2

i) Differentiate between Arabian, Robusta and Liberian Coffee?

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ii) What type of soils are good for coffee growing?

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iii) How is decaffeination of coffee done?

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18.4 Cocoa

Botanical name: *Theobroma cacao* (from the Greek words theos – God, and broma – food, "Food of the Gods")
Family: Sterculiaceae
Common name: Cacao, Cocoa or Chocolate tree. The term 'Cacao' is often employed for the tree and its parts, and 'Cocoa' for the manufactured products.
n = 10

It is believed to have originated in the slopes of Andes, South America. Like coffee, production of cocoa is now highest in areas far removed from its place of origin, but within the same latitudes, between 20° North and South of equator. Since 1988, Cote Divoire is in the lead (680,000 t), followed by Brazil (347,000 t), whereas Ghana (West Africa) now stands at third place (290,000 t). Ghana was the leading producer in 1975, followed by Brazil, Nigeria and the Ivory coast. Other countries that produce cocoa are Dominican Republic, Papua New Guinea, Mexico, Togo, Colombia, Venezuela, Indonesia, The Philippines and Sri Lanka. The production in Southeast Asia has gone up due to increase in cultivation in Malaysia (220,000 t), surpassing Nigeria (140,000 t). In India, cocoa is mainly grown in the foothills of the Nilgiris and in some parts of Kerala. The subspecies of *T. cacao* and its forms interbreed readily to give fertile F_1 hybrids; this has given rise to a large number of recognizably distinct local populations.

From commercial point of view, two varieties of *T. cacao* are important: 'criollo' and the 'forastero' (Table 18.8). The 'criollo' is mainly grown in Venezuela, Colombia and Central America, whereas 'forestero' is grown in Africa and South America, particularly Brazil. This accounts for 80 per cent of the cocoa beans entering the world market. Another variety 'trinitario' probably a hybrid of 'coriollo' and 'forastero' is grown chiefly in Trinidad.

Table 18.8: The major differences between typical Criollo and Forastero Cocoas.

Characteristics	Criollo	Forastero
Fruit colour	Yellowish-red, spotted	Greenish-yellow
Fruit form	Elongated, pointed	Oval
Fruit surface	Uneven, warty, deeply furrowed	Smooth, shallow furrows
Fruit husks	Thin and soft	Firm and tough
Seed size	Large, round,	Small, flat
Number of seeds in a fruit	20-40	30-60
Colour of cotyledons	Creamish to rose	Purplish
Aroma	Strong	Weak
Yield	Low	High

Morphology

The cocoa tree grows to a height of 8-10 m, but under cultivation it is kept low by pruning. The root system mainly consists of the tap-roots, reaching about 2 m deep into the soil. The feeding roots arise from the root collar (5-6 m long), and are found in the upper 15-20 cm of the soil. The branching pattern of the cocoa plant is characteristic (Fig. 18.8). The stem grows orthotropically in the first 14-18 months. When a height of 1.2-1.5 m has been reached, it stops growth, and the main stem (chupon) divides into generally 5 meristems. From the meristems arise the plagiotropic fan branches, which have indeterminate growth. This group of plagiotropic branches is called a 'jorquette' or 'fan'. After sometime, an axillary bud develops just below the jorquette into a vertical orthotropic shoot, the 'chupon', which again forms a jorquette a few feet higher up, then another vertical shoot arises just beneath the second 'jorquette'. Thus in the course of years, a number of tiers of plagiotropic branches are formed. Both chupon and fan branches bear flowers and fruits.

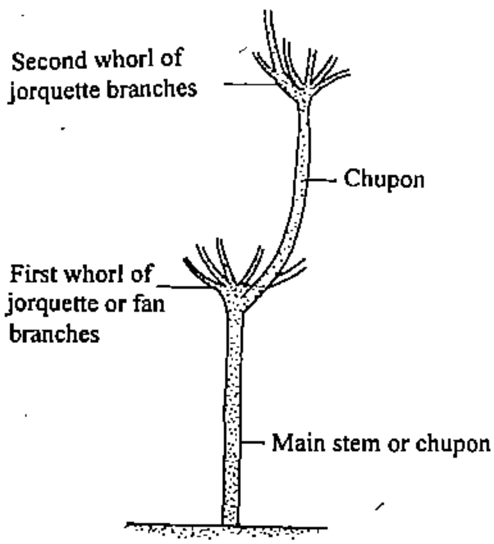

Fig. 18.8: Diagrammatic representation of the branching pattern of cocoa plant. Note the production of successive chupons each in turn bearing a group of jorquette branches that arise at the same point. (From Kochhar, 1998).

The leaves are spirally arranged on the main stem and subsequent chupons but are alternately arranged on jorquette branches. The mature leaves are dark greenish about 37 cm long and 7.5 cm broad, oblong-oval or elliptic-oblong with prominent veins and veinlets. The short petiole has two articulations.

The inflorescences occur on the old leafless wood of main stem (Fig. 18.9) and fan branches. It is much compressed cincinnal cyme (helicoid cyme) with branches greatly reduced. These branches originate from buds in the axil of reduced prophylls (minute sessile leaves at the base of branch arising from an axillary bud). Branch does not usually grow out, but its shortened and twisted branches broaden into a cushion. Each cushion may bear up to 50 flowers in one season. Peduncles and bracts are pubescent, i.e., covered with short, soft-hairs. When inflorescence is stimulated by a fungal disease (witches' broom), the cushion grows out into a leafy shoot.

The flowers are tiny, white, yellowish or pinkish, pentamerous, pedicellate (1-2 cm long) and bisexual. Sepals are 5, pinkish or white, triangular, fleshy, valvate, shortly united at base. Petals are 5, smaller than sepals; base is obovate 3-4 mm long, expanded into a concave, cup shaped pouch; end of the petal is spatulate (2-3 mm), yellowish, bending outwards and backwards and attached to pouch by narrow connective (Fig. 18.9 a-c). Androecium has 5 outer staminodes with ciliate margins opposite the sepals and they form a ring around the style; the 5 inner fertile stamens bend outwards and the anthers are concealed in the pouches of the corresponding petals. Gynoecium has 5 carpels; ovary is superior, ovules (anatropous) are numerous. At the base of the ovary the placentation is axile and it is parietal above. Style is single, hollow and is shorter than the surrounding fence of staminodes. Stigmas are 5, more or less adherent. Fruit is a drupe, commonly called a pod (Fig. 18.9 d,e). It is borne directly on the stem – this condition is botanically known as cauliflory. The fruit is indehiscent, white, greenish or reddish, variable in size and shade. Pericarp (husk) is usually fleshy and mesocarp is thick. Pods mature in 4-6 months after fertilization including a month for ripening. Seeds are usually called beans. Each fruit has 20-60 seeds. Seeds are arranged in 5 rows, variable in size and shape.

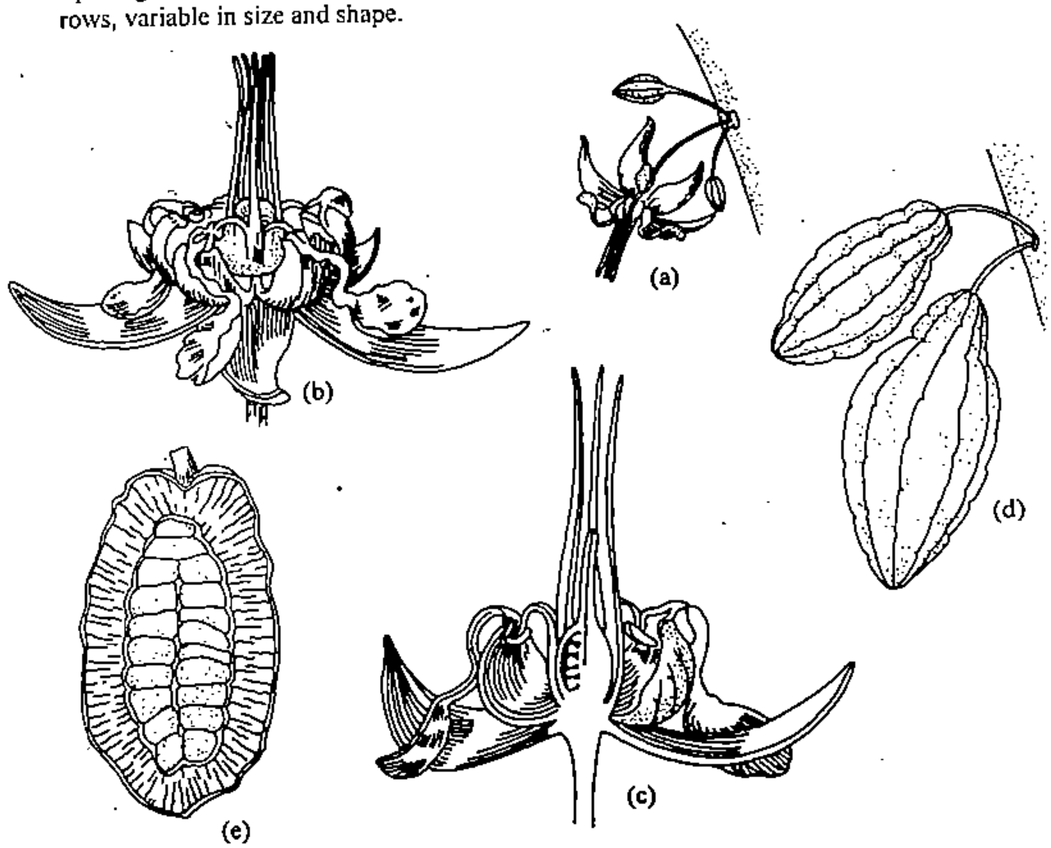

Fig. 18.9: Flowers and fruits of cocoa (chocolate) plant. a) A flower and two buds growing directly from the tree trunk. b) A magnified view of the flower. c) A flower in longitudinal section. d) Two fruits borne directly on the trunk. e) A fruit in cross section. (From Simpson & Conner-Ogorzaly, 1986).

Box 18.3: Cacao and the acrobat bird.

A small black and grey bird known as acrobat, which was christened *Acrobatornis fonsecai* was first sighted by researchers in November, 1994. The conservation of this bird is a matter of great concern! A Roman poet Juvena described this bird as "Rara avis", a rare bird on the earth. According to a researcher in Rio's Federal University, the acrobat is the only example of the ovenbird family in the region; the other members of the family died out after their habitat was dramatically altered by the introduction of the cocoa plantations 200 years ago. The acrobat had survived by adapting to the changes. The cocoa plantations require an extensive forest conopy to protect them from the Sun, and it is in these overhanging shade trees that the acrobat lives. More than 70 per cent of Bahia's cocoa trees have been afflicted by witches' broom disease, a killer fungus (*Marasmis perniciosus*) infection that has no cure. Once the cocoa plantations are destroyed, the acrobat will have lost its only habitat.

Harvesting

The fruits are produced when the cocoa tree is 3-4 years old, although full production is reached only when the tree is 10 years old. Fruiting occurs throughout the year. As mentioned earlier fruits reach maturity in 4-6 months, and the crop may be collected in two flushes: i) from October to February; ii) and from May to August. Fruits are harvested with a hook-shaped knife so as not to damage the cushion like growth on the trunk, the site for the growth of flowers the following year (Fig. 18.10 a).

Processing of Cocoa

Fermentation - Fruits are slit open and the seeds and pulp are scooped out (Fig. 18.10 b) and fermented. In small plantations in W. Africa, cocoa is fermented in heaps or in medium-sized baskets, usually covered with banana leaves to retain the heat. Depending upon the climatic conditions the seeds are left for 7 or 8 days. They may be turned upside down to allow good aeration and to prevent the temperature from rising too high. During microbial fermentation the sugar in the pulp is converted to alcohol by the activity of the yeast (*Saccharomyces* spp.) and finally to acetic acid by *Acetobacter* spp. Seeds are killed by the penetration of alcohol and acetic acid and become brownish. The cotyledons shrink from the seed coat and separate. The characteristic aroma too develops at this stage, and is due to the presence of an essential oil 'cacool'. These changes are brought about in the proteins and polyphenols by the endogenous enzymes which get activated by the rising temperature (40-50°C) of the whole mass of seeds. In large estates the fermentation is done in specially built perforated wooden or concrete 'sweating boxes' or 'fermentation bins' measuring 90 x 90 x 90 cm or 120 x 90 x 90 cm (the depth is not to be more than 90 cm). The sweating boxes are built stepwise; these are put on a raised platform to facilitate aeration (Fig. 18.10 c). At the Cocoa Research Institute (CRI) in Ghana, fermentation is done in trays of 120 x 90 x 7.5 cm, with slotted bottoms made from palm frond midribs; 10 or more trays can be stacked on top of each other and the last one is covered with banana leaves. In 4 days time fermentation is complete.

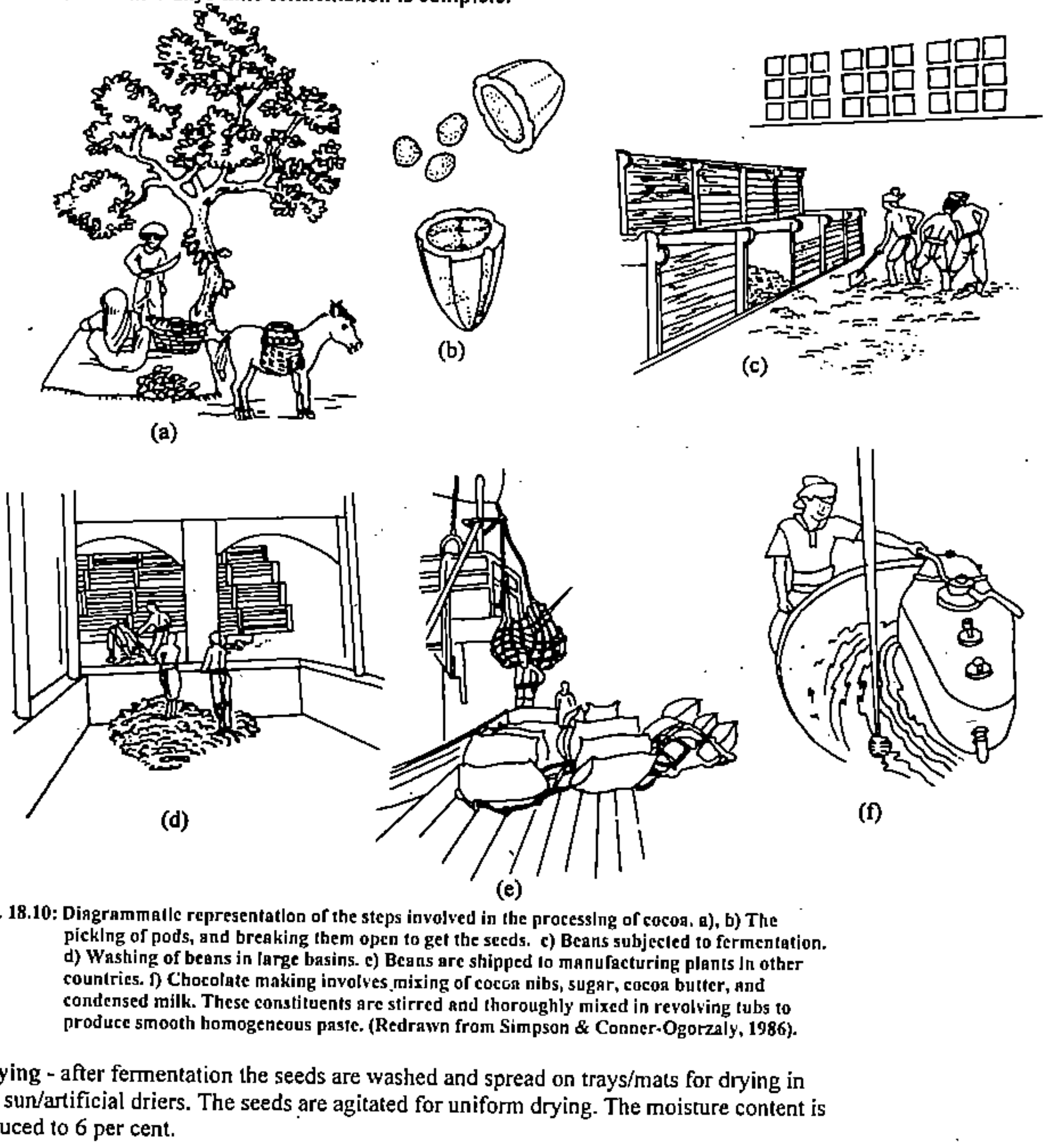

Fig. 18.10: Diagrammatic representation of the steps involved in the processing of cocoa. a), b) The picking of pods, and breaking them open to get the seeds. c) Beans subjected to fermentation. d) Washing of beans in large basins. e) Beans are shipped to manufacturing plants in other countries. f) Chocolate making involves mixing of cocoa nibs, sugar, cocoa butter, and condensed milk. These constituents are stirred and thoroughly mixed in revolving tubs to produce smooth homogeneous paste. (Redrawn from Simpson & Conner-Ogorzaly, 1986).

Drying - after fermentation the seeds are washed and spread on trays/mats for drying in the sun/artificial driers. The seeds are agitated for uniform drying. The moisture content is reduced to 6 per cent.

Polishing (Cleaning) - The seeds are polished either by machine or by trampling the wet seeds with bare feet, a practice known in Trinidad as 'dancing the cocoa'. After the removal of the contaminants such as twigs, stone and dust the seeds are graded and can be exported.

Roasting - After cleaning the beans are roasted in iron drums at 125-140°C (Fig. 18.10 e). Roasting helps to reduce the acidity and astringency, lowers the moisture content, deepens the colour, facilitates shell removal, and develops the flavour of the seeds. The roasted cocoa seed contains:

Fat (cocoa butter)	-	30-36 per cent
Starch	-	15 per cent
Albuminoids and mineral matter	-	15 per cent
Theobromine	-	3 per cent
Caffeine	-	Small quantity

During roasting some of the theobromine from the cotyledons passes into the shell and because of this the extraction of theobromine from the seed residues has become an important industry.

Breaking and winnowing/fanning – The seeds are machine cracked and the heavier cotyledons (also called nibs) are separated from the shell by winnowing. The nibs are ground into an oily paste termed 'bitter chocolate' or 'chocolate liquor' or 'cocoa mass'.

Cocoa manufacture – In the manufacture of cocoa powder two-thirds of the fat from the 'cocoa mass' is removed by hydraulic pressing and the remaining mass (cocoa butter) is pulverised. Cocoa butter is a very stable fat with a storage life of 2-5 years. An alkali treatment is often used to: (a) reduce acidity by neutralizing many organic acids; (b) develop the flavour; and (c) darken the colour. This is also known as Dutching (as this method was developed in Holland).

Chocolate manufacture – (see Fig. 18.10 f) In the preparation of chocolates, extra cocoa butter and sugar are added to the 'chocolate liquor'. The whole mass is repulverised, flavoured and then cast in small sized bars or bricks. In the manufacture of milk chocolates, the 'chocolate liquor' contains more whole milk solids.

Chemical composition

The seeds or 'beans' are a rich source of nutrients and flavour. The cotyledons or 'nibs' are rich in oil (cocoa butter); starch and protein content are about 15 per cent each. There is up to 3 per cent of the alkaloid theobromine, small quantities of caffeine, and traces of various aromatic oils.

Uses

1. Cocoa is a highly concentrated energy food and is also a very nourishing beverage as it contains fats, proteins, carbohydrates and vitamins.
2. Cocoa is the chief natural source of alkaloid theobromine. It is mainly extracted from seed residues and is transformed to caffeine and much of it is used in 'colas'.
3. Cocoa powder may be flavoured with spices, vanilla and other natural or artificial flavours and is used for cakes, puddings and icings.
4. Cocoa beverages produced in water or milk have a mild stimulating effect.
5. Cocoa butter is used in confectionery, pharmaceutical ointments and toiletries.
6. The cocoa shells are used as livestock feed, fertilisers, mulch, fuel and an adulterant of cocoa powder and chocolate.
7. In the Philippines, some of the raw cocoa beans are still used for chewing.

Adulterant

Powdered mesocarp of the fruit of carob tree, Hindi – Kharnub [(*Ceratonia siliqua*), (family Caesalpiniaceae)] native of E. Mediterranean region, also grown in Punjab is a rich source of protein and sugar and is used as a chocolate substitute/adulterant.

SAQ 3

1. Why is cocoa known as "Food of the Gods"?

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2. What is 'chocolate liquor'?

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3. Name an adulterant/substitute for chocolate.

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18.5 SUMMARY

In this unit you have learnt that:

- Beverages (exclusive of soft drinks) can be grouped into 2 heads: (i) alcoholic, and (ii) non-alcoholic.
- Alcoholic beverages are depressants.
- Non-alcoholic beverages like tea, coffee and cocoa are stimulants because they contain chemicals primarily caffeine (alkaloid) and its relatives which cause physiological reactions in our body.
- Tea, coffee and cocoa are tropical crops.
- Tea – *Camellia sinensis*; family-Theaceae; centre of origin – S.E. China and India. It is an evergreen woody shrub. Leaves are used in the preparation of the beverage. The type of processing of the leaves depends on the final type of tea desired; commercially, tea is fermented to bring about alteration of various chemical constituents of the leaf. Green tea is unfermented. Oolong tea is semi-fermented. Tea is a health promoting beverage if consumed moderately. Adulterant – stalks, dust.
- Coffee – *Coffea arabica, C. canephora, C. liberica*; family – Rubiacae; centre of origin – Eithiopia, Africa. It is an evergreen shrub or a small tree. Seeds commonly called beans, are used in the preparation of the beverage. Coffee seeds are processed by either: (i) dry or (ii) wet method. Coffee has a stimulating effect on central nervous and vascular system. Adulterants – dried roots of chicory, dandelion, cereal grains, roasted tamarind seeds.
- Cocoa – *Theobroma cacao*; family – Sterculiaceae; centre of origin – slopes of Andes, South America. The cocoa tree has a characteristic branching pattern. Seeds (usually called beans) and pulp are scooped out of the fruits (drupe) and fermented, dried, polished and roasted; the cotyledons are ground into an oily paste termed 'bitter chocolate' or 'chocolate liquor' or 'cocoa mass'. Cocoa and chocolate are manufactured from the cocoa mass. Cocoa is a very nourishing beverage as it contains fats, proteins, carbohydrates and vitamins. Adulterant – powdered mesocarp of the fruit of carob tree (*Ceratonia siliqua, Caesalpiniaceae*).

18.6 TERMINAL QUESTIONS

1. Fill in the blanks:

   i) The characteristic aroma and flavour of tea is due to the presence of ....

   ii) The stimulating and refreshing characteristic of tea is due to the presence of ....

   iii) .... are responsible for brightness, body and strength of tea.

   iv) Coffee is often intercropped with .... for greater economic returns.

   v) Decaffeinated coffee is obtained by removing the caffeine from .... coffee beans/seeds.

   vi) The seeds are polished either by machine or by trampling the wet seeds with bare feet, a practice known in Trinidad as ....

   vii) Powdered mesocarp of the fruit of .... is a rich source of protein and sugar and is used as a chocolate substitute or an adulterant.

   viii) The most common coffee additive is .... which can be considered an adulterant or a flavour enhancer.

   ix) Tea bags are manufactured from leaf fibres of ....

   x) The characteristic coffee aroma and flavour is due to ....

2. Expand the following terms:
   (i) CTC ....
   (ii) CCRI ....
   (iii) CRI ....
   (iv) ICO ....

3. Where are the following located:
   (i) Cocoa Research Institute ....
   (ii) Headquarters of International Coffee Organisation ....
   (iii) Tocklai Experimental Station ....

4. What is the difference between Black, Green and Oolong tea?

5. Describe the event called 'Boston Tea Party'.

6. What are CTC, Brick, Leppet-so and Legg-cut teas?

7. How many calories are there in a cup of tea (a) with, and (b) without addition of one tablespoon of milk and one lump of sugar?

8. Sketch and label parts of t.s. *Camellia sinensis* leaf.

9. Write the steps involved from the time coffee berries are plucked until drinking coffee powder is prepared.

10. How is instant coffee powder obtained?

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11. Which are the coffee growing states in India?

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12. Distinguish between 'Criollo' and 'Forastero' varieties of cocoa.

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13. Describe the branching pattern of the cocoa plant.

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14. Describe the manufacture of chocolate, write all the steps involved from the time the fruits are harvested until the preparation of chocolate bars or bricks.

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15. What type of inflorescence is seen in Cocoa tree?

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18.7 ANSWERS

Self-Assessment Questions

1. i) The bushes are often pruned to encourage maximum leaf production and also to keep them at plucking height.
   ii) See Fig. 18.2, and Section 18.2.
   iii) See Table 18.3.
   iv) Tea bags are manufactured from leaf fibre of *Musa textilis* (Musaceae).

2. i) see Section 18.3, Table 18.6.
   ii) see Section 18.3, 'Agroclimatic conditions'.
   iii) see Section 18.3, 'Caffeine-free (decaffeinated) coffee.

3. i) Cocoa is known as "Food of the Gods" because the Mayans (tribe in Central and South America) thought that cocoa had a divine origin and Linnaeus named it *Theobroma cacao* (from the Greek words theos – God, and broma – food).
   ii) see Section 18.4, 'Chocolate manufacture'.
   iii) see Section 18.4, 'Adulterant'.

Terminal Questions

1. i) essential oils/theol
   ii) theine/alkaloid/caffeine
   iii) polyphenols

iv) bananas/figs/black pepper
v) unroasted/greenish
vi) dancing the cocoa
vii) carob tree/*Ceratonia siliqua*
viii) chicory/*Cichorium intybus*
ix) Abaca/*Musa textilis*
x) caffeol/essential oils

2. i) Crushing, Tearing and Curling
   ii) Central Coffee Research Institute
   iii) Cocoa Research Institute
   iv) International Coffee Organisation

3. i) Ghana
   ii) London
   iii) Jorhat, Assam, India

4. See Section 18.2, Table 18.4
5. See Box 18.1
6. See Section 18.2.
7. (a) 4 calories
   (b) 40 calories
8. Refer to Fig. 18.2
9. See Sections 18.3.
10. Refer to Section 18.3.
11. Refer to Section 18.3.
12. See Table 18.8
13. See Section 18.4.
14. See Section 18.4, 'Processing of Cocoa'.
15. Compressed cincinnal cyme (helicoid cyme)

UNIT 19 MEDICINAL AND AROMATIC PLANTS

Structure

19.1 Introduction
- Objectives

19.2 Medicinal Plants
- 19.2.1 Rauwolfia
- 19.2.2 Indian Aconite
- 19.2.3 Quinine Tree
- 19.2.4 Yam
- 19.2.5 Belladona
- 19.2.6 Foxglove
- 19.2.7 Periwinkle
- 19.2.8 Opium Poppy
- 19.2.9 Nux-Vomica
- 19.2.10 Ergot

19.3 Fumitory and Masticatory Materials Yielding Plants
- 19.3.1 Indian Hemp
- 19.3.2 Tobacco
- 19.3.3 Betel Palm

19.4 Essential Oil Yielding Plants
- 19.4.1 Sandalwood
- 19.4.2 Vetiver
- 19.4.3 Other Important Sources

19.5 Summary

19.6 Terminal Questions

19.7 Answers

19.1 INTRODUCTION

Many chemicals found in plants are not only of great significance but are also essential to the sustenance of life on earth - both plant and animal life. Life on earth is carbon based; the simple sugar molecule, glucose is formed as a result of interaction of sunlight with the cells of the green plants during photosynthesis and this is the basis for all the food chains in nature. These simple sugars aid in the formation of other molecules such as amino acids through complex biochemical pathways. Amino acids, as you know, are the building blocks of proteins and they constitute the basic framework of the living system. Some 20 amino acids are essential in sustaining life and its accompanying biochemical processes (metabolism). The pathways of metabolism that are essential to life constitute primary metabolism and the compounds that are directly involved in these pathways are called primary compounds or **primary metabolites**, e.g., glucose, and the essential amino acids. Many compounds, produced by plants through secondary pathways (from primary metabolites such glucose in the formation of glycosides) are called **secondary metabolites**. These include alkaloids, glucosides, glycosides or phenolic compounds. A large number of plants have medicinal value, aromatic or fragrant properties, contain secondary compounds, probably as survival adaptations or defense mechanisms and these also have great value for animals and human beings. The understanding and the use of these secondary plant substances, their analogs and semi-synthetic forms is going to be of immense value in our daily lives in the times to come.

In this unit we have taken up the commonly used medicinal and aromatic plants of our country for detailed study. We have discussed them under three sections dealing successively with medicinal plants, fumitory and masticatory materials-yielding plants, and essential oil-yielding plants.

Objectives

After studying this unit you should be able to:

- differentiate between primary and secondary metabolites;
- appreciate the importance of studies of medicinal and aromatic plants;
- explain the significance of major classes of plant derived compounds;

- describe some commonly used medicinal plant sources, plants for fumitory and masticatory materials, and essential oil-yielding plants; and
- differentiate between fixed oils and essential oils.

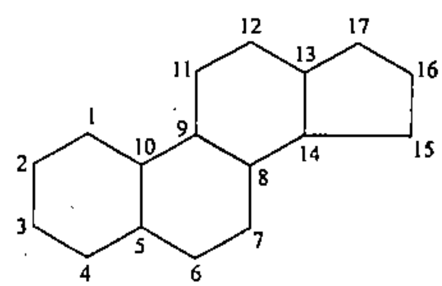
19.2 MEDICINAL PLANTS

Many ancient plant remedies for diseases have in some way or another played a significant role in modern medicine. For example, aspirin, is the most widely used, medicine in the world and is entirely synthetic (a - , from acetyl; and - spirin, from *Spiraea* species of family Rosaceae, one of the sources of salicylic acid); but knowledge of the pain-relieving agent we know today as aspirin is traceable to the use of willow (*Salix* species, Salicaceae) bark by the ancient Greeks to alleviate pain. An active ingredient, salicin was isolated in 1827 from the leaves of willow. Salicin could not be taken internally, but a derivative, acetylsalicylic acid produced in Germany in 1899, provided relief from all types of pains. The point to be noted here is that the prototype of this drug was a natural product form plants. Similarly, a large number of drugs, which are available in synthetic form today invariably have a botanical history - in the use of some sort of crude extract. The classical medical systems, such as Ayurveda of India and Chinese medicine depend on plant drugs; earlier this was viewed with scepticism by the western world but today there is special interest in these systems. An inventory of medicinal plants used by people in different countries has been compiled by the World Health Organisation.

Modern drugs contain plant products like fatty acids and essential oils, gums, resins, alkaloids and steroids. Oils and gums are used as emulsifiers in many of the present drug preparations. Volatile oils and resins are often used to help penetrate tissues and also as antiseptics. The two major classes of plant-derived compounds used in medicine are: (1) steroids, and (2) alkaloids (see Boxes 19.1 & 19.2). They can occur with one or more sugar molecules attached. Such forms are called glycosides and these are generally the medicinally active forms of the compound.

Box 19.1: Steroids

Steroids are complex compounds which have the following fundamental structure comprising four carbon rings called the steroid backbone.



Steroid backbone

The addition of different chemical moieties at different places of the backbone leads to the production of a variety of different steroidal compounds. Addition of sugar molecules to the steroidal backbone produce steroidal glycosides. These are also called secondary products, and no direct physiological functions for steroids in plants have been found. On the contrary, they have a pronounced effect on animals, particularly vertebrates. Many biologists believe that the production of these compounds is for the protection of the plants from animals. For example, the monarch butterfly in its larval stage (as a caterpillar) feeds on milkweeds, i.e., the members of Asclepiadaceae. Milkweeds are toxic to humans because they contain steroidal glycosides. Monarch larvae store the compounds in parts of their bodies and are not poisoned by the glycosides. When the caterpillars metamorphose into butterflies, these stored glycosides occur primarily in their wings. Thus, the butterflies become toxic to their vertebrate predators such as birds. Interestingly the birds quickly learn to avoid these toxin-containing butterflies.

Box 19.2: Alkaloids

> Alkaloids as a group defy definition. The word alkaloid means alkaline but there is no uniform model for an alkaloid molecule. Alkaloid molecules generally have single or multiple rings and contain nitrogen. In plants, alkaloids have in the past been considered as waste products or secondary products of metabolism with no clarity about their roles. However, there is strong evidence to show that unlike steroids, alkaloids enter the primary metabolism of plants. They have also been found to play an important role in chemical defense in plants, precisely in controlling animal predation. In animals especially mammals, the effect of many alkaloids, even in minute quantities, can be profound. The most universal effect of alkaloids in animals is on their nervous system; however their other systems too are affected. The consideration of a plant as poisonous versus medicinal is often only one of dosage.

There are various methods to group medicinal plants. They can be classified in terms of:

- the chemical nature of the compounds involved,
- the effect they produce, or
- the source from which the drugs are obtained.

For convenience, we have classified the plants on the basis of the source from which the drug is obtained.

19.2.1 Rauwolfia

Botanical name: ***Rauwolfia* spp.**
Family: Apocynaceae
Common names: Rauwolfia root, Snake root, Serpent wood, Chandrabhaga, Chota-chand, Sarpgandha
n = 10,11,12,22

The genus *Rauwolfia* was named after the 16th century German physician and explorer Dr Leonhard Rauwolf.

Ecology and propagation: The plant grows in tropical or sub-tropical regions and flourishes in hot humid conditions. These are best raised from root cuttings. Seeds and stem cuttings are also used for propagation. Although pharmaceutical companies have tried to mass cultivate the plants, they have not been successful and commercial supplies still come from nature. Indonesia was once a major source, but its once extensive supply of trees (*R. vomitoria*), and shrubs has been exhausted. Presently, the leading producers are India and Thailand.

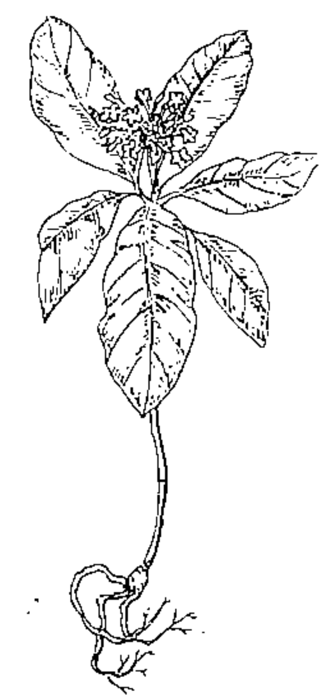


Fig. 19.1: ***Rauwolfia serpentina*. A young plant showing its snake-like roots, that are the chief source of the alkaloid. (Redrawn from: Simpson & Conner-Ogorzaly, 1986).**

Morphology: *R. serpentina* (Fig. 19.1) is an erect, evergreen, perennating glabrous undershrub. Its roots are greyish brown, tuberous and have a characteristic slightly wrinkled and coarse surface. The cylindrical, tapering and often twisted taproot is of commercial value; the bark of the root is considered more valuable than the wood. Roots are harvested from 2 -3 year old plants after they have shed their leaves. At this stage they are richer in alkaloids than the roots dug at earlier stages. The leaves and stems too contain small amounts of alkaloids. The leaves are simple, glabrous, lanceolate or obovate; and are arranged in whorls of 3 or 4, crowding the upper part of the stem. Inflorescence is generally terminal but sometimes axillary. It usually consists of dense cymes (Fig. 19.1). Flowers are tubular, pinkish white or greenish white. Fruits are small (0.5 cm), oval, fleshy drupes, they become shiny black when ripe.

Rauwolfia species contain about 80 or more alkaloids, of which reserpine, rescinnamine, ajmaline, ajmalicine and serpentine are of commercial importance (See Table 19.1). Of these the most important is reserpine. It is chemically similar to seratonin, a substance in the brain and is related to LSD (Lysergic acid diethylamide).

Table 19.1: Some distinguishing features of species of *Rauwolfia.*

Features	Species of *Rauwolfia*		
Botanical names	*R. serpentina*	*R. teteraphylla*	*R. vomitoria*
Vernacular names	Sarpgandha, Chota-chand	Barachandrika	—
Origin	N. Indian, East Pakistan, and parts of Malaysia	West Indies	Tropical America
Distribution	Sub-Himalayan tract from Punjab to Nepal, Sikkim, Bhutan, Thailand, Assam, E. & W. Ghats and the Andamans	U.P., Bihar, Orissa, M.P., West Bengal, A.P., Karnataka, Tamil Nadu & Kerala	Guinea Coast & Mozambique
Morphology	Erect evergreen shrub (ht. 0.6 – 1 m)	Small, branched shrub	Small tree (ht. 6 m)
Alkaloid content	0.7 – 3 per cent roots used for the extraction of reserpine, ajmaline, and serpentine	--- roots used as an adulterant with *R. serpentina* alkaloids	0.5 – 1 per cent It is mainly used for the extraction of reserpine and ajmaline. Reserpine content is twice that of *R. serpentina*

Uses

1. For centuries in India, powdered taproots have been used for the treatment of "moon disease", or lunacy, and also against snakebites (hence the common names Chandrabhaga, Chota-chand and Sarpgandha) and insect stings. Reserpine was also employed as medicine in U.S. in the treatment of the mental disorder known as schizophrenia.
2. As a result of the discovery that reserpine was hypotensive, that it could lower blood pressure, it found even greater use in the treatment of high blood pressure (often in combination with other drugs) than of schizophrenia. The use of reserpine in hypertension therapy is based on the action of the drug in dilating blood vessels and thereby reducing pressure.
3. An extract of the leaves has also been used as a cure for the opacity of the cornea.
4. Extracts of roots are used for intestinal disorders; sometimes they are mixed with other plant extracts and used in the treatment of cholera, colic and fever; root extracts also stimulate uterine contraction and is used in child-birth.
5. It enjoys a traditional reputation of a fever reducing agent and as an emmenagogue – an agent that brings on menstruation.

19.2.2 Indian Aconite

Botanical name: ***Aconitum ferox***
Family: Ranunculaceae
Common name: Balnag, Vachnag, Bish

Origin: Temperate and sub-alpine regions of the Himalayas.

Distribution: Himalayas from Sikkim to Garhwal and Assam, Central Nepal to Bhutan.

Morphology: It is a perennial plant (1-2 m) with conical tuberous taproot-like stock. Its stems are stout. Leaves are deeply incised almost to the base into 5-lobes; lobes differ in size and shape from linear to elliptical. Flowers are dark blue in long spike like terminal clusters. Upper petal forms a rounded hood, that is broader than long, and has a short acute beak. Lower bracts pinnately lobed whereas the upper ones are entire.

Ecology and propagation: It grows in moist rich pastures and in mountainous regions. It is propagated by tubers. These are dug when the plant starts flowering. They are dried either in shade or in sunlight. Tubers are dark-brownish but whitish internally.

Chemical composition: Aconite is very poisonous. It contains a toxic alkaloid pseudoaconitine.

Uses: When aconite is boiled in milk its poisonous property is removed and is then used as a: diuretic, antiarthritic, expectorant, narcotic, nervine toxin and, stomachic. Its Homoeopathic preparations are taken for sciatica, neuralgia and chills.

19.2.3 Quinine Tree

Botanical name: *Cinchona* spp.
Family: Rubiaceae
Common names: Quinine tree, Cinchona, Peruvian bark
n = 17

Origin : Andean region (South America - from Bolivia to Colombia).

Distribution : India and Indonesia. It is also grown in Tanzania, Sri Lanka, Myanmar (Burma), Australia and the Caucasus. In India *C. calisaya* (yellow cinchona bark) grows at the Himalayas and in Sikkim. *C. ledgeriana* (pale brown cinchona bark), *C. succirubra* (red cinchona bark), and *C. robusta* are acclimatized in Bengal and Tamil Nadu. *Cinchona* spp. (Fig. 19.2) occur wild in the Andean montane rainforests.

Morphology : *Cinchona* spp. are evergreen shrubs or trees. Leaves are opposite, simple, entire, and have interpetiolar stipules. Inflorescence is a terminal panicle. Flowers are small and fragrant. Calyx united; corolla tubular with 5 spreading lobes with frill of hairs along margins; gynoecium - bicarpellary, syncarpous and inferior, heterostylous, i.e., in microsytyled plants,5 exserted anthers alternate with corolla tube and stigma reaches half the length of corolla tube; in macrostyled plants stamens are half the length of corolla tube and stigma is exserted. Fruit is a capsule with 40-50, small, flat, winged seeds.

Cinchona has been in use for over 300 years now. Historical records indicate that in the year 1638, the countess of Chinchon of Perk was cured of malaria by using the cinchona bark. In 1820 two French scientists, Pierre Joseph Pelletier and Joseph Caventou, identified quinine and named it after *quina*, the native Indian word for bark.

In 1944 quinine was synthesized by Robert Woodward of Harvard and William Doering of Columbia University. No perfect substitute for the natural drug has yet been found. Almost all the world's supply of quinine still comes from *Cinchona* bark.

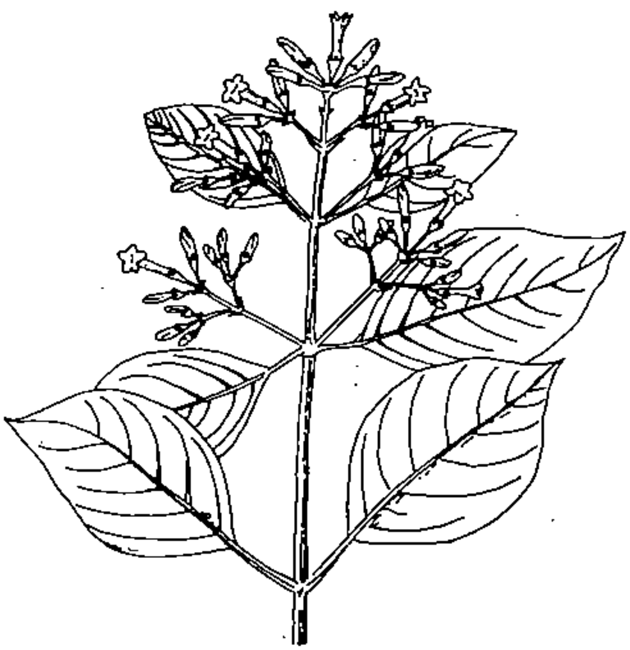


Fig. 19.2: *Cinchona succirubra*. A twig with flowers. (from Johri & Srivastava, 1978).

The alkaloids occur in the bark of the roots, trunks and branches. The roots contain the highest concentration of total alkaloids (about 30 alkaloids have been isolated), but the bark of the trunk is the richest source of quinine ($C_{20} H_{24} N_2 O_2$). Quinine, its isomer quinidine, cinchonine ($C_{19} H_{22} N_2 O$) and its isomer cinchonidine - all four are collectively known as 'totaquine'. The alkaloids exist in the bark in combination with cinchotannic acid, quinic acid, free organic acids, tannins, colouring matters, gums, starch, vegetable matter and traces of volatile oil.

Uses

1. Quinine is used for the treatment of malaria.
2. Quinidine is used today to treat abnormal rhythms of the heart, to relieve muscle cramps, and to aid in the treatment of headaches.
3. Quinine, quinidine and their compounds are employed in insecticides for the preservation of fur, feathers, wool, felt and textiles.
4. The residual bark of *Cinchona* left after the extraction of alkaloids is used as a tanning agent.

19.2.4 Yam

Botanical name: ***Dioscorea***
Family: Dioscoreaceae
Common names: Kat rit alu, Khamalu, Chuprialu, Gaithi, Ratalu.
n =.10

Origin: West Africa, Southeast Asia, China, Mexico, Guatemala (endemic to the moist tropics and the temperate regions of the world).

Distribution: *Dioscorea* has about 600 species. In Mexico and Guatemala, yams from wild dioscoreas are harvested. The most important cultivated species of African origin is *D. rotunda* (white guinea yam) which accounts for most of the world's production of diosgenin. In India the following 8 species have been reported (see Table 19.2).

Table 19.2: Species of *Dioscorea* found in India.

S. No.	Species	Common names	Vernacular names	Habit	Native of	Cultivation in India, and uses
1.	*Dioscroea alata*	White yam, Asiatic yam	Khamalu, Chuprialu	Climbing shrub	E. Asia	Assam, Gujarat (Baroda), Tamil Nadu, Bengal, M.P. – tuber used as vegetable
2.	*D. bulbifera*	Potato yam or aerial yam	Gaithi, Ratalu	Climbing herbaceous perennial	Wild in Asia & W. Himalayas	Throughout the country, tubers are eaten after detoxication
3.	*D. deltoidea*	--	--	Shrub	Wild in India & W. Himalayas	Punjab, Karnataka, Kashmir, N.W. Himalayas. Tubers yield cortisone used in rheumatic diseases and opthalmic disorders, 7-8% diosgenin on dry weight basis.
4.	*D. esculenta*	Lesser yam, Karenpotato	Susnialu	Prickly climbing shrub	S.E. Asia	M.P., U.P., Orissa, Bengal, Assam, E. Himalayas, Nagaland, Khasi Hills, Andamans
5.	*D. hamiltonii*	--	--	Climbing shrub	S.E. Asia	W. Ghats, Sikkim, Assam, Orissa and Bengal. Tubers are edible.
6.	*D. pentaphylla*	--	Kanta alu	"	Tropical Asia	Throughout India. Tubers are edible.
7.	*D. prazeri*	--	--	"	"	Bengal, Assam and E. Himalayas. Tubers are source of cortisone which is used for rheumatism.
8.	*D. tomentosa*	--	"	--	"	South India. Tubers are a source of steroid.

Morphology: Yams are deeply rooted, climbing, dioecious, perennial vines (Fig. 19.3). Rhizome is modified to produce an annual tuber (size varies from a small potato to those weighing as much as 45 kg and 1.8 - 2.8 m long). Internally the yam is white although a few are purplish or yellowish, and may be coarse, dry, mealy, tender, crisp or mushy. They mature in 8-10 months; each tuber usually produces only one main stem which may branch.

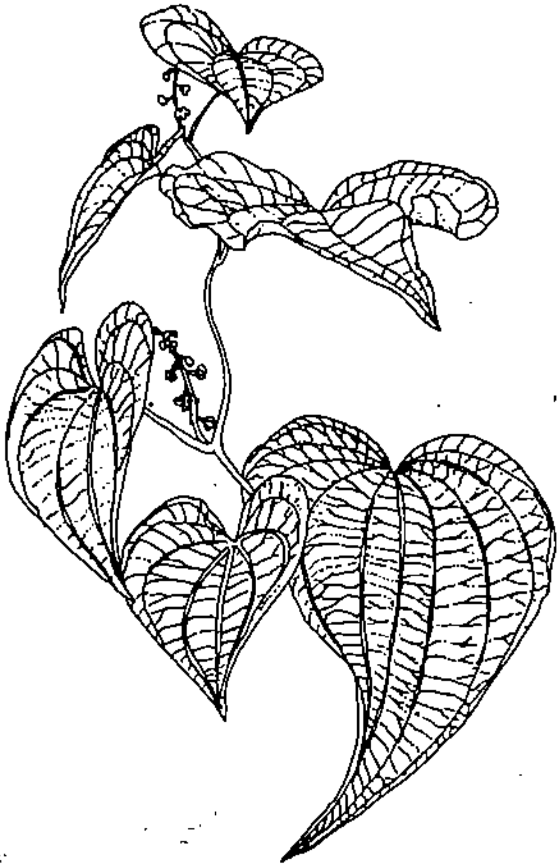


Fig. 19.3: *Dioscorea* sp. A part of twig (Redrawn from Simpson and Conner –Ogorzaly, 1986).

Stem - (3-12 m); length depends on the species; they are weak and climb supports by twining either to the right (anti-clockwise) or to the left (clockwise). The direction is characteristic of each species. The stem may be with or without spines; it may be glabrous or hairy.

Leaves - simple (rarely compound), cordate (heart-shaped) or deeply lobed, opposite or alternate, have long petioles. Some species (*D. bulbifera*) produce large, edible bulbils that are the means of vegetative reproduction, and occur in the axil of their leaves.

Male inflorescence is an axillary raceme, panicle or a cyme. Female inflorescence is an axillary spike, or the flowers are single or in pairs in the leaf axils. The flowers are tiny, rarely more than 4 mm across, and are insect pollinated. Flowers have white, greenish or brownish perianth. The male flower has six stamens, and the female flower has a three-locular ovary. Fruit is a dehiscent capsule which contains six flat winged seeds, that are dispersed by wind.

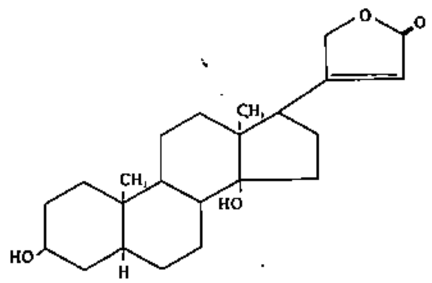
Ecology: Yams are well adapted to tropical rain forests. The eleven cultivated species differ in their climatic requirements. They can be grown in regions with an annual rainfall between 1000-3000 mm or can be grown in temperate climates.

Propagation: Small tubers, tuber cuttings (the tip or 'crown' of the tuber containing buds or eyes) or bulbils are used for vegetative propagation; but propagation is best-carried out from 50-70 g tuber pieces, which are kept in a raised bed under shade, covered with sand and watered regularly for a month before planting in the field.

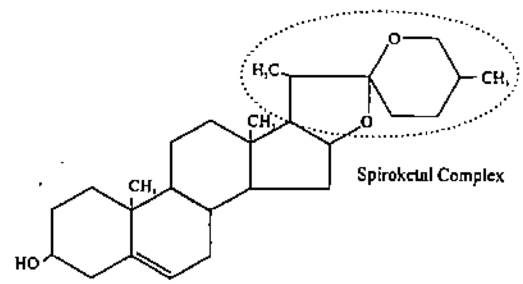
Chemical Composition: Fresh tubers of most species may be bitter or even poisonous because of the presence of certain alkaloids or oxalic acid and oxalates. They are more nutritious than cassava because they are rich in proteins and vitamin C. The average composition of fresh yam is water: 60-70 per cent, carbohydrates: 15-25 per cent and proteins: 4 - 8 per cent. Wild species contain diosgenin. Diosgenin proved suitable to serve as the starting steroid nucleus from which a variety of valuable steroid compounds could be manufactured,e.g., cortisone, hydrocortisone and sex hormones such as androgens, progestogens.

Box 19.3: Steriods from *Dioscorea*.

Between 1936-1940, it was discovered that certain members of the yam genus *Dioscorea* contain particular type of steroids called saponins (they are actually in the form of sapinogens, saponins to which one or more sugars are attached. The name "saponin" is used because these compounds make a soaplike foam when shaken with water). Various cardiac glycosides and steroid hormones are produced with the addition of particular chains or extra rings to the steroid backbone. Cardiac glycosides (digitoxigenin) have a unique ring attached to the 17th carbon of the steroid backbone, e.g., Diosgenin are common in the Liliaceae, Agavaceae and Dioscoreace. They differ from other steroids because they have a spiroketal complex attached to the steroid skeleton. This complex makes them especially useful as precursors of human steroid hormones.



Digitoxigenin



Diosgenin

Uses

1. Most of the hormones synthesized from diosgenin are used in: (a) birth control pills, (b) for the production of hormones to regulate menstruation cycles, or (c) as a component of fertility drugs.
2. Cortisone and hydrocortisone are two other hormones that are synthesized from diosgenin. They are used, for the treatment of: (a) severe allergenic reactions, (b) for arthritis, and (c) for Addison's disease caused by malfunction of the adrenal glands.
3. Yams are a source of carbohydrate foods (30-40 per cent) and are more nutritious than cassava because they have more protein (4-8 per cent). They are not left bitter after they have been peeled, boiled or roasted. Fufu, a dish prepared by grinding fresh yams is prized in West African homes.

19.2.5 Belladonna

Botanical name: ***Atropa belladonna***
Family: Solanaceae
Common names: Deadly nightshade, Yebruj, Girbuti, Suchi, "Witch's berry"
n = 36

Fig. 19.4: ***Atropa belladona.*** **A flowering twig (From Johri & Srivastava, 1978).**

Origin: Central and Southern Europe, and Asia Minor.

Distribution: United States of America, Europe and India. In India it is chiefly grown in Kashmir.

Morphology: *A. belladonna* is a herbaceous, perennial, 90-120 cm high plant that has a creeping rootstock; ovate leaves, unequal in size on the upper parts of stem, are arranged in alternate fashion (Fig. 19.4). Flowers solitary, purplish-brown, bell-shaped, bloom during June-July, arise from the leaf axils. Berries are glossy black with inky purple juice.

Ecology and Propagation: The plants are raised from seeds. Vegetative propagation is done through splitting of old rootstocks. The soil should be calcareous, well-drained loam, containing decomposed humus and good quantity of minerals like potash and soda.

Chemical Composition: All parts of the plants contain alkaloids but are more abundant in the physiologically active cells. The leaves and tops are collected during the flowering season, when the alkaloidal concentration is maximum (0.9 to 1.23 per cent). A large number of alkaloids, collectively known as 'belladonna alkaloids', have been isolated from this plant. Atropine ($C_{17}H_{23}O_3N$), its isomer hyoscyamine and scopolamine ($C_{17}H_{21}O_4N$) are the three most important alkaloids.

Uses

1. Opthalmologists or eye specialists use atropine to dilate pupils for eye examination.
2. They are basic ingredients in the preparation of medicines - for colic and peptic ulcers.
3. Externally, belladonna ointment is occasionally applied to treat gout and rheumatism.
4. The belladonna alkaloids are prescribed for victims of Parkinson's disease to decrease stiffness and tremors.
5. These alkaloids are also given to patients before surgery as a relaxant and to reduce salivation.
6. They are also helpful in cases of mushroom poisoning.

19.2.6 Foxglove

Botanical name: ***Digitalis*** **spp.**
Family: Scrophulariaceae
Common name: "Witch's Bells"
n = 7

Origin: *D. purpurea* - Europe and the U.K., *D. lanata* - Austria.

Distribution: United States of America, Central Europe, England and Argentina. In India, *D. purpurea* is cultivated chiefly in Kashmir and the Nilgiri hills; while *D. lanata* is grown in Kashmir (at altitudes of above 2100 m) and Uttar Pradesh (Chakrata).

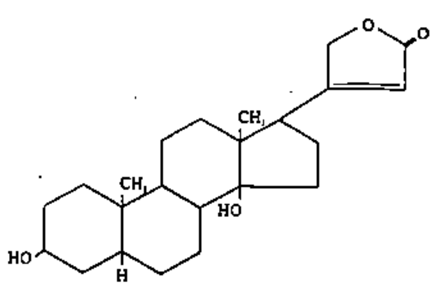
Ecology and Propagation: For cultivation, disease-free strains of the seeds are selected to produce healthy plants. Soil should contain manure and leaf mould. Seedlings are hand transplanted.

Morphology: The plants are biennial (rarely perennial) herbs (height 45-150 cm). Leaves are lance-shaped to oval, alternate or opposite, hairy. A rosette of long-stalked leaves is formed in the first year. Inflorescence is raceme (Fig. 19.5). Flowers are purple or yellowish, hermaphrodite, zygomorphic with protruding lower lip. The flowers are conspicuously spotted on the inner bottom surface of the tube (Fig. 19.5). Calyx – 5; corolla gamopetalous, 5 petals, 2-lipped with indistinct lobes. Androecium – 4, epipetalous stamens. Gynoecium – bicarpellary, bilocular ovary; axile placentation.

Fig. 19.5: ***Digitalis purpurea.*** **A part of twig showing the inflorescence (Redrawn from Simpson & Conner-Ogorzaly, 1986).**

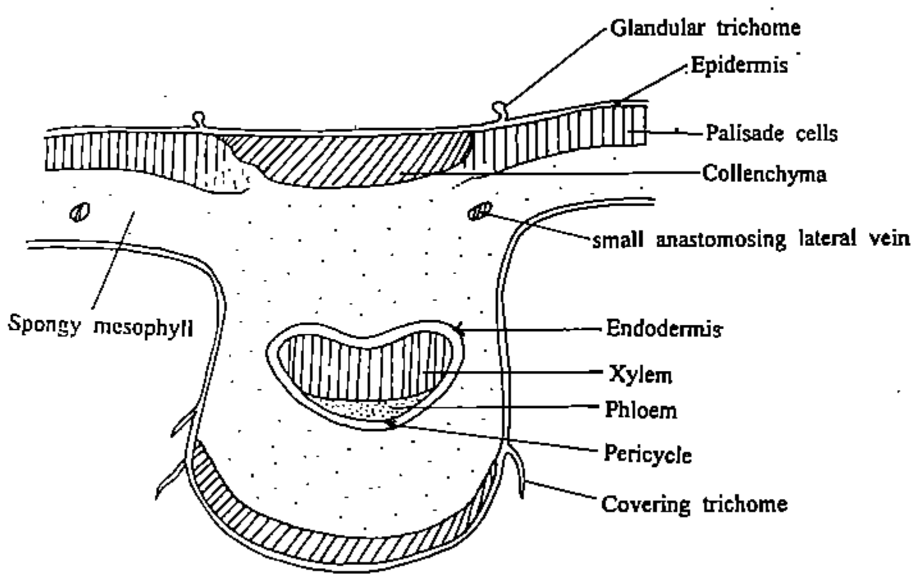
Box 19.4: Glycosides

Glycosides are non-reducing organic substances which on hydrolysis yield an aglycone usually known as genin, and sugar (occur as oxide rings). All cardiac glycosides are steroids or cyclopentanophenanthrene derivatives; they have an unsaturated lactone at C_{17} position. Digitalis glycosides are C_{23} glycoside and have 5-membered lactone ring. Addition of sugar molecules to the steroidal backbone produce steroidal glycosides.



Digitoxigenin

Leaf anatomy - *Digitalis* leaf is dorsiventral (Fig. 19.6). The trichomes are uniseriate, usually 3 to 4 cells long with an acute apex and finely warty cuticle. The glandular trichomes have a short unicellular stalk and bicellular or rarely unicellular head. These glandular trichomes are usually located over the veins. Also, anomocytic type of stomata are also present on the lower surface.



Fog. 19.6: *Digitalis* sp. An outline diagram of a leaf cut in transection through its midrib.

Caution!
The leaf is extremely poisonous. A leaf chewed and swallowed may cause paralysis and sudden heart failure.

Chemical Composition: The first year leaves contain the highest percentage of glycosides. Harvesting is done before flowering and then they are thorougly dried at temperatures not exceeding 600°C. The active constituents of digitalis are mainly confined to the epidermal and subepidermal collenchyma and the endodermal cells. *D. purpurea* leaves contain 0.2 - 0.45 per cent of a mixture of cardenolides. The physiologically active glycosides digitoxin, gitoxin and gitalin are derived from the naturally occurring purpurea glycoside A, purpurea glycoside B, and purpurea glycoside C, respectively by the loss of a glucose residue.

digitoxin → digitoxigenin
gitoxin → (on hydrolysis) gitoxigenin
gitalin → gitaligenin

These are aglycones or genins - the nonsugar portion. These are weaker in cardiac action than the glycosides.

Digitoxin is the most potent of the digitalis glycosides. Its activity is 1000 times that of powdered digitalis.

Digitalin is another active cardiac glycoside obtained from the seeds of *D. purpurea*. *Digitalis lanata* has stronger medicinal properties and its side effects are not as toxic as *D. purpurea*. The active glycosides of the leaves are digitoxin, gitoxin and digoxin and these are derived from the naturally occuring or primary glycosides, lanatoside A, lanatoside B and lanatoside C respectively (also known as digilanids A, B and C).

digitoxin → digitoxigenin
gitoxin → (on hydrolysis) gitoxingenin
digoxin → digoxinenin

Lanatoside C has no counterpart in *D. purpurea*. Digoxin produces the same cardiac effect as digitalis. It is 300 times more potent than that prepared from digitalis leaves.

To date, no laboratory has been able to produce a substitute for digitalis.

Uses

Cardiac glycosides have a strong effect on the cardiac (heart) muscles. When used medicinally they can also improve: (a) circulation in general, (b) relieve oedema (dropsy) which is often associated with heart failure, and (c) help renal secretion.

19.2.7 Periwinkle

Botanical name: *Catharanthus roseus*
Family: Apocynaceae
Common names: Madagascar Periwinkle, Sadabahar

Origin: Native to West Indies and Indian Ocean island of Madagascar.

Distribution: *Catharanthus roseus* (*Vinca rosea*, Fig. 19.7) is cultivated as an ornamental throughout the world and on commercial basis in India, Israel and the USA (International Trade Centre, 1982). In India it is cultivated on commercial scale chiefly in Ramnathpuram, Triunelveli, and Madurai districts of Tamil Nadu.

Propagation: Fresh seeds are used for propagation.

Morphology: It is a perennial or an erect subshrub of height 1 mm; it branches near the base and spreads over an area of some 60- 70 cm in diameter. The plant is cloacked in smooth, glossy, dark green leaves up to 5 cm long. There are two flower varieties, alba (white) and roseus (pink) in the natural state, and several hybrids. The flowers are borne throughout summer at the ends of the branching stems. The flowers are fragile, and have purplish-red or yellowish circular nectar guide at the mouth of the corolla tube. Salverform corollas range from hot pink to mauve and white. The fruit is a cylindrical follicle containing many black seeds.

Fig. 19.7: *Catharanthus roseus*, A part of twig with flowers. (Redrawn from Simpson & Conner-Ogorzaly, 1986).

Chemical Composition: The interest of the scientific community arose in the 1950's after hearing of a "periwinkle tea", that was drunk in Jamaica for its antidiabetic properties. All parts of the plant contain alkaloids but leaves are used as a commercial source for the isolation of the two important anticancer alkaloids - vincristine and vinblastine. These are known to inhibit the growth of tumors. Today, we know that periwinkle is endowed with other medicinal properties also. In all, it contains more than 90 known alkaloid agents.

Uses

1. Vinblastine sulphate is mainly used for the treatment of Hodgkin's disease (cancer of the lymphatic system).
2. Vincristine sulphate is useful for leukaemia in children, and lymphocytic leukaemia.

Box 19.5: Earlier Medicinal Uses of Periwinkle.

Long before modern researchers learned of the plant's medicinal properties, folk healers in faraway places used the Madagascar periwinkle for a number of medicinal uses. In India, wasp sting was treated with the juice from the leaves. In Hawaii, an extract of the boiled plant was used to stop bleeding. In Central America, it was used for gargle to ease sore throats and chest ailments. In Cuba, Puerto Rico, Jamaica, and other islands, an extract of the flowers was commonly used as an eyewash.

19.2.8 Opium Poppy

Botanical name: *Papaver somniferum*
Family: Papaveraceae
Common names: Pasto, Aphina, Afin, Post, Afim, Afium, Kashakasha; Aphu, Khuskhus, Abini, Gash agasha, Abini, gasagasalu; Khashkhashufaid.
n = 11

Origin: Eastern Europe and Western Asia.

Distribution: Nepal, India, Turkey, Russia, Laos and Cambodia. In India it is cultivated in the states of Madhya Pradesh, Uttar Pradesh and Rajasthan.

Morphology: It is an erect, annual, glaucous herb (height 30-100 cm). The leaves are ovate-oblong, with leaf bases embracing the stem and are often shallowly pinnately lobed. Flowers solitary, bisexual, and actinomorphic (Fig. 19.8). Sepals 2, falling before flower opens; petals 2 + 2; stamens numerous with bluish anthers; ovary superior, unilocular with numerous ovules, placentation parietal, stigma disc-shaped with deep marginal lobes. Fruit is a capsule; seeds small with minute embryo, endosperm oily. All parts of the plant contain latex.

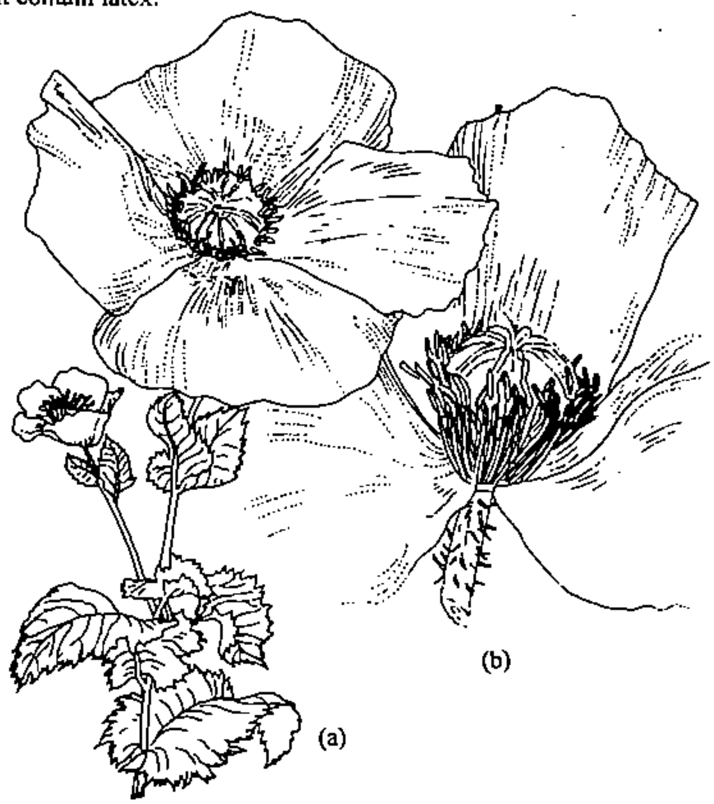


Fig. 19.8: *Papaver somniferum*. a) A part of flowering twig. b) Central portion of the flower enlarg to show prominent stigma with deep marginal lobes, and numerous anthers. (Redrawn fro Simpson & Conner-Ogorzaly, 1986).

Ecology and Propagation: In India, the opium poppy is cultivated as a **rabi** (winter) crop. The seeds are sown in October-November and the latex is collected the following March-April. The plants prefer a well drained sandy loam. It cannot tolerate extreme cold. Propagation is by means of seeds. For growing opium poppy, a well drained rich alluvial soil is required. Propagation is from seeds, and flowering starts after 90 - 115 days. Three to four days after flowering, petals fall and capsule development begins. When the capsule turns from green to yellowish, lancing (incisions are made in the capsule from the bottom upwards with the help of specially designed tools) is carried out in the afternoon and the opium is collected early the following morning.

Chemical composition : Opium (latex obtained from the capsules) is a complex blend of dextrose, pectin, wax, pigments, volatile oil, triterpenoids and alkaloids (20-30 per cent on a dry weight basis) occurring as salts derived from a number of acids including meconic, lactic, citric, succinic, sulphuric and phosphoric.

Crude opium contains about 40 alkaloids, and some of the important ones from the commercial and medicinal points of view are (as percentage of opium on a dry weight basis):

i) morphine [named after Morpheus the god of dreams] (9 - 14 per cent)
ii) codeine (2 - 3 per cent)
iii) thebaine (5 - 7 per cent)
iv) narcotine (noscopine, 5 - 8 per cent)
v) papaverine (1 per cent)

The complete structure of morphine was established in 1952, although its first pure preparation was reported in 1803 by a German pharmacist F.W. Sertuner, who was then only 20 years old.

The seeds of the opium poppy are free from narcotic constituents.

Box 19.6: Morphine and its derivative.

In an attempt to develop a non-addicting pain-killer, scientists discovered that morphine could be chemically altered by the addition of two acetyl groups. The end product is a semisynthetic compound known as *heroin*. It is an even more powerful analgesic than morphine, but it is physically addicting and produces pronounced withdrawal symptoms once the habit has become established. The main cause of death for heroin addicts is by overdose.

Uses

1. Morphine is a powerful analgesic and narcotic, which also stimulates the central nervous system.
2. Codeine is an important analgesic and an anticough agent, which compared with morphine is less sedative and less toxic.
3. Thebaine is a convulsant (that induces violent irregular motions of the body), poison and is used only as a raw material for the manufacture of codeine or other semisynthetic analgesics and narcotic antagonists (neutralize the effect of narcotic) such as nalorphine and etorphine.
4. Narcotine is a mild antitussive and is generally used in the preparation of cough medicines.
5. Papaverine is a smooth muscle relaxant and cerebral vasodilator. It has been used in the treatment of asthma and angina pectoris.
6. The poppy seeds are quite nutritious and have a pleasant nutty flavour, and are often sprinkled on breads and cakes. The seeds are also a source of a fatty oil called poppy oil used in the preparation of sweetmeats.

19.2.9 Nux-Vomica

Botanical name: ***Strychnos nux-vomica***
Family: Loganiaceae (Strychnaceae)
Common names: Dogbutton, Strychnine tree, Kuchla
n = 12

Origin: Southern Asia and Australia. *S. ignatii* is indigenous to Philippine islands

Distribution: India, Sri Lanka, Malaysia, China and Australia. Its trees are found throughout tropical India. For commercial purposes, seeds are collected from Andhra Pradesh, Tamil Nadu and Kerala.

Morphology: It is a medium sized, evergreen tree (height 12 m or more), with a thick frequently crooked trunk. It is often spiny (Fig. 19.9 a). Leaves are large (9 cm long), opposite, simple and ovate. Small, loose clusters of greenish white flowers are borne in terminal cymes at the end of the branches. Fruit is a large orangish-red berry (3.5 cm wide), resembling a Chinese orange in shape and colour. Each fruit contains 3-5 seeds. Seeds are greyish, hard, flat and button-like (Fig. 19.9 b). The silky white sheen or lustre of the seeds is due to the presence of many closely appressed hairs.

Chemical Composition : The seeds contain two powerful alkaloids (1.5-3.5 per cent), strychnine and brucine. Strychnine is extremely bitter and can be tasted even when diluted in a solution that is 400,000 parts water. Other plant parts such as old roots, wood, bark, leaves, blossoms and the fruit pulp also contain varying amounts of alkaloids.

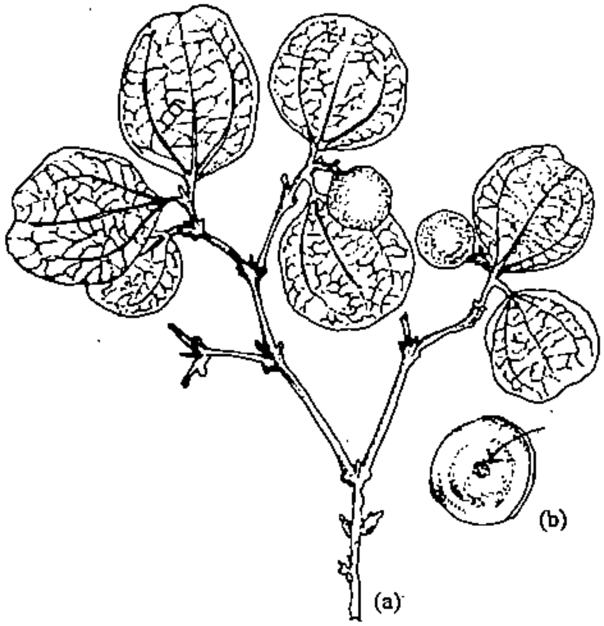


Fig. 19.9: *Strychnos nux-vomica*. a) A twig with fruits. b) A seed enlarged to show a distinct hilum (arrow). Redrawn from Kochhar, 1998.

Uses

1. Strychine is both a stimulant (enhances sensations of sight, smell, touch and hearing, i.e., it affects the central nervous system) and a convulsant, or an agent that causes uncontrolled fits or spasms. Its action can be instantaneous. Today, strychine is used in controlled doses to increase muscular activity. It is also an antitode to poisoning caused by alcohol and other depressnt drugs.
2. Because it tends to induce intestinal movement, physicians have selectively administered the drug in the treatment of severe constipation.
3. Strychine is commercially used in the preparation of pellets used as a poison for moles, called "mole nuts" or "poison peanuts".
4. The fruit pulp is non-poisonous and is eaten by birds, cattle and monkeys.

In 15th century Europe the seeds were imported from Inida to kill the rodent population.

19.2.10 Ergot

Botanical name: *Claviceps purpurea*
Family: Ascomycetes (Fungi)
Common name: Ergot

Drug obtained from: The purple sclerotium (fruiting body) of the fungus collected from ergotized seeds of cereals and grasses mainly rye (*Secale cereale*).

Morphology: *C. purpurea* is a spore-bearing fungus in which the dormant phase is a hard, club-shaped fruiting body or sclerotium (Fig. 19.10). The fungus derives its nutrition from the ovaries of various grasses; the ergot bodies may replace the kernels of the grain in infected plants. The sclerotium is a dark brown-purple black, brittle, banana-shaped structure. It consists of a pseudoparenchymatous mycelial mass rich in oil globules (Fig. 19.10).

Ergot was first cultivated artificially in 1940 in Switzerland. In India ergot is cultivated on rye crop in the Nilgiri Hills.

Chemical Composition: Ergot is rich in many types of alkaloids, some of which are toxic, and others are medicinally valuable. Ergotoxine, ergotamine and ergonovine are some of the important alkaloids isolated from ergot fungus and Lysergic acid diethylamide (LSD) is one of the worst habit forming drugs known; it is also suspected of causing chromosomal aberrations. Ergot also contains sclereythrin (a red or violet pigment), ergosterol, clavicepsin, ergochrysin, ergoflavin, inorganic salts and large number of bases and amino acids. The ergot alkaloids and related compounds are toxic and are capable of inducing varied effects, including hallucinations, and cause a disease known as *ergotism*. When contaminated rye is harvested and ground into flour, the sclerotia also get ground with it.

LSD is related to seratonin, a substance in the brain.

Uses

1. *C. purpurea* produces sclerotia which contains alkaloids that stop the bleeding. These agents were widely used to control haemorrhages after childbirth.

2. It is used extensively to increase the blood pressure (as a hypertensive agent).
3. It is also used in psychiatry.

SAQ 1

Mark the following statements as T (True) or F (False).

i) The prototype of aspirin was derived from the bark of willow tree.

ii) Alkaloids and steroids are two major plant derived compounds used in medicine.

iii) The chief source of the alkaloid reserpine is *Claviceps purpurea.*

iv) The tubers of the Indian Aconite plant are dug for drug extraction when the plant starts flowering.

v) The richest source of quinine is the root bark of *Cinchona* tree.

vi) The tubers of yams are rich in proteins and are also important sources of vitamin C.

vii) Alkaloid concentration is maximum in a Belladona plant during its flowering season.

viii) Digitalin the glycoside used in cardiac disorders, is obtained from the seeds of *Digitalis purpurea.*

ix) Vincristine and vinblastine - the world famous anti-cancer drugs are extracted from the leaves of yams.

x) Opium poppy is cultivated as a Kharif crop in our country.

xi) The most abundant alkaloid found in crude opium is papaverine.

xii) The chief source of strychnine is the seeds of *Strychnos nux-vomica.*

xiii) Diosgenin is both a stimulant and a convulsant.

xiv) Ergotism is linked to the fruits of *Claviceps purpurea.*

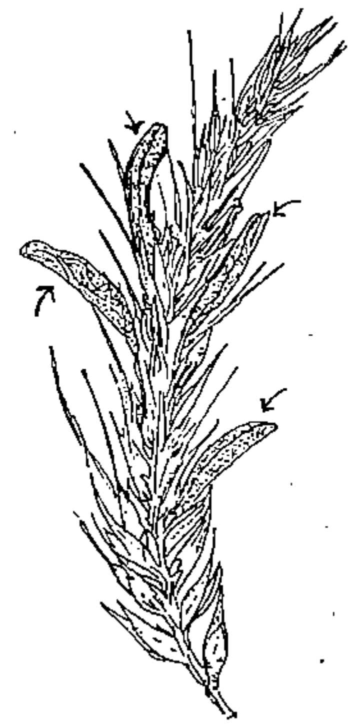


Fig. 19.10: An inflorescence of rye (*Secale cereale*) bearing four ripe fruiting bodies (sclerotia) of ergot (*Claviceps purpurea*). (Redrawn from Kochhar, 1981).

19.3 FUMITORY AND MASTICATORY MATERIALS YIELDING PLANTS

Some fumitory and masticatory materials are smoked or chewed for pleasure or to increase the functional activity of the body or to produce illusions. These materials possess constituents that stimulate or depress the central nervous system. *Stimulants* are chemical agents or drugs that produce rapid momentary increase of vital energy in an organism or some part of it. In this category we can include caffeine beverages, tobacco, betel and coca; although tobacco smoking is harmful and is known to cause respiratory diseases.

Depressants are chemical agents that reduce the functional activity of an organism, i.e., they have a soothing effect (sedative). The word "**narcotic**" has been used by most people for any habit-forming drug or any drug used illicitly. Interestingly, some narcotics for example opium in exceedingly small quantities are legitimate medicines relieving anxiety and pain and often used for inducing sleep. True narcotics have been classified under three main headings:

a) hypnotics,
b) sedatives, and
c) hallucinogens or psychedelic drugs.

a) **Hypnotics** are drugs that induce sleep or a state resembling deep sleep, e.g., kavakava, *Piper methysticum* (Piperaceae) that is indigenous to Fiji and other Pacific islands.
b) **Sedatives** are drugs that reduce excitement, irritation, and pain; and have a soothing or sleep inducing action, e.g., cocaine and opium.
c) **Hallucinogens** are drugs that alter the state of consciousness, that is, produce changes in perception (of time, space or self), mood and thought. In other words, produce illusions, an apparent perception of external objects not actually present.

The different categories sometimes lead to confusion because many drugs act in a combination of ways. For example many of the so-called depressants like the narcotic analgesics and the solanaceous alkaloids can also act as hallucinogens. Stimulants like nicotine and cocaine can cause visions if taken in sufficient quantities.

In this section we shall discuss three plants: (1) *Cannabis sativa*, (2) *Nicotiana tabacum* (from which fumitory materials are obtained), and (3) *Areca catechu* (from which masticatory materials are obtained).

19.3.1 Indian Hemp

Botanical name: *Cannabis sativa*
Family: Cannabinaceae
Common names: Ganja, Bhang, Charas
n = 10

Origin: Native to Western and Central Asia.

Distribution: *Cannabis* is widespread throughout the temperate and tropical regions of the world. In India, it is grown by a few licensed growers in Bengal, Karnataka and Tamil Nadu.

Ecology and Propagation: The plant (Fig. 19.11) grows as a weed of wasteland. Under cultivation it thrives best on fertile, well drained soil. It is a heavy feeder and a soil exhausting crop. For enhanced production of drug and oil, the plants should be grown widely spaced; male plants should be removed to prevent fertilization and increase female flowering. Tropically grown marijuana is more potent than that from cool temperate countries, where very little resin is produced by the plants. Since the resins help to protect vulnerable plant parts from desiccation, the resins are produced in greatest quantity when the plants are exposed to heat and sun.

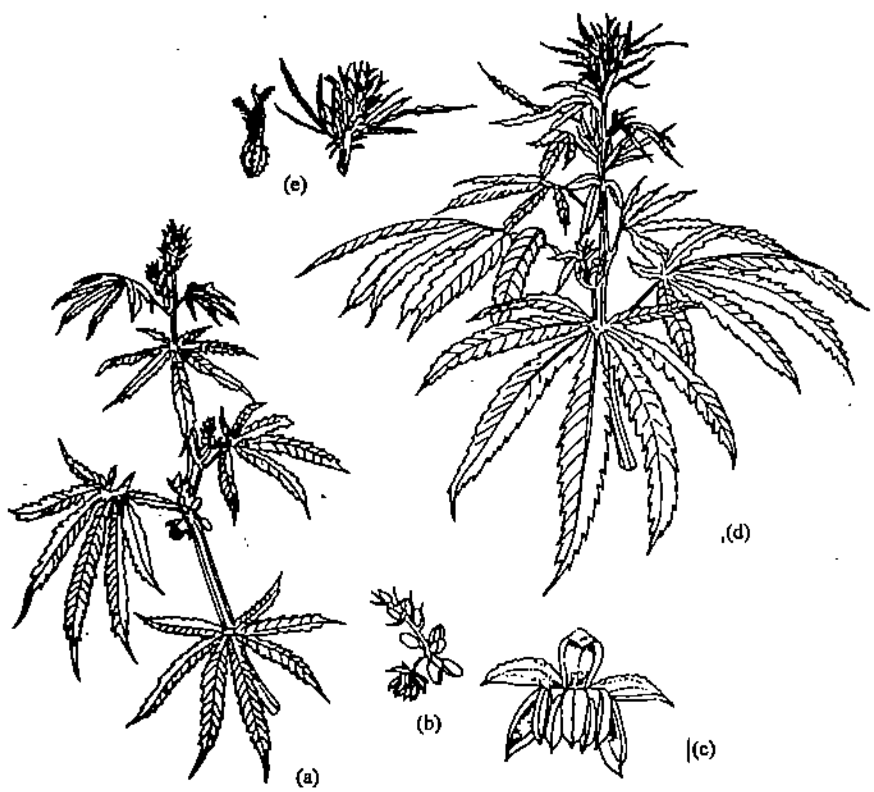


Fig. 19.11: *Cannabis sativa*. a) A male twig. b, c) Male flowers in an enlarged view. d) A female twig. e) The tip of d (on right-hand) and a female flower (on left-hand) enlarged. (Redrawn from Simpson & Conner-Ogorzaly, 1986).

Morphology: The plant is a tall (about 1.2-4.5 m), robust, annual, dioecious herb. It bears palmately divided leaves. Male inflorescence is a long drooping axillary and terminal panicle with few leaves. Female flowers are in short axillary leafy spikes. Flowers are small and greenish yellow. All parts of the plant are covered with glandular hairs; these are more abundant on young foliage, especially the bracts surrounding the female inflorescence. The narcotic constituents are mainly concentrated in the resin produced by the glandular hairs. The fruit is an achene.

Three types of narcotics are obtained from *Cannabis* plants:

1. Bhang (marihuana or marijuana) represents the dried leaves, stems and flowering shoots of male and female plants, both cultivated and wild; these have a low resin content, and therefore less potent than ganja and charas.
   a) It is used in beverages.
   b) The dried mixture is often mixed with tobacco and smoked.
   c) It is also used in sweetmeats.

2. Ganja (Majun) generally refers to dried unfertilised female inflorescence of special cultivars from which no resin has been removed, i.e., relatively pure resin.
   a) It is used medicinally as a sedative and hypnotic.
   b) It is used in beverages.
   c) It is also used for smoking.
   It has a relatively higher resin content than bhang.

3. Charas (Hashish) consists of the undiluted, unadulterated sticky yellowish exudation from the leaves and unfertilised inflorescence of cultivated female plants.

   The crude resinous secretions are collected by rubbing the tops of the plants with hands or beating them with a cheese cloth. The skicky resin is then scraped off from the cloth. Freshly obtained charas is a dark green, viscous substance; on storage it becomes brittle and dark brownish. The narcotic power seems to diminish on exposure to air and is gradually lost. It produces a higher degree of intoxication in comparison to 'bhang' owing ot its high resin content (35-45 per cent).

Chemical Composition: The resinous exudate contains the highest concentration of an active hallucinogenic compound Δ-transtetrahydrocannabinol (THC). There are a number of other chemical compounds which have been isolated from the resin:

a) Cannabidiolic acid (antibacterial agent and sedative)
b) Tetrahydro-cannabinol-carboxylic acid
c) Cannabigerol (sedative)
d) Cannabichromene (euphoric)

Uses

1. The active principal (THC) is effective in reducing the pressure exerted against the eyes of glaucoma patients.
2. Use of the drug compound also reduces the nausea experienced by cancer patients undergoing radiation or chemotherapy treatment.
3. Since THC dilates the bronchial vessels, it provides relief to asthma sufferers.
4. Heavy use of the drug has been correlated with several psychological and physiological problems.
5. A recent study has indicated that marijuana is safer than its legal, more widely used counterparts, alcohol and tobacco.
6. Its fibre is used for making rope, twine and coarse cloth.
7. The seeds are an ingredient of many commercial birdseeds.
8. Painters use hempseed oil to mix colours and as a varnish.

19.3.2 Tobacco

Botanical name: ***Nicotiana*** **spp.**
Family: Solanaceae
Common name: Tambaku
n = 9,10,12,16

Origin: *N. tabacum* originated in South America (Mexico and West Indies) from a natural cross between *N. sylvestris* and *N. otophora*, (the sterile hybrid on chromosome duplication gave *N. tabacum*). *N. rustica* is a native of Mexico and Texas. It originated as a result of natural hybridization between two wild species, *N. undulata* and *N. paniculata* and on chromosome duplication gave *N. rustica*.

Distribution: *N. tabacum* (Fig. 19.12) producing nations are United States, Brazil, Canada, Turkey, Greece, Italy, Zimbabwe, Malawi, China, India, Japan, Pakistan and Indonesia. *N. rustica* is cultivated to some extent in Turkey, Russia, India and some European countries. In India, it is grown in Andhra Pradesh, Gujarat, Karnataka, Orissa, Tamil Nadu, West Bengal, Bihar, Maharashtra, and Uttar Pradesh.

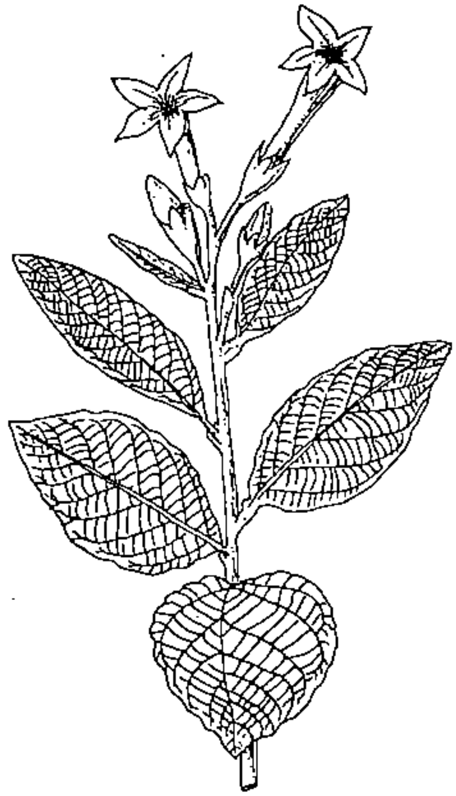


Fig. 19.12: *Nicotiana tabacum*. A flowering twig. (Redrawn from Johri & Srivastava, 1978).

Box 19.7: History of tobacco use.

At least 1000 years before Columbus landed in the West Indies (1492), tobacco was smoked, eaten and snuffed by native peoples throughout the New World. Linnaeus named the genus after Jean Nicot, the French ambassador to Portugal who made a fortune importing and popularizing the use of this plant in Paris. British promoted tobacco cultivation in their colonies to ensure a national supply. Virginians started growing tobacco in 1612, because one acre of land planted with tobacco yielded four times the revenue of an acre planted with corn.

Ecology: It grows rapidly in warm climates. It requires a frost-free period of 90-120 days from transplanting to harvesting. The optimum mean temperature for the growing season is 70-80°F. Strong illumination is required. Minimum rainfall required is 10 mm during growing seasons but 20 mm gives better growth. Drier weather is required for its ripening and harvesting. *Nicotiana* is very sensitive to small variations in soil and this determines the type and subsequent use of the leaf produced; different soil types also affect its flavour and aroma significantly.

Propagation: Commercial tobacco is always grown from seed.

Morphology: Among the numerous species of *Nicotiana*, only two species are the chief source of tobacco – *N. tabacum* and *N. rustica* (see Fig. 19.13). *N. tabacum* is grown in 90 per cent of the world's acreage. The main differences in these two species are given in Table 19.3.

Table 19.3 : Differences between *Nicotiana tabacum* and *N. rustica.*

N. tabacum	*N. rustica*
• It is a stout, sticky annual herb, height 1.2-2.7m. • It rarely assumes a shrubby appearance due to the development of lateral branches. • Leaves are alternate, ovate or oblong-lanceolate, they are large (60 cm long and 25 cm broad). • Leaves sessile with clasping leaf bases, glandular hairs are present on the surface of the leaves and they secrete gums and oils. • Flowers in terminal panicle are pinkish carmine or whitish. • Fruit is two (sometimes 4) valved, ovoid capsule (1.5-2 cm long) almost completely covered by calyx; numerous, tiny oval to spherical seeds with reticulate markings.	• It is a small plant height about 0.6 – 1.2 m. • It grows under relatively rigorous climate, usually develops suckers (lateral branches). • Leaves are alternate, broadly oval, they are short but thick, have uneven (puckered) surface. • Leaves petiolate, petiole unwinged. Secretions same as in *N. tabacum.* • Flowers are pale yellow to greenish, in a panicle. • Capsule avoid (0.7 to 1.5 cm) long, with numerous minute seeds.

Fig. 19.13: Outline diagrams of two species of tobacco to show their external appearance. a) *N. rustica.* b) *N. tabacum.* (Redrawn from Simpson and Conner-Ogorzaly, 1986)

Harvesting and Curing: The leaves are ready for harvesting 90-130 days after transplanting; they become greenish yellow and tend to become brittle and tough. The fresh leaves contain 75-85 per cent moisture. The leaves or their stalks are tied into bunches called "hogsheads" for curing. Curing is essentially a process for oxidation or dry fermentation. During this process the moisture content in the leaves is reduced from about 80 to 20 per cent. Slow drying permits aerobic fermentation but prevents the growth of molds or fungi. Starches are converted to sugars. Some proteins are broken down enzymatically. The green colour of the leaves is lost and they become tougher. The principal methods of curing are:

1. Flue curing
2. Air curing
3. Sun curing
4. Fire curing

1. **Flue curing:** About 36 per cent of the world's production of tobacco is flue cured and most of it is used in the manufacture of cigarettes. Flue curing is done in brick barns, in which temperature and humidity are controlled. Heat is supplied through a

series of metal pipes or 'flues', emerging from a small furnace. This process takes about 4 to 6 days, and it involves three steps:

a) Yellowing of the leaf: harvested leaves strung on bamboo sticks are kept in the barn at a low temperature (32-38°C) and high relative humidity (80-85 per cent); water is often sprinkled on the floor or wet sacks are placed on the pipes. This step requires 20-40 hours. The leaves become yellowish and only the midribs are slightly greenish, the starch in the leaves is converted to sugars.

b) Fixing of the colour: The temperature is raised to 54-60°C and relative humidity (RH) is lowered to 25-30 per cent by opening the ventilators. This process takes 12-20 hours. The leaf dries and the bright yellowish colour is fixed. The leaf cells become dead; only the midrib contains a little moisture.

c) The Complete drying of the leaf: The temperature is further raised to 77°C and RH is lowered to 8 per cent. This operation is continued till the leaf is completely dry.

The flue cured leaves have good elasticity, are mildly aromatic, and bright yellow without any blemish. They reabsorb moisture from the air and become soft, gummy and pliable.

2. **Air curing:** About 20 per cent of the world's tobacco is air cured and is mainly used in the manufacture of cigars. It is a slow process and takes place under normal atmospheric conditions (humidity 80 per cent) in well ventilated barns. The barn temperature is maintained at 21-24°C and is never allowed to exceed beyond 43°C even in the final stage. Good circulation of air in curing barns is important. During this process the leaf becomes brownish due to oxidation of phenolic compounds. As a result of gradual starvation lasting six to eight weeks, the proteins are dissolved and there is a loss of nicotine. Air cured tobacco contains only a small percentage of starch and sugars.

3. **Sun curing:** Oriental or Turkish tobacco is sun dried, accounting for about 14 per cent of the world's total output and mostly used in **Hookah** (hubble-bubble) and 'bidi tobacco'. This type of curing is done in areas with a dry period and sunny weather soon after harvesting. It is a modification of air-curing, the only basic difference being that the tobacco is cured in direct sunlight and not in the shade. The leaves are hung vertically and spaced close together. The leaves are left on drying frames for 1-1½ months. The leaves dry during the day and become moist with the dew during the night, this is called rack curing. Sometimes the entire plants or heaps of leaves are left in the field to dry for a few days and are periodically turned upside down, this is known as **ground curing**.

4. **Fire curing:** This is the oldest method. It was practised by the American Indians. Today, a little over one per cent of tobacco is dried over smoke and it is used for snuff, chewing and as plug tobacco. In this method of curing, thoroughly wilted cut plants are hung on poles and are smoked by kindling or burning hardwoods, charcoal or coconut husk in pits on the floor of the curing barn. In the initial stages the temperature should be maintained around 38°C and later it can be increased to 52°C. The fire is extinguished at night and the leaves are allowed to soften. This alternate softening and drying is repeated over a period of three to four weeks. During this process the leaves acquire a distinctive aroma. The aroma of cured leaves is due to the creosotic substances (colourless oily fluid obtained from wood-tar), that are readily absorbed from the smoke.

Fermentation and ageing

Cured tobacco leaves are tied in bundles and bulked into rectangular stacks (2 x4 m) on the floor of the fermentation barn for varying period ranging from 4-6 weeks. The internal temperature of the pile is kept between 40-60°C. The colour, aroma and combustibility of tobacco leaves are greatly improved. The leaves are then graded according to the following three characters: (a) size, (b) colour, and (c) texture. Different grades of leaves are tied in bundles and these are also called 'hands'. They are then baled and shipped for export.

The tobacco is 'aged' in large warehouses for a period of 6 months to 3 years. Here tobacco bales are moistened to facilitate complete fermentation during which the final aroma develops. The amount of nicotine is gradually reduced during ageing and the harshness, bitterness and some other objectionable qualities are removed and the tobacco is ready for marketing and use (also see Table 19.4).

Table 19.4: The market classes of tobacco.

S. No.	Class of tobacco	Soil Type	Characteristics of Leaves	Used for	Largest Producers	Major Exporting Countries
1.	Flue-cured	Light sandy loams or fine sandy loams	• Good elasticity • mildly aromatic • bright yellowish • no blemishes • no gummy material • sweet flavour • weakly acid smoke (high sugar/protein ratio)	The manufacture of cigarette, pipe & chewing tobacco	USA China Japan Zimbabwe Malawi Canada India	USA India
2.	Fire-cured	Heavier silt or clay loams	• Leaves are large • thick • good elasticity • dark mahogany colour • without blemish	Snuff (powdered product) & chewing tobacco; cheroots (simple cigars with both ends open); 'bidis', hookah (water-pipe) smoking	India China Canada	
3.	Air-cured (a) *light air cured*	Silt loam to sandy loam	Light in body (thickness), light to reddish-brown	Cigarettes, cigars, and pipe tobacco	USA China India Brazil Japan Zimbabwe Pakistan Canada	USA Indonesia
	i) Cigar filler (Air-cured)	Loam or silt loam	• brown, or reddish brown, • heavy bodied • sweet, pleasant flavour • burns evenly with a white ash	Filling the inner core of cigars	Central America Cuba Brazil Puerto Rico	
	ii) Cigar binder (Air-cured)	Silt loam to sandy loam	• fine texture, • more elasticity than other types	Holding the filler of cigar in shape	- do -	
	iii) Cigar wrapper (Air-cured)	Light sandy loam, or fine sandy loams under cheese cloth shades	• leaves are free from flavour • thin, • silky, • elastic, • fine viened, • uniform in colour, • without blemish • have a high burning quality • high in nitrogenous matter • free of starch and sugars (alkaline flavour and aroma)	Final wrapping over the cigars	- do -	
	(b) *Dark air cured*	Heavier silt or clay loams	Dark-coarse	Chewing, and plug tobacco	- do -	
4.	Sun cured Turkish Tobacco	Intermediate between heavy silt and clay loam	• Small (7.5 cm-15 cm) • Yellowish to light reddish brown • Distinctive aroma	Cigarettes	Middle East, Zimbabwe	Turkey

Chemical Composition: The dried processed leaves on an average contain: moisture 10-15 per cent; organic matter 85-90 per cent (this includes carbohydrates, nitrogenous compounds, organic and inorganic acids, polyphenols, pigments, oils, alkaloids, enzymes and some organic matter); mineral matter 12-25 per cent; essential oils and resins which are secreted by the glandular hairs and are responsible for aroma and flavour; Nicotine ($C_{10}H_{14}N_2$) - the principal alkaloid, occurs throughout the plant (except the seeds) but its concentration in the leaves is the highest.

Nicotine content is 4-6 per cent in *N. tabacum* and 12 per cent in *N. rustica*. It is determined by: (a) the species and variety, (b) the cultural requirements, especially soil and climatic conditions, (c) the type of curing (air and fire cured tobacco contains 4-4.5 per cent nicotine, flue cured has 2.5-3 per cent), (d) position of the leaves on the plant (the lower leaves usually contain less nicotine). Nicotine originates in the roots and from there it is translocated into the leaves.

Uses

1. The cured and aged tobacco after blending the different grades, is manufactured into various forms such as snuff, chewing tobacco or smoking tobacco. The quality of the tobacco products can be improved by additives such as glycerine or sorbitol (humectants retain moisture and make the tobacco less susceptible to environmental changes), vanilla, chocolate, rum, etc.
2. The widely used cigarettes are machine made (desirable nicotine content 1.5-2.8%). The paper used in cigarettes is made from flax (*Linum usitatissimum*) or hemp (*Cannabis sativa*).
3. 'Bidi' is made by rolling 0.25-0.5 g of tobacco flakes with finger, in a rectangular piece of dried tendu leaf, *Diospyros melanoxylon* (Ebenaceae). In India, the annual 'bidi' consumption (178,000 million) far exceeds that of cigarettes.
4. The alkaloid nicotine is used in agriculture, as a contact insecticide for control of sucking insects such as aphids, leaf-hoppers, thrips and cabbage butterfly larvae. Nicotine bentonite (suspension of bentonite and nicotine in water) is an effective insecticide.
5. Tobacco seeds do not contain nicotine. Refined tobacco seed oil can be used as a substitute for groundnut oil; also used for illumination and in the oil, paint and varnish industries.
6. The seed cake is used as a feed for cattle and horses.
7. In the cured leaf, nicotine is bound to organic acids and is released only on smoking. Tobacco tar (includes everything that can be removed from cigarette smoke with an extremely fine filter, except for the water) is suspected of causing lung cancer. Smoke also contains health promoting ingredients such as the amino acids glutamine and glutamic acid and the water soluble vitamins niacin and niacinamide.

19.3.3 Betel Palm

Botanical name: ***Areca catechu***
Family: Arecaceae
Common names: Areca, Catechu, Black cutch, Supari, Khair, Khadira
n = 16

Origin : Malaya, Nicobar Islands

Distribution : Southeastern Asia mainly India, Bangladesh, Sri Lanka, Malaysia and Indonesia. In India it is grown in the coastal areas of south Mumbai, Tamil Nadu, Karnataka, West Bengal and Assam.

Ecology: The areca palm flourishes in maritime climates of the tropics. It is grown from sea level to 900 m. It requires an ample supply of soil moisture and a plentiful rainfall throughout the year, i.e., about 1500-5000 mm. It can be grown on a variety of soils, but clay loams seem to be preferred by it.

Propagation: *Areca* palms are propagated by seeds. Fully grown dried fruits are planted in shallow pits 2.5 cm apart and covered with sand. After three months, when the seeds sprout, they are transferred to nursery beds with a spacing of 30 cm. The beds are shaded sometimes by interplanting bananas. *Areca* seedlings are transferred to the field when they are 1-2 years old.

Morphology: A slender, erect, monoecious palm (Fig. 19.14); may live between 60-100 years. Adventitious roots are produced from the basal trunk; top-shaped pneumathodes present. Aerial roots are occasionally produced from base of the stem. It is single, unbranched, straight, cylindrical (30 m tall and 25-40 cm in diameter). It is ringed with scars. The internodal region reduces as the palm grows. Leaves are borne in a terminal crown of 6-9 large pinnate leaves; pinnae 30-50, lanceolate, longest in the centre of leaf. About 6 new leaves are produced in a year. Flowering begins 4 to 6 years after planting. Single inflorescence is produced in the axil of each leaf sheath. The inflorescence consists of a much branched spadix (fleshy, spike-like inflorescence) enclosed by a boat-shaped spathe (hood-like bract). Male flowers are numerous, deciduous (falling at the end of one season of growth), minute, borne above female flowers and are arranged in pairs in two rows, ebracteate, sessile and creamish.Perianth has 6 tepals in 2 whorls. Stamens are 6, arranged in 2 whorls. Female flowers are 250-500 per spadix, borne on thickened bases of secondary and tertiary branches.Perianth persistent; outer perianth 3, greenish and inner 3, longer and creamish white. Staminodes 6 tiny, ovary is trilocular. Fruit is a fibrous ovoid, yellowish-orange drupe develops 8 months after pollination. About 50-400 fruits are produced in a spadix (a tree produces some 50-1000 fruits each year). The seed is ovoid, globose or ellipsoidal and weighs 10-20 g; endosperm is ruminate (uneven contours) with hard reddish tissue from inner integument running horizontally into pale brownish endosperm. Embryo is conical and is present at the base of the seed.

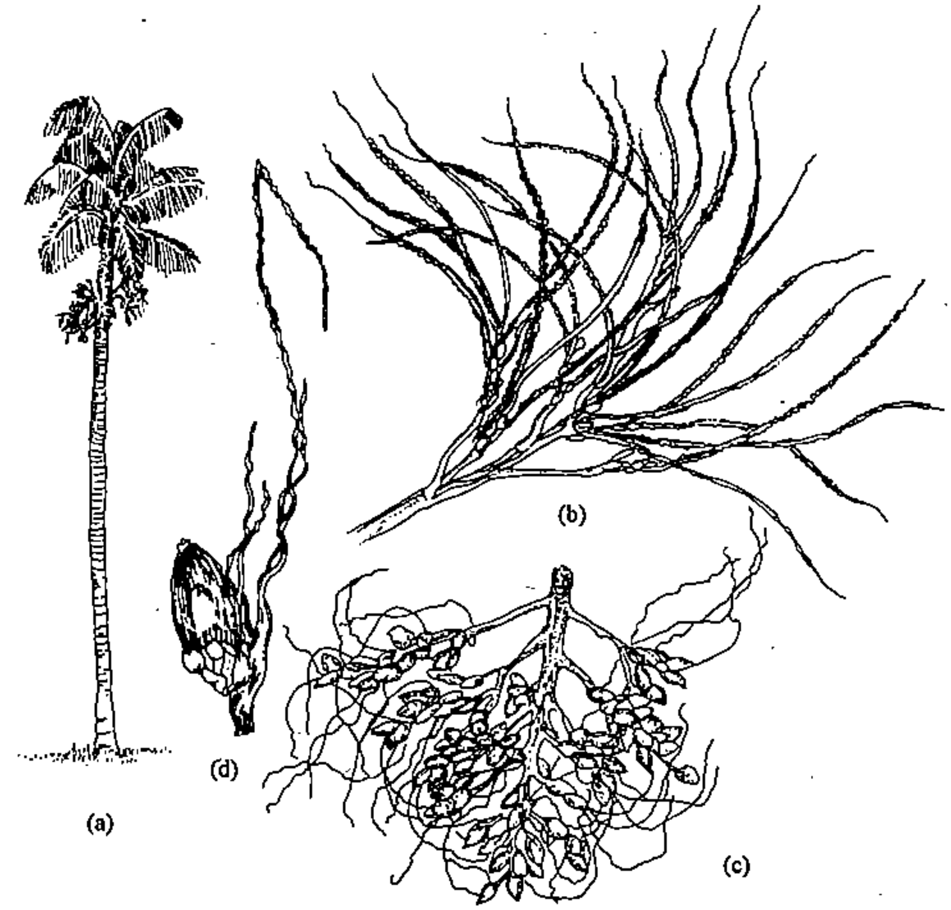


Fig. 19.14: ***Areca catechu.*** **a) Whole plant. b) Inflorescence. c) A bunch of fruits. d) A fruit enlarged. (Redrawn from Purseglove, 1988).**

Chemical composition: The endosperm of areca nut contains a number of alkaloids. The most active and important alkaloid is arecoline ($C_8 H_{13} O_2 N$) that is about 0.1-0.5 per cent of the total. The other alkaloids include arecaidine, arecolidine, guvacine and guvacoline. It contains 11-26 per cent of catechol tannins, which is reduced during ripening. The approximate value of the other constituents is: water 30 per cent; protein 5 per cent; fat 5 per cent; carbohydrate 47 per cent.

Uses

1. The hard dried endosperm of ripe and unripe seeds (called 'nut') is chewed as a narcotic by people in southeast Asia, outranking chewing gum.
2. Small pieces of the nut are wrapped in a leaf of *Piper betle* (pan) to which a dap of slaked lime has been added. The other ingredients include cutch made from the heartwood of *Acacia catechu*; tobacco; and cardamoms (dried fruits of *Elettaria cardamomum*). The betel-pepper leaf may be fastened with a clove (dried flower buds of *Eugenia caryophyllus*).
3. It is used also as a vermifuge.
4. The central bud of the palm is sometimes eaten.
5. The palm is grown as an ornamental plant.

In addition to Indian Hemp, tobacco, and betal palm, salient features of two more sources of masticatory materials are listed in Table 19.5 (see also Fig. 19.15).

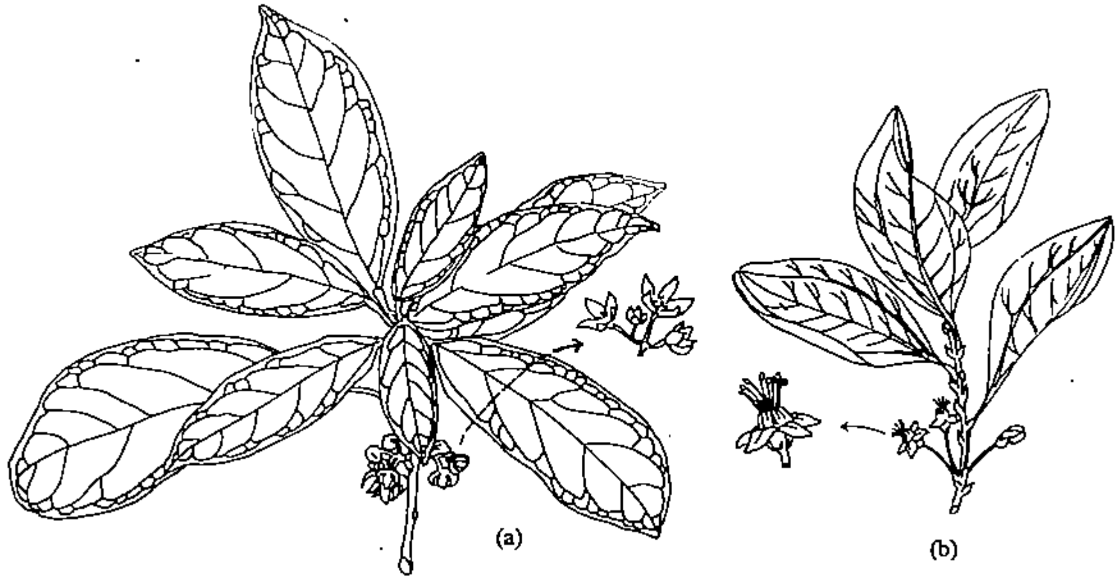


Fig. 19.15: a) *Cola nitida*, a flowering twig, and a portion of the inflorescence enlarged. b) *Erythroxylum coca*. A flowering twig, and a flower enlarged. [Redrawn from: a) Purseglove, 1988; b) Simpson & Conner-Ogorzaly, 1986].

Table 19.5: Other Masticatory materials from plants.

S. No.	Botanical Name	Common Name	Family	Origin	Distribution	Part of the plant used	Chemicals	Uses
1.	*Cola nitida* (Fig. 19.15 a)	Kola	Sterculiaceae	Tropical rain forests of western Africa	Nigeria Sierra Leone, Liberia, Cote Divoire, Ghana, West Indies, Brazil, and Asia	Seeds and leaves	Kola red, Caffeine, Theobromine, Kolanin (Glycoside)	The nuts (seeds) are chewed in tropical Africa & the coca leaves in South America. This causes mild stimulation of the central nervous system.
2.	*Erythroxylum coca* (Fig. 19.15 b)	Coca or Cocaine plant	Erythroxylaceae	Andean highlands	South America, Java, Sri Lanka, Taiwan, and India	Leaves	Cocaine is a mixture of a number of alkaloids: • cocaine, • tropococaine • cinnamyl-cocaine	In small doses induces: • a pleasing excitation, • increased physical strength; • mental alertness; • relief from fatigue; • reduction of hunger; The stimulation, however, is short-lived and is usually followed by fatigue and mental depression. High dose causes restlessness, convulsions and hallucinations.

SAQ 2

i) Define the following terms:

stimulants, depressants, hypotics, sedatives and hallucinogens.

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ii) Which of the following statements are True or False? Write T for True and F for False statement in the space provided below.

a) Marijuana plants growing in tropical regions are more potent than the ones growing in temperate countries. [ ]

b) Bhang produces a higher degree of intoxication in comparison to Ganja. [ ]

c) Tobacco requires a frost-free period of 90-120 days. [ ]

d) The soil type is an important factor determining the flavour and aroma of tobacco. [ ]

e) Ageing of tobacco leaves is a process that results in an increase in their nicotine content. [ ]

f) The ruminate endosperm of areca nut contains a number of alkaloids. [ ]

19.4 ESSENTIAL OIL YIELDING PLANTS

Two kinds of oils are produced by plants: (1) fixed oils, and (2) essential oils. The fixed, non-volatile oils are usually food reserves and these are commercially important. They are produced in plants through the synthesis of fatty acids from carbohydrates, and three molecules of fatty acids combine with glycerol to form triglycerides. Therefore, the fixed plant oils are true glycerides of saturated and unsaturated organic acids. Even among species of the same genus different kinds of oils may be stored. The variation is due to the fact that vegetable oil is a mixture of different fatty acids, which vary in the degree to which they are saturated; that is they differ in the number of double bonds in their molecules. The less saturated the fatty acid in the oils, the less stable it is in air, and the more readily it is oxidized to form a thin, elastic, water-proof surface film.

Essential oils are a mixture of highly aromatic, steam volatile organic compounds obtained from plants. During the middle ages throughout Europe, pharmacists explored the medicinal properties of a wide variety of plants, and began the search for the essential principle of plant tissue which they believed was responsible for the curative effects on the human body. By the process of steam distillation from different plants, a number of pleasant smelling, highly volatile liquids were obtained. These were considered essential constituents of the plants and hence the term 'essential oil' which has persisted to the present day.

Production of essential oil

Oil formation seems to be highest in regions of photosynthetic activity but the oil as such is not transported in the plant body. The composition of the oil changes during the development of the plant; in some species oils of quite different chemical nature are produced in different parts of the same plant. Essential oils are secreted in the plant either into external glands or epidermal hairs, or into internal glands which may develop in any part of the plant. When produced inside the plant, the oil is secreted between the cells. Increasing deposition separates the walls of the adjacent cells and a cavity develops between them. Many such cavities may eventually link up to form a short canal. The cells around the cavities or canals break down to form a definite boundary to isolate the oil sac and protect the living tissues around it. The age of a plant or its parts and environmental factors may influence variations in the amount and composition of essential oils.

Part of the plants in which essential oil is found

Essential oils are isolated from various parts of the plants; some examples are given below:

leaves - patchouli
bark - cinnamon
root - vetiver
rhizome - ginger
wood - sandalwood
flower bud - clove
flower - rose, jasmine, tuberose violet
fruit - orange
seed - nutmeg

- The factors which determine the site of accumulation of essential oils are not known. For example, in *Santalum album* (Chandan), the heartwood is scented, while the sapwood and bark are not.

- In *Pandanus odoratissimus* (Keowra) the male inflorescence is scented while the female is not.
- Some plants like *Citrus aurantium* (Khatta) have orange blossom oil or neroli oil in the flowers, petitgrain oil in the leaves and twigs, and bitter orange oil in the fruit. That is, the same plant may contain different essential oils in different parts.
- In an unusual instance, it has been observed that in *Aquilaria agallocha* (agar wood), the scent develops in response to an infection by certain fungi.
- Over 3000 essential oils have been identified from a number of plants belonging to some 87 families of flowering plants.

Chemistry: Essential oil is a mixture of a wide variety of natural organic compounds and chemicals of several functional groups and molecular structures. Over 200 components may be present in an essential oil, and the characteristic odour may depend on trace amounts of one or several compounds. The most important chemical constituents are the terpenes (they are hydrocarbons made up of isoprene units - C_5H_8, and exist as unsaturated straight chain molecules, or as ring structures, and readily combine with other organic groupings). Most essential oils also contain camphors, and the more odoriferous compounds present consist of oxygen derivatives of terpenes, alcohols, esters, aldehydes and ketones.

Functions: The essential oils have been found to have the following functions.

- Promoting insect pollination because their scent attracts them to the plant.
- As protectional aid against animals and parasites, and in allelopathic strategies.
- Act as wound fluids, e.g., oleo-resinous exudes of certain plants act as protective seals against pathogens and insects when the plants are wounded.
- As reserve food substances.
- Role in water conservation by reducing the transpiration rate due to their heat screening effect.
- These are by-products of the general metabolism of the plant, that after having fulfilled some function (e.g., acting as hydrogen donors in oxidation-reduction reactions) are then stored by the plant in such a manner and in such tissues as to isolate them from the main centres of metabolic activity. Nevertheless, these chemically active components take part in metabolic reactions.
- These are important ingredients of spices, cosmetics, perfumes and natural food flavourings.
- These are used in aromatherapy.
- These have bacteriostatic and often bactericidal properties.
- They are used in the preparation of antiseptics, insecticides and aerosols.
- Essential oils are applied to furs, wool and silk clothing as these provide protection from certain insects.
- These are used in the manufacture of paper, plastics, leather textiles and paints.

Methods of extraction of essential oils

The essential oils present in various plant parts can be extracted from their tissues by the following four methods:

1. Distillation
2. The eucelle method (separation by expression)
3. 'Enfleurage' or 'cold-fat extraction' method
4. Solvent extraction method

1. **Distillation:** The most ancient and simplest method of extracting the oils is by distillation. During this process, the vapours are recovered by condensation. Hydrodistillation is commonly used in the extraction of essential oils. There are three hydrodistillation techniques:

   (a) Water distillation
   (b) Water and steam distillation
   (c) Direct steam distillation

(a) **Water distillation method** - In this method the plant material is allowed to stand in water in a copper still, and is heated to boiling either by direct heat, or with a steam jacket or steam coil. The oil vapourises with the steam and passes into a condenser. On cooling the oil separates from the water and is then removed. Clove and nutmeg oils are generally obtained by this method.

(b) **Wet steam distillation (water-steam dislillation)** – The still is filled with water up to a level below the grid. The plant material is packed on a grid, which is some distance above the bottom of the still, and the still is heated. The steam rises through the material, and the steam and oil vapours together are condensed and collected in a small receiving vessel in which the oil separates out. The advantage of this method is that the oil compounds volatilize at a lower temperature as compared with water. This is a rapid method and is used for the production of oils from pine (*Pinus* spp.), peppermint (*Mentha piperita*), *Eucalyptus* spp., cedar (*Juniperus virginiana*) and Lemon grass (*Cymbopogon citratus*).

(c) **Direct steam distillation** – The plant material is kept in a separate vessel on a grid and saturated steam is passed through it by means of open or perforated coils. Sometimes the chemical constituents of essential oils may be changed, so that the distillation is carried out in a partial vacuum, so that the temperature is kept as low as possible. Irone or ionone which is the basis of the best violet perfumes, is distilled in this way from the rhizomes of *Iris florentina* (Orris).

2. **The eucelle method:** To avoid the destruction of chemical constituents of the essential oil by heat, separation by expression is practised. For example, *Citrus* fruits are placed in a revolving vessel with spikes, which break up the oil cells to release the oil.

3. **The 'enfluerage' or 'cold fat extraction' method:** In this method a fat (tallow or lard) is spread on a glass plate and fresh petals such as those of jasmine (*Jasminum* spp.) or tuberose (*Polianthes tuberosa*) are spread on the fat. After two or three days old petals are replaced by fresh ones. This procedure is repeated until the fat becomes saturated with the floral essences. The resulting fat forms a 'pomade' from which the essential oil can be extracted with alcohol to obtain the 'floral concrete'. To isolate 'floral absolute', the alcohol can be evaporated.

4. **Solvent extraction method:** A solvent such as petroleum ether is passed through flowers kept in a sealed vessel. The aromatic substances along with other plant oils and waxes are removed by this process. The solvent is evaporated in vacuum, leaving a residue; this can be further purified to obtain the essential oil.

19.4.1 Sandalwood

Botanical name: ***Santalum album***
Family: Santalaceae
Common names: Chandan, Safed chandan
n = 5,10

Origin: It is found in the wild state in India from Nilgiris to the north of Mysore.

Distribution: India, Java, Timor, Celebes and Sumbawa, Karnataka state, and Tamil Nadu. Introduced in Uttar Pradesh, Rajasthan, Madhya Pradesh and Orissa.

Morphology: It is a medium sized (15-20 m) evergreen tree that lives for 40-60 years. It is a root parasite; the seedlings establish a haustorial connection with a host (over 200 species) within a month after germination. Leaves are opposite. Inflorescence is a panicle of small, bisexual maroon-coloured flowers. Fruits are blue-black and the birds eat the pulp and disperse the seeds.

Every sandalwood tree, whether it grows in the temple, park or private garden is Government property. Despite strict laws there is large scale smuggling of wood. Another threat is *Spike disease*, which is caused by mycoplasma-like-organism.

Source of oil: Heartwood. The roots are known to accumulate the maximum amount of oil.

Method of oil extraction: Oil is extracted by distillation method. Steam is passed through coarsely powdered sandalwood, packed in stills, which are perforated at the base.

The vapours pass through the bent neck of the stills and are collected in the receivers. The crude oil is stored in airtight containers and refined by redistillation under vacuum. The oil is light yellow and viscous. It has a lasting, sweet, heavy odour.

Major aromatic constituents: The fragrance of sandalwood oil is because of the presence of a mixture of α- and β- santalols (sesquiterpene alcohol 90-95 per cent). The other constituents are santalal, santalone and santene.

Uses

1. Sandalwood oil is used for the preparation of oriental perfumes.
2. The oil is also used for the manufacture of soaps, talcum powders, creams, hair oils and hand lotions.
3. The oil is also used in medicines for its cooling, diaphoretic (stimulates perspiration), diuretic (increases urination), and expectorant properties (promotes ejection of phlegm or mucus from the chest).
4. The paste of wood is applied to burns in fevers and headache; also used in religious ceremonies.
5. Seeds yield an oil which is used in skin troubles.
6. Sandalwood is one of the finest wood for carving.
7. Its sawdust is used as incense, for scenting clothes and cupboards.

19.4.2 Vetiver

Botanical name: ***Vetiveria zizanioides***
Family: Poaceae
Common names: Khus, Gandar
n = 10

Origin : India and Sri Lanka

Distribution: It was introduced throughout the tropics. However, its nátural strands are found in Uttar Pradesh, Rajasthan and Punjab. The plant is a densely tufted perennial grass (height 2m). The roots are aromatic; they are cleaned and dried to make mats, screens and various other goods. The root stock has erect culms (0.5-1.5 m in height). Leaf blade is stiff, long, narrow (75 cm long, 8 mm or less in width), glabrous, but rough on the edges (they are odourless). Infloresence - panicle; spikelets in pairs, awnless; one sessile and hermaphrodite, 3 stamens and 2 plumose stigmas; the other spikelet pedicelled and staminate. Some cultivated forms flower rarely.

Ecology and propagation: Vetiver often grows on river banks up to an altitude of 600 m. It requires a hot and humid climate. It should be grown on sandy soils. Vetiver is propagated by roots which are separated and planted at a distance of 40 cm.

Source of oil: Roots are harvested 15-24 months after planting.

Method of oil extraction : The roots are dried in the shade. They are crushed or powdered before distillation (sometimes solvent extraction method is also used). The most valuable constituents are contained in the high-boiling fractions. In India, vetiver oil is sometimes collected over sandalwood oil and the product is called 'attar' or 'ittar'.

Major aromatic constituents:

- Vetiver oil is a viscid, dark oil with a sweet, persistent odour.
- The principal constituent is vetiverol.
- Vetivenyl, vetivenate and α- and β- vetivones are also said to be responsible for the characteristic odour.
- The oil content of the dried root is 0.5 - 3.0 per cent.

Uses

1. The roots are used for making screens, mats, pillows, hand fans and cooling jackets during hot dry summer months. They are also sometimes put with clothes because of their scent and in the belief that they repel insects.
2. Vetiver oil is often used as a fixative for more volatile constituents, for scenting soaps and in the preparation of cosmetics.

3. The grass is widely used for planting on the contours as an anti-erosion measure, for protective partitions in terraced fields, and as a border for roads and gardens.
4. It is also used for making sherbets.

19.4.3 Other Important Sources

Besides sandalwood and vetiver, a large number of esential oil-yielding plants are used in a number of ways, and these form an important part of our culture. We are not giving detailed accounts of these plants. However, concise information about some important plants is provided here in Table 19.6 (given on page no. 84).

SAQ 3

i) Differentiate between 'fixed oils' and 'essential oils'.

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ii) What are the chief locations of esential oils in plants?

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iii) Write the main processes involved in the following procedures for extracting essential oils:

Distillation, Eucelle method, 'Enfluerage' and Solvent extraction.

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iv) Fill in the blanks with appropriate words.

a) .... is one of the finest woods for carving.

b) .... and .... are the chief sources of sandalwood oil.

c) The aromatic .... of vetiver are used to make, screens, and cooling jackets.

d) The .... and .... are the chief source of camphor.

e) .... or tulsi is an important part of Indian mythology.

Table 19.6: Some important plants which produce essential oils.

Sl. No.	Botanical name	Common name	Vernacular Name	Family	Native of	Distribution	Plant part used	Major aromatic components	Uses
1.	*Anethum graveolens*	European dill	Soya	Apiaceae	Eurasia	Jammu & Kashmir	Fruits	Carvone (+) – Limonene (+) – phellandrene	Flavouring foods and beverages
2.	*Aquilaria agallocha*	Agar wood	Agar	Thymelacaceae	Bhutan, parts of Bengal, the hills of Assam and Burma	Eastern Himalayas, hills of Garo, Naga, Cachar, Sylhet	Fungus infected wood	agarol	Manufacture of agar attars, agarbathies, and in perfumery as a retainer and blender
3.	*Artemisia absinthium*	Wormwood absinthe	Vilaiti afsantin	Asteraceae	Europe	Kashmir	Leaves, flowering tops	∝&β-thujones, phellandrene thujyl alcohol artabasin. Drug-santonin	Flvouring alcoholic beverages, vermifuge, stimulant and tonic
4.	*Cananga odorata*	Ylang-ylang, Macassar oil		Annonaceae	Malaysia	Plantation at Amabalavayal Research Station, Wynad, Kerala	Flowers	P-cresol, geraniol, linalool, eugenol, benzyl alcohol, ∝-cadinene	Perfumes, soaps, face powder
5.	*Cinnamomum camphora*	Camphor-tree	Mushkapur	Lauraceae	China, Japan	Plantation at Ootacamund, Tamil Nadu	Wood, leaves	Bisalbolene camphor (+) - ∝ -pinene dipentene cineol, terpineol, caryophyllene	Flavouring foods, pharmaceuticals, beverages
6.	*C.cassia*	Cassia, chinese cinnamon dry fruits called cassia buds	In India dry fruits are called Kala Nagkesar	Lauraceae	China	Not grown in India but it is imported from China, Malayan region	Twigs, leaves, dried fruits called cassia buds	Cinnamaldehyde, cinnamylacetate	Flavouring foods, perfumery; Russia & Germany prefer Cassia buds to cinnamon buds because of stronger aroma
7.	*C. tamala*	Tejpat, Indian Cassia	Tejpat	Lauraceae	Indian subcontient	Subtropical Himalayas, Khasi and Jaintia hills (Sikkim, Manipur & Arunachal Pradesh)	Leaves & Bark	Eugenol (+) - ∝ - phellandrene	Flavouring foods, leaves are carminative and used for colic and diarrhoea. Bark used as an adulterant for true cinnamon (*C. zeylanicum*)
8.	*Coriander* sp.	Coriander	Dhaniya	Apiaceae	Mediterranean region	M.P., Maharashtra, Rajasthan, A.P., T.N., Karnataka and Bihar	Fruits	Linalool ∝-terpinene d-carvone, ∝-β pinenes P-cymene	Flavouring foods and alcoholic beverages
9.	*Crocus sativus*	Saffron	Kesar	Iridaceae	Kashmir	Kashmir, Bhersar and Chaubatia U.P.	Stigma	Safranal	Colouring and flavouring foods
10.	*Cuminum cyminum*	Cumin	Jeera	Apiaceae	Mediterranean region	Punjab, U.P.	Fruits	Cuminaldehyde, Cuminyl alcohol P-cymeme, ∝-,β-pinenes β-phellandrene	Flavouring foods, cordials and liqueurs
11.	*Curcuma zedoaria*	Zedoary	Kachura	Zingiberaceae	North-east India	Cultivated throughout India	Rhizome	(+)-∝-pinenes (+)-camphene cineol (-) zingiberene	Perfumery, cosmetics and liqueurs
12.	*Cymbopogon citratus*	Lemon grass	Sugandh rohisha, Aghyaghas	Poaceae	Malaya or Sri Lanka	Widely distributed in the tropics	Leaves	Citronellal, geraniol, and myrcene	Flavouring soup, curries, tea and sherbet, soaps, isolation of citral for commercial synthesis of vitamin A.

(Contd..)

13.	*Cyperus rotundus*	Nut grass, motha	Motha	Cyperaceae	Pantropical Asia	Cultivated throughout India	Dried tubers	(-)- and α- pinene, isocyperol, α-cyperone	Tuber used as incense and in medicine. cyperiol oil used in perfumery, soap and for flavouring tobacco
14.	*Elettaria cardamomum*	Cardamom	Chhoti elaichi	Zingiberaceae	India	Western ghats in Karnataka, Kerala, Parts of Madurai, the Nilgris and Tirunelveli in Tamil Nadu	Fruits, seeds	Cineol, (+)-α- terpineol terpinene limonene, terpinyl acetate	Condiments, for flavouring beverages, sweets, pharmaceuticals
15.	*Eucalyptus citriodora*	Lemon-scented Eucalypt	--	Myrtaceae	Australia Tasmania Papua New Guinea	Brazil, Guatemala, India (Punjab, U.P, A.P), U.S.A.	Leaves	Citronella, citronellol, esters	In making toilet soaps, mixed with olive oil and used as rubefacient and for rheumatism. Used also for chronic bronchitis and asthma
16.	*Jasminum officinale* var. *grandiflorum*	Jasmine	Chameli	Oleaceae		Grasse (S. France)	Flowers	Benzyl acetate, Benzyl alcohol, Benzyl benzeate Cresol, Eugenol, Geraniol	For worship, ceremonial purposes, hair decorations, for making attars, perfumed hair oils, soaps and creams, in air freshness, anti-perspirants and deodorants.
17.	Mentha spp. *M. arvensis*	Field Mint	Pudina	Lamiaceae	Temperate Europe	W. Himalayas Kashmir, Punjab, Kumaon and Garhwal	Leaves and flowering tops	Menthol, menthylacetate	As a condiment for preparation of chutnies, beverages, chewing gums, pharmaceuticals and dental preparations, mouthwashes, cough drops.
18.	*Michelia champaca*	Champak	Champa	Magnoliaceae	Himalayas	Eastern Himalayas, north-eastern India and the Deccan	Flowers	Cincole, isoeugenol, benzaldehyde	It is an important perfumery raw material
19.	*Myristica fragrans*	Nutmeg	Jaiphal, Jatri	Myristicaceae	Moluccas Islands	Nilgiris, Kerala, Karnataka, W. Bengal	Aril, seed	α-β-pinenes (+)- camphene dipentene, P-cymene (+)- Linalool terpineol, geraniol. safrole	Pharmaceuticals, flavouring foods. Liqueurs, soaps, tobacco, dental cream. confectionary, perfumery
20.	*Ocimum americanum*	Hoary basil	Kali tulsi. Mamri	Lamiaceae	Tropics	Found throughout India	Shoots	Methyl chavicol	Soaps, cosmetics. Seeds are considered diuretic, for coughs, dysentery, as mouth wash for relieving toothache.
21.	*O. basilicum*	Sweet basil	Ban tulsi	Lamiaceae	-do-	-do-	Leaves/ shoots	Citral, linalool, geraniol, eugenol	Used for flavouring seeds used in dysentery and chronic diarrhoea.
22.	*Ocimum gratissimum*	Shrubby basil	Ram tulsi	Lamiaceae	-do-	-do-	Shoots, leaves	Eugenol, myrcene, citral, geraniol	Used as a mosquito repellent, should be used as a measure of biological control of mosquitoes
23.	*O. sanctum*	Holy basil	Tulsi	Lamiaceae	India	-do-	Leaves/ shoots	–	Oil has the property of destroying bacteria and insects. Juice of leaves is useful in bronchitis, catarrh, digestive complaints; applied externally on ringworm and other skin diseases. Seeds used in urinary problems.
24.	*Pandanus fasicularis* syn. *P. odoratissimus*	Pandang Screw-pine	Keora	Pandanaceae	India	Along the coast of India and the Andamans	Male flowers - source of most powerful perfume, occur in spadices enclosed in spathes (extraction by enfleurage method)	Methyl ester, β-phenylethyl alcohol, dipentene, (-)- linalool, citral	For scenting clothes, tobacco, cosmetics and agarbattis. Lower part of fruit is eaten in S. India. Leaves used for making baskets, cordage, papermaking, used in leprosy, small pox, scabies.

(Contd...)

25.	*Pimenta dioica*	Pimenta, Allspice	Pimento tree	Myrtaceae	West Indies, tropical America	Bengal, Bihar, Orissa, Bangalore	Unripe fruits	Eugenol	Spice, perfumery, soap
26.	*Polianthes tuberosa*	Tuberose	Gulshaba	Agavaceae	Mexico	Grown throughout India	Flowers	Geraniol, nerol, farnesol, benzl benzoate	High grade perfumes, base in gardenia perfumes
27.	*Pogostemon cablin*	Patchouli	Patchouli	Lamiaceae	Philippines, wild in Singapore, Malayasia & Indonesia also	Malaysia, Singapore, Indonesia	Leaves	*Norpatchoulenol* benzyaldehyde, eugenol, cinnamaldehyde	It blends with other essential oils like vetiver, sandalwood, geranium, lavender. No synthetic chemical is available to replace it. Used for soaps, cosmetics, incense sticks, antibacterial & insect repellant properties.
28.	*Rosa damascena*	Rose	Gulab	Rosaceae	It is a cultural variety, does not grow wild.	Best selections in Bulgaria, India (Feb. to April), U.P (Ghazipur, Kannauj)	Flowers	(-)- cetronellol geraniol Bulgarian rose- β-damascenone & rose oxide	Otto of roses or attar (rose oil) is soluble in water& is used as rose water in India. Used in perfumes, beverages cosmetics, eye-washes. Rose petal + sugar = gulkand (mild laxative).
29.	*Salvia officinalis*	Sage	Salbia sefakuss, seesti	Lamiaceae	Mediterranean region	Grown as an ornamental	Leaves	α- pinene, β-pinene thujone, camphor, borneol, bornyl acetate	Deodorant, flavouring foods, herbal tea, insecticidal preparations, as a carminative.
30.	*Trachyspermum ammi*	Ammi, Carum, or Lovage	Ajowan	Apiaceae		Sudan to India M.P., A.P., Gujarat, Maharashtra, U.P., Rajasthan & Bihar	Fruits	Thymol, carvacrol, thymene	As spice, in perfumery, as a flavouring agent, antifungal, carminative, antiseptic insecticidal properties
31.	*Vanilla planifolia*	Vanilla		Orchidaceae	Southern Mexico, Central & S. America (Northern part) & W. Indies	Malagasy Republic the Comoro Islands Reunion - grow 90% of the worlds supply. Nilgiris, Wynad Coorg & Karnataka	Cured unripe fruits	Vanillin, a group of substances called balsam	[Synthetic vanillin from lignin sulphonic acid – byproduct of sulphate pulping of softwoods (Pines)]. Natural vanilla is still the best. Used for flavouring, perfumery, sachet powders as bait for fruit flies & grasshoppers.
32.	*Viola odorata*	Sweet violet	Banafshah	Violaceae	Europe	Kashmir	Flowers, flowering tops, leaves also.	2, 6 - nonadien -1- al 2, 6-nonadien-1-01	Perfumery soap; medicinally as demulcent (soothing to skin) and in lung troubles. Used in Ayurvedic and Unani systems. Fresh herb used in homoeopathy. Blood purifier.
33.	*Zingiber officinale*	Ginger	Adrak	Zingiberaceae	S.E. Asia	Kerala, U.P., W. Bengal, Maharashtra, Himachal Pradesh (Sirmur district) and Andhra Pradesh	Rhizome	Zingiberene, Zingiberol β-bisabolene farnesene, methyl heptenone, cineole bovneol, geraniol, linalool.	Flavouring candy, baked products, liquers, soft drinks, condiments.

19.5 SUMMARY

In this unit you have studied about:

- the importance of plant chemicals in our daily lives.
- the modern drugs which contain plant products like fatty acids, essential oils, gums, resins, alkaloids and steroids. In animals the effect of these substances, especially alkaloids and steroids, even in minute quantities can be profound.
- the botanical name, common names, family, morphology, ecology, propagation, chemical composition and uses of the medicinal and aromatic plants. These have also been listed in Table 19.7.
- two kinds of oils which are produced by plants: (1) fixed oil or non-volatile oils which are true glycosides of saturated and unsaturated organic acids, and (2) essential oils are a mixture of highly aromatic, steam volatile organic compounds isolated from various parts of the plants.
- the secondary metabolites produced by the plants help in protecting the plants from animals and parasites; for humans they are important ingredients of spices, cosmetics, perfumes, antiseptics, insecticides and aerosols.

Table 19.7: Medicinal and Aromatic Plants.

S. No.	Botanical Name	Family	Part used	Importance chemical constituent
1.	*Rauwolfia spp.*.	Apocynaceae	Root	Reserpine
2.	*Aconitum ferox*	Ranunculaceae	Root	Aconite
3.	*Cinchona spp.*	Rubiaceae	Bark	Quinine
4.	*Dioscorea* spp.	Dioscoreaceae	Tuber	Diosgenin
5.	*Atropa belladonna*	Solanaceae	Leaves	Atropine
6.	*Digitalis spp.*	Scrophulariaceae	Leaves	Digitalin
7.	*Catharanthus roseus*	Apocynaceae	Leaves	Vincristine & Vinblastine
8.	*Papaver somniferum*	Papaveraceae	Latex from capsules	Opium
9.	*Strychnos nux-vomica*	Loganiaceae	Seeds	Strychnine
10.	*Claviceps purpurea*	Fungi, Ascomycetes	Sclerotium (Fruiting body)	Ergotamine
11.	*Cannabis sativa*	Cannabinaceae	Leaves, stems, flowering shoot	Bhang, Ganja, Charas } tetrahydro-cannabinol
12.	*Nicotiana* spp.	Solanaceae	Leaves	Nicotine
13.	*Areca catechu*	Arecaceae	Hard dried endosperm	Arecoline
14.	*Cola nitida*	Sterculiaceae	Seeds and leaves	Kola red, caffeine, theobromine, kolanin (glycoside)
15.	*Erythroxylum coca*	Erythroxylaceae	Leaves	Cocaine
16.	*Santalum album*	Santalaceae	Heartwood	α - and β- santalols
17.	*Vetiveria zizanioides*	Poaceae	Roots	Vetiverol

19.6 TERMINAL QUESTIONS

1. What are secondary plant metabolites and what role do they play in the plants that produce them?

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2. What is the importance of plant chemicals in our lives?

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3. Distinguish between the following:

a) Ganja and Charas

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b) Steroid and alkaloid drugs.

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c) Essential oils and fixed oils

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4. Give the botanical name, family and the part of the plant which yield the drugs for treatment of:

a) Cardiac disorders

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b) Malaria

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c) Sex hormonal problems

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d) Hypertension

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e) Parkinson's disease

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f) Hodgkin's disease

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h) Haemorrhages after childbirth

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5. Name the principal states of India where the following crops are cultivated extensively:

a) Tobacco

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b) Sandalwood

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c) Fever bark tree

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19.7 ANSWERS

Self-assessment Questions

1. i) T
   ii) T
   iii) F
   iv) T
   v) F
   vi) T
   vii) T
   viii) T
   ix) F
   x) F
   xi) F
   xii) T
   xiii) F
   xiv) T

2. i) Refer to Section 19.3
   ii) a, c, d, f are T, and b, e are F

3. i), ii), iii) Refer to Section 19.4
   iv) a) Sandalwood
       b) Heartwood, roots
       c) roots
       d) woods, leaves
       e) *Ocimum sanctum*

Terminal Questions

1. See Section 19.1

2. See Sections 19.1 and 19.2.

3. a) Refer to Subsection 19.3.1
   b) See Section 19.2
   c) See Section 19.4

4. a) *Digitalis purpurea, D. alata*; Scrophulariaceae; leaf
   b) *Cinchona* spp., *C. calisaya*; Rubiaceae; bark

c) *Dioscorea rotunda, D. deltoidea, D. prazeri*; Dioscoreaceae; tuber
d) *Rauwolfia serpentina*; Apocynaceae; root
e) *Atropa belladonna*; Solanaceae; leaf
f) *Catharanthus roseus*; Apocynaceae; leaf
g) *Cannabis sativus*; Cannabinaceae; leaf, stem, flowering shoot (Tetrahydrocannabinol).
h) Alkaloids from *Claviceps purpurea*, rust fungus on grains, sclerotia or fruiting body.

5. a) Andhra Pradesh
b) Karnataka
c) South India (Nilgiris, Tamil Nadu) and Sikkim

UNIT 20 WOOD, FIBRE AND RELATED PRODUCTS

Structure

20.1 Introduction
Objectives
20.2 Commercially Important Timber Yielding Plants
20.2.1 Teak
20.2.2 Shisham
20.2.3 Pine
20.2.4 Cedar
20.3 Woods for Different Uses
20.3.1 Fuel
20.3.2 Constructional Materials
20.3.3 Containers
20.3.4 Chemical Products
20.4 Cork
20.5 Rubber
20.6 Commercially Important Fibre Yielding Plants
20.6.1 Cotton
20.6.2 Jute
20.6.3 Coconut
20.7 Summary
20.8 Terminal Questions
20.9 Answers
Appendix 20.1: Features of Wood

20.1 INTRODUCTION

By now you are well aware that we use plants for various purposes such as foods, beverages, medicines and essential oils. In addition several plant products provide us shelter and clothing. The process of secondary growth in gymnosperms and dicotyledonous plants results in the formation of woody tissues which helps to support the increasing weight of the plant. Besides giving us the wood for timber and fuel, these tissues yield many useful products such as gum, resin, turpentine, paper, rayon, cork and rubber. Different types of plant fibres serve as the raw material for conversion into various products such as cloth, mats, bags and ropes. In this unit you will study about the wood and fibre-yielding plants and their related products.

Objectives

After studying this unit you should be able to:

- list the important wood and fibre-yielding plants and describe their important features;
- list the properties and characteristics of different woods and fibres because of which they are put to various uses;
- describe the processing of various woods and fibres for commercial use;
- explain the process of paper-making; and
- prepare an illustrated account on cork and rubber.

20.2 COMMERCIALLY IMPORTANT TIMBER YIELDING PLANTS

Wood has been an important and indispensable forest product used by mankind for ages. Primitive man used it for construction of shelters, implements and utensils. We too, use it in numerous ways, for construction, as fuel and as a raw material in the paper and rayon industry. Till today, we have not been able to find substitutes for wood in many of its uses, in spite of the availability of various metals and synthetic products. Wood will continue to play an important role in our lives, since it can remain an inexhaustible natural resource, if utilized with proper care. You will now study about four such sources of wood which are used at commercial scale in our country.

20.2.1 Teak

Botanical name: *Tectona grandis*
Family: Verbenaceae
Common names: Teak, Rangoon or Burma teak, Moulmein teak, Singuru, Sagwan
n = 12, 18

Distribution: It is native to South-east Asia and Malaya, and is one of the most important commercial timbers of the tropics. Myanmar and Thailand have extensive forests. In India, teak forests occur in Madhya Pradesh, Maharashtra, Gujarat, Karnataka, Rajasthan, Kerala, Tamil Nadu and Andhra Pradesh.

Characteristics: Teak (Fig. 20.1) is a large, deciduous tree with a probable age of over 200 years. The sapwood is white and rather susceptible to attack by termites and wood rotting fungi. The heartwood is golden yellow to golden brown when freshly sawn, turning darker after exposure and is relatively immune to insect attack. The wood is greasy to touch and smells like old leather. It is hard, and does not warp, split or crack and is thus valuable for general construction. It is resistant to decay and termites even when unprotected by preservatives, and is renowned for stability. Teak wood is not very difficult to work with and also it takes very good polish. The grain is normally straight, and the texture is coarse and uneven. The average weight is between 609-689 kg/m^3 when dry. It shows distinct growth rings. The wood is ring porous (see Appendix 20.1) and is marked by the presence of large vessels. Tyloses are quite common.

Uses: Teak ranks among the best timbers of the world. It is the chief railway carriage and wagon wood of India. It is superior to oak in ship building. Its wood is used in construction of houses; building bridges; making cabinets and boats; for carving; plywood manufacture; for flooring; making toys, and in many other ways.

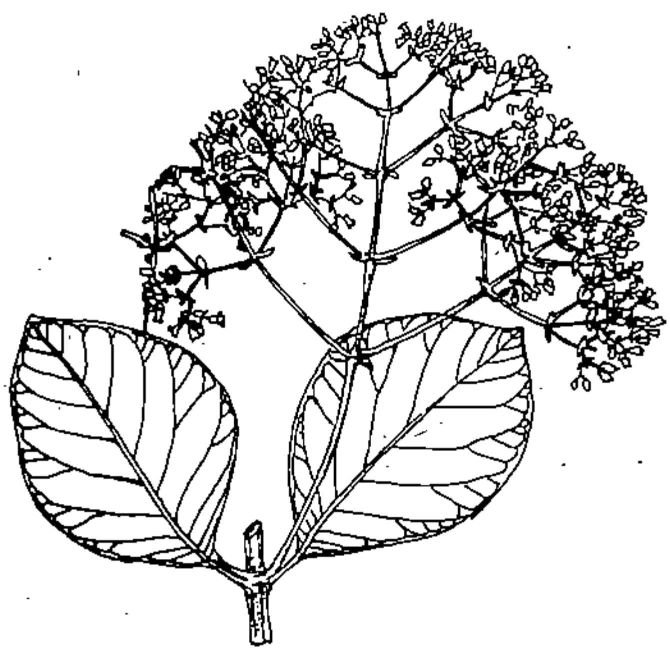

Fig. 20.1: Teak (*Tectona grandis*). A flowering branch.

20.2.2 Shisham

Botanical name: *Dalbergia sissoo*
Family: Fabaceae
Common names: Shisham, Rosewood, Sissoo
n = 10

Distribution: *Dalbergia* is a genus of tropical trees providing valuable dark timber. *D. latifolia* (Indian rosewood) and *D. sissoo* (sissoo) are important Asian species and are amongst the finest of India's cabinet and furniture woods. Sissoo (Fig. 20.2) occurs throughout the sub-Himalayan tracts from Ravi to Assam up to 1530 m, and it grows freely along water channels. Indian rosewood is found in central and southern India and also in sub-Himalayan tracts. Other common *Dalbergia* species are *D. nigra* (Brazilian rosewood), *D. melanoxylon* (African blackwood), *D. retusa* (cocobolo) and *D. stevensonii* (Honduras rosewood).

Characteristics: The trees have pinnate leaves, and panicles of small, yellow or white papilionaceous flowers. In sissoo the sapwood is white to brownish and the heartwood is golden brown to dark brown. It is a durable, heavy wood with an average weight of 800-850 kg/m^3. In Indian rosewood the sapwood is yellowish but the heartwood varies from dull brown to almost purple. It is a durable wood, especially under water. It weighs around 800-960 kg/m^3. Although not easy to work with, it carves well.

Uses: *Dalbergia* is a high class furniture and cabinet-wood. It is valued as a construction and general purpose timber and is used for railway sleepers, musical instruments, hammer handles, shoe heels and tobacco pipes. It is good for charcoal making, and is used for decorative veneers as well.

Fig. 20.2: Sisoo (*Dalbergia sissoo*). A twig with fruits.

20.2.3 Pine

Botanical names: *Pinus roxburghii, P. wallichiana*
Family: Pinaceae
Common names: Chir, Blue pine respectively
n = 12

Distribution: In India, *Pinus roxburghii* (chir) and *P. wallichiana* (kail) are the two most popular species of *Pinus* that yield timber. *P. roxburghii* occurs in the outer hill ranges of Siwalik and the valleys of Himalayas. *Pinus wallichiana* occurs at higher altitudes. Pines are common in Himachal Pradesh, Jammu & Kashmir, Punjab and Uttar Pradesh. Other commercial pine timbers come from *P. strobus* (American yellow pine), *P. monticola* (Western white pine). *P. sylvestris* (Scots pine), *P. ponderosa* (Ponderosa pine) and many more.

Characteristics: Pines are generally tall trees that bear characteristic needle-like leaves and distinct male and female cones (See Fig. 20.3). Pine timber falls into two broad categories – the soft or white pines, and the hard, yellow or pitch pines. The former have soft, light coloured wood tinged pink in the heartwood and nearly white in the sapwood. The latter have a resinous, heavy, hard, strong and durable wood, with a pronounced grain pattern. The wood is light, easy to work but is not durable. The timber is straight grained and has little resin.

Uses: Soft pines are used for making matches, crates, boxes and rough carpentry work. Hard pine are used in construction of buildings, bridges, and ships.

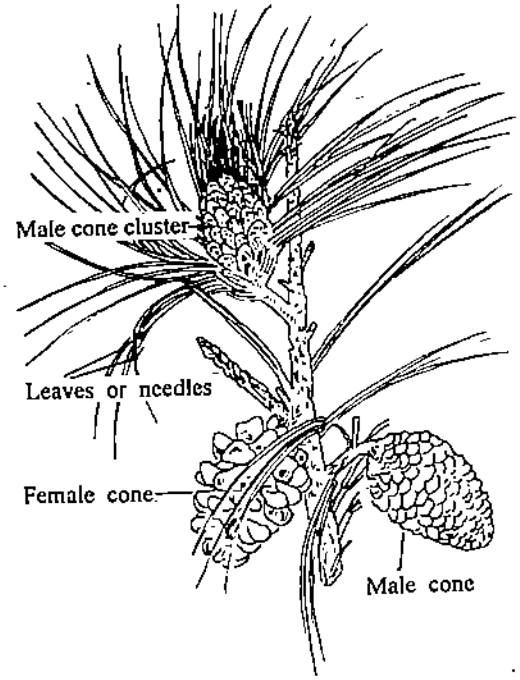

Fig. 20.3: Pine (*Pinus roxburghii.*). Diagrammatic sketch of a pine branch with male and female cones.

20.2.4 Cedar

Botanical name: ***Cedrus deodara***
Family: Pinaceae
Common names: Deodar, Himalayan Cedar
n = 12

The true cedar is any one of the following four species of *Cedrus* – *C. atlantica* (Atlas or Atlantic cedar); *C. libani* subsp. *brevifolia* (cyprus cedar), *C. libani* (Cedar of Lebanon) and *C. deodara* (Deodar or Himalayan cedar, see Fig. 20.4).

Distribution: Deodar is the most important and strongest of Indian softwoods, growing chiefly in the northwestern Himalayas in Kashmir, Himachal Pradesh, Uttar Pradesh and Punjab.

Characteristics: It is a large tree (45-60 m height) with wide spreading horizontal branches giving it the characteristic skyscraper appearance. Its sapwood is white but the heartwood is light yellow, turning brown on exposure to air. The timber is very durable, very rarely being attacked by white ants or fungi. The wood is straight grained, having moderately fine and uniform texture. It is slightly difficult to glue or polish because of the high oil content. It is resinous and therefore not good for interiors.

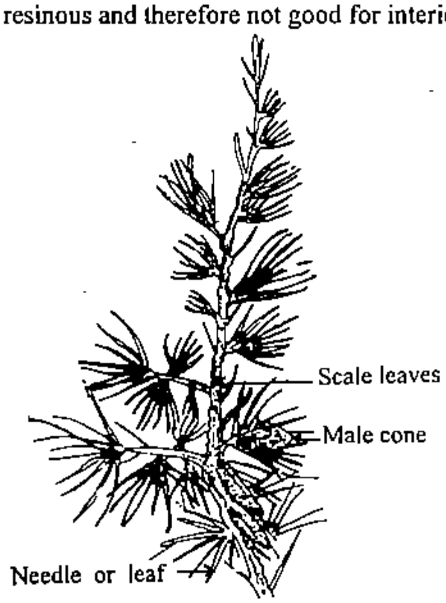

Fig. 20.4: Cedar (*Cedrus deodara*). Diagrammatic sketch of a twig. The leaves are needle-like and spirally arranged.

Uses: It is mainly used for railway sleepers, beams, posts, doors, window frames, bridge construction, carving and packing cases. It is not suited for veneers because of the presence of knots.

SAQ 1

Write the salient features of the timbers: shisham, teak, deodar and pine.

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SAQ 2

Suggest some source(s) of wood for the following purposes:

i) Furniture making ....

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ii) For making music instruments..

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iii) Construction of houses and bridges...

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iv) Making matches ....

....

v) For rough carpentery work ....

....

vi) Making beams, posts, doors and window frames ....

....

20.3 WOODS FOR DIFFERENT USES

Woods, before being put to different uses are variously processed to make them suitable for the requisite purpose. Different woods are used for different purposes. Some of the common examples are discussed below.

Processing wood for use: Trees are felled by cutting across the trunk as close to the ground as possible. The side branches are then removed and the trunks are cut into suitable lengths, known as sawlogs. The use of powered saws is increasingly replacing the hand saws in several parts of the world and processing of fresh logs for future use is becoming increasingly mechanised. Wood is unique among the world's important raw materials, and not many substitutes have replaced it. Its uses are numerous such as fuel, construction work, furniture, containers, mechanically reduced products, chemically derived products and so on.

20.3.1 Fuel

The use of wood as a fuel for heating and cooking, dates to prehistoric times, and only recently has been replaced to some extent by fossil fuels or electricity. Still, the consumption of wood for fuel exceeds its use for any other purpose. Wood is an excellent fuel, since 90% of the oven dried wood is combustible. Woods vary greatly in their fuel value, which depends mainly on their density, chemical composition, and the amount of moisture (Fig. 20.5). The best fuel woods are hardwoods such as beech, oak, maple and birch. The average calorific value of seasoned wood is around 4600 cal/kg.

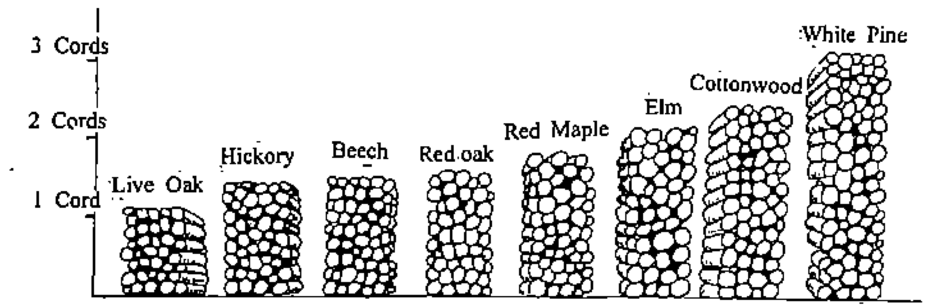

Fig. 20.5: This diagram shows that variable quantities of different woods provide equivalent quantities of heat. The amount of heat given out by a particular kind of wood is a function of its density, chemical composition and water content.

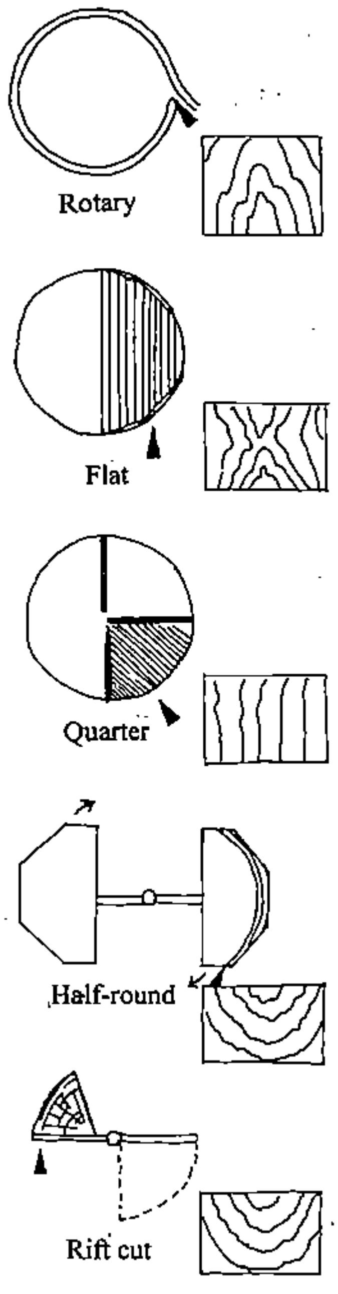

Fig. 20.6: Diagrams showing different methods of cutting veneers and their resultant products. (Redrawn from Villiard, 1975).

20.3.2 Constructional Materials

Poles – Employed chiefly for telephone, telegraph and electrical transmission lines. Durable wood, which is light, straight and strong to resist stresses is used. Coniferous trees are the principal sources. Such woods are also used in construction of shelters.

Pilings – Used for the construction of docks, bridges, and wharves. These are straight, round timber, driven beneath water for construction work. Pines are commonly used and so is oak, the latter mainly for dock and harbour work and for marine pilings.

Posts – Used for the erection and maintenance of fence lines along farm and ranch boundaries, railroads and highways. Strength, lightness and durability are the main requirements. Any available local species can be used.

Mine timbers – Include a variety of wooden supports such as props or legs, cross-bars or caps used in the construction of mine tunnels to prevent debris from falling or where the underground formations are likely to cave in. Mostly those hardwoods that are durable and strong and are resistant to decay and corrosion, are employed for the purpose.

Railroad ties or sleepers or cross ties – Used to support and hold railroad rails. The wood should be durable, treatable and be able to withstand the impact and pressure of heavy and speedy traffic, hold spikes and screws and be easily available and inexpensive. Oak is the most widely used wood for this purpose. The wood is usually treated with preservatives and can last up to 30 years.

Veneers – These are thin sheets of wood of uniform thickness, produced by peeling, slicing or sawing logs (Fig. 20.6). Veneers are made by one of the following three methods - rotary cutting, slicing or sawing. Of these, rotary cutting is the most common method employed. Logs selected for this process are debarked and softened by steaming or steeping in hot water. This facilitates cutting and also minimises the danger of splitting. They are then cross-cut to desired lengths. Many woods like Douglas fir, Ponderosa pine, and Poplars are used. Fine veneers are made from expensive woods like walnut, teak and rosewood.

Plywood – It is a thin board made up of an odd number of three or more very thin sheets of veneers glued together under pressure, ranging in thickness from 3-25mm. Successive veneers are positioned in such a way that the grain of each is at right angles to the adjoining sheet (in a cross-banded way), making the structure as strong and even stronger than the wood itself. The major advantage that plywoods have over solid woods is dimensional stability and that it is much less likely to warp or twist than ordinary wood. Plywood has the strength distributed in both directions, and the nails and screws can be driven close to the edge without any danger of splitting. Also, it can be moulded, and it comes in much larger sizes and can be used for partitions, walls and roofs. Durable timbers such as oak and teak are used. Plywoods are used for inner cabinet work, roof and wall sheathing, flooring, automobile body parts, boards, ceilings, counters, desks, drawers, and furniture.

20.3.3 Containers

Cooperage – It's the art of making wood containers such as barrels, tubs, tanks and the construction of wooden pipelines for transporting city water supplies. There are two principal divisions of the cooperage industry, namely, slack (or dry) cooperage made for packaging, storing and transporting dry material, and tight (or wet) cooperage for holding liquids such as beer, whisky, and wine syrups. Woods selected for slack cooperage must be cheap, light, easy to work, elastic and free from warping. Pine, beech, oak and maple are commonly employed. For making tight cooperage the inner walls are coated with an inert material such as paraffin, silicate of soda or glue to prevent leakage and contamination of liquids. Hardwoods, especially oak are commonly used because of their strength and durability, impenetrable nature and thermal insulation properties. Woods used for the purpose are red gum, white ash, yellow birch and Douglas fir.

20.3.4 Chemical Products

Wood is mainly made up of cellulose, hemicellulose and lignin; and also varying amounts of tannins, resins, gums and latex. It serves as a basic raw material for deriving several chemical products using various methods. Some examples are given below:

Wood distillation – This is an ancient process. One of the chief sources of wood for destructive distillation is the waste left by lumbering operations and sawmills. The wood is heated in a cast iron or steel retort or oven in the absence of air. Charcoal residue is left behind in the retort, and the escaping vapours are conducted through water-cooled condensers. The condensate (pyroligneous acid) is allowed to settle, and tar and oils are separated out from the liquid above. Meanwhile the non-condensable gases are trapped and are used to help heat the oven.

Based upon the kind of wood used, distillation can be classified into hardwood and softwood distillation. Denser and heavier woods like sugar maple, birch, oak and beech are employed in hardwood distillation and the products are:

(i) charcoal – the solid residue;
(ii) pyroligneous acid – a yellowish green, ill smelling liquor or condensate consisting of water, acetic acid, methanol and dissolved tar;
(iii) wood tar – the water insoluble fraction that settles at the bottom of the aqueous pyroligneous acid; and
(iv) the non-condensable wood gas, used as fuel or for illumination purposes.

On the other hand, softwood distillation utilises resinous pinewoods, chiefly of long leaf and slash pines. The principal distillation products are charcoal, wood turpentine, pine oil, dipentine, pine tar, tar oils, wood gas and a small amount of wood alcohol (methanol) and acetic acid.

Tapping for naval stores industry – The term 'Naval Stores' was initially used to designate the pitch obtained by tapping pine trees. Pitch and its derivatives were used extensively by the European maritime industry in the late sixteenth century for caulking the planks of wooden sailing ships and for water proofing riggings and hawsers. The species used now-a-days are the long leaf and slash pines in the USA, maritime pine (*Pinus pinaster*) in Europe, and *Pinus roxburghii* in India. Besides pines, Douglas fir, spruces and larches are the other conifers tapped for the purpose. Three different types of products are obtained by this industry: (i) gum turpentine and gum rosin, derived from the gum (oleoresin) bled from living trees; (ii) wood turpentine and wood rosin, obtained by the action of steam and suitable solvents on macerated or chipped stumps and roots left behind after lumbering; and (iii) sulphate turpentine and sulphate rosin, important by-products of pulp mills employing the sulphate process for pulping resinous woods.

Crude turpentine is collected by tapping when the trees have attained a girth of 23 cm or more. The bark near the base of the tree is shaved off and a shallow slanting cut is made a few centimetres above the ground level. A V-shaped metal trough is fixed to direct the flow of crude turpentine into a collecting vessel. A shallow wound is then made in the bark above the gutter, from which the exudates drips. Chipping on all sides takes 10-20 years; the tree is then abandoned as these wounds never heal because the cambium is removed in the process. The crude turpentine contains about 20% spirit of turpentine, 65% rosin, 5 to 10% water, some plant tissues and dust. It is distilled in steam distillation plants to isolate its useful components. The distillate consists of water and spirits of turpentine while the hot molten amber to dark-red residue that remains behind is the *rosin* of commerce.

Spirit of turpentine is used as a thinning material in the paint and varnish industry, as a solvent for rubber and gutta-parcha, and for the manufacture of printing cloth, waterproofing compounds, leather dressings, synthetic camphor, many pharmaceuticals such as liniments and a large number of other chemicals. Rosin is used for preparing paints and varnishes, polishes, waxes, soaps, oil cloth, linoleum, sealing wax, printing ink, roofing and floor covering adhesives, plastics, rubber, wood preservatives, disinfectants, drugs and chemicals. Rosin is also used in the paper industry for sizing, i.e., for imparting lustre and weight, and hindering absorption of ink or moisture. Rosin oil is used in the manufacture of greases, lubricants and solvents.

Cellulose Derived Products

Cellulose is a carbohydrate $[(C_6H_{10}O_5)_n]$ and is an important component of cell walls. Cotton was originally used as a source of cellulose, but now wood pulp is generally employed. It is used in the manufacture of such products as paper and rayon.

Manufacture of wood pulp – Woods are converted into a fibrous mass (wood pulp) by any of the following three processes – (i) mechanical (most economical and highest yielding), (ii) chemical, and (iii) semi-chemical.

(i) Mechanical pulping (or ground wood process) – Only the light-coloured and long-fibred coniferous woods especially spruce are used. In India, salai-wood (*Boswellia serrata*) is most widely used for the process. The debarked wood is ground against a rapidly revolving grindstone. The pulp obtained is washed and processed further. The process is high-yielding (about 95% of the dry weight of wood). However, lignin and other non-cellulose products do not get removed and the pulp and its products deteriorate in strength and turn yellow with age. But the paper has good opacity, bulk and printing quality. Such pulp is largely used for newsprint, wrapping and wall papers.

(ii) Chemical pulping – Softwoods with little or no resin (spruce, fir, hemlock) and some hardwoods are used in this process. The wood chips are cooked in various chemical solutions at high temperatures to dissolve lignin, hemicellulose and other non-cellulose components of cell walls, leaving behind nearly pure cellulose fibres in the form of a pulp. Although it is a low-yielding process (45-60%), it gives a high grade paper, and most of the wood pulp currently used is prepared by chemical methods. The bark of the wood is removed and the logs are reduced to small chips (12-25 mm long and 3-4mm thick). Pulping is carried out in large steel digesters by the sulphite, sulphate or the soda process. Steam is blown in until the desired pressure and temperature are obtained. At the end of the cooking process, the entire steam is blown out through a valve at the bottom of the digester. The sudden release of pressure blows the chips apart and the fibres are separated. The sulphite pulp is used in the manufacture of printing, bond, tissue and wrapping papers, in rayon and newsprint. Soda pulp (mixed with sulphite pulp) is used in the manufacture of printing paper for books, and better grade magazines. Sulphate pulp is used for making a strong brown kraft wrapping paper (used in craft work and as cover paper), paper bags and paper board.

(iii) Semi-chemical pulping – Hardwoods are generally used in this process. Wood chips are at first softened by mild chemical action and thereafter defibration is accomplished by mechanical action. This method yields 65-85% pulp of the dry weight of wood. The higher yield in comparison to chemical pulping is because of the retention of about 50% of the lignin and 30-40% of the hemi-cellulose. Neutral sodium sulphite is the most widely used chemical for cooking. Wood is still in the form of solid soft chips after cooking, and is defibred mechanically. These pulps are well suited for making corrugated board, roofing felt, insulating board, and low grade wrappings. Good quality newsprint is manufactured from a mixture of semi-chemical pulp from softwoods and mechanical pulp from hardwoods.

Paper Making

Cotton and linen rags were the principal sources till the last century and are still used for the manufacture of the finest grade paper. Presently, wood fibres are the most important raw materials used (Fig. 20.7). About 97% of the world's paper and paper-board is made from wood pulp, of which nearly 85% is derived from coniferous woods like spruces (*Picea* spp.), firs (*Abies* spp.) and pines (*Pinus* spp.). The hardwoods used in paper making are poplar (*Populus* spp.), birch (*Betula* spp.), beech (*Fagus* spp.) and eucalypts

(*Eucalyptus* spp.). Other paper making materials include textile fibres such as jute, hemp, Manila and sisal hemp, crop wastes and also rejects from textile factories or cotton linter recovered during the processing of cotton seed. In India, the main fibrous raw materials are bamboos (especially *Bambusa arundinacea* and *Dendrocalamus strictus*), sabai-grass (*Eulaliopsis binata*), bagasse and salai-wood (*Boswellia serrata*). Rags, hemp ropes, jute wastes and waste paper are also converted into pulp.

The pulp is then washed, screened, bleached and lapped. Screening holds back knots, uncooked chips and other foreign matter and separates the pulp into different grades by regulating the size of perforations in the screen. The remaining non-cellulose fraction is removed by bleaching with chlorine and its compounds. It whitens the pulp and helps in the removal of residual lignin. The pulp may need to be bleached several times. Washing with water follows bleaching.

Pulp obtained from chemical and semi-chemical processes is subjected to a treatment called beating (see Fig. 20.8). Besides separating the fibres from one another, it shortens and bruises them. Consequently, they cling firmly forming a uniform sheet on the paper-making machine later. The degree of beating influences the texture of the paper obtained. A variety of materials are added to the pulp stock in the beater to improve the quality of the paper. Mineral fillers give weight and opacity to the paper by filling the interstices. China clay, talc, calcium sulphate, zinc sulphide, titanium oxide and calcium carbonate are some important fillers. Sizings such as rosin, soap, wax and starch make the surface smooth and impervious to ink. Currently, emulsions like polyvinyl acetate, polyesters, vinyl chloride and acrylic resins are also being used for sizing.

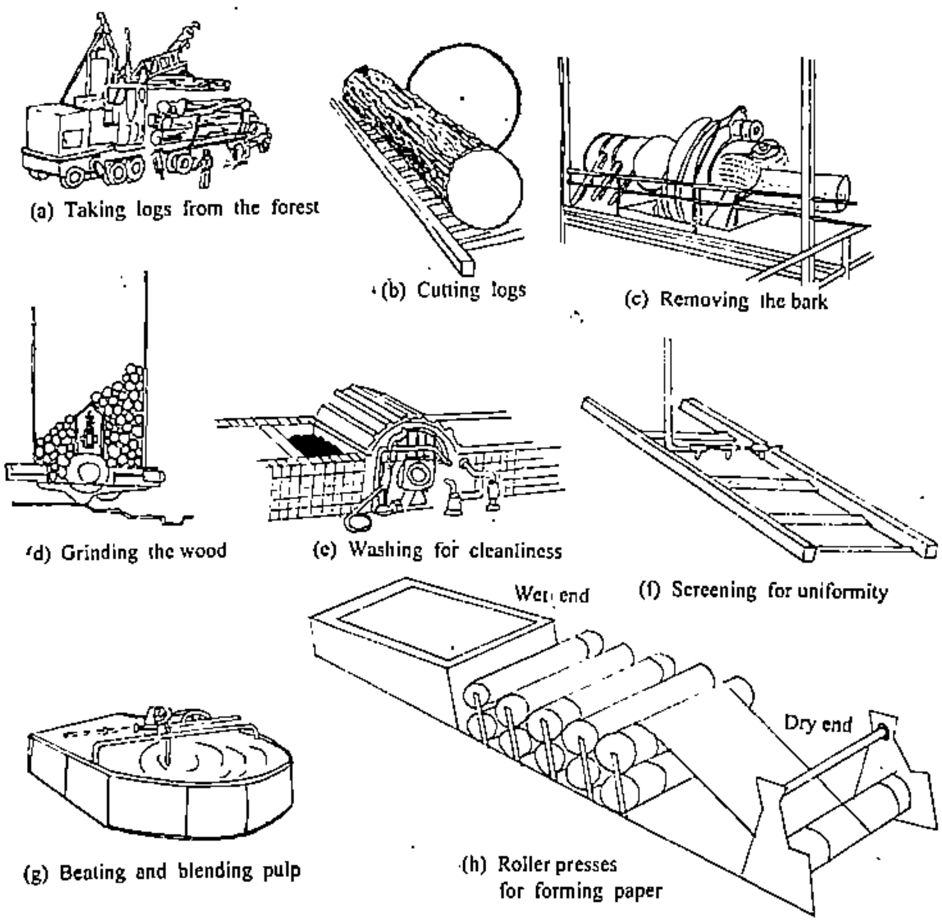

Fig. 20.7: The mechanical wood grinding process of paper making. This process leaves pectins and lignins in the pulp, that causes the yellowing of paper with time (After Simpson & Conner-Ogorzaly, 1986).

After the pulp has been mixed thoroughly with all the ingredients, it is sent to the paper-making machine. External sizings can be applied to dry sheets of paper. This paper is then calendered by passing it between pairs of highly polished rollers to impart a smooth finish.

Rayon – Highly purified cellulose pulp (89-98% cellulose) is employed as a basic material in the manufacture of rayon or artificial silk, acetate filaments and fabrics, transparent films (cellophane, cellulose acetate and nitrocellulose films), lacquers, plastics and explosives. Rayon filaments are produced using various solvents employed to dissolve the cellulose. Viscose rayon is produced using sodium hydroxide and carbon disulphide as solvents and is the most common. Pure cellulose is digested in a strong sodium hydroxide solution and then with carbon disulphide to make 'xanthate'. The resulting foamy pale-yellow viscous mass (viscose) is passed into a solution of dilute sulphuric acid. The solvent is removed here and the cellulose coagulated into fine filaments. The cellulose filaments are caught by revolving reels and are then twisted into threads. Later, they are given a glycerine bath to make them flexible.

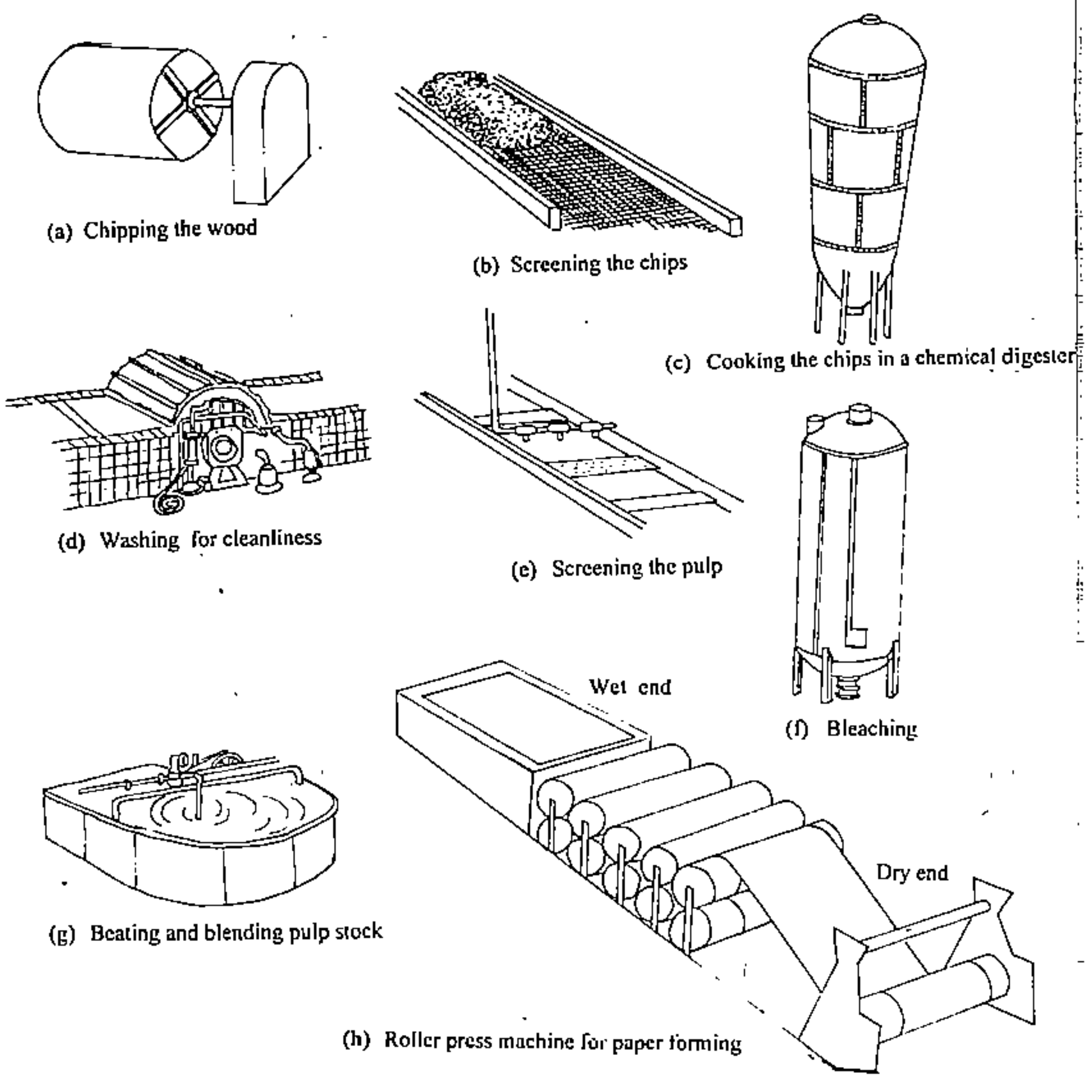

Fig. 20.8: Diagram showing the chemical process of paper making. The logs are chipped (a), screened (b), and sent to the digester tank containing chemicals (c). Here chemical dissolution of the wood sections takes place to liberate the fibers. Lignins are also removed leaving relatively pure fibers. The fibres are then washed (d), screened (e), bleached (f), blended (g), and roller-pressed (h) to form paper. (From Simpson & Conner-Ogorzaly, 1986).

SAQ 3

Answer the following questions briefly.

i) What makes wood an excellent fuel?

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ii) What properties govern the varying fuel values of different woods?

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iii) What is the average calorific value of seasoned wood?

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iv) Name the products of hardwood distillation.

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SAQ 4

Match the items of Column I with those of Column II. Column I lists certain purposes for which wood is required, and Column II lists combinations of characteristics of wood. Write your answers in the boxes given below.

Column I	Column II
i) Veneers	a) hardwoods that are strong and resistant to decay and corrosion.
ii) Poles	b) light, yet strong and durable.
iii) Mine timbers	c) minimal splitting.
iv) Fence posts	d) durable, able to take heavy pressures, and hold spikes and screws.
v) Railway sleepers	e) light, elastic and free from warping.
vi) Slack cooperage	f) light, straight, strong to bear stresses, and durable.

i) ☐

ii) ☐

iii) ☐

iv) ☐

v) ☐

vi) ☐

20.4 CORK

Botanical name: *Quercus suber*
Family: Fagaceae
Common name: Cork Oak
n = 12

Cork comes from the outer bark or phellem (see also Subsection 10.8.2 of LSE-06).

Distribution: It is a native of the western Mediterranean region. In India cork oak trees are grown in the Nilgiris but not too successfully.

The cork oak is a small to medium sized evergreen tree. The cells of cork are laid down in annual layers like those of wood by the activity of the cork cambium lying underneath the epidermis (Figs 20.9 & 20.10). The first stripping of the cork oak tree begins at the age of 20 years, and the tree can subsequently be stripped every 10 years or so, for up to 150 years. The harvest is stacked, air-seasoned and then boiled. It is then air-dried, trimmed, graded and baled.

Characteristics: Commercial cork is highly valuable because of its following properties – (I) buoyancy and lightness; (ii) resilience and compressibility; (iii) insulating properties and low thermal conductivity; (iv) chemical inertness; (v) high resistance to deterioration; (vi) non-conduction of electricity; (vii) imperviousness to water and other liquids; (viii) lack of odour; (ix) ability to absorb sound and vibration; (x) high coefficient of friction; and (xi) slow to catch fire.

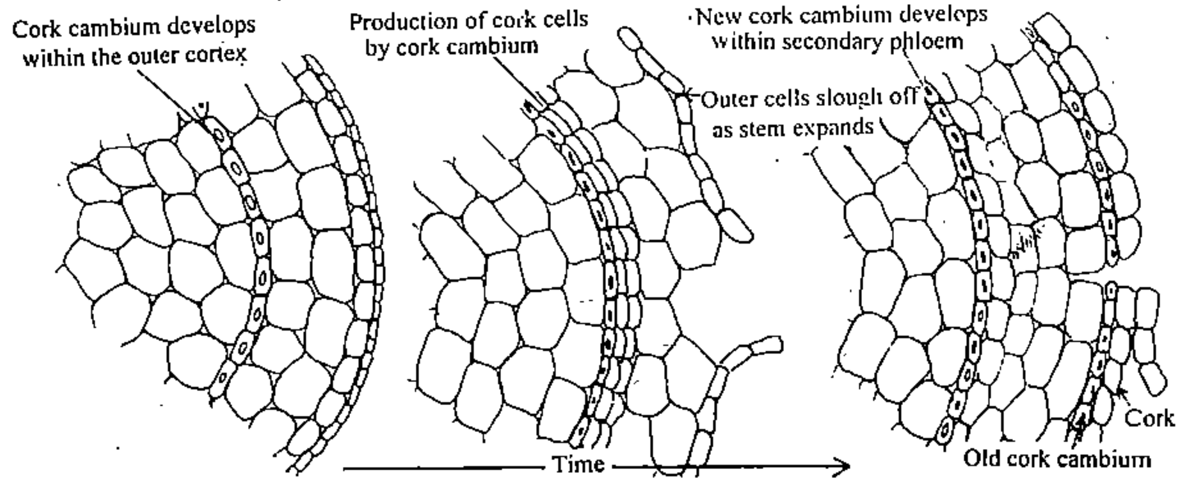

Fig. 20.9: Diagrammatic sketches showing the production of cork, as seen in the transverse sections of stems.

Uses: Cork is used either in its natural, or in a modified state as composition cork. Natural cork is used in the manufacture of bottle stoppers, insulating materials, sealing liners, marine articles, fishing rod handles, shoe-insoles, sporting goods, carved jewellery boxes, picture frames, and in many other ways. Composition cork is manufactured by combining pure, soft granules of cork with suitable glues, synthetic resins and a plasticiser such as glycerine. It is used in the manufacture of gaskets or seals for automobiles, linoleum and floor tiles, shoe-insoles, sealing liners for crown caps, printing press blankets, bathing shoes, and beach sandals. Cork insulation board is produced by heating pulverised natural cork with binders and then pressing into large moulds and beating further. It is used in refrigeration, air-conditioning, prevention of moisture condensation, machinery isolation and sound-proofing.

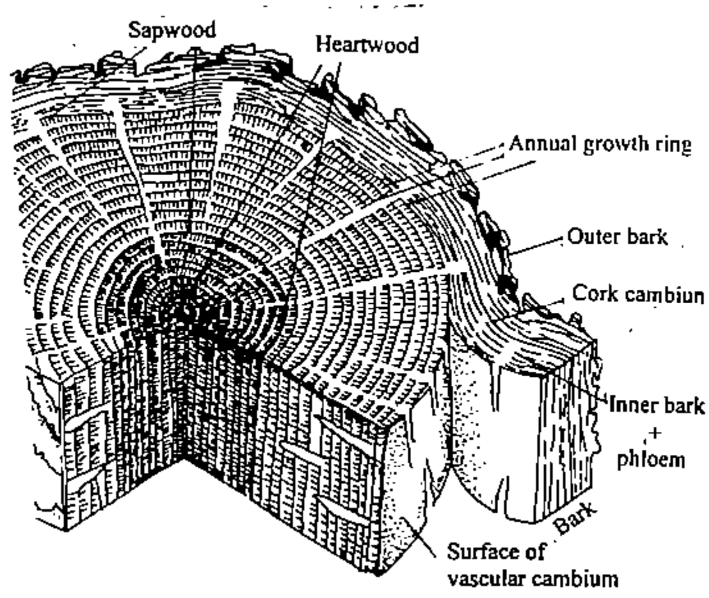

Fig. 20.10: Outline sketch of an Oak stem cut in transverse section. Note the cork cambium and the outer layers of the bark. (From Simpson & Conner-Ogorzaly, 1986).

20.5 RUBBER

Rubber is obtained from the milky juice, or latex of various woody plants of the tropics or subtropics. Chemically, rubber is a polyterpene, consisting of a long chain (500-5000) of isoprene units joined together end to end to form giant molecules called polymers which are coiled up like tiny springs. Latex occurs in special cells (laticifers) which permeate the bark, leaves and other soft parts of the tree. Usually, the latex from the lower part of the trunk is commercially important. Rubber generally occurs as microscopic particles suspended in an aqueous fluid, the serum, contained in specialised latex vessels and latex tubes or cells. Fresh latex contains the rubber hydrocarbon (C_5H_8 – 25-40%) and varying proportions of non-rubber constituents such as proteins, resins, sugars, glycosides, tannins, alkaloids, mineral salts, and waxes.

Botanical name: ***Hevea brasiliensis***
Family: Euphorbiaceae
Common names: Para rubber tree, Caoutchoue tree
n = 18

Distribution: The most important rubber-yielding tree species is *Hevea brasiliensis* (Fig. 20.11). It is a native of the tropical rain forests of the Amazon valley. The principal rubber producing countries are Malaysia, Indonesia, Thailand and Sri Lanka. In India, most of the rubber production comes from Kerala, and the remainder from Tamil Nadu, Karnataka and Andamans.

Morphology: It is a tall tree, growing up to a height of 20 m. The trunk is 2-3 m in girth and bears at the top a spreading or conical leaf canopy. The leaves are trifoliate compound with long petioles; the leaflets are short-stalked, elliptic to obovate, with an acuminate apex. The flowers are small, green, sweetly scented, in pubescent panicles with female flowers at the top and males present in the lower portion. The fruit is a tripartite capsule, with one seed in each compartment. It dehisces explosively at maturity. The seeds are rich in oil.

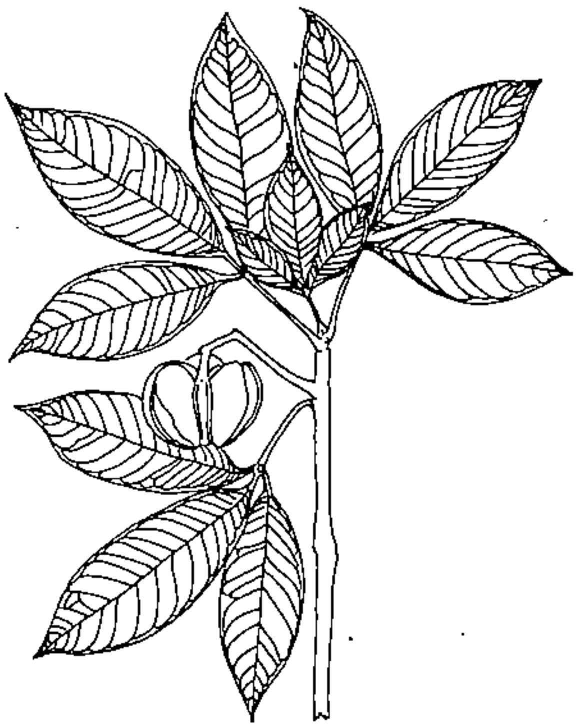

Fig. 20.11: Rubber tree (*Hevea brasiliensis*). A shoot with a dehiscing fruit.

The latex vessels do not run precisely vertically but in anti-clockwise spirals to the right hand side. They are arranged in concentric rings in the bark alternating with the rings of secondary phloem (Fig. 20.12). The vessels are laterally interconnected with each ring, but the connections are disrupted as the trunk increases in circumference. Latex vessels are more numerous in the inner bark than in the outer. The trees are ready for tapping when they are about six or seven years old, but the yield of latex is maximum at the age of 12 years. The trees are abandoned after 25-30 years when they are no longer commercially profitable.

Tapping and Processing of Rubber – Originally, latex was gathered by cutting down the wild trees, but later tapped by making haphazard wounds with the help of crude heavy hand-axes (machadino method). Damage to the growth layer was common, and such a method made the trees vulnerable to attack by pathogens. Later, small tapping knives with U-shaped heads were used and a series of separate parallel cuts were made into the trunk (Amazonas method). These techniques were extremely wasteful and inefficient. The latex thus obtained was coagulated by pouring it over the already dried coagulum sticking to a long pole, and rotating it over the smoke from a smouldering fire. This was repeated until a gigantic ball of rubber weighing 70 to 90 kg. was obtained.

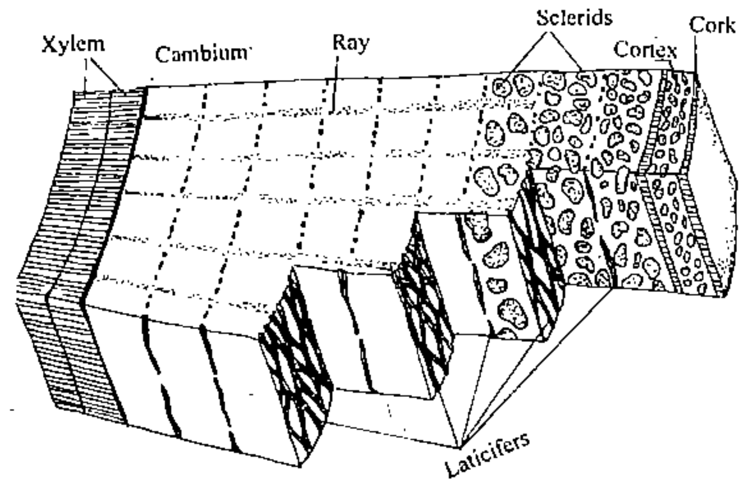

Fig. 20.12: Diagrammatic sketch of cross section of a *Hevea* stem showing the location of laticifers. (From Simpson & Conner-Ogorzaly, 1986).

Currently, tapping and processing latex from the para rubber tree are highly systematised, and scientifically managed. A thin shaving or paring of bark 1.25 – 1.50 mm in thickness is removed (excision method) at regular intervals rather than making a series of vertical incisions in the bark (Fig. 20.13).

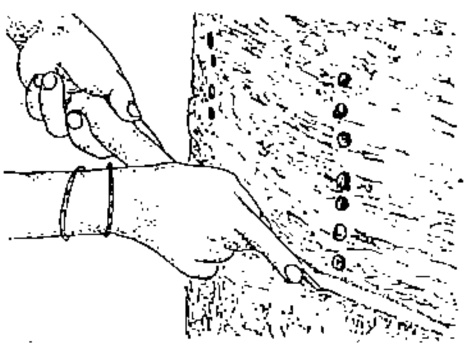

Fig. 20.13: Tapping a rubber tree.

Depending on the type and extent of the cuts, three different methods of tapping are recognised: V-cut system, herring bone system, and spiral panel (or Jebong) system. In the V-cut system two slanting incisions are made like the two arms of a V, and at the bottom of their junction metallic spouts are inserted to conduct latex into the receiving cup. In the herring bone system, a number of oblique cuts, all converging to a vertical line are made into the bark. The cuts could be on both sides or on either side of the line. The latex runs down the cuts into the central one which conducts it to the cup placed at the bottom. In the spiral panel system, a cut at an angle of 30°-35° is made from the upper left to the lower right, half way around the tree (half spiral panel) or completely around the circumference of the trunk (full spiral panel). A specially designed Jebong's knife of high quality steel is used. The knife has a V-shaped head which can be adjusted to cut the proper thickness of bark (about 1mm). Thus, the latex vessels are severed transversely. Tapping is started early in the morning when the flow of latex is copious owing to high turgor pressure. The pressure goes on slackening and finally stops at midday. Latex runs down the channel to the cut to a spout and into a small receptacle to which a few drops of an anticoagulant (ammonia, formaldehyde or sodium hydroxide) are added.

The trees are tapped on alternate days, and each subsequent cut is made immediately below the previous one. If the early tappings are carefully done, new bark regenerates in the region of the tapped panel because of the meristematic activity of the underlying cambium.

The rubber is shipped either as concentrated liquid latex or in a solid form. For use in concentrated form, the latex is either centrifuged or treated chemically with alginates that cause the rubber particles to swell. Water and other non-rubber constituents are drained off the processing tank. An anticoagulant is added to the concentrated mass of latex which is then exported in drums.

To prepare solid rubber, the strained and diluted latex is transferred to large aluminium tanks to which acetic or formic acid is added. The tiny rubber particles dispersed through out the latex clump together on the top as a soft, white, spongy mass. This soft coagulum or slab is washed, passed through a succession of rollers to squeeze out the excess water and to flatten it to a desirable thickness, and air dried, thus producing sheets of crepe rubber. Quite often, the sheets are smoked by exposing them to the pyroligneous acid vapours from burning wood. The smoked product is known as sheet rubber. Most of the rubber is exported in this form, but has to be broken down (milled) in a rubber mill, before chemicals can be mixed.

Uses – Around 70% of rubber production is consumed in the manufacture of tyres, tubes and other articles associated in the automobile industry; about 6% is utilised for footwear; and nearly 4% for wire and cable insulation. Other rubber articles are rubberised fabric, raincoats, hot water bags, gloves, shock absorbers, washers, gaskets, belts, hoses, sports goods, toys, erasers, adhesives, rubber bands and so on.

Hard rubber, vulcanite or ebonite (highly sulphurised rubber) is used in the electrical and radio engineering industries, for protective lining in chemical plants, and also in the fabrication of battery boxes, fountain pens, barrels, tobacco pipes, telephones, and combs.

Concentrated latex is used for most dipped goods such as gloves, balloons, and contraceptive appliances. Sponge rubber from foamed latex is used in upholstery, i.e., seating cushions, mattresses, pillows, in life belts and in carpeting. Rubber is also used in military clothing, pressurised suits for aircraft personnel operating at high elevations, frogmen's suits for divers and insulated suits for use in Arctic zones.

Substitutes of Para-rubber – Besides *Hevea brasiliensis* the search has always been on for other rubber-yielding species. Some of these are:

- *Castilla elastica* – It's a tall tree. Yields Castilla or Panama rubber, and was the chief source till the middle of the nineteenth century.
- *Ficus elastica* – It's a huge tree. The source of India or Assam rubber which is of low grade, and of little commercial importance at present.
- *Funtumia elastica* – A large tropical tree, yields lagos silk rubber
- *Landolphia heudelotti* – A woody climber; yields landolphia rubber.
- *Parthenium argentatum* – It's a low semi-shrub, and its roots are the main source. It yields guayule rubber. It is grown on a plantation scale. Rubber is extracted by macerating the plant with water.
- *Taraxacum kok-saghyz* – Tap roots are the main source, and the entire plant has to be sacrificed for obtaining the latex. It yields dandelion rubber.

In the recent years, to fulfill the increasing demand of wood and various forest produce, natural forests spread over vast stretches have been tapped. As a result of which these forests have undergone fast degradation. On one hand, while steps have been taken for restoring the degraded areas, there is also a need to search, and grow on large-scale the plant species, that could fulfill the human needs. Information given in Boxes 20.1 and 20.2, would give you an idea of some such species that are very well suited for the purpose.

Box 20.1: Woody Plants in Land Reclamation.

Indiscriminate use of forest resources and unsustainable land-use practices have led to the loss of green cover from vast tracts of land. To evolve a good land use policy the Union Government of India has constituted an apex body, the National Land Use and Wastelands Development Council, and Conservation Board, and the National Wastelands Development Board (NWDB). The NWDB has categorised wastelands into two groups - culturable and unculturable. The culturable wastelands are defined as lands having the potential for development of vegetation cover and not being used due to different constraints. Salt-affected lands, degraded forest lands, gullied/ravinous lands, shifting cultivation areas, overgrazed pastures and grasslands are included in this category. The unculturable lands are those which cannot be developed for vegetation cover and include barren, rocky or stony areas, steep sloping areas, and snow covered/glacial areas.

There is an urgent need to restore the green cover of such lands in order to prevent further erosion of topsoil, salinization and desertification, and to preserve the existing green cover of the earth so as to maintain its ecological balance. The green cover can be created through the planting of different types of plants, and if these can also meet our requirements of timber, fuel and fodder, we shall be able to solve many problems of the human population.

Judicious selection of such multipurpose plant species is a very important and crucial step in the process of land reclamation. These species should not only be suited for the specific climatic and soil conditions, but should also be fast growing and capable of improving the soils (nutrients, organic matter, moisture), as well as capable of promoting the ecological successional processes, besides being economically useful. Native species should always be given preference over introduced or exotic ones, as these are already well adapted to the local conditions and are therefore less likely to fail or cause any further damage.

1. *Acacia* spp. (Family: Fabaceae, Subfamily: Mimosoideae) Thorny shrubs or trees; several species are native to India and many have been introduced. These control wind, water and rain erosion; some are salt resistant, and many fix atmospheric nitrogen. These thrive in most severe environmental conditions and can be planted on bare lands, sand dunes and salt affected soils. Also yield timbers, gums, tannins, fodder and feed.

2. *Albizzia* (Family: Fabaceae; subfamily: Mimosoideae) These are medium sized trees. Twelve species are native to India. *A. amara* is native to drier regions of South India. It can grow on deeply sandy soils. It is recommended for afforesting arid zones. It yields timber, fuel and fodder.

3. *Eucalyptus* spp. (Family: Myrtaceae) These are evergreen aromatic trees, native to Australia. They are tall, fast-growing, straight and clear boled trees. These were introduced into India in the late 18th century near Bangalore and are adapted to various climatic, edaphic and ecological conditions. Some prefer hot and arid climate, and some moist areas. Some species have become popular for large-scale plantations, but are suspected to cause many short and long term damages, leading to serious ecological disturbance in soil, including nutrient and water conditions and even the wildlife.

   E.camaldulensis is a promising species, well adapted for moist swampy areas, saline and alkaline soils. It yields termite-resistant timber; its leaves yield essential oil which has medicinal value.

   E.citriodora is a fast growing, straight boled species. It grows on poor gravelly soils. It is recommended for reclaiming hills, skeletal soils and ravines. It yields timber, and fuel; and can be converted into charcoal; its leaves yield lemon scented oil.

4. *Prosopis* spp. (Fabaceae; subfamily: Mimosoideae) These are fast growing spiny shrubs or trees and are generally adapted to arid conditions.

   P.cineraria is a small shrub or a large tree growing in the semi and arid areas of north and north west India. It can withstand dry climates and is suitable for areas experiencing extremes in temperature. It helps control erosion in sand drift areas, gullies and ravines, and stabilizes sand dunes. It is well adapted to lopping. It increases organic matter and nitrogen in soil. Leaves are used as green manure and fodder. It yields timber and firewood, and is useful for making charcoal. Unripe pods are consumed as food.

   P. juliflora is a highly variable fast growing tree. It is native to central America and can grow on a wide variety of soils and is a good soil binder. It yields timber, firewood and charcoal; leaves are used as fodder. Although this species has many uses, and can green vast areas in short duration, it is highly aggressive and can invade intact or disturbed natural forest areas and become a dominant species.

5. *Leucaena latisiliqua* (Fabaceae, subfamily: Mimosoideae) is a large, unarmed, evergreen, fast growing shrub or small tree. Native to tropical America. It is a multipurpose tree, ideal for wastelands and checks erosion in desert soils, denuded areas, gullies, ravines, mined wastelands, and canal banks. It is recommended for green manuring and composting. It fixes nitrogen, yields timber, fodder and firewood which makes good quality charcoal.

Box 20.2: Petro Crops.

Wood and petroleum reserves have been the chief sources of energy. The consequences of their over-use and not being fast replenished they have become a cause of concern. The need for searching alternative energy providing sources has intensified. Recent findings indicate that hydrocarbon producing plants have the potential of emerging as alternative sources which can be inexhaustible, and ideal for deriving liquid fuels. This idea becomes all the more attractive if such lands that are not covered by forests, and those unsuitable for conventional agriculture (marginal lands) could be used for the cultivation of such plants.

The most critical step in bioenergy production is the selection of plant species that produce substances from which useful products can be extracted in an economically viable way. Many such promising species belong to the families Asclepiadaceae, Euphorbiaceae, Anacardiaceae, Caprifoliaceae, Asteraceae, Lamiaceae, Moraceae and Convolvulaceae.

Low molecular weight, non-polar constituents are extracted from certain plant species. This biocrude can be obtained by tapping the latex, followed by coagulation, or by extraction of the dry biomass using a suitable solvent in cases where latex tapping is not possible. Biocrude is a complex mixture of liquids, triglycerides, waxes, terpenoids, phytosterols and other modified isoprenoid compounds. It can be catalytically upgraded for use as liquid fuels. Hydrocracking of biocrude can convert it into several useful products like gasoline (automobile fuel), kerosene, and gas oil. A lot of research on this aspect is being carried out at the Indian Institute of Petroleum (IIP), Dehradun, in collaboration with the National Botanical Research Institute (NBRI), Lucknow.

Some potential Petro-crop species are:

	Plant species	Family
1.	*Euphorbia antisyphilitica*	Euphorbiaceae
2.	*Euphorbia caducifolia*	"
3.	*Pedilanthus tithymaloides*	"
4.	*Calotropis procera*	Asclepiadaceae
5.	*Calotropis gigantea*	"
6.	*Cryptostegia grandiflora*	"
7.	*Asclepias curassavica*	"
8.	*Pittosporum resiniferum*	Pittosporaceae
9.	*Copaifera longsdorfii*	Fabaceae
10.	*Parthenium argentatum*	Asteraceae
11.	*Simmondsia chinensis*	Simmondsiaceae

SAQ 5

What are the properties based on which a cork is graded for commercial use?

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....

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....

SAQ 6

i) How will you define rubber in chemical terms?

....

ii) In which form does rubber exist in a plant?

....

iii) Which plant, and its specific part would you suggest to tap for extracting raw form of rubber on a commercial scale?

....

....

iv) What features would you look for to identify the 'rubber tree'?

....

....

....

....

20.6 COMMERCIALLY IMPORTANT FIBRE YIELDING PLANTS

Fibre-Yielding Plants

Plants that yield fibres have been used by man for a long time and have influenced the advancement of civilisation. Plant fibres have had more extensive use than wool, silk ai other animal fibres. Presently too, plant fibres are of immense importance in our daily lives.

Botanically, a 'fibre' consists of very long narrow cells, many times longer than they ar broad. These are thick walled cells with a small lumen with simple, often oblique pits o their walls. Mature fibre cells are non-living and give mechanical strength to the plant body. Fibres are mainly composed of cellulose (64-94%) – a polymer of glucose $[(C_6H_{10}O_5)_n]$.

Classification of fibres

Fibres have been variously classified, the most common being on the basis of: i) origin and structure; and ii) use.

(i) **Origin and Structure** – Vegetable fibres (excluding wood fibres) can be grouped into three types according to their botanical origin – (a) soft, stem or bast fibres; (b) hard, leaf or structural fibres; and (c) surface fibres.

a) **Bast fibres** – These are associated with the phloem, pericycle and cortex, and are present mostly in the dicotyledonous plants. They occur as groups of mai cells strongly cemented to adjoining fibres by their middle lamellae. Some so fibres producing plants are jute, flax, hemp, and kenaf.

b) **Structural fibres** – These are strands of small, short, lignified cells ensheathing both xylem and phloem (fibrovascular bundle), and are found scattered in the leaves of monocotyledonous plants. The entire fibrovascular bundle serves as a unit fibre, and acts both as supporting and conducting tissu These fibres are highly lignified, coarser and weaker than the soft fibres. Son examples are sisal, Manila hemp and New Zealand hemp.

c) **Surface fibres** – Such fibres are borne on the surface of stems, leaves, fruits and seeds. The most important members of this group are the fibres arising a single-celled outgrowths from the seeds or inner walls of the fruits. Cotton ai kapok are commercially important surface fibres.

(ii) Use – Fibres can be classified into the following six categories, depending upon th use to which they are put: (a) textile, (b) brush, (c) plaiting and rough weaving, (d) filling, (e) natural, and (f) paper making.

a) **Textile fibres** – All fibres used for the manufacture of fabrics, netting and cordage are included in this category, for example, cotton and jute.

b) **Brush fibres** – Twigs, leaves and bark of various plants are used for making brushes and brooms. The most important of these are istle and sisal (hard fibres), piassava (surface fibres of palm leaves and stems), and broomcorn (th dense, bristly inflorescence of *Sorghum vulgare* var. *technicum*).

c) **Plaiting and rough weaving fibres** – More elastic flat strands or strips (plait are roughly woven into hats, sandals, baskets, chair seats, matting and thatche roofs of houses. Bamboo strips are used in the manufacture of fishing rods, furniture, baskets, and many more goods. Straw from wheat, rice, rye or barl is used for making hats.

d) **Filling fibres** – These are used in upholstery, and for stuffing cushions, and mattresses. These are also used for reinforcement and wallboard insulation. The chief stuffing fibres are kapok, cotton, jute, several hard fibres and grass

e) **Natural fibres** – Tree basts with tough interlacing fibres are sometimes extracted from the bark in layers and sheets, which yield rough clothing after pounding. The best known is 'tape cloth' which is obtained from the bark.

f) **Paper-making fibres** – Wood fibres, textile fibres and various grasses and sedges are used for making paper and paper products.

).6.1 Cotton

ıtanical name: ***Gossypium*** **spp.**
ımily: Malvaceae
ımmon names: Cotton, Kapas
= 13, 26

ıtton is one of the oldest fibre plants used by man, and presently too, it is the world's ɔst important non-food agricultural plant. Cotton fibre is the most valued textile fibre ıongst the many known to man.

orphology

ıe main stem bears spirally arranged leaves and branches, but no flowers. The leaves ar two kinds of buds – axillary and extra-axillary. Cotton exhibits dimorphic branching, ., vegetative (monopodial) and fruiting (sympodial) branches, the former developing ım the axillary buds, and the latter from extra-axillary buds of the upper nodes ig. 20.14). The leaves are large, palmately-lobed (3,5 or 7 lobes) and clothed with ılticellular stellate hairs. Flowers are large and showy, each surrounded by an ⁄olucre of large, leafy bracts (epicalyx) that are generally persistent. The fruit (boll) is ;pherical or ovoid, leathery capsule consisting of 3 to 5 locules. The content of each ⁄ision or loculus is called a lock within which six to nine seeds are present. The surface each seed is covered with hairs – long hairs or lint floss or staple, and short hairs or zz or linter. The capsule cracks at maturity and the contents expand into a white fluffy ıss which is pushed outside the capsule wall.

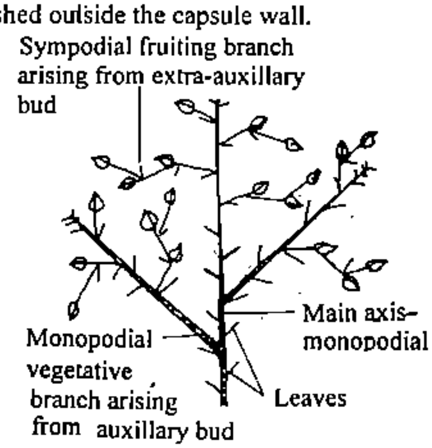
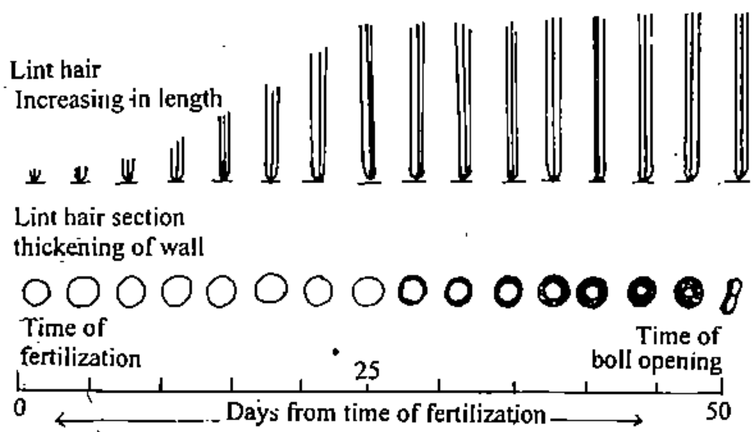


Fig. 20.14: The branching pattern in *Gossypium* spp. (From Kochhar, 1998).

ıe Cotton fibres are epidermal prolongations of the seed coat cells. Their primary wall is :hin elastic layer coated with cutin. The lumen is narrowed down by the deposition of perimposed layers of cellulose on the inner surface of primary walls during the course of eir development (Fig. 20.15). A mature fibre looks like a translucent, flattened, twisted, ore or less tubular structure with a broad base and an untwisted tapering apical end. The ımber of twists or convolutions per inch vary from 150 to 300. The outer surface of the ɔre is covered by a protective wax-like covering which gives it an adhesive quality.



;. 20.15: Diagram showing various stages in the development of lint hairs in a maturing cotton boll. (from Cobley & Steele, 1976).

Based on staple length, cotton fibres can be classified into three categories:

1. Long staple fibres – 2.5 to 6.5 cm in length, with fine texture and good lustre. This includes Sea-Island, Egyptian and American Egyptian cotton fibres. These are least common and most difficult to cultivate.
2. Standard medium or intermediate staple fibres – 1.3 to 5 cm; somewhat coarse. These include American upland cotton; high yielding of lowest value.
3. Short staple fibres – 9.5 to 19 mm; short, coarse and lustre less fibres. It includes Indian and other Asiatic cottons. It is used in making inexpensive fabric, carpets and blankets.

Commonly Cultivated Species

The four cultivated cotton species with a large number of varieties and hybrid forms can be classified into two groups – (1) **New World** or **American cottons** (*Gossypium hirsutum* and *G. barbadense*); (2) **Old World** or **Asiatic cottons** (*G. arboreum* and *G. herbaceum*). We shall.take-up these four species in brief.

Gossypium hirsutum (n=26), Upland cotton, American cotton, Bourbon cotton (Fig. 20.16).

Origin and Distribution: This species (Fig. 20.16) is native to Mexico and Central America, and most of the cotton grown in the world today is Upland cotton. It is grown in southern United States, South Brazil, Uganda, South and West Africa, Iraq, part of China, Turkey, Greece, India, Pakistan, and Australia.

On the basis of staple length, two important varieties of *G.hirsutum* are recognised – (1) American Upland short staple cotton (16-27 mm), and (2) American Upland long staple cotton (28-38mm).

Characteristics: Plants are small shrubs or trees with a few vegetative branches. The leaves are large, cordate, hairy and three to five lobed (Fig. 20.16). The bolls are large and rounded, but unlike *G. barbadense* they are usually green and smooth with a few oil glands. The seeds are covered all over with a white fuzzy coating.

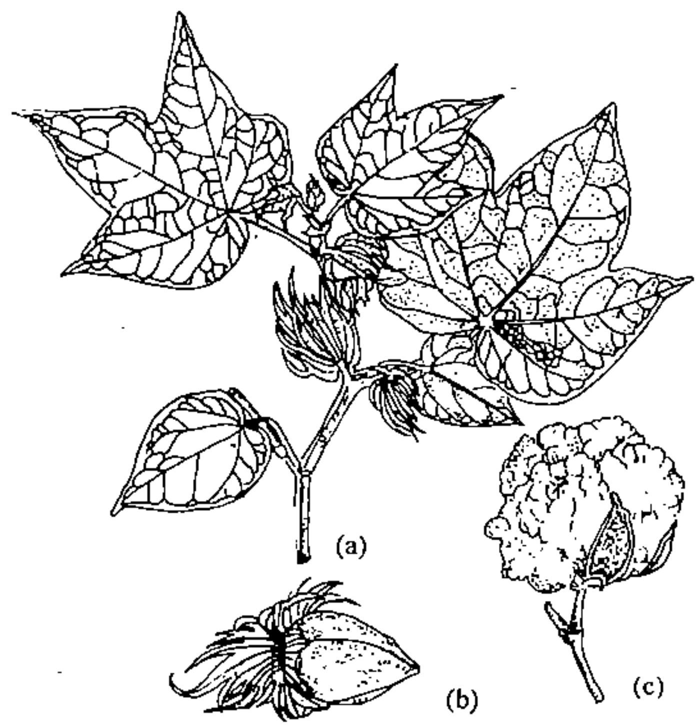


Fig. 20.16: *Gossypium hirsutum*. a) A sympodial branch, b, c) unopened, and opened bolls, respectively. (From Purseglove, 1988)

Gossypium barbadense (n=26), (Sea-Island, Egyptian cotton, Brazilian cotton, Peruvian cotton, Kidney cotton (Fig. 20.17).

Origin and Distribution: It is believed that this tetraploid cotton has evolved through accidental hybridisation between Asiatic and American diploid species, followed by doubling of their chromosome number. It is a native of South America and is highly esteemed for the length and fineness of its lint. The varieties Sea-Island cotton and Egyptian cotton are especially famous.

Sea-Island cotton (Fig. 20.17) is the finest of all cultivated cottons and is largely grown in the lesser Antilles of the West Indies, in Fiji and along a narrow strip of coastal mainland and islands off the coast of Florida, Georgia and southern Carolina in USA. The fine spun yarn is used in the manufacture of laces, cambric and fine hosiery. Egyptian cotton is grown in the Nile valley of Egypt and Sudan, to a limited extent in Turkestan, New Mexico, Arizona and California. The fibre is mainly utilised in the manufacture of goods where great strength is needed.

Characteristics: The plants are tall, annual shrubs, reaching up to three metres in height, bearing a few to many strong ascending vegetative branches. The leaves are three to five lobed. The bolls are usually large (3.5 to 6 cm long), dark green, prominently pitted with plenty of oil glands. The bracteoles are large, and are divided at the apex into 10-15 long, acuminate teeth. The fruit may be three or four-valved, each containing five to eight or more seeds that are fuzzy at the ends. The varieties differ in texture, length and colour of lint. In Sea-Island cotton the fibres are white or light cream coloured, silkier and lustrous, 38-51 cm long. The staple of Egyptian cotton is dark cream or buff coloured, 38-44 mm long and is somewhat inferior.

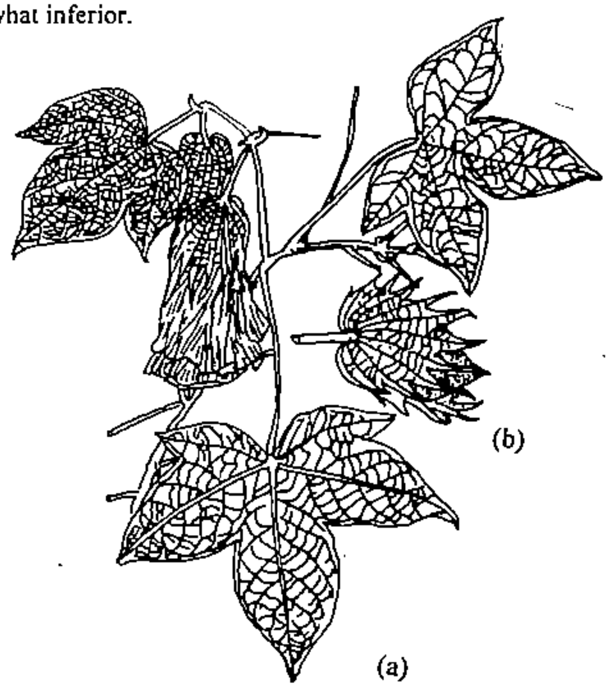


Fig. 20.17: *Gossypium barbadense.* a) A flowering twig. b) An unopened boll. (From Purseglove, 1988).

Gossypium arboreum (n = 13), Ceylon cotton, Chinese cotton or tree cotton (Fig. 20.18).

Origin and Distribution: It is native to the Indo-China region and at present is cultivated throughout India, Myanmar, Malaysia, the East Indies, China, Korea, Japan and Taiwan and Africa. In fact, India and Africa are the largest producers of this type of cotton.

Characteristics: The plants are annual or perennial shrubs, about 3 m high, with few or no vegetative branches. The bolls are three-celled (rarely four or five-celled), tapering structures, profusely pitted and have prominent oil glands on the pits (Fig. 20.18). The fruits open widely when ripe and contain up to 17 seeds per loculus. The seeds are small and are covered with greyish-green or rust coloured short hairs called fuzz. Staple, floss or lint (long hairs) are yellowish white or rusty-white, coarse and without lustre, but are strong and very short (9.5-19 mm).

Fig. 20.18: *Gossypium arboreum.* a) A sympodial branch. b) An unopened boll. c) An opened boll. (From Purseglove, 1988)

Gossypium herbaceum (n=13); Levant cotton (Fig. 20.19)

Origin and Distribution: This species is probably a native of tropical Africa and the Middle East and is now grown in China, Indonesia, North-western India, Pakistan, Iraq, Iran, Turkestan, Turkey, Greece and many parts of Africa.

Characteristics: The plants (Fig. 20.19) are shrubby, reaching a height of 1-1.3 m. The leaves are divided into 3 to 5 lobes (rarely seven). The bracteoles are widely flaring. The boll is three-celled, rounded, beaked, smooth surfaced and rarely with promenent pits. The fruit opens at maturity into 3 or 4 loculi, each containing up to 11 seeds. The seeds usually bear two coats of hairs – long lint hair (staple or floss) and short fuzz hairs (linter). The staple in short (9.5 –19 mm) and grey.

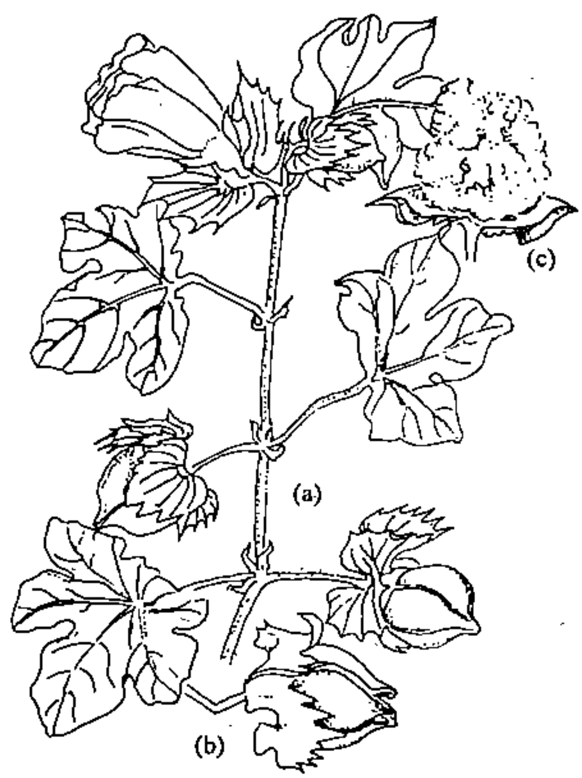


Fig. 20.19: *Gossypium herbaceum.* a) A twig with flower and fruit. b) An opening boll. c) An opened boll. (From Purseglove, 1988)

Cultivation

Cotton is basically a tropical crop and requires a minimum frost free growing season of 200 days, an abundance of sunshine and warm uniform temperature not below 21°C, but can withstand a temperature up to 43°C. The crop is susceptible to heavy rains, but adequate soil moisture (about 100 cm rainfall) is required in the early stages of growth, a relatively drier season during flowering and no rainfall during ripening or picking. Cotton grows well on deep friable soils with good humus content.

More than 80 per cent of the world's cotton production comes from just ten countries – Russia, USA, China, India, Pakistan, Brazil, Turkey, Egypt, Mexico and Sudan. The major cotton growing states in India are Maharashtra, Gujarat, Karnataka, Madhya Pradesh, Punjab, Andhra Pradesh, Tamil Nadu, Rajasthan and Haryana and the commonly grown species are *G.hirsutum* (50% in area), *G.arboreum* (29%) and *G.herbaceum* (21%).

Harvesting and Processing of Cotton

It begins about six months after sowing and is the most expensive operation of cotton cultivation. Where cheap labour is easily available, cotton is hand-picked, and picking is continued over a period of two months or more because all the fruits do not ripen at the same time. Cotton is picked as soon as the boll opens. If left for longer period cotton may fall or get damaged. It is desirable to pick dry cotton free from trash. Where labour is scarce, mechanical harvesters, which work on the principle of suction, are employed. The plants are defoliated first using chemicals like calcium cyanamide, which also forces all the capsules to ripen simultaneously.

Raw cotton is passed through a number of processes before it can be spun into yarn and woven into cloth (Fig. 20.20). For a long time, hand separation of fibres was the only way to remove fibres from the seeds. The invention of the cotton gin in 1793 revolutionised the cotton industry and eased the tedious method of hand processing. The various steps in the processing of raw cotton are as follows:

1. Ginning – After the raw cotton has been cleared of dirt and other plant fragments, it is conveyed to the hopper of a gin to separate the fibres.
2. Baling – The fibre coming out of the gin is pressed hydraulically into bales of around 200 kg, which are partially wrapped in jute or hessian covers (baggings), bound with iron bands called 'ties' and are marketed in this form.
3. Picking – Baled cotton is first broken and then the fibres are passed through a 'scutcher' where they are beaten, shaken and rolled to remove all the foreign matter and the strands are separated and delivered in a uniform layer. At the last picking machine the cotton is condensed into a sheet form called 'lap'.
4. Carding – The remaining lumps of fibres are further separated into individual fibres on the carding machines which help to place the fibres parallel, and also facilitate the removal of immature fibres and impurities.

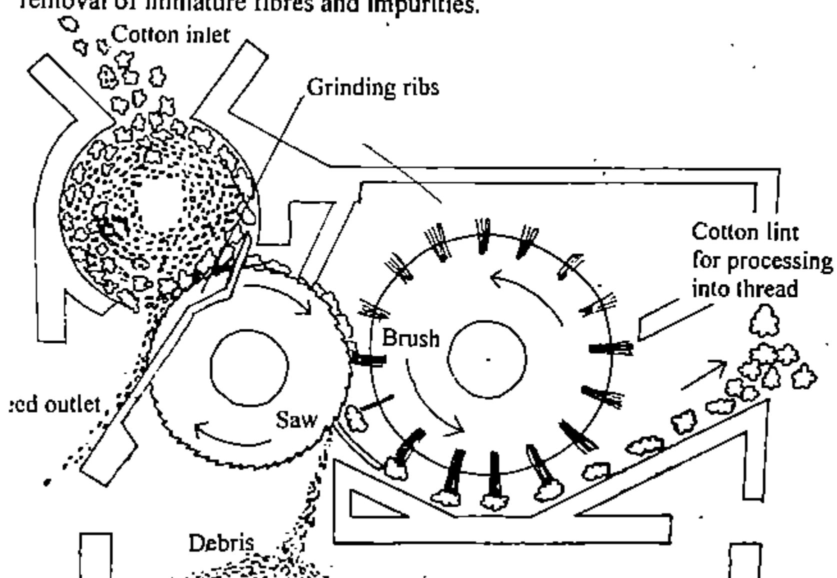


Fig. 20.20: A diagrammatic representation of initial processing of cotton fibre. (From Simpson & Conner – Ogorzaly, 1986)

5. Combing and drawing or drafting – Combing is a process wherein short fibres are removed, while drawing consists of straightening and aligning the fibres. Generally, two drawing operations are employed after carding and two after combing.

The fleecy lap is condensed through a funnel into a soft untwisted rope or 'silver'. It is further drawn out, slightly twisted and wound on spools. In the spinning process, the cotton is further drawn out and twisted into a fine yarn of required strength and firmness. The finished yarn is wound on bobbins or spools and sent to the weaving machines.

Properties of Cotton

Cotton is an exceedingly valuable fibre because it is soft and supple. It has high tensile strength , i.e., it can withstand tearing or breaking under stress and it is stronger when wet. Cotton fabrics have dimensional stability, i.e., resistance to change in length or width. It also has a long life which makes it suitable for industrial uses (tyre cord, machinery belts, twines). Cotton resists repeated bending over a longer period than most other fibres. It has good weaving quality and launderability.

Utilisation of Cotton

Cotton is a major cash crop and its utilisation is varied. The major use is of lint from the seed which is used for clothing, household fabrics (towels, sheets, upholstery), and industrial articles (bags, belts, industrial thread, tents, tarpaulins, hoses, insulation, cellulose). The seed yields cotton seed oil; seed cakes are used as livestock feed and fertilizer. The hull is used as low-grade roughage and in the manufacture of high grade paper and fibre board, cellophane, rayon, varnishes and explosives. The linter is used for stuffing pillows, quilts and mattresses. The stalks are used as fuel and for paper pulp. Cotton can be modified chemically in a number of ways according to the use to which it is going to be put:

i) Mercerised cotton – It is prepared by treating the yarn or cloth under tension with Sodium hydroxide. The process is named after John Mercer. It gives the cotton a high lustre, makes it easier to dye and produces brighter and fuller shades.
ii) Water repellent cotton – The individual fibres are treated with chemicals such as Sodium ammonium stearate. After drying they are passed through Aluminium acetate. The metallic soap-like deposition on the fabric gives it water repellency and it is used in awning, tents and other protective coverings.
iii) Absorbent cotton – It is prepared by removing the oily or waxy coating on the fibre so that it can absorb more water. It is used in the manufacture of underclothing, towels, napkins and bandage materials.

SAQ 7

Match the items given in Column I with those of Column II. You can indicate the correct match with arrow.

Column I	Column II
Jute	Brush fibre
Sisal	Bast fibre
Cotton	Structural fibre
Sorghum	Textile fibre

SAQ 8

State whether the following statements are **true** or **false**.

i) Cotton fibres orginate in the seed coat epidermis.

ii) *Gossypium barbadense* is the source of Egyptian cotton.

iii) *Gossypium herbaceum* yields long-staple fibre.

iv) Cotton is the world's most important non-food agricultural plant.

0.6.2 Jute

otanical name: *Corchorus* spp.
amily: Tiliaceae
ommon name: Jute (*Corchorus capsularis* – White jute, Narcha;
C. olitorius – tossa jute; Jew's mallow)
= 7

ıte is the least expensive, but most important of all the bast fibres. The fibre is obtained om the stems of two cultivated species of *Corchorus* – *C.capsularis* (Fig. 20.21) and *olitorius* (Fig. 20.22).

rigin and Distribution: The primary centre of origin of *C.olitorius* is Africa with a condary centre in India or Indo-Burma. *C.capsularis* probably originated in Indo-ırma. At one time it was a monopoly crop of India, which produced 99% of the world's oduction. India and Bangladesh are the major producers these days followed by China, yanmar, Nepal, and Brazil. Bangladesh is the largest exporter of raw jute while India ads in the export of manufactured jute products. In India, the major jute growing states e West Bengal, Assam, Bihar and Orissa.

ʒ. 20.21: *Corchorus capsularis.* a) A twig with fruits, b) A fruit. (From Purseglove, 1988).

Fig. 20.22: *Corchorus olitorius.* a) A twig with various developmental stages of fruits, b) A fruit. (From Purseglove, 1988).

ant Morphology

ıth the cultivated species are woody, branched annuals having simple, ovate, serrate ırgined leaves with peculiarly curved bristles (auricles) near the base (see arrows). ›wers are solitary or arranged in few flowered cymes. *C.capsularis* has glabrous leaves ntaining a bitter glycoside (corchorin). Small yellow flowers give rise to small, more less globular, much wrinkled capsules, flattened at the top and enclosing brown seeds. *›litorius* is a much taller species having leaves with a shining upper and a rough under ·face, and with no bitter taste. The yellowish flowers are larger than *C. capsularis*. The it is a long cylindrical, ridged capsule with an elongated beak. Seeds are small, bluish ·en to steel grey or black.

ltivation

capsularis forms about 75% of the jute crop in India. Jute is a rainy season crop and ıws best on warm, humid and rich loamy or alluvial soils, with an annual rainfall of)-250 cm, an average temperature of 17-38°C and Relative Humidity around 70-90%. ͽ fertile alluvial soils of the river delta of the Ganges and Brahmaputra, and their ıutaries are highly suitable. Seeds are broadcast and the plant matures within 3 to 5 nths.

Harvesting and Processing of Jute

Plants are harvested when nearly 50% of them are fruiting. At this stage both the yield and quality of fibre are good. Plants are cut close to the ground with a sickle or pulled out by hand when growing under water. The cut stems are tied in small bundles and left in the fields for two or three days till the leaves wilt and drop off.

The fibres occur in long wedge-shaped bundles outside the xylem. They are grouped in concentric rings alternating with the thin-walled tissue of the phloem which disintegrates during retting. Each of the fibre bundles is one strand or filament (reed) composed of four to fifty cells. The individual fibre cells are seldom longer than two or three mm.

The bundles of stems are taken to a stagnant pool or ditch and laid flat in the water, arranged side by side so as to make a regular platform. Another layer of bundles is placed on top at right angles to the first. The surface of the bundles is covered with wee or other refuse and then heavily loaded with stones and logs to keep them submerged. This process is known as **retting** and it takes 10 to 30 days time. It is considered complete when the bark can be easily peeled off. For stripping the plants of their bark, the workers stand in waist deep water. First the root or butt ends of the stems are beaten with a wooden mallet to loosen the fibres. Then the free ends of the loosened fibres are wrapped firmly round the fingers and the stems are jerked backward and forward in water, thereby separating fibres from the stick. The stripped fibres are lashed on the surface of the water to remove the adhering bits of periderm and pith, washed in clean water and wrung out. They are then spread out in the sun on bamboo racks for two to three days and rolled into bundles. The average yield of fibres is about six per cent of tl stem fresh weight.

Properties of Jute

Jute fibre strands range from 1.8 to 3 m in length, are pale yellow or yellowish white in colour, and possess a silk-like lustre. The fibres tend to deteriorate when exposed to dampness. Normally they are stiff, brittle and coarse with low stretchability and elasticity. During processing, the ends of some of the individual fibres in the bundle are loosened, resulting in a varying amount of hairiness which prevents slipping. The individual fibres vary from 2 to 5 mm in length, are polygonal in cross section and have smooth surface. They have a wide lumen. They take dye quite well, but jute is difficul to bleach.

Utilisation of Jute

Jute is the world's most important bagging and wrapping textile. About 75% of the ju produced annually is used in the manufacture of sacks and bags. It is also used in t manufacture of rugs, blankets, carpets, tarpaulins, cloth backing, carpets, twine, ro upholstery, curtains and coarse cloth. The leaves and young shoots are an importa source of vegetable food in Egypt, Sudan and Greece. Jute 'butts' are used in t manufacture of paper and paperboard.

SAQ 9

Label the True statements as 'T' and False as 'F'.

☐ i) Jute fibres occur as wedge-shaped, bundles outside the xylem.

☐ ii) Retting of jute takes about a months time.

☐ iii) Jute is easy to bleach.

☐ iv) Leaves and young shoots of jute are edible.

☐ v) A very small percentage of the jute produced annually is used in t manufacture of sacks and bags.

0.6.3 Coconut

otanical name: ***Cocos nucifera***
amily: Arecaceae
ommon names: Coconut, Nariyal, Dab.
= 16

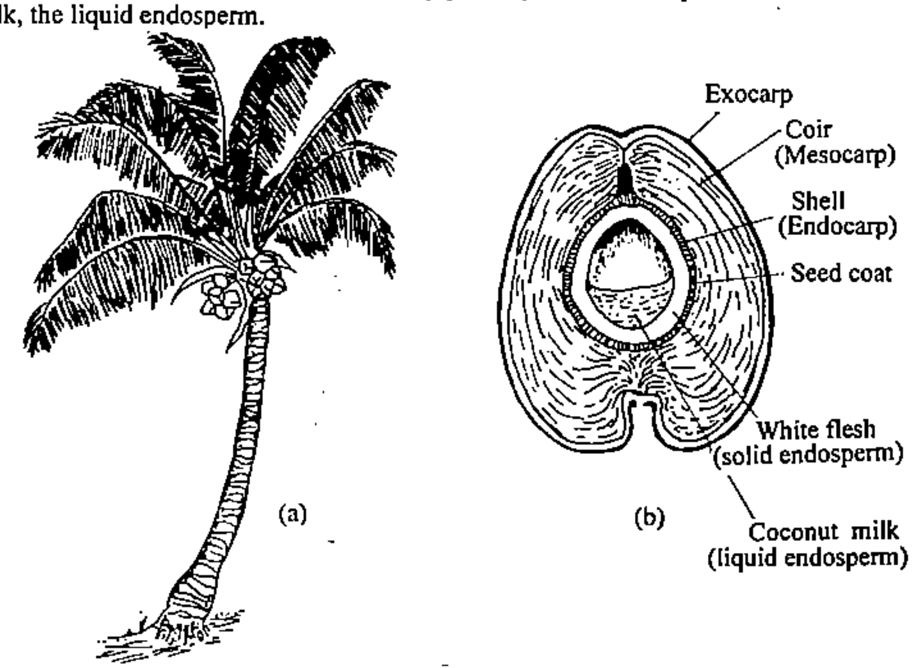
ommercial coir is obtained from the fibrous husk (mesocarp) of the fruits of coconut ılm.

rigin and Distribution: Coconut is believed to have originated somewhere in the Indo ıcific region from where it has been scattered throughout the coastal regions of the orld by sea currents. The plant is widely grown in the coastal and deltaic regions of opical and subtropical countries. Philippines, Indonesia, India, Mexico, Papua New uinea, West Malaya and Sri Lanka are the major countries growing coconut, USA being e largest importer. In India, coconut cultivation is mostly confined to coastal areas of rissa, Kerala, Tamil Nadu, Karnataka and Andhra Pradesh.

lant Morphology

oconut palm is a tall tree (15 to 30 m) having an inclined trunk (towards light and along e direction of wind) marked by prominent ring-like leaf scars (Fig. 20.23). The main em is swollen at the base and is covered by 20 to 30 large paripinnate leaves about 8 to 6 m long, each weighing 10 to 15 kg. The inflorescence is axillary, and consists of central axis with up to 40 lateral branches. The whole inflorescence is enclosed by a athe. Male flowers are numerous (200 to 300) borne singly or in 2's or 3's in the upper ırt of the floral axis. Female flowers are few, and located usually singly at the base of e inflorescence branches.

he fruits ripen in about 9-12 months. Generally, 3 to 7 fruits mature per inflorescence. he mature fruit is a fibrous drupe, usually ovoid, 1.2 to 2 kg. It is differentiated into xocarp' which is tough, smooth, hard and green when young and is shed off at maturity; iddle thick 'mesocarp', constituting the coir of commerce; the inner, hard dark brown ndocarp' enclosing a single hollow seed with a thin brown testa; solid endosperm or ıeat – the copra of commerce; and a cavity partially filled with liquid which is coconut ıilk, the liquid endosperm.



ig. 20.23: Coconut (*Cocos nucifera*). a) A coconut tree bearing fruits. b) L.S. of a coconut fruit. Coir, the fibre of commercial importance is obtained from the mesocarp. [After: a) Purseglove, 1988; b) Simpson & Conner–Ogorzaly, 1986].

'he fruits are harvested when still green to obtain the best quality coir. The fruit is ehusked in two ways – by ramming the coconuts against a sharp iron spike fixed firmly ı the ground at an inclined level and splitting the husks into three or four pieces, or by ɔlitting with a cutlass and with the help of bursting machines. The husk is then ıbjected to retting to remove the tough interstitial substances closely adhering to the fibrous mass. Retting is usually done by submerging the husk in lagoons or soaking pit just within reach of brackish sea water. The pits are covered with palm leaves and weighted down with mud to prevent the husks from floating.

Retting time is just two weeks for the production of bristle and mattress fibres, but up tc nine months for the manufacture of coir yarn. On completion of retting, the husks are taken out of the water and washed thoroughly and repeatedly to remove mud and dirt. The skin is peeled off and the husks beaten with wooden mallets to knock out the pith a; other extraneous matter. Disentangled fibres are rinsed and sun-dried. The fibres are further cleaned and hackled with steel combs to separate the stiff fibres and are then graded.

Coconut fibre strands are up to 0.3m in length, the surface of the fibre bundle is occasionally covered with small lens-shaped silicified stegmata. Each fibro-vascular bundle consists of a thick-walled sclerenchymatous sheath surrounding a collateral bundle which disintegrates on maturity resulting in a hollow cavity that encloses air and helps in buoyancy.

Properties of Coir: The fibre is valued for its lightness, elasticity, exceedingly high resistance to mechanical wear and dampness, especially in sea water, and its sound insulating qualities. However, it is less durable and has more rough surface than other vegetable fibres.

Utilisation of Coir

The fibre has a natural resilience, durability and resistance to water and is used in the manufacture of cordage, especially marine cables and hawsers for ships and sailing craft Coir fibres have a wide application in the manufacture of mats, matting and coarse cloth rubberised coir, coir bags for lifting coal from mines; packing material; insulation board as a source of furfural and tannins; and as paper pulp. Bristle fibres are used for making brushes, brooms and many other items.

SAQ 10

State whether the following statements are **True or False**.

☐ i) Exocarp of coconut yields the coir of commerce.

☐ ii) Brazil is the largest exporter of coconut.

☐ iii) Coconut fruits are harvested when still green to obtain the be quality coir.

☐ iv) Coconut fibres are separated by subjecting husk to retting.

☐ v) Coir is more durable and softer than other vegetable fibres.

20.7 SUMMARY

- In this unit you have studied about wood, fibres, cork, rubber and related products.
- Four commercially important wood sources – teak, shisham, pine and cedar have bee dealt with, particularly highlighting their distribution, wood characteristics and specific uses.
- Wood used for varying purposes is procured from diverse sources, and is processed t make it suitable for specific purpose such as fuel, making containers, obtaining their chemical derivatives, paper making and so on.
- Cork is obtained from mature cork oak tree. It is formed as a result of secondary growth activity of the plant. Cork being light, buoyant, resilient, insulating, chemically inert, non-conductor of electricity, impervious to liquids, absorbing sound and vibrations, highly resistant to deterioration, and slow to catch fire, is an ideal material for a wide range of uses.
- Rubber derived from the latex of woody plants is a versatile material. The latex is subjected to various treatments to produce different kinds of rubber products.

- Fibres derived from plants, have numerous applications in our daily lives. Cotton, jute and coir are well known plant fibres of this region. The fibres originate in different tissues of the plant such as phloem, the cells enclosing the vascular bundles, surface of plant organs such as stems, leaves, fruits and seeds. The fibres containing plants are harvested and variously processed to separate the fibres from other tissues. The fibres thus isolated are woven into a variety of products.

20.8 TERMINAL QUESTIONS

1. Write a brief account on any one commercially important timber yielding plant of our country, commenting on its distribution, characteristics and uses.

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2. Write short notes on the following:

   i) Wood distillation.

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   ii) Tapping for Naval Stores.

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   iii) Processes of making wood pulp.

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3. What are the basic steps involved in paper making? Write a brief account.

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4. i) From which region of the plant is cork derived?

ii) What kind(s) of tissue(s) is cork made of?

iii) Which properties in a cork make it suitable for commercial purposes?

iv) List a few uses of cork.

5. Name a commercial source of rubber. How is it tapped from the plant and made a marketable product?

6. Compare the fibre characteristics of *Gossypium barbadense* and *G. hirsutum*.

7. List the properties of cotton fibre, because of which it is put to so many uses.

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8. Describe the process of retting of jute.

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9. List the major uses of jute.

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10. List the properties and uses of coir.

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20.9 ANSWERS

Self Assessment Questions

1. See Section 20.2

2. See Section 20.2

3. i) See Subsection 20.3.1. Hint: 99% of the dried wood is combustible.
   ii) Hint: The density, chemical composition, and amount of moisture.
   iii) About 4600 cal/kg.
   iv) Charcoal, pyroligneous acid, wood tar and wood gases.

4. i) c
   ii) f
   iii) a
   iv) b
   v) d
   vi) e

5. See Section 20.4

6. i) See Section 20.5
   ii) See Section 20.5. Hint: as latex.
   iii) One example is *Hevea brasiliensis*; the lower part of the tree trunk.
   iv) See section 20.5.

7. Jute Bast fibre
   Sisal Structural fibre
   Cotton Textile fibre
   Sorghum Brush fibre

8. i) True
   ii) True
   iii) False
   iv) False

9. i) T
   ii) T
   iii) F
   iv) T
   v) F

10. i) False
    ii) False
    iii) True
    iv) True
    v) False

Terminal Questions

1. See Section 20.2
2. i), ii) and iii) See Subsection 20.3.4
3. See Subsection 20.3.4
4. i), ii), iii) and iv) Refer Section 20.4
5. See Section 20.5
6. Refer Subsection 20.6.1
7. See Subsection 20.6.1
8. Refer Subsection 20.6.2
9. See Subsection 20.6.2
10. See Subsection 20.6.3

APPENDIX 20.1: FEATURES OF WOOD

Wood is a secondary tissue produced chiefly in the stems of gymnosperms and dicotyledons as a result of the activity of meristematic layer(s), the cambium. Refer to Sections 10.2, 10.3 and 10.4 of LSE-06 course. The active cambium continues to produce inwardly secondary xylem and outwardly secondary phloem year after year so that the stem increases progressively in thickness. Secondary xylem persists and eventually forms the great bulk of the plant body while the secondary phloem is pushed farther out and is gradually crushed and sloughed off the tree.

Wood is a heterogenous tissue, composed of several different types of cells which perform different functions such as: (1) giving mechanical support; (2) conduction of water; and (3) distribution and storage of carbohydrates. In woods of gymnosperms (softwoods) the first two functions are carried on in cells known as 'tracheids'. In woods of angiosperms (hardwoods), mechanical support comes from several types of wood fibres which make up a large part of the woody tissue, while conduction of water is carried on in tubular cell fusions known as vessels. Tracheids are present occasionally. The third function of wood elements is carried on by the thin-walled parenchymatous cells which are the only physiologically active cells in wood. These cells may be the wood parenchyma cells which are arranged vertically in the stem or the ray parenchyma cells which are arranged horizontally.

Diagnostic features of woods

The different arrangement of the various types of cells helps us to identify different types of woods. The gross morphological characteristics that help distinguish woods are **pores, early and late wood, growth rings, rays, sapwood and heartwood, grain, and figure.** See also Sections 10.4 and 10.5 (LSE-06). These features help us to determine the economic importance of different woods, and also their efficient utilization for different purposes.

(i) **Non-porous and porous woods:** Pores are vessels when seen in cross section, and their presence or absence is an easy means of classifying woods. Softwoods lack vessels and hence pores, and such woods are called "non-porous woods".

Hardwoods have vessels, and thus are "porous woods". Porous woods can be classified into two distinct types – a) **diffuse porous** where the vessels are almost uniform in size or diameter and are distributed randomly throughout (example – *Acer, Populus, Betula*); (b) **ring porous** where vessels of early wood are distinctly larger than those of the late wood, or they may be restricted to the early wood. The pores seem to be arranged in concentric circles when seen in a transverse section. The outer and inner portions of these circles differ with regard to the number and size of pores.

(ii) **Early and late wood** : In temperate regions, and in those parts of tropics with pronounced wet and dry seasons, the cambium experiences alternating periods of activity and dormancy, resulting in the formation of definite concentric rings of secondary xylem. During spring and early summer, when growing conditions are favourable due to abundant water supply, the cambium cuts off fairly large and thin-walled wood elements with large lumen. These wood elements form the 'spring or early wood'. As the season progresses and water supply diminishes, a denser type of wood is laid down in which the wood elements are smaller with thicker walls and narrow lumen. These elements form the summer or late wood. Thus there is a sharp transition between the cells produced at the end of the growing season and those formed at the beginning of the succeeding one. This cyclic pattern of activity is repeated year after year giving rise to what seems like concentric rings, in a cross section of stems, and is known as growth rings. See Box 10.1 (LSE-06) also.

(iii) **Sapwood and Heartwood** : Sooner or later many of the wood cells lose physiological activity and serve only to give strength to the tree. As wood stems grow older, the inner-most growth rings lose their vital functions of conduction and storage. They die out completely, become plugged by tyloses (outgrowths from parenchyma cells through a pit cavity into a tracheary cell, partially or completely blocking the lumen of the latter, become variously coloured and resistant to decay owing to a lack of moisture and deposition of gums, resins, and other waste materials in them (see Fig. 10.11 B, LSE-06). These cells of the inner darker region form the **heartwood or duramen**. Such heartwood is usually capable of a high polish, and is very good for making furniture and other high grade wood working industry. The outer light coloured region of varying width forms the **sapwood or alburnum**. The cells of the sapwood are physiologically active. The boundary between the two is commonly irregular. The innermost part of the sapwood is continuously being changed, resulting in a progressively expanding core of heartwood.

(iv) **Texture, Grain and Figure** : **Texture** refers to the relative size and quality of the various wood elements. Woods with many large vessels are said to have a coarse texture, and these are rough to touch. Those woods with no vessels or very small vessels are said to have a fine texture, and are smooth to touch. **Grain** refers to the structural arrangement, i.e., alignment and sorting of the wood elements. Woods are straight grained when the fibres are oriented parallel to the main axis. Woods are also designated as spiral grained, interlocked grained, even and uneven grained, depending upon the orientation of the fibres. **Figure** refers to the design or pattern that appears on the surface of wood and may be due to the kind of grain or the colouring matter that has penetrated the tissues, or both. It can make the wood highly valuable for decorative purposes. This is due to the different types of grains in combination with the rays, rings, sapwood, heartwood and other cell arrangements. The figure of a wood varies greatly with the plane in which it is cut.

Chemical properties of wood

Dry woods contain three major chemical constituents – cellulose (45-60%), hemicellulose (15-30%), collectively termed holocellulose, and lignin (20-35%). Additionally, many minor chemical compounds like resins, oils, fats, tannins, alkaloids, gums, minerals and traces of organic acids and their salts could be present which vary from species to species. Cellulose forms the basic structural framework and is economically the most important. Lignin fills the spaces within the cellulose network where it is chemically bonded and contributes to the stiffness and rigidity of the cell walls, although it does not increase the tensile strength. Woods with a high percentage of cellulose and a low content of gums, resins, dyes and tannins are used in the manufacture of paper, rayon, cellophane, explosives and lacquers. On the other hand, woods with high content of tannins, resins and certai essential oils, which increase the durability of wood, are used in construction work.

Physical properties of wood

These include both its **non-mechanical** and **mechanical** properties. The non-mechani properties of wood are its moisture content, density, durability, surface characteristics (lustre, odour, taste, colour, and irritants) and thermal properties (thermal conductivity electrical conductivity, acoustic properties). Mechanical properties of wood include strength, toughness, hardness, cleavability and stiffness.

(A) Non-mechanical properties

i) **Moisture content** – Freshly felled timber may contain 30 to 200 per cent moistu by dry weight. Sapwood is generally more moist than heartwood. Hardwoods do show much difference in moisture content of sapwood and heartwood. The wood begins to lose moisture as soon as it is exposed to the dry atmosphere. The free water (from cell cavities) evaporates first and its loss is not accompanied by shrinkage or any other appreciable change in the properties of timber. Further dry often leads to the loss of all the free water resulting in the compaction of cells. Al the fibres become stiffer and stronger, thereby altering the mechanical properties wood. Woods shrink chiefly at right angles to the long axis and very little lengthwise. This whole process is known as **seasoning** of wood, which results in an increase in strength, hardness, stiffness and durability of wood. However, seasone woods do tend to absorb water and swell in humid conditions, as you might have experienced yourself when doors seem to get stuck during the rainy season.

ii) **Density** – Density of wood refers to the mass of cell wall material per unit volum However, while determining wood density, the amount of infiltration products is also taken into account as it is not separable from the wood substance proper. Therefore, it is often referred to as the relative density of wood, and is usually expressed in terms of **specific gravity**, i.e., the ratio of the weight of a piece of wood in air to the weight of an equal volume of water. Woods of varying specific gravities are known. For example, the specific gravity of *Aeschynomene* (Fabacea is 0.04, and that of *Krugiodendron ferreum* (Rhamnaceae) is 1.40. Most woods ha a specific gravity of less than 1.0 and are lighter than water, enabling them to float If immersed long enough, the air in the wood gets displaced by water and it sinks. Density is often taken as an indicator of the strength of wood, and it is assumed th heavier woods are stronger. But this may not always be so, because the presence o gums, resins and other infiltrated compounds, and water could affect the weight without affecting the strength. Density of a wood also affects its elasticity, which i turn affects its ability to conduct sound. This property is used in the construction o buildings and musical instruments. Woods that absorb sound waves and do not reflect them are used for panelling concert halls to reduce echoes. On the other han some woods if not affected by decay causing organisms, on tapping produce a clea ring and are used in constructing musical instruments like pianos and violins.

iii) **Durability** – The natural ability of woods to resist the attack of decaying organism such as bacteria, fungi and insects is known as durability. Wood can be damaged b wood-inhabiting fungi, wood boring insects, and marine borers. Wood rotting fung (a type of wood-inhabiting fungi) can actually digest the cell walls of tracheids and fibres through their enzymatic action, greatly altering their physical and mechanica properties. Wood staining fungi and moulds (also wood inhabiting) do not secrete digesting enzymes, and derive most of their food from the cell contents. This does not alter the strength much but causes discolouration. Moulds cause only superficia colouration, while stain fungi penetrate deep into the sapwood resulting in deep staining, and reducing the decorative value.

Among the wood boring insects, insect larvae of various species attack felled timber. Many of these hatch from eggs laid in the inner bark and later tunnel and ruin the sapwood. In some cases adult insects such as subterranean termites, ambrosia beetles and carpenter ants are responsible for deterioration, making holes which reduce the structural strength of wood. Termites tunnel in the near ground timber and may completely destroy the inner structure, leaving the surface untouched.

Among the marine organisms, marine borers like gribble (crustaceans) and shipworm (molluscs) bore into underwater wooden structures such as dockage, and hulls of boats.

Woods are usually protected from attack of wood-destroying organisms by seasoning, or by treatment with chemical preservatives like Pentachlorophenol, Copper naphthenate, Zinc chloride, or compounds of Mercury, Chromium and Arsenic.

Surface characterisitcs – **Lustre** is the ability of wood to reflect light and depends on the angle at which light strikes the surface, the plane of the section in the direction of exposure, the cell wall structure and compostion, and infiltration products contained in the wood.

Odour is dependent upon volatile compounds such as essential oils which are themselves not a part of the wood substance. It is generally more pronounced in green than in seasoned wood. Several woods have a very characteristic odour which can either be pleasant (sandalwood) or unpleasant (bald cypress and catalpa).

Colour and **figure** of a wood determine its aesthetic value and vary from species to species, and even within a species. Colour of the sapwood is not distinctive and can vary from grey to pink or red, while that of heartwood is distinctive for a species (light yellow of Citrus family; purple or rose red for *Juniperus virginiana*).

The ability of wood to take polish, i.e., to permit the imparting of a smooth, glossy surface to the faces of exposed cell walls greatly determines its usefulness in interior decoration.

Thermal properties – Wood is a poor conductor of heat, electricity and sound, which makes it useful for many applications. Lack of thermal conductivity makes dry wood resistant to the passage of heat, making it highly suitable as a building material and as handles of cooking utensils. Perfectly dry wood is also resistant to the passage of electric current, but moist wood is a partial conductor.

) **Mechanical Properties of Wood**

ese properties express the behaviour of wood under applied forces and enable it to thstand external stresses that could alter its shape and size or cause deformations.

Strength – This is measured by different kinds of primary stresses to which a wood is subjected and in general is influenced by the direction of the grain. Several types of strength are recognised:

a) **Crushing or compression strength** – is a measure of the ability of a wood to resist a load that tends to crush the wood components, and is directly proportional to its specific gravity. It is an important consideration in making columns and posts which support buildings.

b) **Tensile strength** – is the resistance of a wood to forces operating from opposite direction that tend to pull the wood apart (parallel or at right angles to the grain).

c) **Shearing strength** – is the ability of the wood to resist forces which tend to make the fibres slide past one another, or is the measure of resistance offered to opposite forces which tend to tear (or shear) it apart, may be applied parallel to the grain, perpendicularly or obliquely.

d) **Cross breaking, static or bending strength** – is usually applied to beams, girders, barn rafters, stringers and scaffold platforms which are supported at both ends and loaded between these points. It refers to forces that can cause the beam to break. This involves all the above three types operating together.

) . **Toughness** – This is a measure of the capacity of a wood to withstand repeated, sudden, sharp blows or shocks. A tough wood is one that will not split or tear apart easily. This shock-resistant property is very useful in the manufacture of athletics goods, wheel spokes, hammer or axe handles. The toughness of wood depends mainly upon the amount of wood substances present, the composition of cell walls and the middle lamella, and the grain of the wood.

iii) **Hardness** – This is the ability of a wood to resist indentation, abrasion and wear. It is greatly influenced by factors such as weight, number and arrangement of wood fibres, presence of knots, and decayed areas.

iv) **Cleavability** – This refers to the ease with which a wood can be split into two. Woods with high cleavability are suitable for conversion into firewood or kindling. High resistance to cleavage is desirable for nail or screw holding purposes.

v) **Stiffness, and flexibility or resilience** – Stiffness is the measure of a wood's ability to resist forces that tend to change its shape, while flexibility or resilience is the ability of wood to withstand temporary deformation and return to its original shape when the stresses are removed. The flexibility of a wood is governed by the nature of its elements and the amount of air contained within the cells, and is important in the selection of woods for the manufacture of rail blocks or railroad ties (railway sleepers).

;LOSSARY

dulterant - spurious substances employed in admixture.
nti-spasmodic - relieving or preventing spasms
arminative - expelling gas from the stomach and intestines, a carminative medicine
iuretic - increasing the secretion and flow of urine
yspepsia - impaired digestion / indigestion
xpectorant - gas or wind in the stomach or intestines
ubefacient - causing redness, as of the skin. Any external application of the skin

FURTHER READING

1. Kochhar, S.L. 1998 (Second edition). Economic Botany in the Tropics, Macmillan Indian Limited, New Delhi.
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Uttar Pradesh
Rajarshi Tandon Open University

UGBY -02
PLANT DIVERSITY-II

Block

4

FAMILIES OF ANGIOSPERMS

UNIT 21	
Dicot Families – 1	**5**
UNIT 22	
Dicot Families – 2	**63**
UNIT 23	
Monocot Families	**133**
UNIT 24	
Some Unusual Plants	**175**

BLOCK 4 FAMILIES OF ANGIOSPERMS

The first three units of the block, i.e., 21, 22 and 23 deal with the taxonomic study of dicotyledonous and monocotyledonous taxa. These units titled as 'Dicot Families –1', 'Dicot Families-2' and 'Monocot Families' respectively, have been designed in such a way that you could get a flavour of the wide spectrum of diversity found in the various dicot and monocot families, particularly those found in this subcontinent. Also, you could get a glimpse of the range of diversity within the single family. To put it in other words, you would view diversity in the families dealt with here both at the macro- and the micro-levels. The two main considerations in the selection of these particular dicot and monocot families for study are the following. *One*, those families that could present to you a fair spread of variance in plant forms, and the different structures. *Two*, the representatives of these families be easily available in your region to enable you to make their study meaningful. In addition to the broad objectives of such a study, that are mentioned below, we have also outlined a long-term objective. By this, our intention is to evoke your thought-process, so that you think further, explore, and try to find answers to various questions that may arise in your mind related to these studies. Some of these could be as follows. (i) What makes the members of families so diverse in structure? (ii) How does the diversity in form and structure help the members of various families? (iii) What causes the ecological success of certain families, that is reflected by their wide-spread occurrence? (iv) And on the other hand, why do certain families remain restricted in their distribution? (v) What are the various evolutionary interlinkages between the various dicotyledonous and monocotyledonous families? And many more such questions.

In each of these families special attention has been given to their geographical distribution, important vegetative and floral characters, anatomy, palynology, embryology and economic importance.

Unit 24 is the last unit of this plant diversity course. The angiosperms show a vast variety of diversity and adaptability which is indicated by varied habitats that they have invaded. Today most areas of the world are more or less dominated by angiosperms. The adaptability has caused some extreme variation in plant forms. Some of the interesting variations such as the carnivorous plant, and total parasitism, variations in size of the plant, the inflorescences, leaf structures and seeds are described in this unit which will keep your interest on-going in plant diversity. Nevertheless, on the basis of a number of studies, it appears that the dominance of angiosperms can not be expected to be unending and may be another group of plants in near future will supersede the angiosperms.

Objectives

After studying this block you should be able to:

- identify the family of a given unknown dicot or monocot plant on the basis of your study of the related families dealt with here;
- appreciate and value, the vast range of diversity found both across the various dicot and monocot families, and within each of the families; and
- appreciate the extreme variations founds in angiosperms.

UNIT 21 DICOT FAMILIES – 1

Structure

21.1 Introduction
Objectives
21.2 Ranunculaceae
21.3 Brassicaceae
21.4 Malvaceae
21.5 Rutaceae
21.6 Fabaceae
21.6.1 Mimosoideae
21.6.2 Caesalpinioideae
21.6.3 Papilionatae
21.7 Myrtaceae
21.8 Cucurbitaceae
21.9 Apiaceae
21.10 Summary
21.11 Terminal Questions
21.12 Answers

21.1 INTRODUCTION

The flowering plants or angiosperms are the most well-known members of the Plant Kingdom and most of us are aware of these in some form or the other. In the earlier units of this course, you have studied about various aspects ranging from the structure, function and economic value of these plants. We shall now take up yet another aspect that is how to know and identify these plants? You have already been introduced to this aspect in the 'Taxonomy and Evolution' (LSE-07) course. We now take off from that point and these three units, i.e., 21 to 23 will give you a glimpse of the huge diversity encountered in the flowering plants.

There are some 25,000 species of angiosperms known to us, but it is not possible to study all of them in a limited time frame. The systems of classification help us to summarize knowledge of these large number of plants. Some representative groups or families of plants can help us to understand the diversity in angiosperms. With this view we have designed Units 21 and 22 covering some selected dicotyledonous families of angiosperms, and Unit 23 that deals with a few families of monocotyledons.

These units shall follow a basic pattern for studying families that you would know a little while from now. But before beginning your study of these units, it would be worthwhile to revise the related units from the course Taxonomy and Evolution (LSE-07). You are particularly advised to have a look at the areas dealing with plant nomenclature and the systems of plant classification. You would recall that names of plant groups follow certain rules of nomenclature. These rules are laid out in an 'International Code of Botanical Nomenclature (ICBN)'. According to these rules we must remember that names of plant families are based on the name of one genus of that family. For example, the family name Malvaceae is based upon the generic name *Malva*. According to the ICBN, this generic name, which provides the name to the family, is also referred to as the **Type genus** for the family. Names of some families are not based on a Type genus, but are still used in taxonomy. For example, the names Cruciferae, Leguminosae, Labiatae, Umbelliferae, Arecaceae, Gramineae are not based on a Type genus. The ICBN permits the usage of these names and at the same time suggests alternate names for these families based on the Type genus. Such relevant information is provided in this unit. In addition to this you will know the correct botanical names of the families that you would study along with their common English names and the names of their respective Type genera. This will be followed by information about the size and distribution of the family as well as the number of genera and species, which occur in India. Then you would know how members of each family could be recognised in the field. This data has been listed under the heading 'Field recognition characters' in the description of each family.

The 'morphological diversity' encountered in each family forms the major focus of attention. Important vegetative and floral chasacters of the plants discussed in each family are being explained. Therefore, by a careful study of the general characters of each family, you will be able to know about its 'diagnostic features'. These characters will be listed separately also for your easy access.

Next the 'systematic position' of each family in different systems of plant classification is dealt with. In LSE-07, Block 1, Unit 2 you have already studied about the natural system of classification proposed by **Bentham & Hooker**. In this course, all the family classifications are according to this system. You may also remember the phylogenetic systems of classification proposed by **Engler & Prantl,** and **Takhtajan***. The systematic position of each family would then be discussed in these two systems of classification. The information will help you to have a comparative account of the three systems of classification with reference to the selected families that you will study. In addition, in this unit you would also know about other families, which are related to the families that you would study.

Information about the 'economically important plants' of each family has also been included in the description. This shall emphasize the importance of vegetation as nature's gift to mankind.

Do not forget to go through the 'Tips for Effective Study' given in the adjacent margin space.

Tips for Effective Study

First, study two families (maximum) in one sitting.

Second, after completing the study of the area earmarked for one sitting, close your eyes, sit for a while, and recall the main study points of the family(ies) in your mind. Feel free to refer to the block whenever needed.

Third, write down the 'Points to Remember' in the margin space or the box space provided in the unit.

Fourth, try to procure the fresh material of the families that you have studied. Observe them minutely, and see whether they match with the description given in the unit, or they exhibit some variation(s). Note these observations also.

You may seek the guidance of your Counsellor in knowing as to which member(s) of the family(ies) are available locally. Also get information about the precise location of the spot.

A word of caution while collecting fresh, live plant materials for study. Collect the right amount of material that would suffice for your study. Let us not waste any of this precious material. It would be excellent, if you could possibly observe the material while it is intact on the plant. For this you would have to develop a habit of carrying a small hand-lens, a pair of mounted needles, a fine pair of forceps and a sharp blade, alongwith a copy or writing pad, and a pen or pencil for writing observations in the field.

Fifth, You could discuss with your Counsellor about the new and interesting findings, and do not hesitate to clarify your doubts.

Sixth, when you have completed the study of a number of families, try to compare them by writing their characters in tabular form and see what features make one family different from the other(s). This would be very helpful to you in differentiating clearly between two closely related families.

Hope, following these tips, you would have an enjoyable and a rewarding learning experience.

Objectives

After studying this unit you should be able to:

- appreciate the immense diversity in angiosperms;
- know the correct botanical name, as well as the name of the Type genus of the families described;
- describe the salient vegetative and floral characters of each of the families dealt with;
- analyse and list the diagnostic features of families discussed here;
- classify each of the family of this unit according to the different systems of classification;
- list some of the Indian representatives of each family while appreciating their size and distribution;
- prepare a list of locally available economically important plants of each family studied by you;
- realise the importance of vegetation as nature's gift to mankind, and the need to conserve nature for the future well being of mankind.

*Takhtajan's system has been revised in a recently (1997) published book (Diversity and Classification of Flowering Plants, Columbia University Press, New York). The outline of this revised classification is presented in Appendix–22.1. This has been adopted in the three units 21, 22 and 23 for discussing the 'Systematic Position' of each family.

21.2 RANUNCULACEAE

The Buttercup family
Type genus : *Ranunculus*

General Information

The family Ranunculaceae is distributed in the colder parts of the North Temperate Zone. It comprises 50 genera and 1900 species of which 20 genera and 150 species are found in India.

Field Recognition Characters

Mostly herbs; leaves with sheathing base, lamina often divided; flowers bisexual with spiral arrangement of floral parts, perianth may or may not be differentiated into calyx and corolla; stamens and carpels numerous; nectaries present in the flowers; thalamus well developed.

Morphological Diversity

The plants are generally annual or perennial herbs, which perennate by means of rhizomes or condensed rootstock or by tubers (e.g., *Ranunculus, Aconitum*). They are found in marshy places or they may be typical mesophytes. Some are woody climbers (e.g., *Clematis*).

The primary root dies early and the adventitious roots are formed from the stem. In the stem, the vascular bundles generally do not form a ring as in most dicots, but they are scattered or irregularly arranged, this way resembling the monocots. Interestingly the xylem shows a "Y" shaped arrangement.

Leaf: The leaves are exstipulate, usually alternate and with the leaf base broadened into a sheath. The sheath may sometimes be elongated into a pair of stipule-like lobes (e.g., *Thalictrum*). In *Clematis*, the leaves are opposite. The lamina is simple and entire in some species of *Caltha* and *Ranunculus*. It may be palmately-lobed, divided or adapted to a climbing habit. In the aquatic species of *Ranunculus,* the submerged leaves are dissected and the aerial leaves are entire (Fig. 21.1).

Inflorescence: There is a great diversity in development of inflorescence in this family. There may be solitary flowers (e.g., *Anemone*, *Nigella*) in the axils of the leaves or at terminal ends of the branches. The inflorescence may be cymose (e.g., *Ranunculus*) or racemose or even paniculate (e.g., *Delphinium, Aconitum, Clematis*).

Flower: The flowers are generally bracteate, pedicellate, bisexual, and actinomorphic. However, in *Delphinium* (Fig. 21.2) and *Aconitum*, the flowers are zygomorphic due to the formation of spur by the perianth. The most characteristic feature of the flower is the spirocyclic arrangement of the floral parts on an elongated receptacle or thalamus. Nectaries are present between the perianth and the stamens. There are two views on the origin of the nectaries. One view considers the nectaries to be modified petals, while the alternate view is that the nectaries are derived from the stamens.

The perianth may be sepaloid or petaloid or differentiated into a distinct calyx and corolla. In *Caltha*, *Clematis* and other genera, the perianth is petaloid. There is a transition from a sepaloid to a petaloid condition as the flowers mature in *Delphinium*, *Aconitum* and other genera. A distinct calyx and corolla are observed in *Ranunculus*, *Nigella* and other genera.

The perianth is generally free, but some degree of cohesion occurs in *Delphinium*, *Aconitum*, and *Aquilegia*. In *Nigella* and *Anemone*, an involucre of green leaf-like structures is present below the perianth.

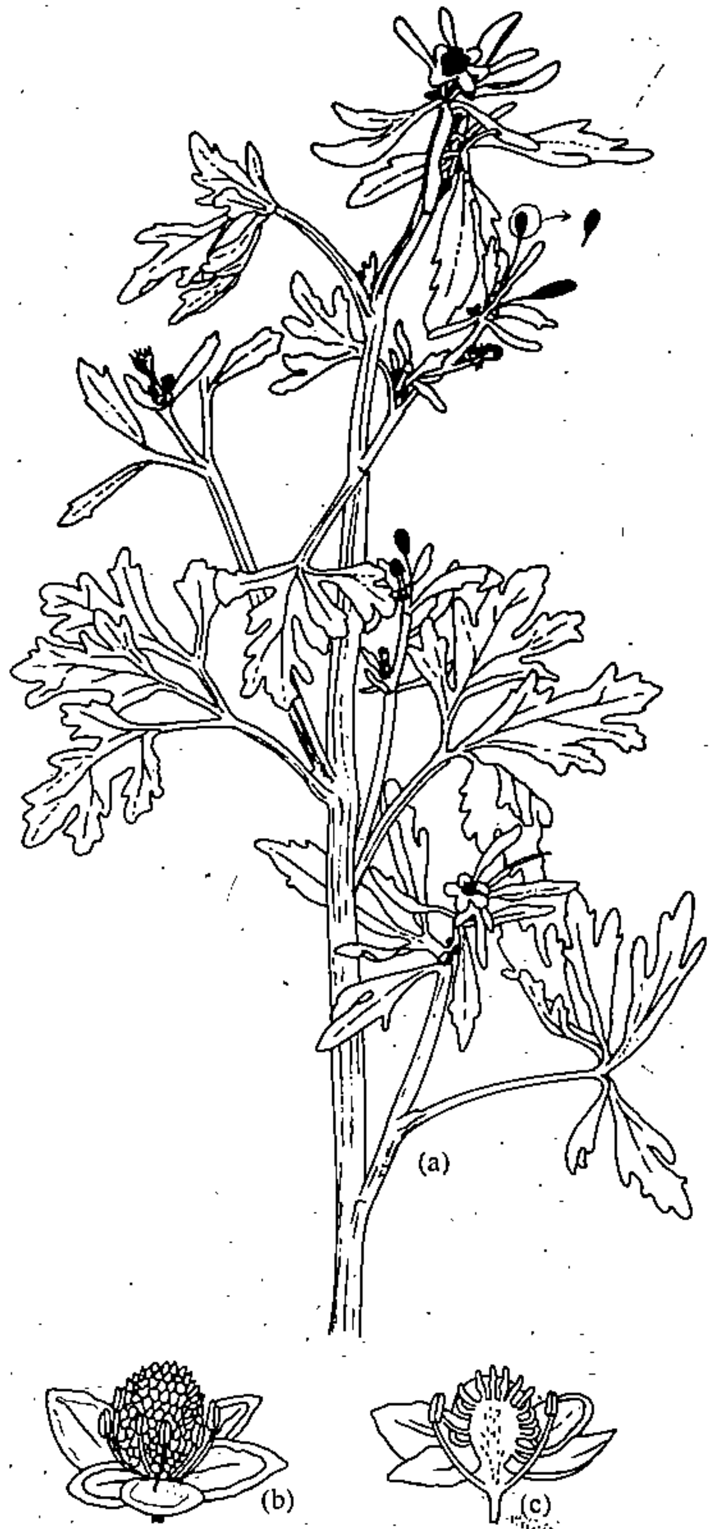

Fig. 21.1: *Ranunculus sceleratus*. a) A twig showing flower and fruits. b) A flower. c) Same in longitudinal section.

Androecium: The stamens are numerous and free. They are spirally arranged on the receptacle. In *Delphinium*, *Helleborus*, and *Nigella*, the spirally arranged stamens may also form 3 rings of 5 stamens each. The filaments may be broad and laminate or narrow and short. They are brightly coloured in *Thalictrum*. The anthers are dithecous and extrorse.

Gynoecium: There are generally numerous carpels, which are free and spirally arranged. There is a reduction in the number of carpels to 5 in *Aquilegia* or 3-1 in *Delphinium*. Besides this reduction in the number of carpels, there is also some

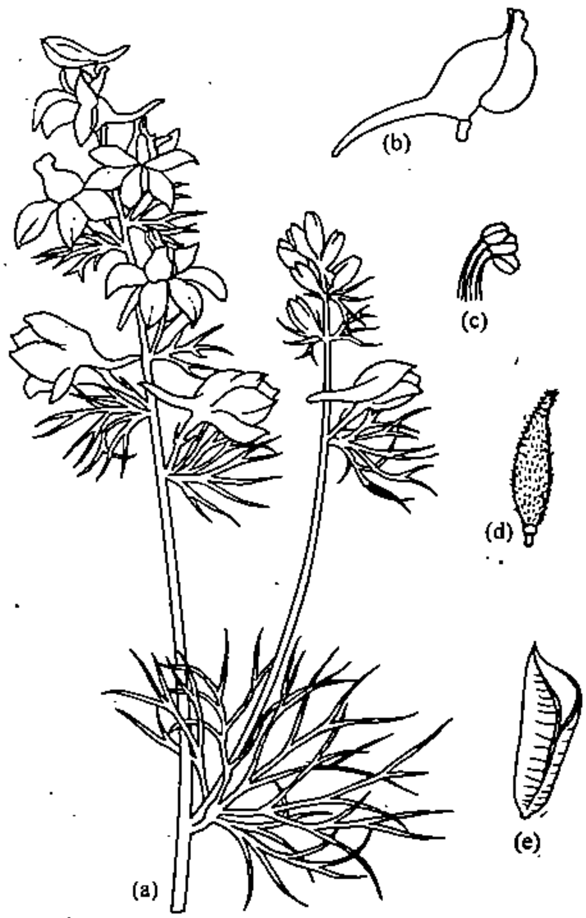

Fig. 21.2: *Delphinium ajacis.* a) A flowering twig. b) A flower. c) A few stamens. d) A gynoecium. e) A follicle.

degree of cohesion of the carpels at the base only, as in *Helleborus*, or a complete fusion to a syncarpous gynoecium. Each carpel shows basal (*Ranunculus*), or apical (*Clematis*), or marginal placentation (*Delphinium*). In *Nigella*, the syncarpous gynoecium, with a pentalocular ovary shows axile placentation. The ovary is superior with generally a short style and capitate stigma. In *Clematis*, the style is long, feathery and persistent.

Fruit: The fruit is aggregate, consisting of a group of few to many-seeded follicles (*Delphinium*) or a group of one-seeded achenes (*Ranunculus*); or is a capsule (*Nigella*). The seed has a small, straight embryo and abundant oily endosperm.

Diagnostic Features of the Family

1. Generally herbs, sometimes woody climbers.
2. Stems with irregularly arranged vascular bundles as seen in transection.
3. Leaves exstipulate with sheathing base; lamina entire or lobed or finely divided; often heterophyllous.
4. Flowers solitary or in cymose or racemose inflorescences.
5. Flowers spirocyclic with all floral parts spirally arranged, generally actinomorphic, hypogynous.
6. Perianth sepaloid or petaloid or differentiated into calyx and corolla.
7. Numerous stamens with extrorse anthers.
8. Numerous carpels, generally free.
9. Fruit a group of achenes or follicles.
10. Seed with straight embryo and abundant oily endosperm.

Systematic position

The family Ranunculaceae is classified in Polypetalae, Series I Thalamiflorae and Order 1 Ranales by Bentham & Hooker. This is the first family of dicotyledons in this system of classification. There are 7 other families in the Order Ranales. In Engler & Prantl's classification, the family Ranunculaceae is classified in the Archichlamydeae and Order Ranales. This Order has 17 other families except the family Dilleniaceae that was included in the Order Ranales by Bentham & Hooker. Takhtajan has classified the family Ranunculaceae in Subclass D Ranunculidae, Superorder Ranunculanae and Order 26 Ranunculales. Interestingly, in Takhtajan's classification some families classified in Ranunculaceae by Bentham & Hooker as well as Engler & Prantl, are classified in Subclass A Magnoliidae. The family Dilleniaceae that was classified in the Order Ranales by Engler & Prantl, is classified in Subclass G Dilleniidae by Takhtajan.

Another aspect of the systematics of the family Ranunculaceae is the relationship of the genus *Paeonia* that was included in this family, but is now separated and classified in the family Paeoniaceae. You have studied the taxonomy of this genus in the LSE-07 Course, Block 2, Unit 7 "Modern Trends in Plant Taxonomy", where the characters which distinguish the genus *Paeonia* from the family Ranunculacae have been listed.

Economic Importance

1. Many members of the family Ranunculaceae are cultivated as ornamentals for their beautiful flowers. These include species of *Aconitum* (monk's hood), *Anemone* (wind flower), *Aquilegia* (columbine), *Clematis* (virgin's bower). *Delphinium* (Larkspur), *Caltha* (marsh marigold), *Nigella* (love-in-a-mist) *Ranunculus* (buttercup), and *Thalictrum* (meadow-rue).
2. Some plants of this family are used in medicine. The well-known medicinal plants are *Aconitum napellus*, *Anemone pulsatilla*, *Adonis aestivalis*, *Delphinium* species and *Helleborus niger*.
3. The seeds of *Nigella sativa* are used as a condiment to flavour food and pickles. They are also used medicinally.

Points to Remember

21.3 BRASSICACEAE

The Mustard family, Cruciferae
Type genus : *Brassica*

General Information

The Brassicaceae is a large family of about 350 genera and 3000 species with a cosmopolitan distribution. It is more common in the north temperate regions especially the Mediterranean area. In India this family is represented by about 50 genera and 140 species, some of which are cultivated as food plants or as ornamentals.

Field Recognition Characters

Herbs with an odorous watery juice; flowers in racemose inflorescence, actinomorphic, hypogynous, with cruciform corolla, tetradynamous stamens, and bicarpellary, syncarpous gynoecium.

Morphological Diversity

The root may become swollen and store food reserves (e.g., radish, turnip), and new aerial shoots arise each year. The stem is condensed and has a radical rosette of leaves in the first year of growth and the flowering shoot is produced in the 2nd year in the biennial species. The stems are covered with unicellular hairs.

Leaf: The leaves form a radical rosette in many species and also occur on the aerial stems. They are usually alternate, exstipulate and simple. The lamina is entire, or lobed or even finely dissected and it is covered with simple or stellate hairs.

Inflorescence: The inflorescence is racemose or a corymb. The raceme in its corymbose form is characteristic of the family.

Flower: The flowers are generally ebracteate and ebracteolate, pedicellate, bisexual, actinomorphic and hypogynous. The calyx consists of 4 sepals arranged in 2 whorls, with 2 sepals median and 2 sepals transverse. The aestivation in each whorl is valvate. The corolla has 4 petals arranged in a single whorl, usually in a cross-like manner (cruciform). Each petal has a broad limb and a small claw-like structure. The aestivation of the corolla is valvate. In some plants, the petals are very small (e.g., *Lepidium*) or may be absent (e.g., *Coronopus*, see Fig. 21.3) in a mature flower.

Androecium: There are six stamens arranged in two whorls. The outer whorl has 2 short stamens and the inner whorl has 4 long stamens. This important tetradynamous character of the androecium was selected by Linneaus as the diagnostic feature of the Class Tetradynamia (one of the 24 classes in his system of classification), which corresponds with the present day family Brassicaceae.

In some species, the number of stamens is reduced and only 2 stamens are present, making the flower diandrous (e.g., *Lepidium*, *Coronopus*). The anthers are dithecous and introrse.

Gynoecium: The gynoecium is bicarpellary, syncarpous with a superior ovary. The ovary is monolocular and shows parietal placentation. The ovary becomes bilocular by the formation of a partition called the **replum**. This is not a true septum, but is an outgrowth of the placenta. The style is short and has a bifid stigma.

Fruit: The fruit is a specialised capsule called a siliqua or silique (if it is at least 3 times as long as broad), or a siliqula or silicle (if shorter). The mature fruit dehisces from the base upwards leaving the replum with the seeds attached to it. The fruit may be flattened either parallel to or perpendicular to the replum. The seeds are small but the embryo is large. The characters of the fruit and seeds are used for classifying the genera and species within the family.

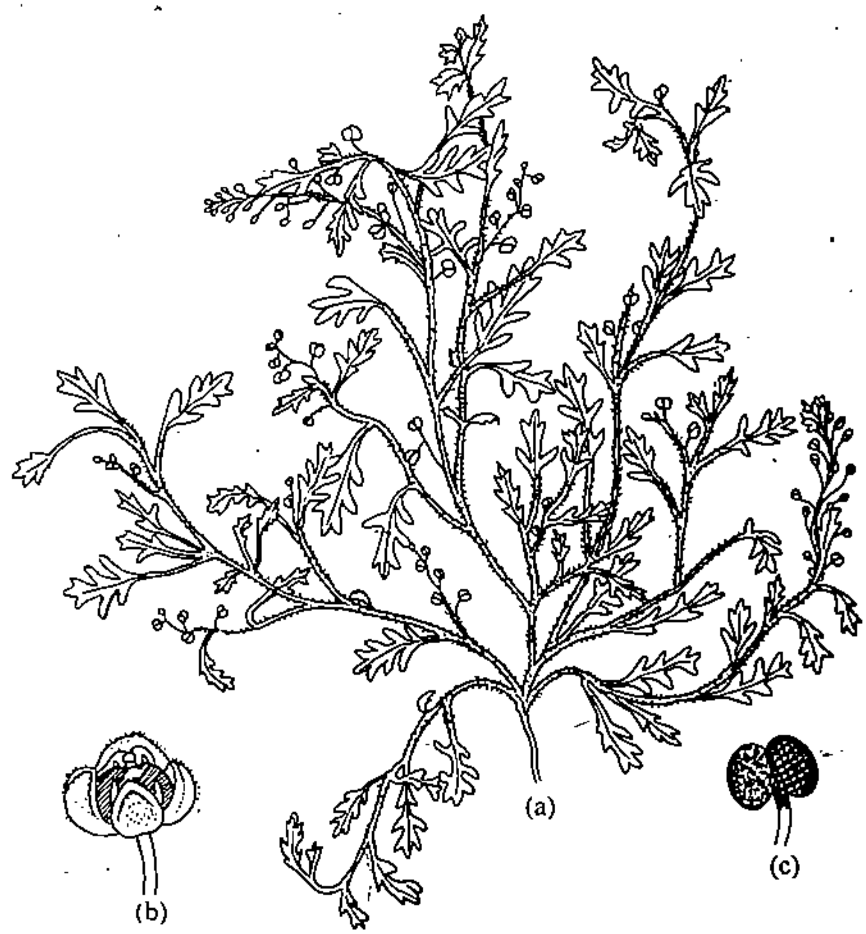

Fig. 21.3: *Coronopus didymus*. a) Part of a plant with flowers and fruits. b) A flower. c) A bilobed pod.

Diagnostic Features of the Family

1. Herbaceous plants with odorous watery sap.
2. Leaves simple, exstipulate, lamina lobed or dissected.
3. Inflorescence is a raceme in corymbose form.
4. Flowers ebracteate, polypetalous.
5. Calyx distinct in two whorls.
6. Cruciform corolla with the petals showing a limb and claw organisation.
7. Tetradynamous androecium.
8. Bicarpellary gynoecium with parietal placentation.
9. Fruit a siliqua or silicula.
10. Seeds small, a major portion of which is occupied by the embryo.

Systematic Position

The family Brassicaceae is classified in the Polypetalae, Series I – Thalamiflorae and Order – Parietales by Bentham & Hooker. They include 9 families in this order, suggesting the relationship of the family Brassicaceae with such families as Capparaceae and Papaveraceae. In Engler & Prantl's classification, the family Brassicaceae is classified in the Archichlamydeae and Order Rhoeadales. This order has 6 families including the Capparaceae and Papaveraceae. Takhtajan in his system of classification has classified the family Brassicaceae in Subclass G – Dilleniidae, Superorder Violanae and Order 84 – Capparales. This order has 6 families only, including the Capparaceae. This classification separates the Brassicaceae from the Papaveraceae, which is classified in Subclass D – Ranunculidae, Superorder Ranunculanae and Order 31 – Papaverales.

Economic Importance

The family Brassicaceae is of considerable economic importance. Several plants are important, as vegetable and oilseed crops, and a large number of them are cultivated as ornamentals.

1. Food Plants

Raphanus sativus – Radish
Brassica oleracea is a species with great diversity and its numerous varieties are consumed as vegetables. *B. oleracea* var. botyritis or cauliflower; *B. oleracea* var. *capitata* or cabbage; *B. oleracea* var. *gemmifera* or Brussel sprouts; *B. oleracea* var. *gongylodes* or knol-khol; *Brassica rapa* – Turnip; *Brassica campestris* var. *sarson* (Fig. 21.4).

2. Oilseeds

Brassica campestris	–	mustard
B. alba	–	white mustard
B. nigra	–	black mustard
B. rapa	–	rapeseed
Eruca sativa	–	taramira

Fig. 21.4: *Brassica campestris* var. *sarson*. a) A flowering and fruiting twig. b) A flower in longitudinal section. c) A pod.

3. Ornamental Plants

Alyssum	–	Basket of gold
Arabis	–	Rock cress
Brassica	–	Kale

Cheiranthus	–	Wall flower
Iberis	–	candy tuft
Matthiola	–	Stock
Nasturtium	–	Water cress

21.4 MALVACEAE

The China-rose family
Type genus : *Malva*

General Information

This family has 75 genera and about 1000 species of tropical and temperate distribution. Of these, about 22 genera and 110 species occur in India. Some of the well-known members are the cotton plant (*Gossypium* species, see Fig. 21.5), Lady's finger or Okra (*Abelmoschus esculentus*, see Fig. 21.6), and several ornamentals including the China-rose or Shoe flower (*Hibiscus rosa-sinensis*).

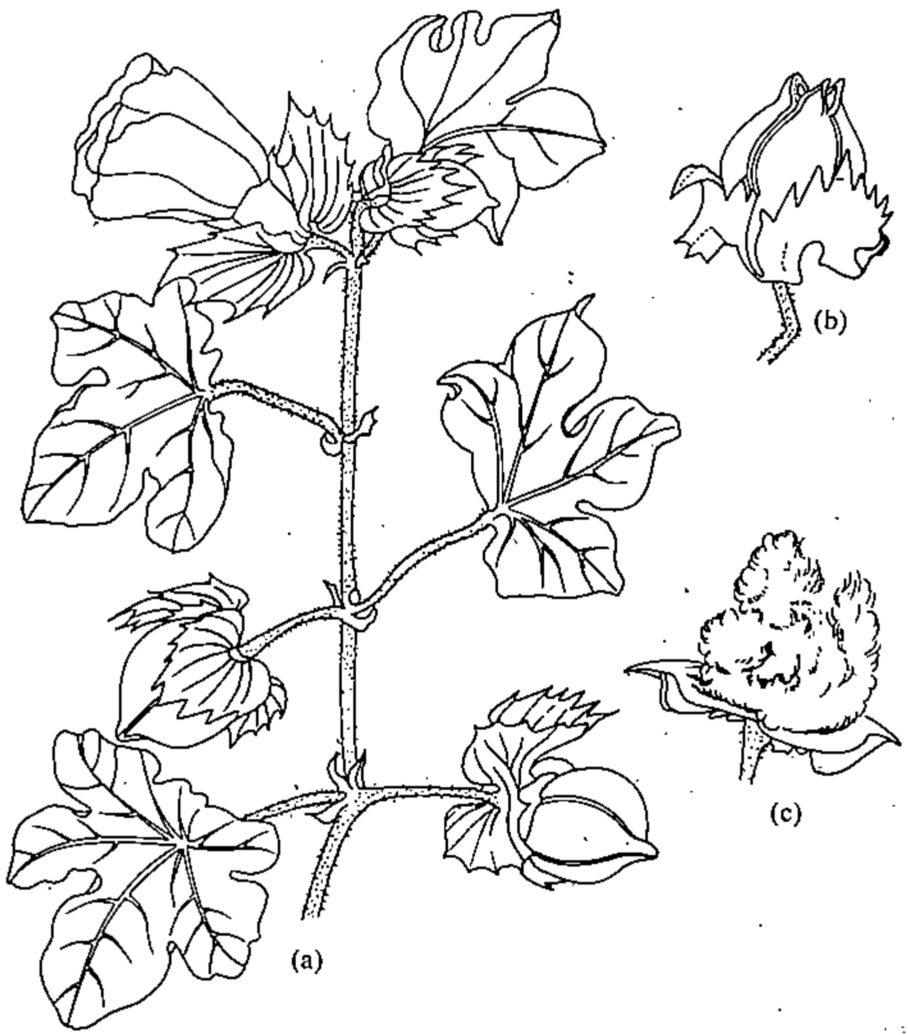

Fig. 21.5: *Gossypium herbaceum*. **a) A flowering twig. b) An opening boll. c) An opened boll.**

Field Recognition Characters

Herbs, shrubs or trees with stellate hairs on young shoots and leaves; flowers solitary or in racemes; epicalyx or bracteoles generally present; stamens numerous and monadelphous with monothecous anthers containing large, spiny pollen.

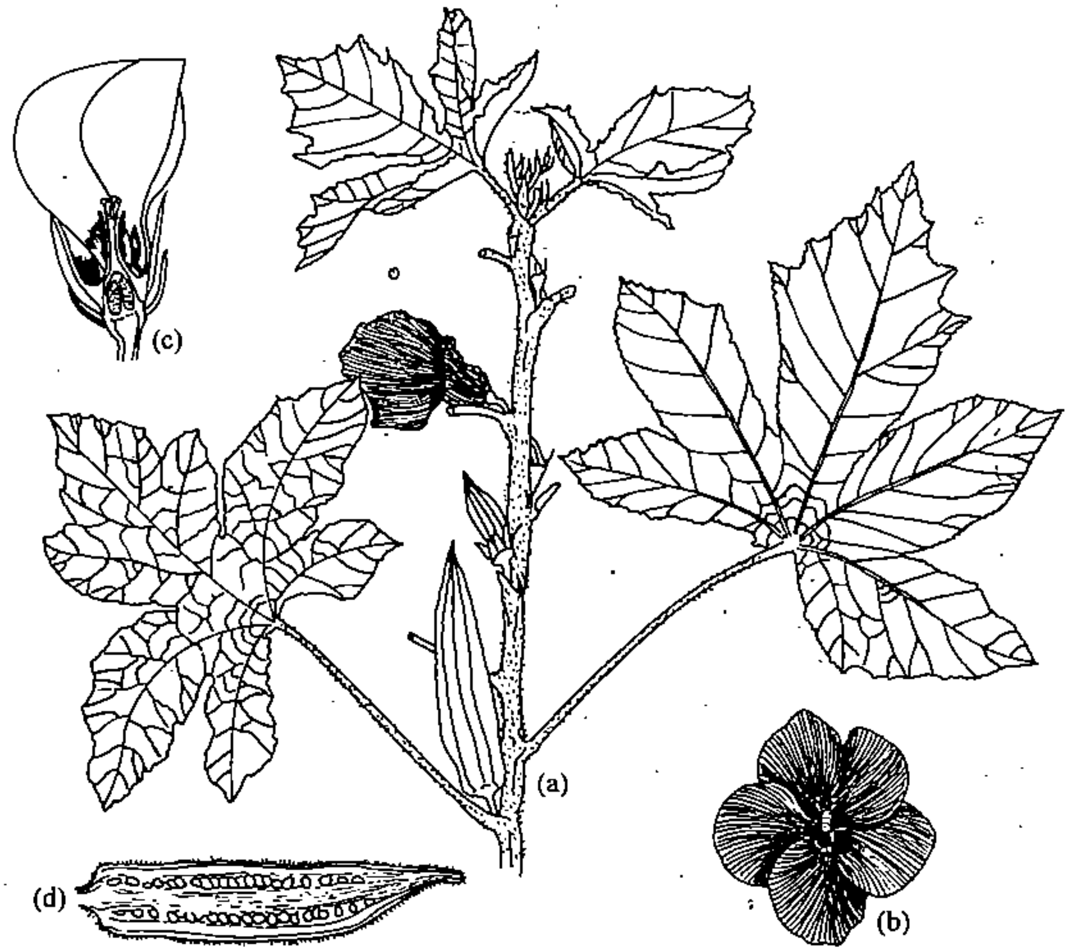

Fig. 21.6: ***Abelmoschus esculentus.*** **a) A flowering and fruiting twig. b) A flower as seen from the top. c) A flower in longitudinal section. d) A longitudinally cut fruit.**

Morphological Diversity

The plants are annual or biennial or perennial herbs, shrubs or small trees. Young herbaceous portions of the stem and the leaves are covered with stellate hairs. Mucilage sacs are present in the soft tissues of the plants.

Leaf: The leaves are alternate, petiolate and simple. They are generally cordate or reniform, but the upper leaves may become palmately divided. The leaves are stipulate, but the stipules fall early so that the older leaves appear exstipulate.

Inflorescence: There is either a large solitary flower in the axil of the leaf (Fig. 21.7) or there may be a racemose inflorescence which may become more complex and made up of cincinni.

Cincinnus (pl. cincinni) – A heliocoid cyme.

Flower: The flowers are pedicellate, bisexual, complete, actinomorphic, pentamerous and hypogynous. In most genera, an epicalyx is formed by a whorl of bracteoles below the calyx. This character is useful for identifying different genera. For example, it is absent in *Abutilon*; in *Malva* (Fig. 21.7) there are 3 bracteoles, in *Urena* (Fig. 21.8) there are 5, while in *Hibiscus* there are 5 or more. In *Gossypium* the 3 bracteoles are large and persistent. The calyx of 5 sepals may be polysepalous or gamosepalous. It shows valvate aestivation. The corolla consists of 5 and free, generally showy petals with contorted or imbricate aestivation. The staminal tube is attached to the base of the petals, and when the flower withers, the corolla falls along with the staminal tube.

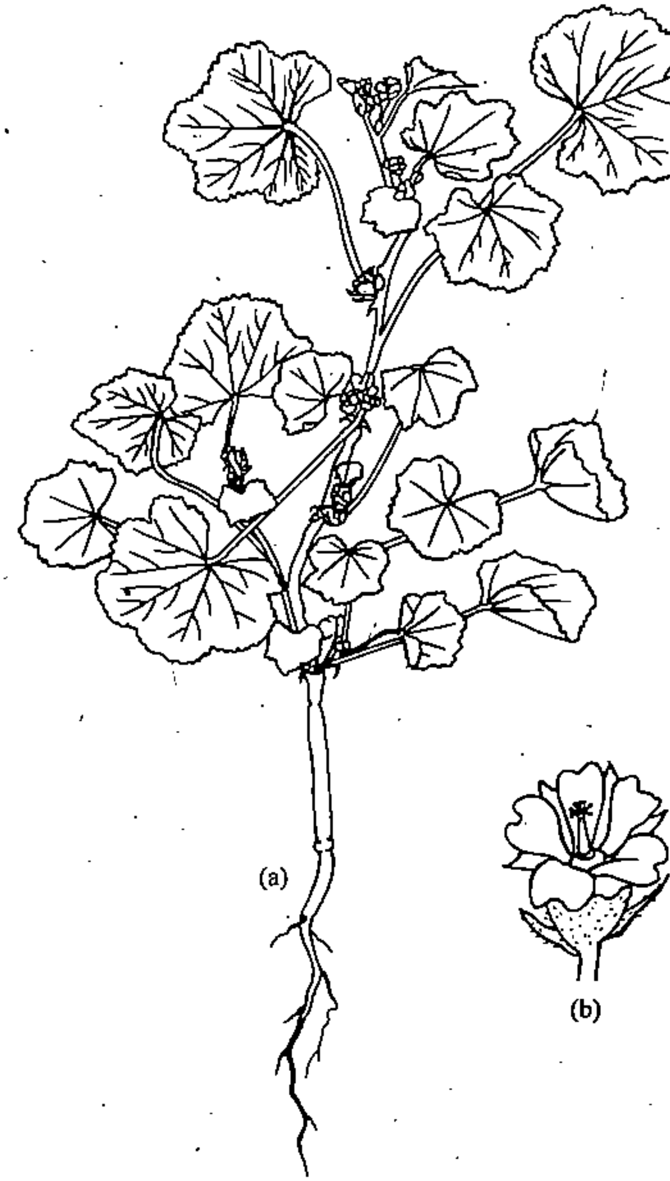

Fig. 21.7: *Malva parviflora*. a) A plant. b) A complete flower.

Androecium: There are numerous stamens, which are united into a staminal tube at the base of the corolla. The androecium is thus monadelphous. The anthers arise near the apex of the staminal tube and each anther is reniform and has only one anther lobe (i.e., it is monothecous). The anthers dehisce longitudinally and the pollen grains are large, spherical and show diverse exine patterns, so that the family Malvaceae is classified as Eurypalynous by palynologists.

Gynoecium: The gynoecium has (1 to many) usually 5 or 10 carpels, which are united. The ovary is superior, multilocular and has axile placentation. The ovules are 1 to many in each locule. The flowers are protandrous, and the style remains enclosed inside the staminal tube. After the dehiscence of the anthers, the style grows out through the staminal tube and terminates in the stigma. There are as many, or twice as many, stigma lobes as the number of carpels.

Fruit: The fruit is generally a capsule (e.g., *Hibiscus*, *Gossypium*) or it may be schizocarpic forming a carcerulus as in *Abutilon*. In *Malviscus*, it is a berry.

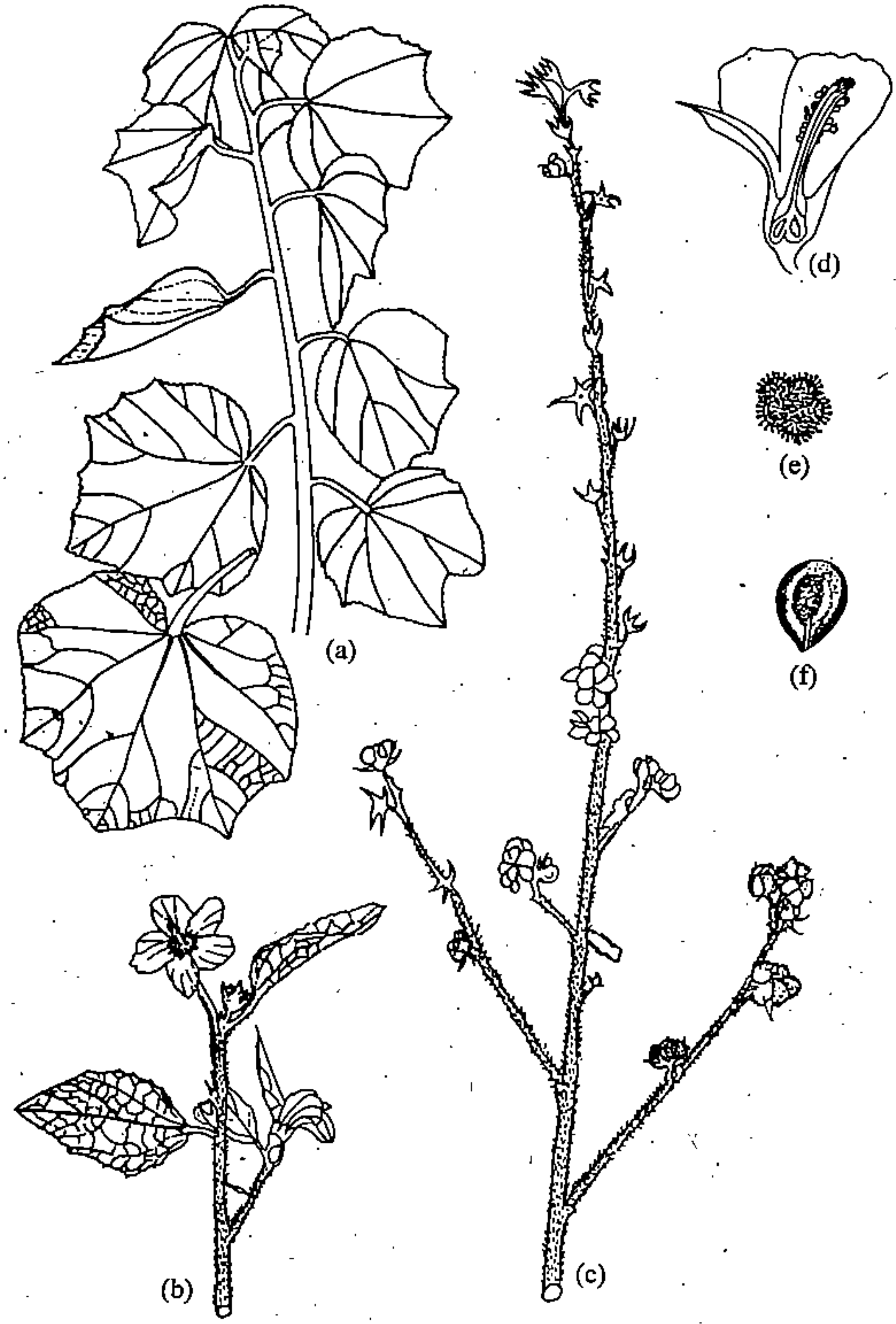

Fig. 21.8: *Urena lobata.* a) A vegetative twig. b) A flowering shoot. c) An inflorescence with fruits. d) A flower cut longitudinally. e) A fruit from top view. f) A seed.

The seeds are reniform or obovoid containing a curved embryo surrounded by the endosperm. The seed may be covered with epidermal hairs as in *Gossypium* (as you may recall from Unit 20).

Diagnostic Features of the Family

1. Herbs, shrubs or trees.
2. Young shoots and leaves covered with stellate hairs.

3. Leaves reniform, cordate or palmately divided.
4. Inflorescence of solitary flowers or racemose and complex.
5. Flowers with epicalyx and pentamerous.
6. Calyx with valvate aestivation.
7. Corolla with contorted or imbricate aestivation.
8. Stamens numerous, monadelphous with reniform monothecous anthers.
9. Pollen, large and spiny.
10. Gynoecium multicarpellary, syncarpous with superior ovary and axile placentation.
11. Fruit a capsule or schizocarp.

Systematic Position

The family Malvaceae is classified in the Polypetalae, Series I Thalamiflorae and Order 6 Malvales by Bentham & Hooker. This order includes the families Malvaceae, Sterculiaceae and Tiliaceae. In Engler & Prantl's classification, this family is classified in the Archichlamydeae and Order 26 Malvales, which has 8 families including the Tiliaceae, Sterculiaceae and the Bombacaceae, which was considered as a part of Malvaceae by Bentham & Hooker. Takhtajan in his classification classifies the family Malvaceae in the Subclass G Dilleniidae, and Order 89 Malvales. He recognises 12 families in this order. In all the systems of classification the affinities of the family Malvaceae with Tiliaceae and Sterculiaceae as suggested by Bentham & Hooker are accepted.

Economic Importance

1. Fibres

The genus *Gossypium* has several species from the Old and New World, which have been cultivated since ancient times for cotton fibre. A detailed account of the economic importance of this genus has been given in Unit 20 of this course.

Besides cotton, there are other plants, which are a source of commercial fibres. *Hibiscus cannabinus*, *H. sabdariffa* and other species of *Hibiscus* as well as species of *Sida*, *Thespesia*, *Pavonia* and *Urena* are used mostly locally for cordage, ropes, coarse sacking and in the manufacture of paper.

2. Oilseeds

The seeds of *Gossypium* and *Hibiscus* are sources of a fatty oil, which is used in the manufacture of soaps, lubricants, and paints. The oilcake is used as cattle feed.

3. Edible Plants

The young fruits of *Abelmoschus esculentus* (Lady's finger or Okra or Bhindi) are consumed as a vegetable.

4. Ornamentals

The common ornamental plants of this family include:
Hibiscus rosa-sinensis, *H. schizopetalus*, *H. sabdariffa*, *H. mutabilis*, *H. syriacus*, and *Althaea rosea*.

Thespesia populnea (Fig. 21.9) is cultivated as an avenue tree for its dense foliage and large flowers. The wood is used for making toys, pencils, and agricultural implements.

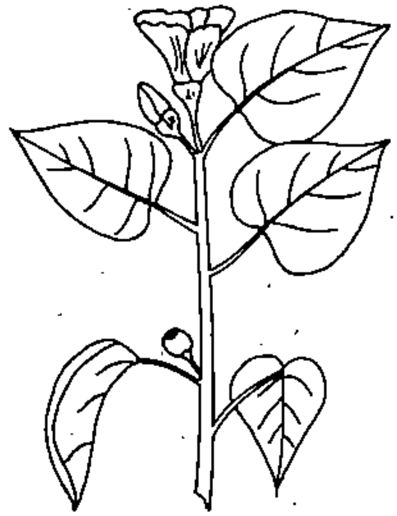

Fig. 21.9: *Thespesia populnea*, a flowering twig.

Points to Remember

21.5 RUTACEAE

The Citrus family
Type genus : *Ruta*

General Information

The family Rutaceae is widely distributed in tropical and temperate regions especially in South Africa and Australia. This family with 150 genera and 1500 species has become important for the citrus fruits and other economically important plants which are grown in many parts of the world. In India, there are about 23 genera and 80 species of this family.

Field Recognition Characters

Shrubs or trees with aromatic oil glands; leaves compound; flowers with a characteristic hypogynous disc. The stamens are in two whorls, the outer one is usually opposite the petals.

Morphological Diversity

The plants are mostly shrubs or trees often having xeromorphic characters. A few are herbs, e.g., *Boenninghausenia albiflora* (an insect-repellent herb that is common in the hill-stations of India). Spines or thorns are present in *Citrus* and *Aegle* or the plants may be unarmed as in *Murraya*.

Leaf: The leaves are generally alternate (rarely opposite), exstipulate, usually pinnately compound but sometimes reduced. In *Citrus*, a simple blade is separated by a joint from the winged petiole (Fig. 21.10). This is regarded as a

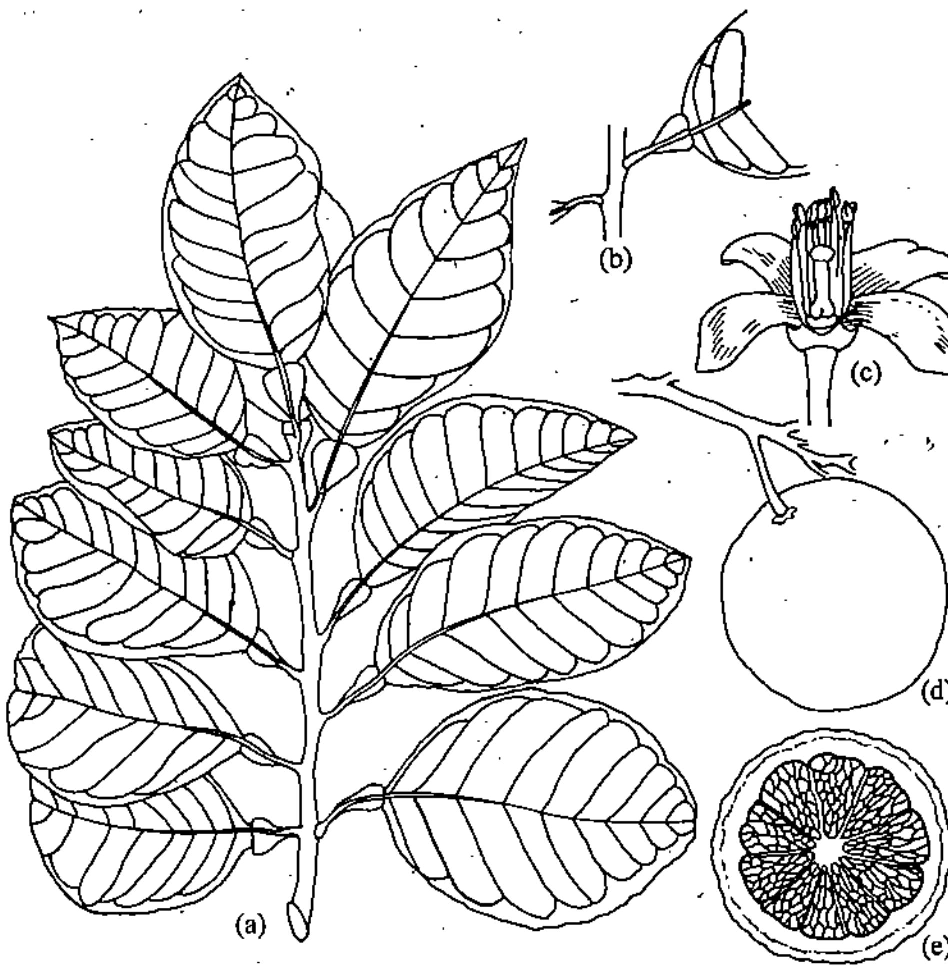

Fig. 21.10: *Citrus aurantium*. a) A vegetative shoot. b) Enlarged view of the base of the leaf. c) A flower in longisection. d) A fruit. e) Same in transection.

compound leaf reduced to a single leaflet. This reduction further leads to the modification of one or two young leaves on a young shoot into thorns or spines. An important character is the presence of oil cavities, which may be present on the entire lamina or only near the margins. Such gland dotted leaves become aromatic.

Inflorescence: The inflorescence is either a solitary flower or it is cymose. Sometimes it may be racemose, e.g., *Murraya* (Fig. 21.11).

Flower: The flower is bracteate as well as bracteolate, pedicellate, bisexual (sometimes unisexual by reduction), actinomorphic (sometimes slightly zygomorphic) and generally pentamerous or tetramerous. An important feature of the floral structure is the development of the receptacle between the stamens and the ovary. This receptacle may be a ring, cushion, or cup-like disc. The disc is hypogynous. The calyx of 5 or 4 sepals is poly- or gamosepalous. The aestivation is imbricate. The corolla has 5 or 4 free petals showing imbricate aestivation. It is conspicuously larger than the calyx and is white, yellow or red. The petals are generally thick and waxy.

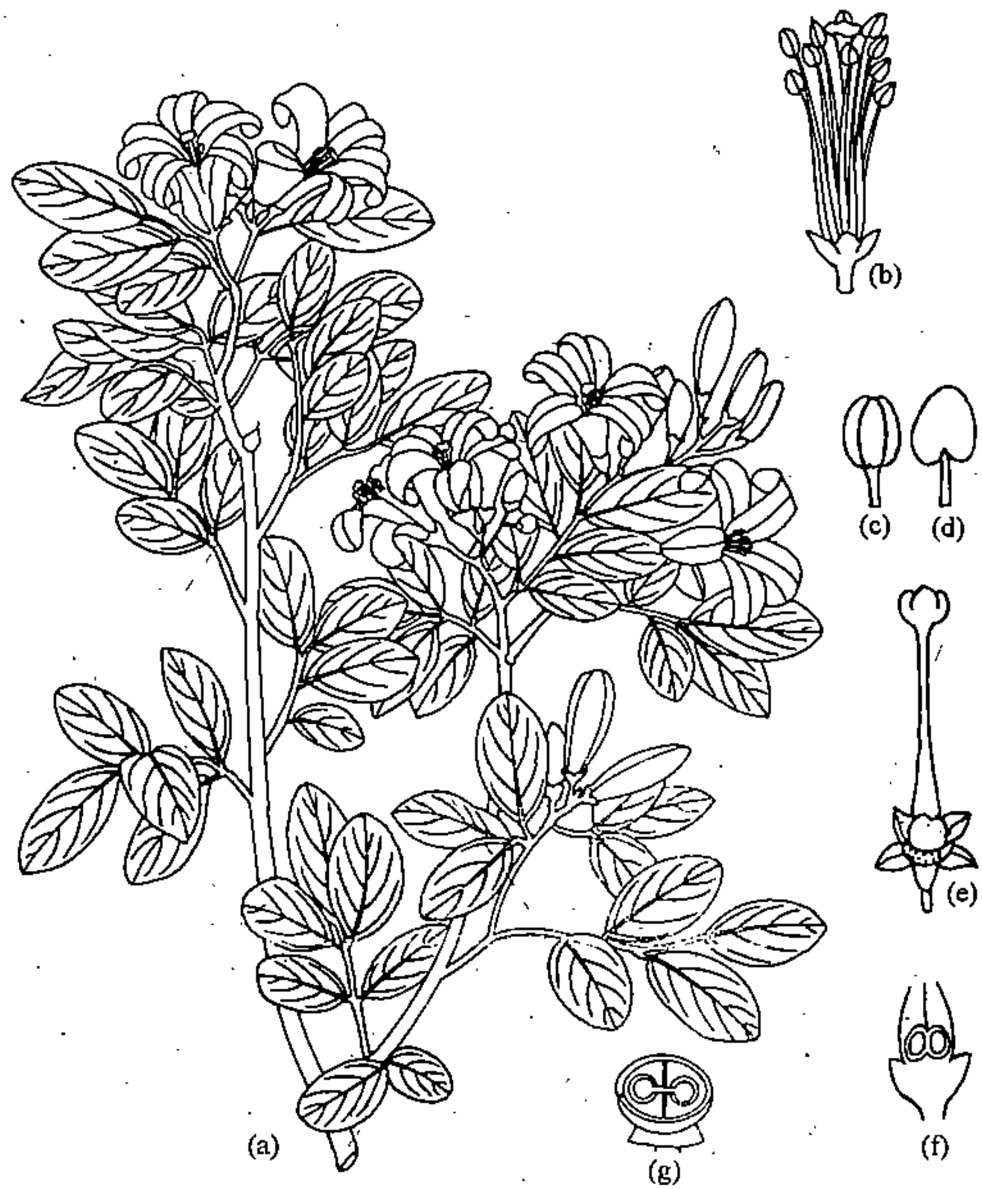

Fig. 21.11: *Murraya paniculata*. a) A flowering twig. b) A flower with its petals removed. A whorl of calyx, androecium and gynoecium can be seen. c) and d) stamens in different views. e) A gynoecium. f) and g) Outline diagrams of ovary in longisection, and transection, respectively.

Androecium: The majority of the members of this family have 10 or 8 stamens. They are obdiplostemonous, i.e., in two whorls with the outer whorl opposite the petals. Sometimes the stamens may be reduced to a single whorl of 5 or less. This single whorl of stamens is antesepalous. In some plants, the stamens are numerous and polyadelphous. The anthers are linear, dithecous and the connective is glandular at the apex. The dehiscence is introrse.

Gynoecium: There are generally 5 or 4 (rarely 3 or 1) carpels. They are usually free at the base but are united above by the styles. The ovary is superior and the disc is present below the ovary. the ovary is multilocular with 2 (sometimes 1) ovules/ovule in each locule on an axile placenta. The ovary may be unilocular with parietal placentation (e.g., *Feronia*). The styles may be united or free.

Fruit: The fruit varies according to the degree of cohesion amongst the carpels. It may be a specialised berry called a hesperidium. In this type of fruit (e.g., *Citrus*) the fleshy pulp is present as large juice sacs. Sometimes the fruit is a drupe (e.g., *Skimmia*) or it may be schizocarpic (e.g., *Dictamnus*). The characters of the fruit are used in the classification of this family.

The seeds contain a large embryo and the endosperm may be present or absent. In *Citrus* many species show polyembryony.

Diagnostic Features of the Family

1. Shrubs or trees (rarely herbs).
2. Leaves compound, gland-dotted, and aromatic.
3. Flowers with a characteristic hypogynous disc.
4. Petals conspicuously larger than the sepals.
5. Stamens obdiplostemonous.
6. Gynoecium of 5 or 4 carpels, free at the base but united above.
7. Placentation axile.
8. Fruit a hesperidium or drupe or schizocarp.
9. Seeds with large embryo.

Systematic Position

The family Rutaceae is classified in the Polypetalae, Series II Disciflorae and Order – 7 Geraniales by Bentham & Hooker. There are 10 other families in this order, including Geraniaceae, Zygophyllaceae, and Meliaceae. In Engler & Prantl's classification the family Rutaceae is classified in the Archichlamydeae and Order 23 – Geraniales. This order includes the family Geraniaceae and 18 other families. In these two systems of classification, the relationship between Rutaceae and Geraniaceae is suggested. Takhtajan in his system of classification has classified the family Rutaceae in Subclass H – Rosidae, Superorder Rutanae and Order 112 – Rutales. This order has 10 families and does not include the family Geraniaceae. This family is classified in the Order 118 – Geraniales of the same Superorder Geranianae.

Economic Importance

The family Rutaceae is of considerable importance as a source of citrus fruits, other edible fruits, curry leaf, medicinal plants and several ornamentals.

1. The genus *Citrus* produces some of the world's most important fruits, the juicy and tasty fruits that are rich in vitamin C. The cultivated species are believed to have originated in south-east Asia but have now spread throughout the tropics and subtropics. Most of the commercial production of citrus fruits is in regions having a Mediterranean climate. The fruits with their sweet juicy pulp are eaten raw or they may be canned. The juice may be extracted and made into squashes. The peel is a source of essential oil used in flavouring and in perfumery. It also provides pectin and is used in making

marmalades. Citric acid can be manufactured from these plants. The better-known species are *Citrus medica* (citron); *C. limon* (lemon); *C. aurantifolia* (lime); *C. grandis* (pummelo); *C. sinensis* (orange); *C. paradisi* (grape fruit); and *C. reticulata* (tangerine). Several other species and numerous hybrids are cultivated in different parts of the world. *Citrus japonica* (also called *Fortunella japonica*) or Chinese orange is cultivated as an ornamental. The fruits are not harvested for human consumption because of their small size and low sugar content. They are bitter in taste.

2. Besides *Citrus* species, there are edible plants in this family. *Aegle marmelos* (Indian Bael or Bel) is widely cultivated in India for its fruits. The globose fruits are specialised berries. The pericarp is hard, smooth and greyish. It encloses a soft sweet pulp, which is eaten raw or dried. A refreshing drink is also made from the pulp. Many medicinal properties are attributed to this fruit. *Feronia limonia* (the India wood apple) with smaller fruits is used as a substitute for *Aegle marmelos*.
3. *Murraya koenigii* (Curry leaf tree of India) is widely used as a flavouring agent. Fresh and dried leaves add a distinct aroma to curries, vegetables, pulses, and soups.
4. *Zanthoxylum armatum* (*Z. alatum*), *Z. limonella* and *Peganum harmala* are used as sources of medicine.
5. Besides *Citrus japonica*, *Murraya paniculata* is cultivated for its fragrant, white flowers and it serves as an excellent hedge. *Ruta graveolens*, *Glycosmis pentaphylla*, *Skimmia arborescens* and *Dictamnus albus* are other well-known ornamental plants of this family.

SAQ 1

1. Choose the most appropriate answer from amongst the following.

   a) Class Tetradynamia of Linneaus classification is equivalent to:

      i) Brassicaceae
      ii) Malvaceae
      iii) Ranunculaceae
      iv) Rutaceae

   b) Monadelphous stamens are found in ....

      i) Brassicaceae
      ii) Malvaceae
      iii) Ranunculaceae
      iv) Rutaceae

2. Name 2 families showing axile placentation.

   i) ....

   ii) ....

3. Define the following terms and name the families in which they have been described:

   a) Epicalyx

   ....

   ....

   ....

   b) Obdiplostemonous androecium

   ....

   ....

   ....

c) Siliqua

....

....

....

d) Spirocylic flower.

....

....

4. Assign the following genera to their respective families and mention one economic use of each genus:

Genus	Family	Use
a) *Aconitum*	....	....
b) *Aegle*	....	....
c) *Alyssum*	....	....
d) *Delphinium*	....	....
e) *Eruca*	....	....
f) *Gossypium*	....	....
g) *Hibiscus*	....	....
h) *Murraya*	....	....

5. a) Of the four families you have studied, name the family classified in Series Disciflorae by Bentham & Hooker.

....

....

b) In which Subclass is this family classified by Takhtajan?

....

....

6. a) Name 2 families classified in the Series Thalamiflorae by Bentham & Hooker.

i) Family ....

ii) Family ....

b) What is the systematic position of the **above two** families in Takhtajan's classification? Write them in the same order as in part-a of the question.

i) Subclass ....
Superorder ....
Order ....

ii) Subclass ....
Superorder ....
Order ....

7. Which is the most important feature for recognising the following:

a) Order Parietales in Bentham & Hooker's classification?

....

b) Class Tetradynamia in Linneaus classification?

....

....

8. Describe the kind of fruit in the four families mentioned below.

   a) Brassicaceae

   ....

   ....

   ....

   b) Malvaceae

   ....

   ....

   ....

   c) Ranunculaceae

   ....

   ....

   ....

   d) Rutaceae

   ....

   ....

   ....

9. List the important characters, which distinguish the family Malvaceae from the family Rutaceae.

Malvaceae	Rutaceae

10. Describe the important vegetative and floral characters of the family Ranunculaceae.

    ....

    ....

    ....

    ....

11. Discuss the systematic position of Brassicaceae in the three systems of plant classification studied by you. List a few economically important plants of this family.

    ....

    ....

    ....

    ....

21.6 FABACEAE

The Legume family, Leguminosae
Type genus : *Faba*

General Information

The family Fabaceae is a very large family having about 600 genera and more than 13,000 species showing a cosmopolitan distribution. Some members are more common in tropical and subtropical areas, while others occur in temperate regions. They are found in all kinds of habitats, with many representatives in all the continents. In India, this family is represented by about 150 genera and more than 900 species, many of these are of great economic importance. These plants are used for food or fodder, or for the fatty oils, dyes, timber or also as ornamentals.

The members of this family exhibit considerable variation in vegetative and floral characters. The vast majority are recognised by their typical fruit which is a legume hence the name Leguminosae for the family. Besides the characteristic fruit, many members of this family have specialised outgrowths on the lateral roots. These root nodules contain colonies of bacteria (e.g., *Rhizobium*) in the cells of the root cortex. This is an example of symbiotic relationship where the roots of the plants provide a 'home' to the bacteria and in turn the bacteria help the plant to assimilate large amounts of atmospheric nitrogen. The plants thus have large amounts of nitrogenous compounds. These are converted into valuable proteins by the plant. The leguminous plants are therefore of great importance for enriching the soil with nitrogenous compounds. They are also used in crop rotation.

Fabaceae, a large family is divided into 3 subfamilies in different systems of classification. Some of the characters are similar, but each subfamily constitutes a distinct group. Therefore, in the following account of the family Fabaceae, the information shall be presented separately for each of the subfamily. The 3 subfamilies are:

a) Mimosoideae
b) Caesalpinioideae
c) Papilionatae or Faboideae or Lotoideae.

These are distinguished from each other by the following characters:

a) Flowers actinomorphic, corolla
   aestivation valvate ------------------------------ Mimosoideae
b) Flowers zygomorphic, corolla
   aestivation imbricate
   2.a) Corolla aestivation ascending imbricate --- Caesalpinioideae
   2.b) Corolla aestivation descending imbricate --- Papilionatae

21.6.1 Mimosoideae

Type genus : *Mimosa*

General Information

This is the smallest of the three subfamilies. The plants are widely distributed in tropical and subtropical regions especially in the Southern Hemisphere. Many plants are common in tropical rainforests as well as in dry areas of Australia. They are absent from Europe.

Field Recognition Characters

Trees or shrubs, few herbs; leaves generally bipinnately compound; flowers in compound inflorescence; actinomorphic, generally pentamerous; stamens 10 to many, usually extended beyond corolla; filaments often brightly coloured.

Morphological Diversity

The plants are mostly trees or shrubs and rarely herbs. A few (e.g., *Entada*) are woody climbers in which the stem shows anomalous secondary growth. In many plants, the pith and medullary rays of the stem contain tannin sacs and gum passages in abundance. These substances make the plants economically important.

Leaf: The leaves are stipulate; the stipules are . metimes modified into thorns (e.g., *Acacia*, Fig. 21.12). The thorns are hollow . d often swollen. They provide shelter to ants. Extrafloral nectaries may also be pr. nt. The leaves are generally bipinnately compound. In *Inga*, they are pinnate. In *Ac. cia auriculiformis* (Australian acacia, see Fig. 21.13) the leaf rachis becomes modified into a distinct phyllode and the very small leaflets may develop at the tip. The leaves also show sleep movements (nyctinastic movements) in response to touch (e.g., *Mimosa pudica* or Touch-me-not, see Fig. 21.14). These movements are brought about by the pulvinus at the base of the leaf.

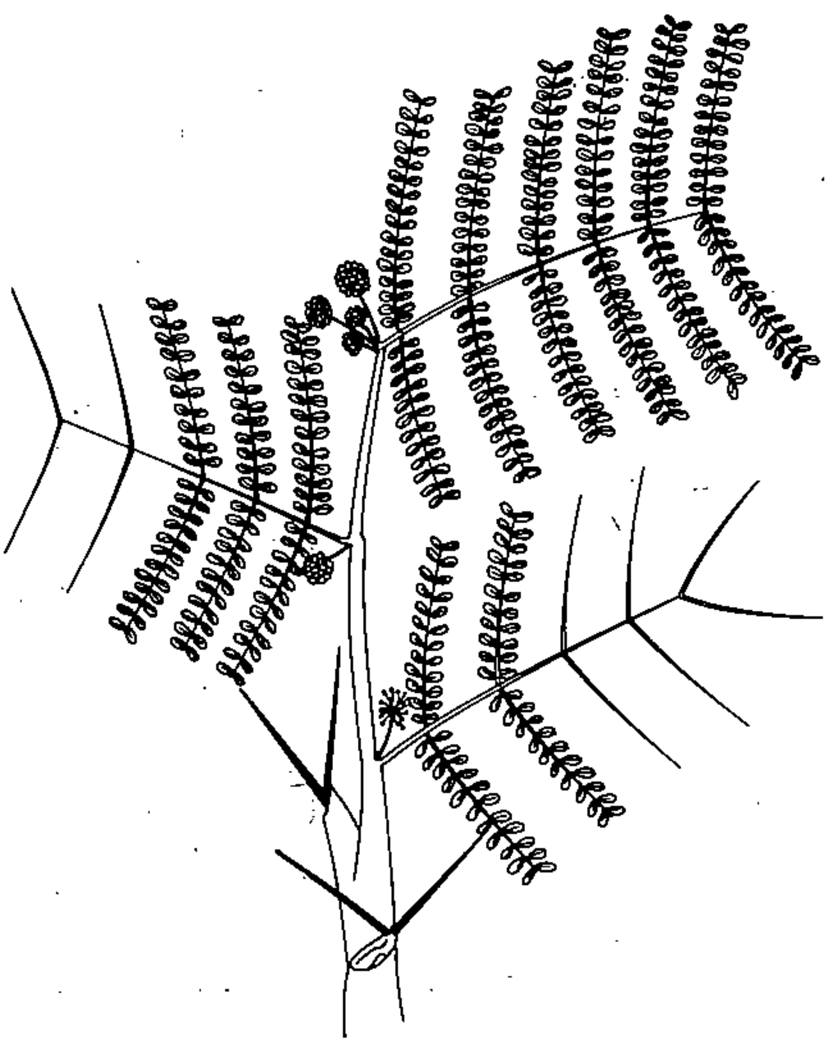

Fig. 21.12: ***Acacia nilotica*. A flowering twig.**

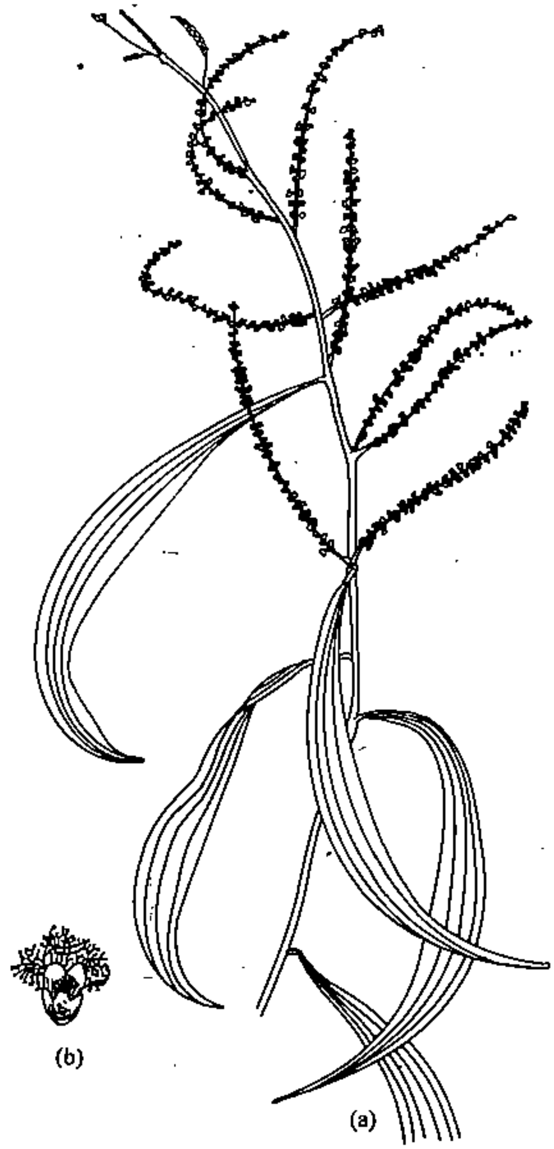

Fig. 21.13: *Acacia auriculiformis*. a) A flowering twig with phyllodes. b) A flower. (From Maheshwari, 1983).

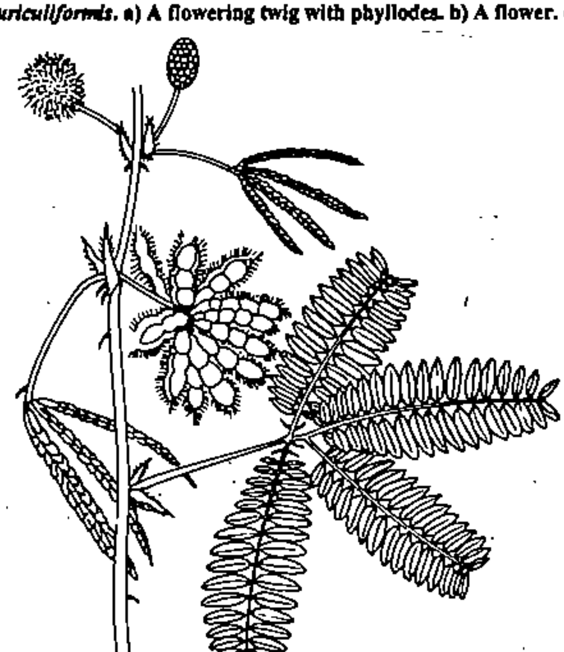

Fig. 21.14: *Mimosa pudica*. A flowering twig, with some leaves expanded and some closed. Also seen are flowering heads at various stages – bud, opened head, and the pods at different stages of dehiscence.

Inflorescence: The inflorescence is usually compound (Fig. 21.15); the flowers are often crowded together in tight clusters or into globose, dense heads. Sometimes the inflorescence is spicate or racemose (e.g., *Prosopis, Acacia*). In *Dichrostachys*, there are 2 kinds of flowers on a single spike. The flowers in the upper half of the spike are bisexual while those in the lower half are sterile or neutral having only long, brightly coloured staminodes and no gynoecium.

Flower: The flowers are ebracteate, pedicellate or more commonly subsessile to sessile. They are actinomorphic, hypogynous and generally pentamerous. Sometimes the flowers may be 3-, 4-, or even 6-merous. *Mimosa pudica* is tetramerous; and *Acacia* has 3- or 4-merous flowers. The calyx is generally gamosepalous forming a small cup-shaped structure at the base of the flower. The aestivation is generally valvate. The corolla may have free petals or the petals may cohere at the base forming a small tube. The petals show valvate aestivation.

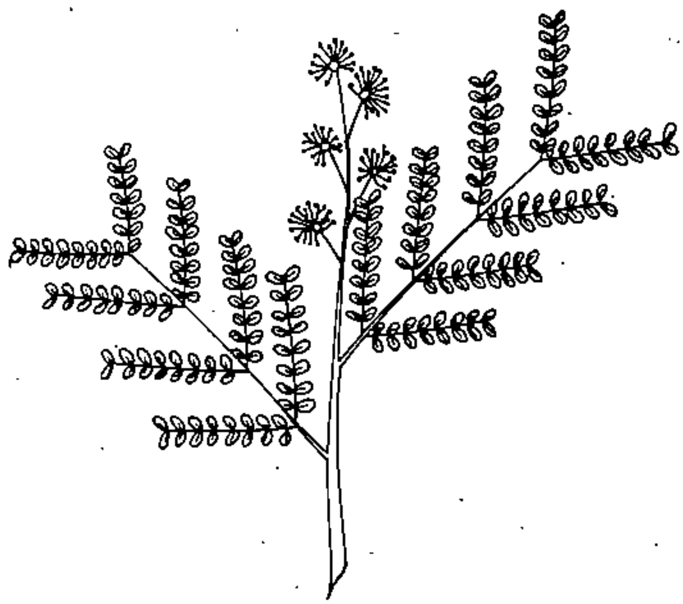

Fig. 21.15: *Samanea saman*, a flowering twig.

Androecium: The stamens vary in number and arrangement. They may be equal to the number of petals as in *Mimosa pudica*; or twice as many as the petals, in two whorls and are diplostemonous. The stamens may be numerous as in *Acacia, Albizzia*, and *Pithecellobium*. They may be free or united. The filaments are long and slender and often are the most conspicuous part of the flower. They are usually extended beyond the corolla and are mostly brightly coloured. The anthers are small, dithecous and show introrse dehiscence. The anther lobes may be divided by transverse septae and the pollen grains massed together in each such chamber.

Gynoecium: It is monocarpellery, with a superior ovary and marginal placentation. The style is short and the stigma is terminal.

Fruit: The fruit is a legume or pod, and is a characteristic feature of the family. It opens or dehisces by both the sutures; there is considerable diversity in size and morphology of the fruit. The largest fruit of the family Fabaceae is found in *Entada gigas* of this subfamily. The fruit here is a woody structure more than a meter long and several centimeters wide. It is composed of many one-seeded discoid joints. The seeds are very large. On the other hand, in many species of *Acacia*, the fruit becomes a lomentum, which is a special type of pod constricted between the seeds and breaking up into one-seeded segments. In other members of this subfamily the legume may vary in size and is a either straight or curved. The seeds vary in size according to the size of the legume. They have very little or no endosperm. In *Inga*, the seed coat forms a shining, soft, wool-like mass while the embryo is a naked, thick, bean-like structure. When the fruit opens, the naked embryo falls out and germinates directly. The dispersal of this naked embryo from the fruit is brought about by birds, which are attracted by the shiny, soft, woolly seed coat. In *Pithecellobium dulcis*, the seeds are surrounded by a sweet edible pulpy aril.

21.6.2 Caesalpinioideae

Type genus : *Caesalpinia*

General Information

This subfamily has plants, which are mostly tropical and subtropical in distribution. A large number of species are found in Brazil and in areas from Southern Europe to India. Many plants occur in tropical rain forests. Species of *Tamarindus, Bauhinia* (Fig. 21.16), *Cassia, Saraca* (Fig. 21.17), *Delonix* (Fig. 21.18) and other genera are well-known throughout our country.

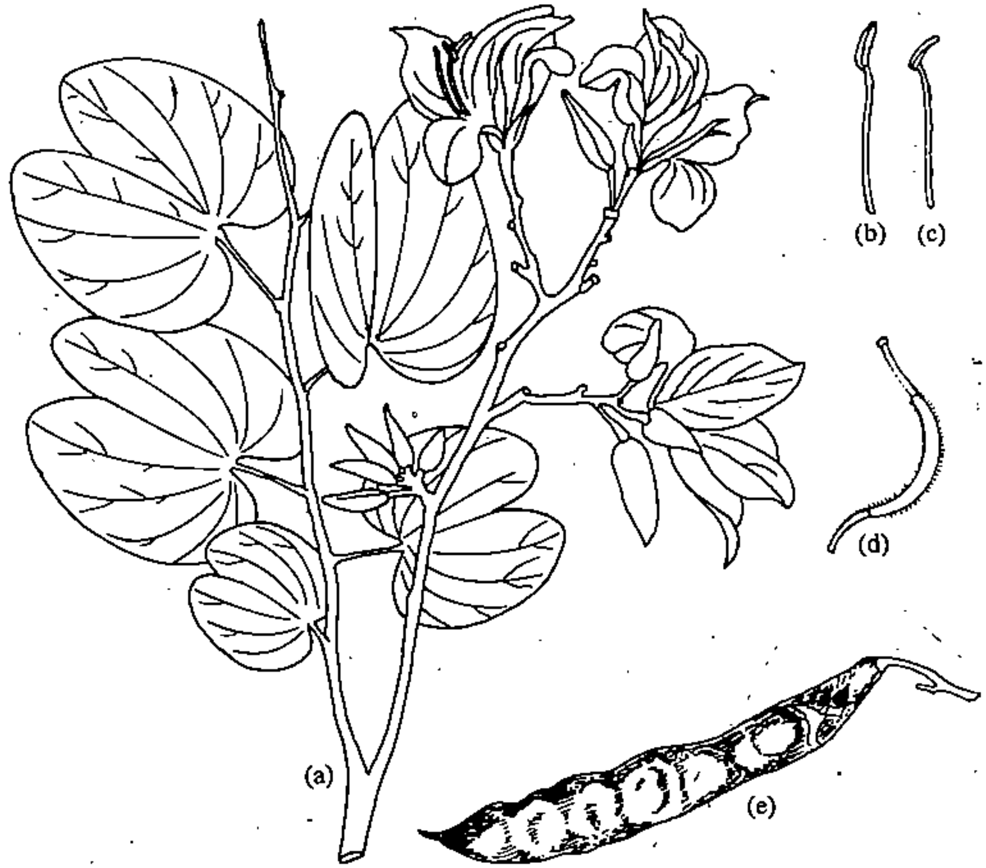

Fig. 21.16: *Bauhinia variegata*. a) A flowering twig. b) and c) stamens in different views. d) A gynoecium e) A pod.

Field Recognition Characters

Small or medium-sized trees or shrubs, rarely herbs, leaves stipulate, mostly pinnately compound, leaf bases usually pulvinate; extrafloral nectaries present; inflorescence racemose; flowers zygomorphic, pentamerous; calyx with odd sepal anterior and imbricate astivation; corolla with ascending imbricate aestivation; stamens 10, some reduced to staminodes, usually free.

The plants are mostly trees or shrubs. Some species are annual herbs (e.g., *Cassia tora*). Sometimes, the plants may be woody climbers. In such plants there may be special sharp prickles or hooks or even tendrils to help the plants to climb. The stem is thick and woody in the tree species; but sometimes it may be curiously flattened and twisted. Such plants become lianas as in species of *Bauhinia* where the stems show a complicated anomalous secondary growth.

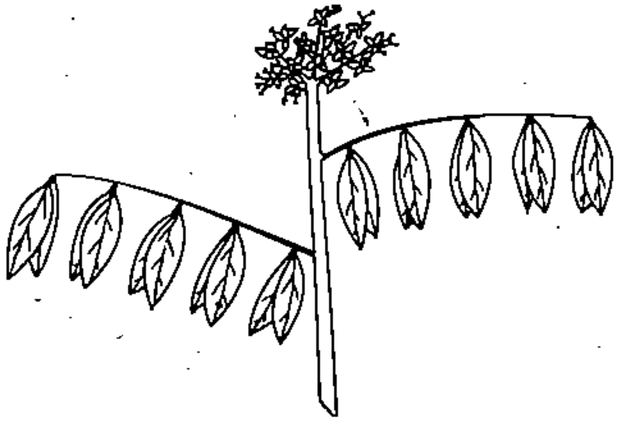

Fig. 21.17: *Saraca indica*. A flowering twig.

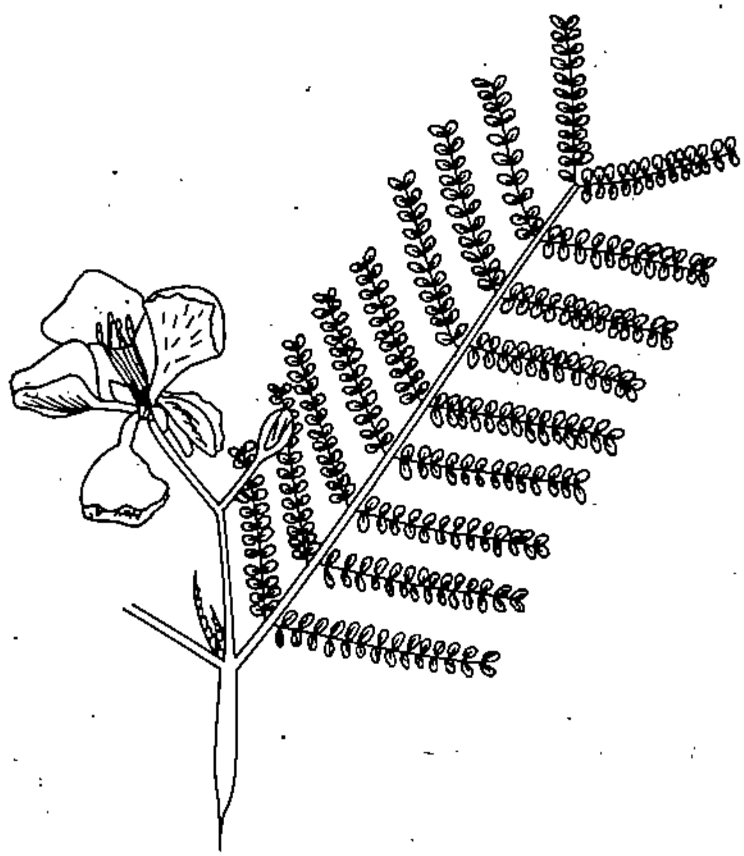

Fig. 21.18: *Delonix regia*. A flowering twig.

Leaf: The leaves are stipulate, alternate and usually pinnately or bipinnately compound. In *Bauhinia*, the leaf is simple, but made up of two equal halves with a deeply lobed apex. The open leaf resembles a camel's foot print. In *Parkinsonia*, the rachis of the pinnately compound leaf becomes flat and pointed. The leaflets are very small or they fall off early or may not even develop. The leaf rachis then resembles a phyllode. The base of the leaf in many plants is pulvinate (i.e., the junction of the leaf base to the stem is swollen). The pulvinus may be associated with extrafloral nectaries, encouraging ants and other insects to constantly visit the plant for nectar.

Inflorescence: The inflorescence is generally racemose. It may be a simple raceme, a panicle or a spike. Sometimes, it may be cymose or reduced to one or two flowers in each leaf axil.

Flower: The flowers are bracteate, bisexual, medianly zygomorphic (sometimes appearing to be actinomorphic), large, showy, hypogynous and pentamerous.

The calyx is generally polysepalous; but in *Tamarindus* the 2 upper sepals are united. In *Bauhinia*, all the 5 sepals are united to form a spathaceous tube, while in *Saraca* the calyx becomes orange or vermilion coloured and petaloid. The calyx shows imbricate aestivation with the odd sepal being anterior.

The typical pentamerous corolla shows variation. All five petals may be of equal size and spread evenly as in *Cassia*. In *Delonix* and *Caesalpinia*, the corolla may be papilionaceous in form having one large petal, which is prominent, and the remaining 4 petals forming 2 pairs of different sizes. Although this type of corolla approaches the typical papilionaceous corolla as observed in the Subfamily Papilionatae, it is distinghished by its ascending imbricate aestivation. Further variation can be observed in *Amherstia nobilis* where 3 petals are well developed and the 2 anterior petals are suppressed. Similarly, in *Krameria*, the 2 anterior petals are represented by glandular scales while in *Tamarindus*, these 2 petals are completely absent. The greatest reduction is observed in *Saraca indica* where the petaloid sepals are prominent and the petals are completely absent. The aestivation of the corolla is ascending imbricate, i.e., the uppermost petals is the innermost or inside the two lateral petals. This is opposite to descending imbricate aestivation observed in the Subfamily Papilionatae where the uppermost petal is the outermost one.

Androecium: There are usually 10 stamens arising in 2 alternate whorls of 5 each (rarely there may be more than 10 stamens). All the 10 stamens may appear to be in a single whorl in a mature flower. In *Caesalpinia* and *Parkinsonia* all the 10 stamens mature and are fertile. In *Cassia* 5 to 7, and in *Bauhinia* 3 to 5 stamens are fertile and the remaining ones are reduced to staminodes. The fertile stamens may be of different sizes, generally those of the outer whorl being larger than those of the inner whorl. In *Tamarindus*, only 3 stamens are fertile, the remaining 7 being reduced to bristles instead of the staminodes. The stamens are generally free, often with coloured filaments. Sometimes the filaments are united. For example, in *Tamarindus* the filaments of the 3 fertile stamens form an open sheath-like structure. In *Amherstia*, the androecium becomes diadelphous where 9 stamens are united by their filaments forming an open tube while the 10^{th} stamen is free. This is a common feature in the Subfamily Papilionatae. The anthers are dithecous, basifixed or dorsifixed, or sometimes versatile. They generally show introrse dehiscence, except in *Cassia* where the dehiscence is poral.

Gynoecium: The gynoecium is monocarpellary, with a superior ovary and marginal placentation. This is a characteristic feature for the entire family. In many members of this subfamily, the ovary is borne on a short or long stalk. The ovary may be straight or falcate (sickle-shaped), with a short or long terminal style and an oblique or a capitate stigma.

Fruit: The fruit is a legume or pod. The number of seeds varies. The seeds show some interesting features. The endosperm may be in a thin layer around the embryo (e.g., *Bauhinia*) or it may be abundant and cartilaginous (e.g., *Cassia*). The cotyledons are generally fleshy or flat or leaf-like. Sometimes the seeds have a very hard testa (e.g., *Tamarindus*) and the seeds are surrounded by a pulpy mass.

3 Papilionatae

pe genus : *Faba*

General Information

This subfamily is also called Lotoideae with *Lotus* as the Type genus. This generic name *Lotus* **does not** refer to the common and familiar aquatic plant called lotus, which is classified in the genus *Nelumbo*. When we use the name Faboideae for this subfamily, then the Type genus is *Faba*.

This is the largest of the 3 subfamilies of the family Fabaceae. The members of this subfamily (Figs 21.19 – 21.23) are cosmopolitan in distribution, but are more common in the warmer regions of both Northern and Southern Hemispheres. Some herbaceous members are an important feature of the alpine vegetation at high altitudes. Others are characteristic of North European and Mediterranean areas. These plants are also important for steppe-formation and in other grasslands. Several papilionaceous plants are characteristic of Eastern Europe, Western Asia, South Africa and Australia.

Fig. 21.19: *Crotalaria juncea*. **a) A flowering and fruiting branch. b) A flower. c) Expanded androecium. d) Gynoecium in longitudinal section. e) A pod longitudinally cut.**

A large number of plants are of great economic importance and are widely cultivated. We are familiar with the peas, beans, pulses and many other members of this subfamily.

Field Recognition Characters

Herbs, herbaceous climbers, shrubs or trees, the roots generally have characteristic nodules containing nitrogen-fixing bacteria; leaves simple or compound; stipules prominent; tendrils present in herbaceous climbers; flowers few or in racemose inflorescence; typically zygomorphic with characteristic papilionaceous corolla; stamens usually diadelphous with the staminal tube enclosing the gynoecium; these structures are in turn enclosed in a keel or a boat-shaped structure formed by 2 petals.

Morphological Diversity

The majority of the members of this subfamily are herbs or herbaceous climbers. A few are shrubs, woody climbers or trees. The roots of many species have nodules, which contain nitrogen-fixing bacteria. These bacterial root nodules help the plant to accumulate nitrogen compounds, hence making the plants important in crop rotation. These plants can also serve as green manure when they are ploughed into the field.

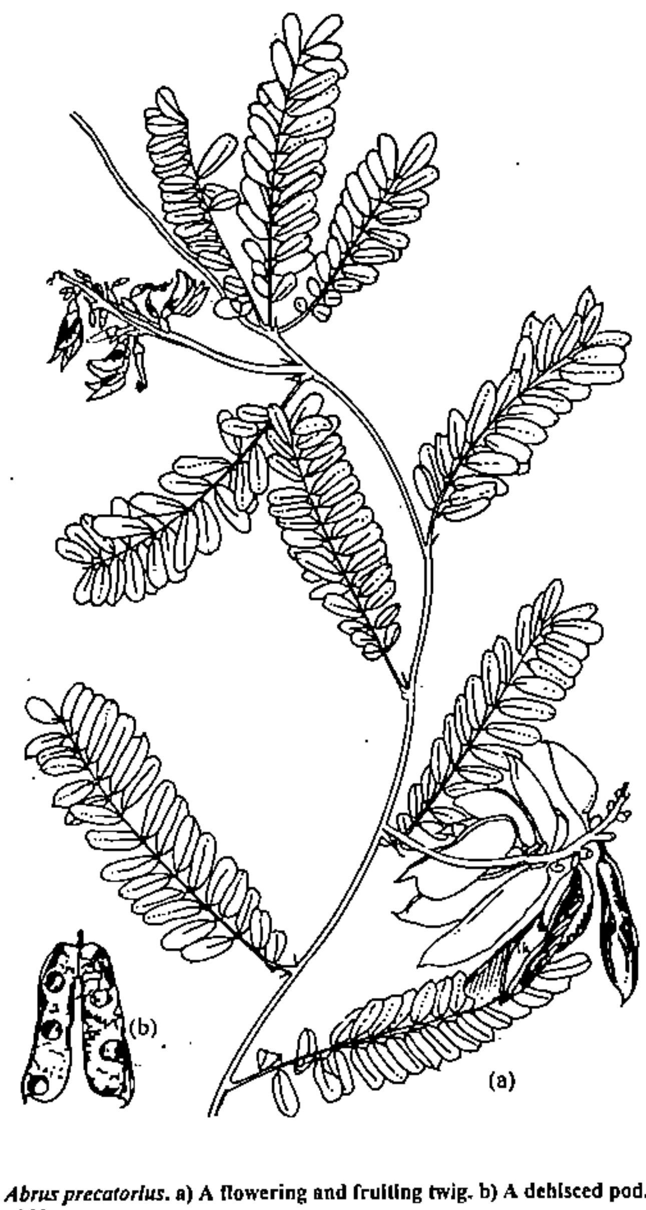

Fig. 21.20: *Abrus precatorius*. a) A flowering and fruiting twig. b) A dehisced pod. (From Maheshwari, 1983)

Leaf: The leaves are alternate, simple (Fig. 21.19) or compound (Fig. 21.20). The compound leaves may be trifoliate (Fig. 21.21 and 21.22), pinnately compound, or palmately compound. All leaflets may be present, or some or all of the leaflets may be modified into tendrils [e.g., *Pisum* (Fig. 21.23), *Lathyrus*, *Vicia*]. The leaves are stipulate and the stipules are generally free. Sometimes, the stipules become foliaceous and serve as organs of assimilation especially when the leaflets are modified into tendrils. Rarely, the stipules are greatly reduced (*Cytisus*) or even absent (*Ulex*). In many plants with pinnately compound leaves, stipels (miniature stipules) may be present at the base of the leaflets.

The leaves of many plants show characteristic light-induced movements. In *Trifolium*, *Phaseolus*, and *Robinia* the leaflets become vertical at night suggesting the condition of sleep. In *Desmodium* leaf movements may be light- or temperature-induced. Two small lateral leaflets show spontaneous upward and downward movement when the temperature is sufficiently high. These leaf movements are regulated by the pulvinous or the swollen base of the petiole. Extrafloral nectaries may be present.

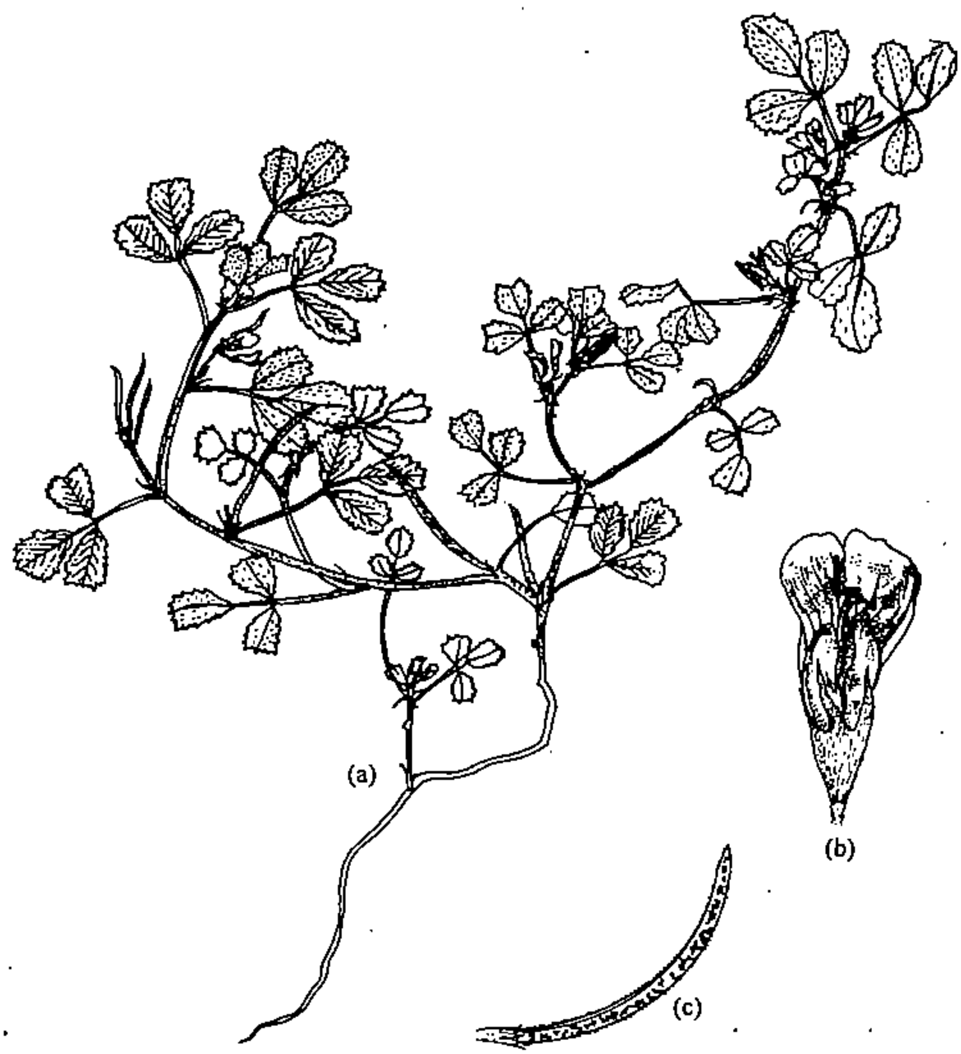

Fig. 21.21: *Trigonella incisa*. a) A plant with flowers and pods. b) A flower. c) A fruit. (From Maheshwari, 1983).

Inflorescence: The inflorescence may consist of a solitary or a few flowers in the axils of the leaves (e.g., *Lathyrus*, *Pisum*). More commonly, the inflorescence is racemose. It may be an axillary or a terminal raceme or panicle. Sometimes it is a dense axillary head.

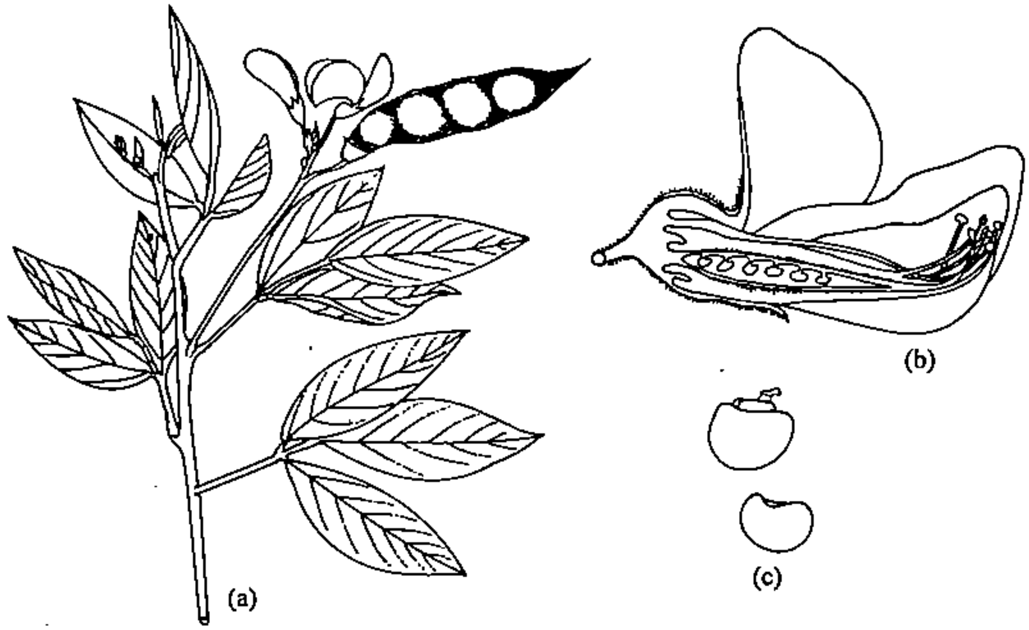

Fig. 21.22: ***Cajanus cajan.*** **a) A flowering twig. b) A flower cut in longitudinal section. c) Two seeds. (From Purseglove, 1988).**

Fig. 21.23: *Pisum* ... a) A twig with flowers and fruits. b) A flower longitudinally cut. c) A pod.

Flower: The flowers are bracteate and generally bracteolate also. They are complete, typically zygomorphic, bisexual, pentamerous and generally hypogynous (or sometimes slightly perigynous).

The calyx has 5 sepals with the first developed sepal (outermost sepal) being anterior. The sepals are generally united forming a tube. They show ascending imbricate aestivation. The corolla has 5 petals, which are of unequal size and form a typical papilionaceous corolla. This is characteristic of this subfamily. There is one very large petal called the "standard" or "vexillum" which is outermost and posterior in position. Then there are 2 lateral petals, which are free, smaller than the standard and form wing-like structures. They are called "wing petals" or "alae". Finally, there are 2 small petals on the anterior side of the corolla. These small "keel" petals are usually united to form a boat-shaped structure called the "carina". These keel petals are innermost and the aestivation of the corolla is descending imbricate (also called vexillary). The two united petals enclose the androecium and gynoecium. This typical papilionaceous flower is adapted for insect pollination.

Androecium: There are usually 10 stamens. They appear as a single whorl in a mature flower although they are diplostemonous in origin. In a majority of the plants, the androecium is diadelphous showing a (9)+1 arrangement. Nine stamens are united into a long open tube and the 10th (posterior) stamen is free. Sometimes this 10th free stamen does not develop (e.g., *Dalbergia*); or the stamens may be monadelphous (e.g., *Crotalaria*). The staminal tube surrounds the gynoecium and these structures are protected by the carina formed by the two small petals.

Gynoecium: The gynoecium is monocarpellary, with a superior ovary and marginal placentation, sometimes the ovary may be partly inferior. The number of ovules varies from one (e.g., *Butea monosperma* – Flame of the forest) to many. The style is single and the stigma is terminal.

Fruit: The fruit is a legume or pod, which usually dehisces by both dorsal and ventral sutures. Sometimes the fruit is indehiscent (e.g., *Dalbergia, Pongamia*). In *Arachis hypogaea* (groundnut), the fruit develops below the soil. Here, the floral stalk grows and elongates after fertilisation, pushing the developing fruit into the soil. The seeds have little or no endosperm and the embryo has flat, leaf-like or fleshy cotyledons. These seeds are rich in starch, protein and fat, making the plant economically important.

Diagnostic Features of the Family

1. Herbs, climbers, shrubs or trees.
2. Leaves stipulate, generally compound, base pulvinate, leaflets show characteristic movements.
3. Inflorescence usually racemose.
4. Flowers bracteate, generally pentamerous, actinomorphic (Subfamily Mimosoideae) or zygomorphic (Subfamilies Caesalpinioideae and Papilionatae).
5. Corolla aestivation valvate (Subfamily Mimosoideae) or ascending imbricate (Subfamily Caesalpinioidae) or descending imbricate (Subfamily Papilionatae). Petals of equal or unequal size.
6. Stamens few to many in Subfamily Mimosoideae with brightly coloured filaments; or some stamens reduced to staminodes in Subfamily Caesalpinioideae; or stamens generally diadelphous in Subfamily Papilionatae.
7. Gynoecium monocarpellary with a superior ovary and marginal placentation.
8. Fruit a legume or pod.

9. Seeds with little or no endosperm and embryo with flat, leaf-like or fleshy cotyledons.

Systematic Position

The family Leguminosae derives its name from its characteristic fruit (legume). It is also called Fabaceae, which is based on the name of the Type genus *Faba*. The name Papilionaceae (although not based on the name of any genus, but based on the papilionaceous corolla) is also used and this is permitted under the rules of the International Code of Botanical Nomenclature.

The family Fabaceae is classified in the Polypetalae, Series III Calyciflorae and Order 11 Rosales by Bentham & Hooker. This order has 8 other families including Rosaceae and Saxifragaceae. This large Fabaceae family is divided into 3 subfamilies by Bentham & Hooker. In Engler & Prantl's classification, the family Fabaceae is classified in Archichlamydeae and Order 21 – Rosales. There are 18 families in this order including 7 of the families classified in order Rosales by Bentham & Hooker. In this classification also, there are 3 subfamilies into which the family Fabaceae is classified. The relationship between Fabaceae, Rosaceae and Saxifragaceae is also accepted. Takhtajan has classified the family Fabaceae in Subclass H Rosidae, Superorder Fabanae and Order 107 – Fabales. The family is classified into 3 subfamilies. In this system of classification, the family Fabaceae is separated from all other families with which it was classified in Order Rosales by Bentham & Hooker as well as by Engler & Prantl. In Takhtajan's classification, Rosaceae is classified in Order 101 – Rosales and the family Saxifragaceae is classified in Order 94 – Saxifragales. Both these orders are separated from the Order 107 – Fabales and they are classified in Superorder Rosanae and Saxifraganae.

Interestingly, there are also suggestions in other systems of classification (Hutchinson's, and Cronquist's) to classify this group of plants as a single order called Leguminales or Fabales, with 3 families: Mimosaceae, Caesalpiniaceae, and Fabaceae or Papilionaceae.

Economic Importance

The Fabaceae is one of the most important families of flowering plants. The economically important plants of this family are used for food, fodder, medicine, dyes and tannins. Many plants are grown as cover crops and nitrogen fixers for enriching the soil and some yield valuable timber. There are also plants, which are cultivated as ornamentals or as shade trees along roadsides and in parks. It would be convenient to list the economically important plants of each subfamily separately.

21.6.1 Subfamily Mimosoideae

In this Subfamily, the genus *Acacia* is very important. *Acacia mearnsii* and other species yield wattle bark. This is the most important tanning material for converting animal hides and skins into different kinds of leather.

A. nilotica or babul yields babul-gum, which is rich in tannin. *A. senegal* or Gum arabic is used in textile and polish industries. It is also used in confectionery and in pharmacy. *A. catechu* or catechu (katha) is used for chewing with betel as a masticatory material.

A. farnesiana commonly known as cassie, its flowers are used as a source of perfume, known as cassie perfume.

Inga dulcis has edible fruits. This and other species are grown in coffee plantations as shade trees. *Samanea saman* or raintree is also planted as a shade tree. *Albizzia* species are planted along roadsides and in parks. A large number of plants are used as fuel wood e.g., *Prosopis, Leucaena glauca,* and *Pithecellobium dulce* are used as fodder plants. Species of *Calliandra* are cultivated as ornamentals for their beautiful inflorescences.

21.6.2 Subfamily Caesalpinioideae

The fruits of *Tamarindus indica* or tamarind are edible and are used in making curries and sauces.

Many species of the genus *Cassia* are important medicinally. *C. angustifolia* or Indian senna, and *C. senna* or Alexandrian senna are commonly used as purgatives. *Cassia auriculata* is used as a tanning material while species such as *C. fistula* and *C. siamea* are cultivated as ornamentals.

Haematoxylon campechianum or log wood is the source of a purplish dye called haematoxylin. This dye reacts with iron salts to give a permanent black colour. It is used for dying cotton, woollen goods, leather, furs and silk. Haematoxylin is also an important histological reagent.

Caesalpinia sappan or sappan wood yields a red dye from its heartwood. This dye was called brasil. Another species *Caesalpinia echinata* or brazil wood, which yields a similar dye, gave the country Brazil its name. *Caesalpinia pulcherrima* is grown as a shade and ornamental tree. *Copaifera officinalis* yields copaiba balsam used in medicine and industry. This and other plant species, e.g., *Hymenaea courbaril* yield copal. This is a hard resin used in paints, varnishes, inks and plastics. *Amherstia nobilis, Bauhinia, Cassia, Delonix regia,* and *Peltophorum pterocarpum* are grown as ornamentals.

21.6.3 Subfamily Papilionatae

Besides being the largest subfamily of the family Leguminosae, it is also economically the most important. These include all the leguminous pulse crops consumed as food by mankind. These are pulses, oil-yielding legumes about which you have studied in Block III A, Units 12 and 15. In addition, there are plants, which yield dyes, fibers, insecticides and medicines. As in the other subfamilies, in this subfamily also, there are plants grown as fodder or cover crops as shade trees and ornamentals. The following list mentions some of the more well-known economically important plants of this subfamily.

1. Food plants

1.	*Arachis hypogaea*	-	Groundnut
2.	*Cajanus cajan*	-	Pigeon pea
3.	*Canavalia ensiformis*	-	Jack bean
4.	*Cicer arietinum*	-	Gram or Chick pea
5.	*Cyamopsis tetragonoloba*	-	Cluster bean
6.	*Dolichos lablab*	-	Multiflora bean
7.	*Glycine max*	-	Soybean
8.	*Lens culinaris*	-	Lentil
9.	*Phaseolus lunatus*	-	Lima bean
10.	*Phaseolus vulgaris*	-	French bean or kidney bean
11.	*Pisum sativum*	-	Garden pea
12.	*Pongamia pinnata*	-	Pongam oil tree
13.	*Vicia faba*	-	Field bean
14.	*Vigna aconitifolia*	-	Mat bean
15.	*Vigna mungo*	-	Black gram
16.	*Vigna radiata*	-	Green gram
17.	*Vigna unguiculata*	-	Cow pea

2. Fibres

Crotalaria juncea; the stems yield sunnhemp fibre used for making ropes and sackcloth.

3. Dyes

Species of *Indigofera* especially *I. tinctoria* and *I. suffruticosa* yield the indigo dye used in textile and paint industries. *Pterocarpus santalinus* or Red sandalwood provides the red santalin dye used in textiles. The flowers *Butea monosperma* (flame of the forest) contain an orange-red dye used for colouring clothes.

4. Medicinal Plants

Glycyrrhiza glabra – liquorice obtained from the roots is used medicinally for treating coughs. *Psoralea corylifolia* – the seeds contain medicinal properties for treatment of skin diseases especially leucoderma.

Trigonella foenum-graecum – fenugreek, used both as a green leafy vegetable and as a medicinal plant because the seeds are aromatic and carminative.

5. Fodder, cover crops or green manure plants

Medicago sativa – leucerne or alfa-alfa and vilaiti-gawuth and several species of *Trifolium* or clovers, *Sesbania, Tephrosia* and *Zornia* are important as fodder plants or as cover crops or as green manure plants.

6. Miscellaneous uses

Abrus precatorius – Ratti, the red and black seeds are used for making necklaces and as unit weights by goldsmiths. The seeds are poisonous, but the leaves and roots are medicinally important.

Aeschynomene elaphroxylon has the lightest wood. It is used for making solar hats.

Species of *Derris* are used as insecticides while species of *Lonchocarpus* yield rotenone used as fish poison and as insecticide.

The shade trees and ornamentals of this subfamily include species of *Gliricidia, Erythrina, Millettia, Dalbergia, Mucuna, Clitoria, Clianthus, Sesbania, Pongamia, Wistaria* and *Lathyrus*.

Points to Remember

21.7 MYRTACEAE

The Eucalyptus family
Type genus : *Myrtus*

General Information

The family Myrtaceae is a large, tropical and subtropical family of 140 genera and nearly 3000 species. It is distributed chiefly in Australia, America and other warmer parts of the world. In India there are 14 genera and 165 species. Some are important for their edible fruits [*Syzygium cumini* (Fig. 21.24), *Psidium guajava* (Fig. 21.25)], spice [*Syzygium aromaticum* (Fig. 21.26)] or for wood and essential oil (*Eucalyptus* species).

Fig. 21.24: *Syzygium cumini*. A flowering twig.

Field Recognition Characters

Woody plants with aromatic leaves, leaves with characteristic intra-marginal veins; flowers with numerous stamens and epigynous discs; ovary inferior with axile placentation.

Morphological Diversity

The plants are trees or sometimes shrubs or rarely creeping undershrubs with woody stems. The stem shows the presence of bicollateral vascular bundles as a constant anatomical character. Besides this, there are numerous oil glands in lysigenous cavities in the cortical parenchyma of young stems and beneath the epidermis of the leaves.

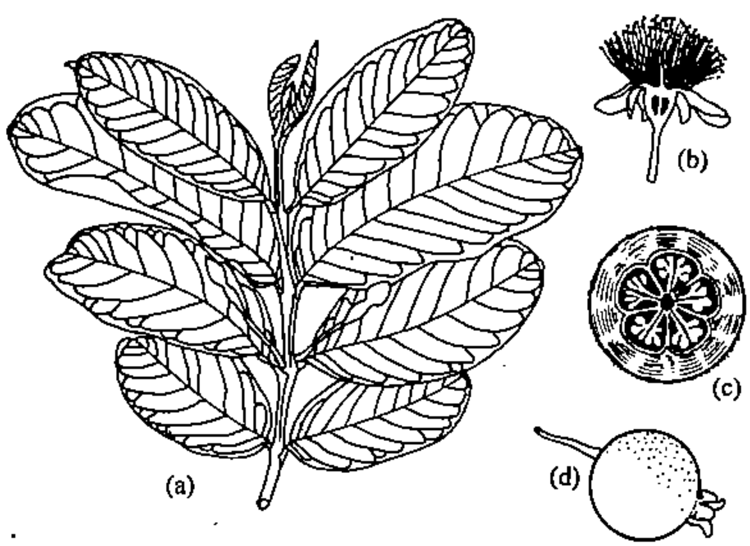

Fig. 21.25: *Psidium guajava*: a) A leafy shoot. b) A flower in longitudinal section. c) An ovary in transverse section. d) A fruit.

Leaf: The leaves are usually opposite, exstipulate, entire, coriaceous and evergreen. An intra-marginal vein is prominently observed in the leaves of many plants (e.g., *Eucalyptus, Syzygium*). In Australia, the plants are adapted to xerophytic conditions. The leaves of such plants may be needle-like, or they may be vertically aligned by the twisting of the petiole. This helps the plants to conserve moisture by avoiding exposure of the blade to direct sunlight.

Inflorescence: There may be solitary flower in the axil of the leaf (e.g., *Psidium guajava, Myrtus communis*) or more often the inflorescence is generally cymose (e.g., *Pimenta, Eucalyptus, Syzygium*). In some species it is racemose (e.g., *Callistemon, Barringtonia*).

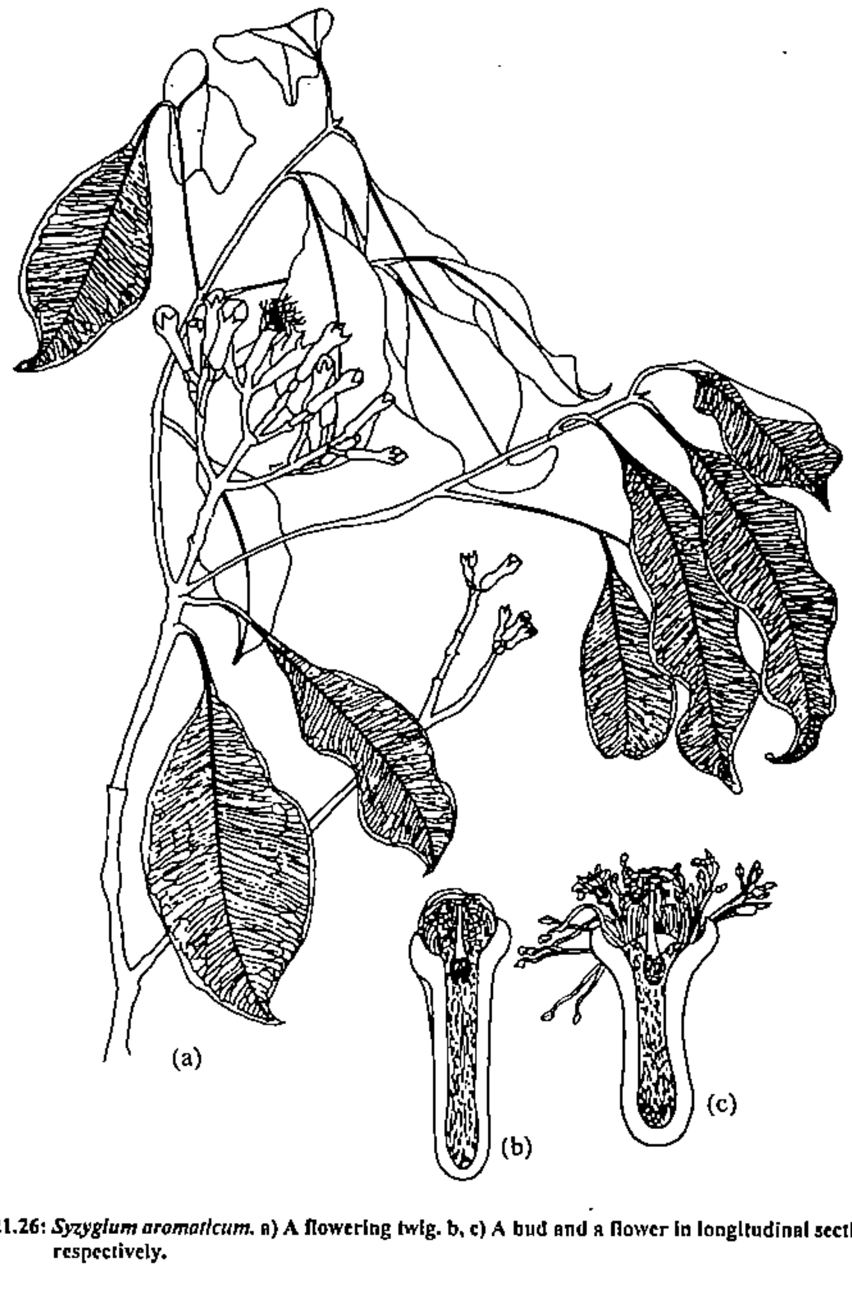

Fig. 21.26: ***Syzygium aromaticum.*** **a) A flowering twig. b, c) A bud and a flower in longitudinal sections, respectively.**

Flower: The flowers are bracteate, bracteolate, pedicellate, tetra- or pentamerous, bisexual, actinomorphic and generally epigynous (e.g., *Psidium, Myrtus*) or perigynous due to incomplete fusion of the ovary and the receptacle. An epigynous disc is usually present.

The calyx is polysepalous or rarely gamosepalous. The aestivation is quincuncial and the sepals are generally persistent in the fruit. The corolla is polypetalous, with the petals spreading outwards. The aestivation is imbricate.

In *Eucalyptus*, the calyx is greatly reduced or even absent, while the corolla is united to form a cap-like calyptra, which separates from the receptacle and falls off when the flower opens.

Androecium: The stamens are generally numerous and free. They are arranged in several whorls on the edge of the receptacle and are usually bent inwards in the bud. Sometimes, the stamens are reduced to just 2 obdiplostemonous whorls or even reduced to a single whorl. The anthers are dorsifixed or versatile and the connective is glandular at the tip. They show introrse dehiscence.

Gynoecium: The syncarpous gynoecium is made up of 2-5 carpels. The ovary is inferior when the disc is completely fused with the receptacle; or the ovary is half-inferior (perigynous condition) when there is incomplete fusion between the ovary and the receptacle. The ovary has 1-many locules with 2-many ovules in each locule. The placentation is usually axile (rarely perietal). The style is long with a simple stigma.

Fruit: The fruit is a fleshy berry (rarely a drupe) or it is a dry capsule (rarely a nut). The seeds have a hard testa and are non-endospermous. In *Eucalyptus*, the seeds are winged.

Diagnostic Features of the Family

1. Woody plants with bicollateral vascular bundles in the stem.
2. Young stems and leaves with numerous oil glands.
3. Leaves exstipulate, coriaceous and with intra-marginal vein.
4. Flowers solitary or in cymose or racemose inflorescences.
5. Flowers bisexual, actinomorphic, and generally epigynous.
6. Receptacle or disc well developed.
7. Calyx and corolla distinct and free or modified into a calyptra, which falls off at anthesis.
8. Stamens numerous, free with gland-tipped connective.
9. Ovary syncarpous, inferior, placentation axile.
10. Fruit a berry or a capsule.
11. Seed with hard testa, and the endosperm scant or none.

Systematic Position

The family Myrtaceae is classified in Polypetalae, Series III Calyciflorae and Order 12 – Myrtales by Bentham & Hooker. This order includes 5 other families. In Engler & Prantl's classification the family Myrtaceae is classified in Archichlamydeae and Order 29 – Myrtiflorae. This order has 10 families including all the families classified in the Order Myrtales by Bentham & Hooker. Takhtajan in his system of classification, classifies the family Myrtaceae in Subclass H Rosidae, Superorder Myrtanae and Order 106 – Myrtales. In this order there are 17 families. The family Rhizophoraceae that is classified with Myrtaceae by Bentham & Hooker as well as Engler & Prantl is classified in a separate order Rhizophorales by Takhtajan. Both these orders belonging to two different superorders are however classified in the same subclass by Takhtajan.

Economic Importance

1. *Syzygium aromaticum* yields the spice, clove that is one of the very valuable products of this family.
2. *Pimenta dioica* (Allspice or Pimento) is an important spice from tropical America. It is also called Jamaican pepper.

3. *Psidium guajava* (Guava or Amrood) and *Syzygium cumini* (Jambalon or Jamun) are important for the edible fruits.
4. The genus *Eucalyptus* provides timber, and it is cultivated in large areas for reforestation. It is also a source of an essential oil used in flavouring and in medicine.
5. Several members of this family are grown as ornamentals. These include *Callistemon*, *Myrtus*, *Melaleuca*, *Syzygium* and *Eucalyptus*.

Points to Remember

21.8 CUCURBITACEAE

The Gourd family
Type genus : *Cucurbita*

General Information

The family Cucurbitaceae with 90 genera and 750 species is widely distributed in tropical and subtropical areas both in the Old and the New World. In India about 35 genera and 100 species of this family are found. Many of these are cultivated for their edible fruits, which are used as vegetables or consumed as table fruits.

Field Recognition Characters

Tendril bearing herbaceous climbers, leaves alternate, flowers yellow or white, and unisexual, fruit a berry or a pepo.

Morphological Diversity

The majority of the plants are annual herbs, trailing on the ground or with a climbing habit (Figs 21.27-21.30). They show a remarkably fast growth and the plant contains large amounts of watery sap. The stem is usually 5-angular and has bicollateral vascular bundles in two alternating rings. The plants climb on an available support such as poles and other plants by means of tendrils. The tendrils may be simple thread like structures which may be branched or unbranched and show clockwise or anti-clockwise twisting. The tendrils may sometimes be

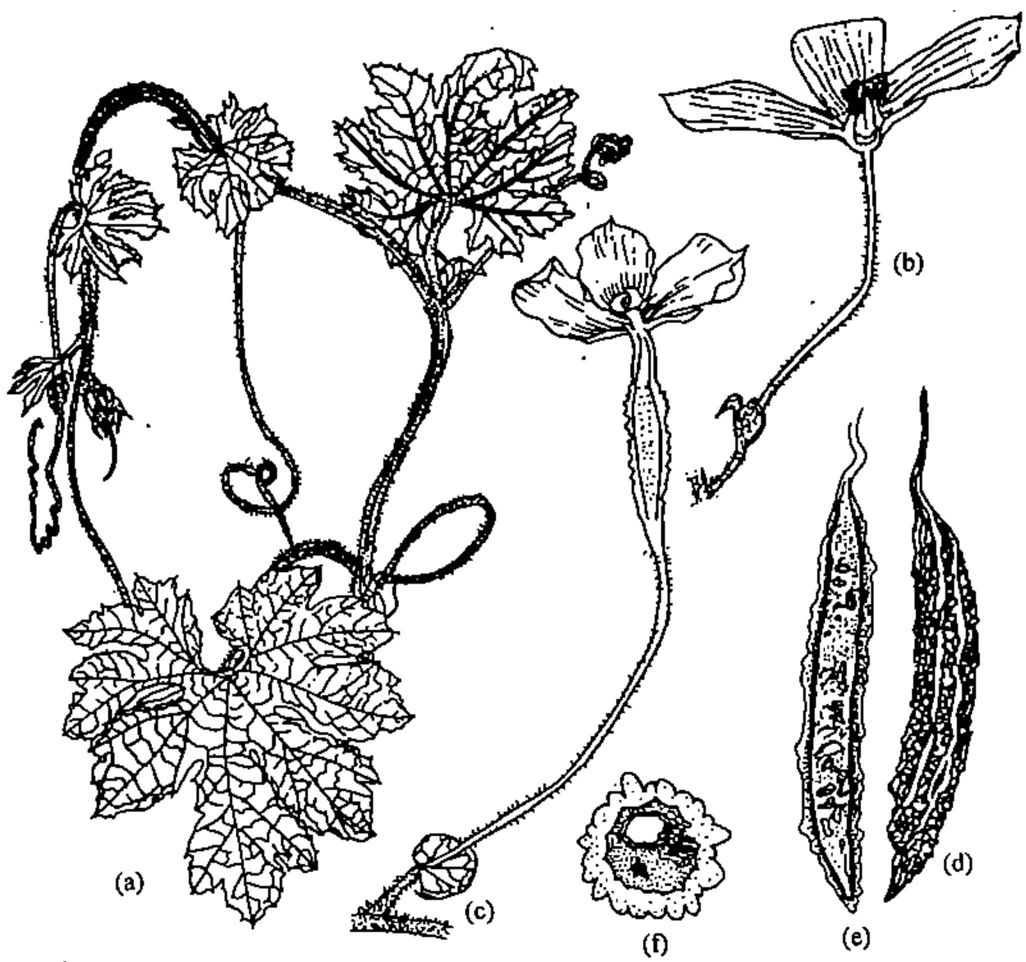

Fig. 21.27: *Momordica charantia.* a) A leafy shoot. b and c) Male and Female flowers respectively in longitudinal sections. d) A fruit. e and f) A fruit in longitudinal and transverse sections, respectively.

leaf-like. They are very sensitive and help the soft stem to climb to considerable heights. The morphological nature of the tendrils has been discussed by several morphologists and they describe it variously as modified stems, leaves, stipules, bracteoles, flower stalks or also as **organs sui generis,** i.e., an independent organ. This suggests that the tendrils of different plants may be modifications of different organs of the plant.

Leaf: The leaves are alternate, exstipulate, long-petioled, and show a considerable variety in shape. They are simple, generally broad, but often palmately-lobed or divided. The petioles are fistular and the lamina shows palmi-nerved reticulate venation.

Inflorescence: The plants have unisexual flowers, which are either solitary in the axils of the leaves, or in cymose clusters. The male inflorescence is usually more elaborate than the female. The plants are generally monoecious having the male and female flowers in the axils of different leaves (e.g., *Momordica charantia*) or sometimes the plants are dioecious (e.g., *Momordica diocia, Coccinia cordifolia*).

Flower: The flowers are pedicellate, actinomorphic, pentamerous, epigynous, usually yellow or white, and generally large and showy. The calyx has 5 sepals, which are united forming a tube. In the male flowers, the calyx tube is attached to the receptacle of the flower while in the female flowers it is adnate to the inferior ovary. The aestivation of calyx is either valvate or imbricate. The corolla has 5 petals which are generally gamopetalous but, sometimes, polypetalous. The aestivation is either valvate or imbricate. The gamopetalous corolla may be rotate, campanulate, or salverform. In *Trichosanthes*, which shows a polypetalous corolla, the petals have fimbriate lobes (Fig. 21.28).

Androecium: There are generally 5 stamens in the male flowers, and they are epipetalous. However, the stamens exhibit a great complexity due to cohesion. Five free stamens are generally seen in *Luffa cylindrica.* There are 3 groups of stamens in *Thladiantha*, consisting of 2 pairs of stamens united only by their filaments and a single stamen. This union of the stamens progresses to the anthers so that the androecium apparently consists of 3 stamens, 2 with 4 anther cells and 1 with 2 anther cells (e.g., *Citrullus, Momordica*). In *Cucurbita, Lagenaria* and other genera, further complication leads to the cohesion of the filaments and anthers thus forming a column with irregularly curved anthers; while in *Cyclanthera* the anthers form 2 ring-like pollen containing chambers at the apex of the central column. The anthers dehisce longitudinally.

Gynoecium: In the female flowers, there are generally 3 (rarely 4 or 5) carpels, which are syncarpous, and the ovary is inferior. The ovary is unilocular and shows parietal placentation (Fig. 21.29) but the 3 placentae may grow and meet in the centre making the ovary falsely trilocular and appearing to have axile placentation. There is a single style with 3 stigmas.

Fruit: The fruit is soft, fleshy and indehiscent forming a berry. When the pericarp becomes very hard, the fruit is called a pepo. The shape and size of the fruit show great diversity. There are many seeds in the fleshy part of the fruit. They are non-endospermic and have a straight embryo. The cotyledons are long, flat or leaf-like and are rich in oil. In the squirting cucumber (*Ecballium*) the ripe fruit is very turgid and explodes when touched, squirting out the seeds with the liquid pulp.

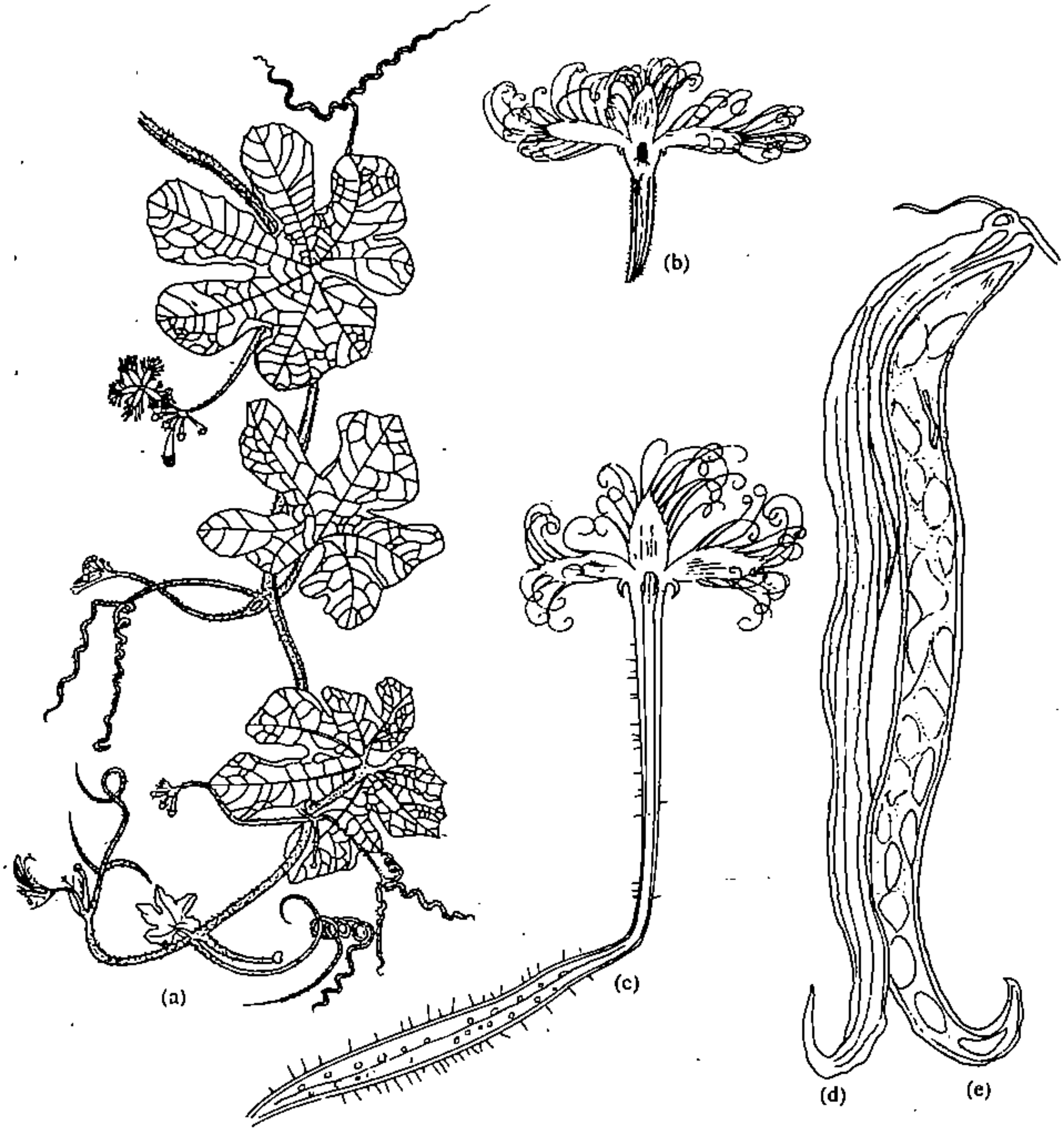

Fig. 21.28: *Trichosanthes cucumerina.* a) A flowering shoot. b and c) A male flower and a female flower in longitudinal section, respectively. d) A fruit. e) Same, longitudinally cut (From Purseglove, 1988).

Diagnostic Features of the Family

1. Tendril-bearing, trailing or climbing herbaceous plants.
2. Stems 5-angular with bicollateral vascular bundles.
3. Leaves with long, hollow petioles, simple or palmately-lobed lamina and palmi-nerved reticulate venation.
4. Solitary flowers or cymose inflorescence.
5. Unisexual, pentamerous flowers.
6. Androecium with convoluted anthers.
7. Tricarpellary, syncarpous, inferior ovary with parietal placentation.
8. Fruit a berry.
9. Compressed seeds with flat cotyledons containing oil.

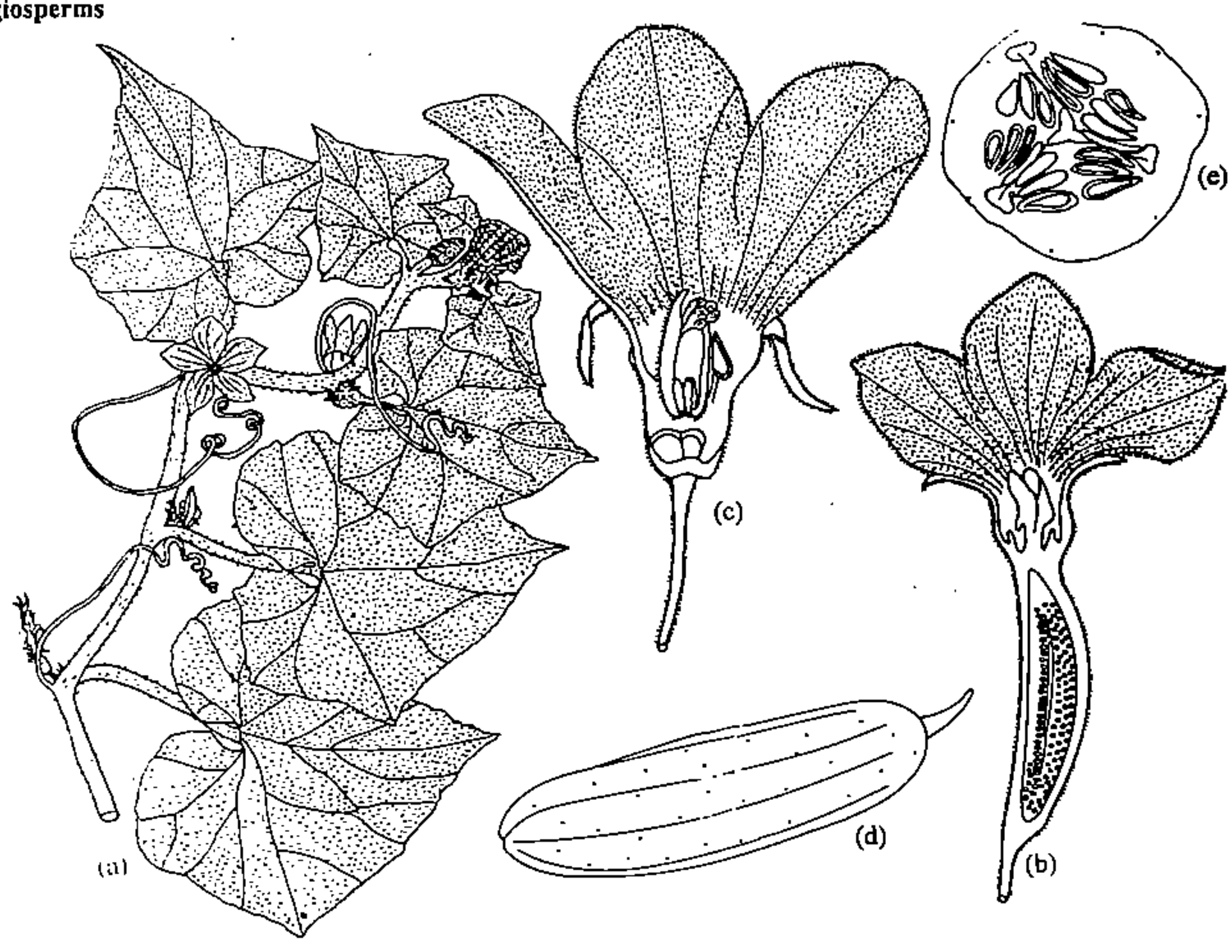

Fig. 21.29: *Cucumis sativus*. a) A flowering shoot. b and c) A female flower, and a male flower in longitudinal sections, respectively. d) A fruit. e) Same, in transverse section (From Purseglove, 1988).

Systematic Position

The family Cucurbitaceae is classified in the Polypetalae, Series III Calyciflorae and the Order 13 – Passiflorales by Bentham & Hooker. This order has 6 other families. In Engler & Prantl's classification, the family is classified in Sympetalae, Order 9 – Cucurbitales and there is no other family in this order. Takhtajan in his classification places the family Cucurbitacae in Subclass G – Dilleniidae, Superorder Violanae, Order 82 – Cucurbitales. As in Engler and Prantl's classification, in Takhtajan's classification also Cucurbitaceae is the only family in the Order Cucurbitales.

Economic Importance

The family Cucurbitaceae provides a large number of edible fruits.

a) *Benincasa hispida* – white gourd. The young and mature fruits are used as a vegetable, while the ripe fruit is candied and sold as a sweetmeet (petha).
b) *Citrullus lanatus* – water melon
c) *Citrullus lanatus* var. *fistulosus* – Tinda
d) *Cucumis melo* – melon
e) *Cucumis sativus* – Cucumber (Fig. 21.29)
f) *Cucurbita moschata* – pumpkin
g) *Cucurbita maxima* – Red pumpkin
h) *Cucurbita pepo* – field pumpkin

i) *Lagenaria siceraria* – Bottle gourd
j) *Luffa acutangula* – angled gourd
k) *Luffa cylindrica* – sponge gourd
l) *Momordica charantia* – Bitter gourd
m) *Sechium edule* – Chow-chow
n) *Trichosanthes cucumerina* – snake gourd
o) *Trichosanthes dioica* – pointed gourd.

Fruits with a hard pericarp are used for making musical instruments (e.g., *Benincasa, Lagenaria*) while the dried fibrous tissue of the fruit of *Luffa cylindrica* is used as a bath sponge.

A few species of *Ecballium, Cyclanthera, Coccinia* and *Sechium* are grown as ornamentals.

Fig. 21.30: ***Lagenaria siceraria.*** **a) A flowering shoot. b and c) A male flower, and a female flower in longitudinal sections respectively. d) A fruit (From Purseglove, 1988).**

21.9 APIACEAE

The Carrot family, Umbelliferae
Type genus: *Apium*

General Information

The Apiaceae is a cosmopolitan family chiefly distributed in the north temperate regions. This is a large family having about 300 genera and 3000 species some of which are very familiar for their fruits that are used as spices (e.g., coriander, fennel, cumin, caraway and others). The roots of carrot plant are edible. In India, 53 genera and 200 species of this family are known to occur.

Field Recognition Characters

Aromatic herbs with fistular stems; leaves compound with sheathing base; umbellate inflorescence.

Morphological Diversity

The plants are annual or perennial herbs with fistular stems (herbaceous, soft and hollow in the internodes). Sometimes the stem may be creeping and filiform (e.g., *Hydrocotyle*, Fig. 21.31) or it my be stout and considerably tall (e.g., *Heracleum, Angelica*). The stems may also be furrowed. An important feature is the aromatic nature of the plant due to the presence of etheral oil or resin or balsam canals in all organs.

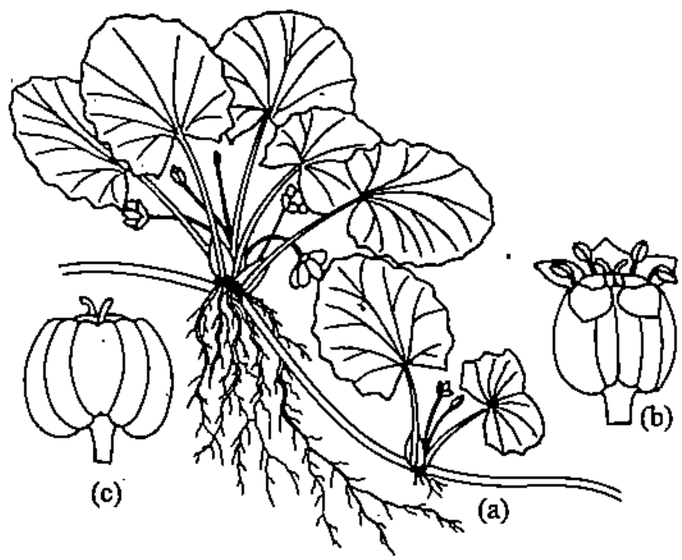

Fig. 21.31: *Hydrocotyle asiatica*. a) A portion of plant bearing flowers. b) A flower. c) A fruit.

Leaf: The leaves are alternate, exstipulate, with a sheathing base and a much divided, pinnately compound lamina (e.g., *Coriandrum*, *Daucus*, *Samicula*, also see Figs 21.32 & 21.33) and rarely simple leaves (e.g., *Hydrocotyle*, Fig. 21.31).

Inflorescence: The characteristic umbellate inflorescence (thus the name Umbelliferae) and the aromatic nature of the plants have been used as important features for recognising this family as a natural unit in classification since ancient times. The inflorescence may be a simple umbel or more commonly it is a compound umbel made up of several smaller umbels (called umbellules). Sometimes it is reduced to a solitary flower (e.g., *Hydrocotyle*). A terminal flower differing from the rest of the umbel may also develop (e.g., *Daucus*). The inflorescence is generally subtended by bracts forming an involucre (at the base of the main umbel) or an involucel (at the base of the umbellule). Sometimes both involucre and involucel may be absent. The conspicuous compound umbel with numerous small flowers is often compared with the capitulum of Compositae as a means of the evolutionary success of the family.

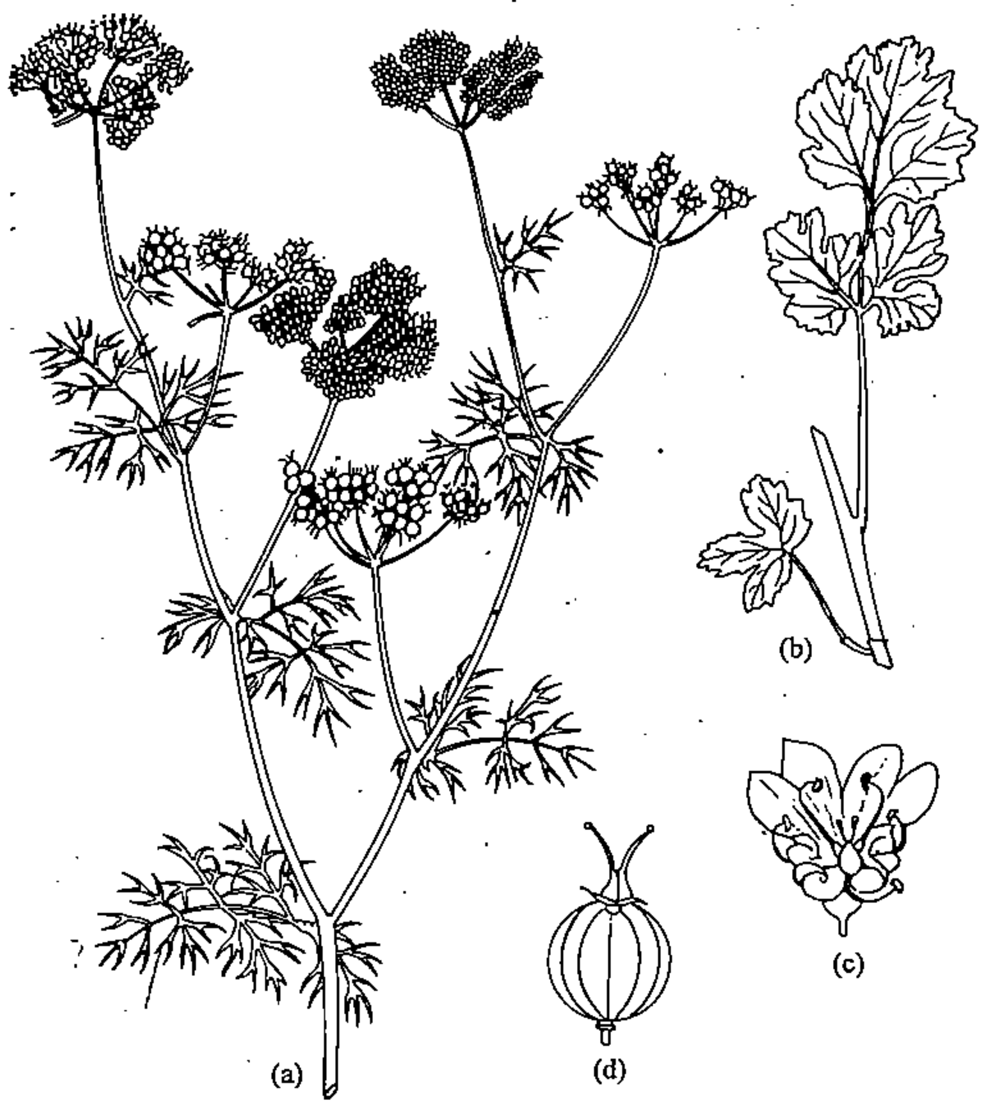

Fig. 21.32: ***Coriandrum sativum.*** **a) A flowering branch. b) A leaf. c) A flower. d) A fruit.**

Flower: The flowers are bracteate, usually bisexual, pentamerous, actinomorphic and epigynous. Sometimes, the peripheral flowers of a compound umbel become zygomorphic due to the enlargement of some petals. Such flowers may also become unisexual by reduction or non-development of the stamens. These flowers serve to attract insect pollinators (compare this feature with the capitulum of Asteraceae when you study Unit 22). The floral development is remarkable in the fact that there is marked protandry. The stamens develop first, followed by the petals and then the sepals while the carpels develop last. There are 5 sepals which often appear as a rudimentary crown on the ovary. The odd sepal is posterior and the aestivation is valvate or imbricate. The five petals are free and show valvate aestivation. The petals may be deeply lobed or emarginate. They are usually white or yellow, rarely blue or purple.

Androecium: The five stamens alternate with the petals. The filaments are long and slender and bent inwards in the bud. The anthers are basi- or dorsifixed, dithecous and show introrse dehiscence.

Gynoecium: The gynoecium is bicarpellary syncarpous, and with an inferior ovary. An epigynous glandular disc or stylopodium is present. The two short styles arise from the stylopodia. Each style ends in a stigma. The ovary is bilocular with axile placentation. There is only one ovule in each locule and the placenta is pushed to the apex because the ovules are pendulous.

Fruit: A dry schizocarp called a cremocarp which splits down the septum into two mericarps. The fruit shows many diverse patterns on its pericarp. These surface patterns of the mericarps provide valuable features for identifying the genera and the species within the family. The seed is often united to the pericarp. It has a small embryo and an oily endosperm.

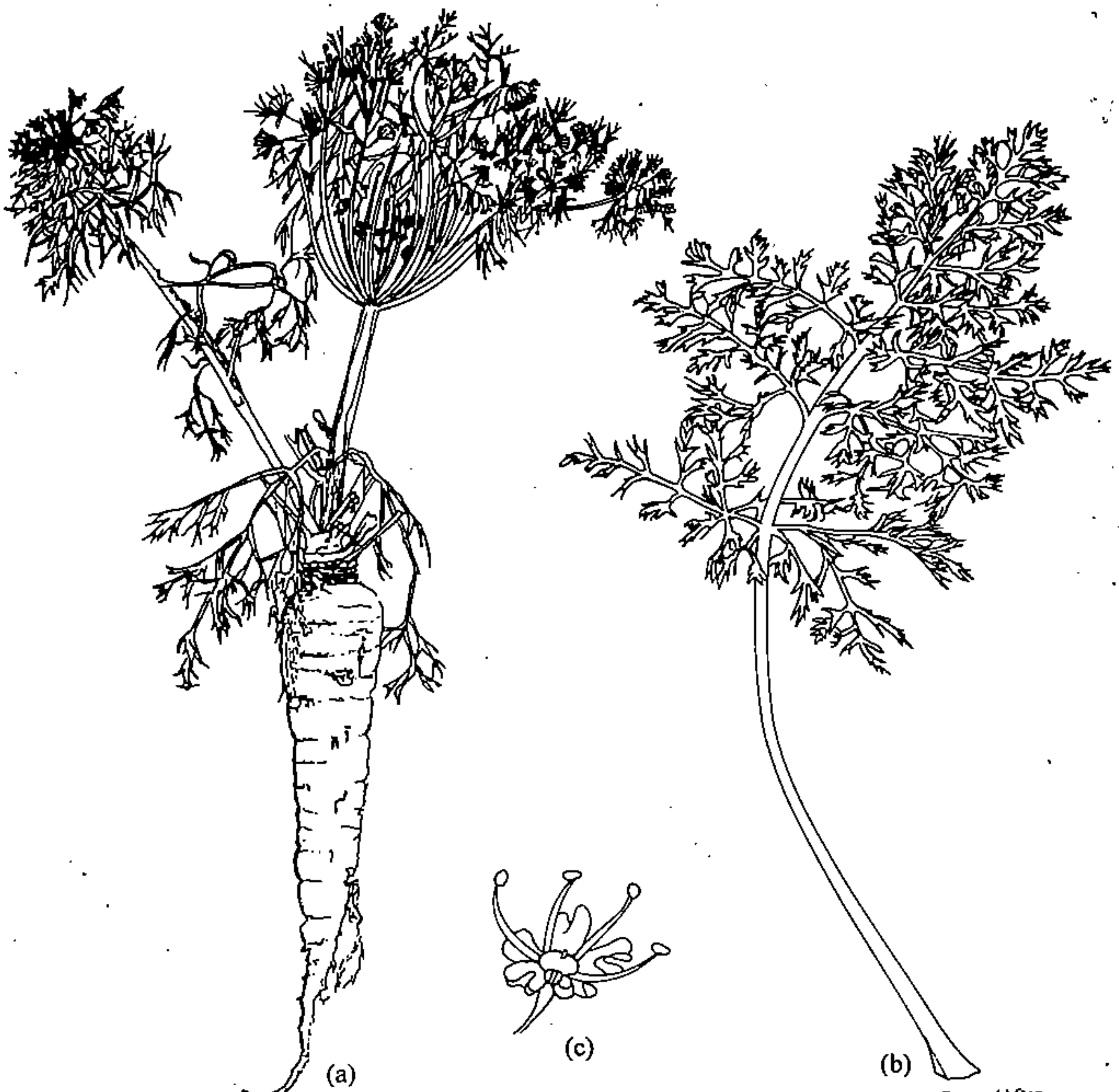

Fig. 21.33: *Daucus carota.* a) A plant with root and flowers. b) A leaf enlarged. c) A flower (After Purseglove, 1988).

Diagnostic Features of the Family

1. Aromatic herbs
2. Fistular stem
3. Leaves with sheathing base and pinnately divided lamina.
4. Umbellate inflorescence
5. Protandrous flowers
6. Reduced calyx*
7. Polypetalous white or yellow corolla
8. Stamens with long slender filaments

9. Bicarpellary, syncarpous gynoecium with inferior ovary
10. Apical placentation with pendulous ovules
11. Distinct stylopodia present above the ovary
12. Fruit a cremocarp made up of 2 mericarps.

Systematic Position

The family Apiaceae or Umbelliferae is classified in the Polypetalae, Series III Calyciflorae and Order 15 – Umbellales by Bentham & Hooker. This is the last order in the Polypetalae and it has 3 families. In Engler & Prantl's classification, the family Umbelliferae is classified in the Archichlamydeae and Order 30 – Umbelliflorae. This is also the last order in the Archichlamydeae and has the same 3 families as in Bentham & Hooker's classification. In these two systems of classification, the affinites of the family Umbelliferae are with Cornaceae and Araliaceae. Takhtajan, in his system of classification has classified the family Apiaceae in Subclass I – Cornidae, Superorder Aralianae and Order 149 – Araliales. This order does not include the family Cornaceae which is classified in Order 141 – Cornales, and there are 5 other families in this order.

Economic Importance

The aromatic properties of the plants make the family Apiaceae important for flavouring food. Thus, a large number of umbellifers are used as spices, condiments and in medicine. Some members are consumed as food and others are cultivated as ornamentals. The more well known economically important plants are listed here.

1. *Daucus carota* – Carrot (Fig. 21.33), the fleshy taproot is eaten raw in salads or cooked in various ways. The juice of raw carrots is consumed as a nutritious drink. Different varieties of carrot showing a wide range of coloration due to the various pigments, are cultivated all over the world.

2. *Petroselinum crispum* – Parsley, this is believed to be the most useful of all the herbs. The leaves are a rich source of vitamin C and are used as a flavouring agent.

3. *Apium graveolens*, *A. gravelolens var. dulce*, it is used in salads, soups and stews. Its seeds are also used for flavouring food and as a medicine.

4. *A. sowa.* the leaves are eaten as a salad and as a vegetable. The fruits are used for flavouring food and in medicine.

5. *Ferula assafoetida*: Asafoetida or "Heeng". This and other species of *Ferula*, yield an oleoresin as a root exudate when the roots are injured. The exudate is collected, dried and used as a flavouring agent and in medicine.

6. A large number of plants of this family provide fruits which are used as spices or condiments. The more common ones include: *Coriandrum sativum* (Coriander), *Cuminum cyminum* (Cumin), *Foeniculum vulgare* (Fennel), *Pimpinella anisum* (Anise), and *Trachyspermum ammi* (Ajwain).

7. Centella asiatica (= *Hydrocotyle asiatica*, Asiatic pennywort or Brahmi, also see Fig. 21.31) has numerous medicinal properties.

8. The common ornamentals of this family are species of *Angelica, Heracleum* and *Pimpinella*.

SAQ 2

1. Choose the most appropriate answer:

   a) The family/families .... is/are **not** classified in Subclass Rosidae by Takhtajan.
      i) Apiaceae
      ii) Cucurbitaceae
      iii) Fabaceae
      iv) Myrtaceae

   b) A superior ovary characterises the family ....
      (Select the correct answer from the choices given below)
      i) Apiaceae
      ii) Cucurbitaceae
      iii) Fabaceae
      iv) Myrtaceae

2. Match the type of placentation listed in Column I with the name of the family in Column II.

Column I	**Column II**
Apical	Fabaceae
Axile	Cucurbitaceae
Marginal	Apiaceae
Parietal	Myrtaceae

3. Name two families which have bicollateral vascular bundles in the stem.
   i) ....
   ii) ....

4. Briefly explain the following terms and name the family in which these structures have been described.

   a) Cremocarp: ....
   ....
   ....
   Family ....

   b) Diadelphous stamens: ....
   ....
   ....
   Family ....

   c) Intra-marginal vein: ....
   ....
   ....
   Family ....

   d) Tendril: ....
   ....
   ....
   Family ....

5. Assign the following genera to their respective families and mention one economic use of each genus.

Genus	Family	Use
a) *Acacia*	....	....
b) *Benincasa*	....	....
c) *Centella*	....	....
d) *Cicer*	....	....
e) *Delonix*	....	....
f) *Ferula*	....	....
g) *Momordica*	....	....
h) *Phaseolus*	....	....
i) *Pimenta*	....	....
j) *Syzygium*	....	....

6. In which system of classification are the following names used?

Order	System of classification
a) Fabales	....
b) Myrtiflorae	....
c) Passiflorales	....
d) Umbellales	....
e) Umbelliflorae	....

7. Name the 3 subfamilies of the family Fabaceae. List 2 characters used to distinguish the members of each subfamily:

a) Subfamily ....
   Characters i) ....
   ii) ....
b) Subfamily ....
   Characters i) ....
   ii) ....
c) Subfamily ....
   Characters i) ....
   ii) ....

8. List the diagnostic characters of the family Myrtaceae.

....
....
....
....

9. Write an account of the floral characters in the family Fabaceae.

....
....
....
....

10. Discuss the systematic position of the family Cucurbitaceae in the 3 systems of classification studied by you.

....
....
....

....

....

11. Write a note on the economic importance of the family Apiaceae.

....

....

....

....

12. Write the diagnostic features of the family Cucurbitaceae.

....

....

....

....

21.10 SUMMARY

The diagnostic features of the families studied in this unit are:

- **Ranunculaceae:** Generally herbs, sometimes woody climbers.Stems with irregularly arranged vascular bundles as seen in transection.Leaves exstipulate with sheathing base; lamina entire or lobed or finely divided, often heterophyllous. Flowers solitary or in cymose or racemose inflorescences. Flowers spirocyclic with all floral parts spirally arranged, generally actinomorphic, hypogynous. Perianth sepaloid or petaloid or differentiated into calyx and corolla. Numerous stamens with extrorse anthers. Numerous carpels, generally free. Fruit a group of achenes or follicles. Seed with straight embryo and abundant oily endosperm.

- **Brassicaceae:** Herbaceous plants with odorous watery sap. Leaves simple, exstipulate, lamina lobed or dissected. Inflorescence a raceme in corymbose form. Flowers ebracteate, polypetalous. Calyx distinct in two whorls. Cruciform corolla with petals showing a limb and claw organisation. Tetradynamous androecium. Bicarpellary gynoecium with parietal placentation. Fruit a siliqua or silicula. Seed small, its major portion occupied by the embryo.

- **Malvaceae:** Herbs, shrubs or trees. Young shoots and leaves covered with stellate hairs. Leaves reniform, cordate or palmately divided. Inflorescence of solitary flowers or racemose and complex. Flowers with epicalyx. Calyx with valvate aestivation. Corolla with convolute or imbricate aestivation. Stamens numerous, monadelphous with reniform, monothecous anthers. Large, spiny, spherical pollen. Gynoecium multicarpellary, syncarpous with superior ovary and axile placentation. Fruit a capsule or schizocarp.

- **Rutaceae:** Shrubs or trees, rarely herbs. Leaves compound, gland-dotted, aromatic. Flowers with a characteristic hypogynous disc. Petals larger than the sepals. Stamens obdiplostemonous. Gynoecium of 4 or 5 carpels, free at the base united above. Placentation axile. Fruit a hesperidium or drupe or schizocarp. Seeds with large embryo.

- **Fabaceae:** Herbs, climbers, shrubs or trees. Leaves stipulate, generally compound; exhibit nyctinastic movements, pulvinate leaflets show characteristic movements. Inflorescence usually racemose. Flowers bracteate, generally pentamerous, actinomorphic (Subfamily Mimosoideae) or zygomorphic (Subfamilies Caesalpinioideae and Papilionatae). Corolla aestivation valvate (Subfamily Mimosoideae) or ascending imbricate (Subfamily Caesalpinioidae) or descending imbricate (Subfamily Papilionatae). Petals of equal or unequal size. Stamens few to many in Subfamily Mimosoideae with brightly coloured filaments; or some stamens reduced to staminodes in Subfamily Caesalpinioideae; or stamens generally diadelphous in Subfamily Papilionatae.Gynoecium monocarpellary with a superior ovary and marginal placentation. Fruit a legume or pod. Seeds with little or no endosperm and embryo with flat, leaf-like or fleshy cotyledons.

- **Myrtaceae:** Woody plants with bicollateral vascular bundles. Young stems and leaves with numerous oil glands. Leaves exstipulate, coriaceous and with intra-marginal vein. Flowers solitary or in cymose or racemose inflorescences. Flowers bisexual, actinomorphic, generally epigynous. Receptacle or disc well developed. Calyx and corolla distinct and free or modified into a calyptra which falls off at anthesis. Stamens numerous, free with gland-tipped connective. Ovary syncarpous, inferior, placentation axile. Fruit a berry or a capsule. Seeds hard and non-endosperm.

- **Cucurbitaceae:** Tendril bearing, trailing or climbing herbaceous plants. Stems 5-angular with bicollateral vascular bundles. Leaves with long hollow petioles, simple or palmately-lobed lamina and palmi-nerved reticulate venation. Solitary flowers or cymose inflorescence. Unisexual, pentamerous flowers. Androecium with convoluted anthers. Tricarpellary, syncarpous inferior ovary with parietal placentation. Fruit a berry. Compressed seeds with flat cotyledons containing oil.

- **Apiaceae:** Aromatic herbs. Fistular stem. Leaves with sheathing base and pinnately divided lamina. Umbellate inflorescence. Protandrous flowers. Reduced calyx. Polypetalous white or yellow corolla. Stamens with long slender filaments. Bicarpellary, syncarpous gynoecium with inferior ovary. Apical placentation with pendulous ovules. Distinct stylopodia present above the ovary. Fruit a cremocarp made up of 2 mericarps.

21.11 TERMINAL QUESTIONS

1. What are the field recognition characters to identify members of the following families:

   a) Ranunculaceae

   ....

   ....

   ....

   b) Rutaceae

   ....

   ....

   ....

   c) Myrtaceae

   ....

   ....

   ....

   d) Cucurbitaceae

   ....

....

....

e) Malvaceae

....

....

....

f) Apiaceae

....

....

....

2. Compare the floral characters of the following families:
   a) Ranunculaceae and Brassicaceae
   b) Rutaceae and Myrtaceae

3. Prepare an account on the economic uses of the members of family Fabaceae.

....

....

....

....

....

....

4. Compare the androecium and gynoecium of the following families:
   i) Brassicaceae, ii) Rutaceae, iii) Malvaceae, iv) Apiaceae.

Family	Androecium	Gynoecium
i) Brassicaceae		
ii) Rutaceae		
iii) Malvaceae		
iv) Apiaceae		

21.12 ANSWERS

Self-assessment Questions

SAQ 1

1. a) (i) Brassicaceae
   b) (ii) Malvaceae

2. i) Malvaceae
   ii) Rutaceae

3. a) An epicalyx is an extra calyx-like structure generally made up of a whorl of bracteoles. It surrounds the calyx whorl that is made up of sepals. Also see Section 21.4.
   b) Obdiplostemonous androecium: In most flowers, the stamens are present in a single whorl and alternate with the petals. In some flowers, there are two whorls of stamens. When the outer whorl alternates with the petals, the inner alternates with the sepals. This condition is described as diplostemonous. But sometimes, the outer whorl of stamens lies opposite the petals thus alternating with the sepals instead of the petals. This condition is described as obdiplostemonous. It is commonly observed in the family Rutaceae.
   c) Siliqua: A siliqua is a special type of a capsule with a pod-like form. It is a dry, dehiscent fruit which is divided into 2 parts by a replum; the two halves of the fruit break away from below upwards, leaving the seeds attached to the replum. A siliqua is at least 3 times as long as it is broad. It is characteristic of the family Brassicaceae.
   d) Spirocyclic flower: In every flower, there are spirally arranged floral parts. The perianth may be differentiated into calyx and corolla. This is a followed by stamens and carpels. The arrangement of these floral parts may be in distinct cyclic whorls. However, these floral parts may be arranged spirally so that the spirally arranged perianth is continuous with the spirally arranged stamens and carpels. Flowers showing this pattern of arrangement of the floral parts are called spirocyclic flowers. They are common in the family Ranunculaceae.

4.

	Genus	Family	Use
a)	*Aconitum*	Ranunculaceae	medicinal
b)	*Aegle*	Rutaceae	edible and medicinal
c)	*Alyssum*	Brassicaceae	ornamental
d)	*Delphinium*	Ranunculaceae	ornamental
e)	*Eruca*	Brassicaceae	oilseed
f)	*Gossypium*	Malvaceae	fibre
g)	*Hibiscus*	Malvaceae	ornamental, fibre
h)	*Murraya*	Rutaceae	flavouring, ornamental

5. a) Family Rutaceae
   b) Subclass H Rosidae

6. a) i) Family Ranunculaceae
   ii) Family Brassicaceae

   b) i) Subclass : D Ranunculidae
   Superorder : Ranunculanae
   Order : 26 Ranunculales

   ii) Subclass : G Dilleniidae
   Superorder : Violanae
   Order : 84 Capparales

7. a) Parietal placentation
   b) Tetradynamous androecium (i.e., the six stamens of the flower are arranged in 2 whorls; the outer whorl has 2 short stamens and the inner whorl has 4 long stamens).

8. a) Brassicaceae: The fruit is a siliqua, see also answer 3 (c) above.
   b) Malvaceae: The fruit is a capsule which is dry and dehiscent. It may also be a schizocarp forming a carcerulus. This is indehiscent and each carpel separates from the central column as well as from one another.
   c) Ranunculaceae: The fruit is aggregate, and is made up of numerous simple fruits. It may be a group of follicles each having a few to many seeds. It may also be a group of one-seeded achenes. Sometimes, the fruit may be a capsule.
   d) Rutaceae: The fruit is a hesperidium. This is a special type of a berry in which the fleshy pulp is present as a large number of juice sacs. It may also be a drupe or a schizocarp.

9.

	Malvaceae	Rutaceae
i)	Leaves and young shoots covered with stellate hairs.	Leaves and young shoots aromatic.
ii)	Leaves simple	Leaves compound
iii)	Epicalyx present	Epicalyx absent
iv)	Hypogynous disc absent	Hypogynous disc present
v)	Stamens monadelphous	Stamens obdiplostemonous
vi)	Anthers reniform and monothecous	Anthers linear and dithecous
vii)	Carpels united	Carpels free at base, united by styles
viii)	Fruit a capsule	Fruit a hesperidium

10. Refer Section 21.2.

11. Refer to Section 21.3.

SAQ 2

1. a) ii) Cucurbitaceae and Apiaceae
   b) iii) Fabaceae

2.

Column I	Column II
Apical	Apiaceae
Axile	Myrtaceae
Marginal	Fabaceae
Parietal	Cucurbitaceae

3. i) Cucurbitaceae
   ii) Myrtaceae

4. a). Cremocarp: This is a type of dry, dehiscent fruit made up of two equal halves called mericarps. These invariably show characteristic patterns on their pericarp. Family Apiaceae.

   b) Diadelphous stamens: The stamens in a single flower can be united to form 2 distinct groups or bundles. This kind of organisation of the stamens in a flower is described as diadelphous. In the family Fabaceae, stamens in a flower, many plants classified in the Subfamily Papilionatae show 9 stamens forming one group and the 10th stamen being free. This (9) + 1 grouping of the stamens is described as diadelphous. Family Fabaceae.

   c) Intra-marginal vein: In dicot leaves with reticulate venation, there are many small veins. When these small veins unite to form a continuous vein internal to the leaf margin, this is called an intra-marginal vein. Family Myrtaceae.

   d) Tendril: A thread-like organ of a plant which clasps around any structure when it comes into contact with it. Tendrils are found in many plants showing a climbing habit. The tendril is a special morphological structure which is a modified stem or leaf or some other plant part. It may be branched or unbranched and shows clockwise or anti-clockwise coiling around the support. Family Cucurbitaceae.

5.

	Genus	Family	Use
a)	*Acacia*	Fabaceae, Subfamily Mimosoideae	tanning material
b)	*Benincasa*	Cucurbitaceae	edible fruit
c)	*Centella*	Apiaceae	medicinal
d)	*Cicer*	Fabaceae, Subfamily Papilionatae	edible seeds
e)	*Delonix*	Fabaceae, Subfamily Caesalpinioideae	ornamental
f)	*Ferula*	Apiaceae	condiment, medicinal
g)	*Momordica*	Cucurbitaceae	edible fruit
h)	*Phaseolus*	Fabaceae, Subfamily Papilionatae	edible seeds
i)	*Pimenta*	Myrtaceae	spice
j)	*Syzygium*	Myrtaceae	spice

6.

	Order	System of Classification
a)	Fabales	Takhtajan
b)	Myrtiflorae	Engler & Prantl
c)	Passiflorales	Bentham & Hooker
d)	Umbellales	Bentham & Hooker
e)	Umbelliflorae	Engler & Prantl

7. a) Subfamily Mimosoideae
   Characters i) actinomorphic flowers
   ii) corolla aestivation valvate

   b) Subfamily Caesalpinioideae
   Characters i) zygomorphic flowers
   ii) corolla aestivation ascending imbricate

   c) Subfamily Papilionatae
   Characters i) zygomorphic flowers
   ii) corolla aestivation descending imbricate

8. Refer to Section 21.7: 'Diagnostic Features of the Family' Myrtaceae.

9. Refer to Section 21.6 and write the floral characters of the 3 subfamilies of the family Fabaceae.

10. Refer to Section 21.8: 'Systematic Position' of the family Cucurbitaceae.

11. Refer to Section 21.9: 'Economic Importance' of the family Apiaceae.

12. Refer to Section 21.8: 'Diagnostic Features of the Family' Cucurbitaceae.

Terminal Questions

1. a) See Section 21.2
   b) See Section 21.5
   c) See Section 21.7
   d) See Section 21.8
   e) See Section 21.4
   f) See Section 21.9

2. a) See Sections 21.2 and 21.3
   b) See Sections 21.5 and 21.7

3. See Section 21.6

4. i) See Section 21.3
   ii) See Section 21.5
   iii) See Section 21.4
   iv) See Section 21.9

UNIT 22 DICOT FAMILIES – 2

Structure

22.1 Introduction
Objectives
22.2 Rubiaceae
22.3 Asteraceae
22.4 Sapotaceae
22.5 Apocynaceae
22.6 Asclepiadaceae
22.7 Solanaceae
22.8 Acanthaceae
22.9 Lamiaceae
22.10 Amaranthaceae
22.11 Santalaceae
22.12 Euphorbiaceae
22.13 Summary
22.14 Terminal Questions
22.15 Answers
Appendix 22.1

22.1 INTRODUCTION

In this unit too, we will continue with the study of taxonomy, and you will study eleven more families of dicots. The format of description of each family is the same as the previous unit, with which you are already familiar. The same objectives as listed in Section 21.1 hold true for this unit too. Nevertheless, they are being written here once again. This will remind you about the outcomes expected of this study. The 'Tips for Effective Study' given on page 6 of this block apply to this unit also. Hope you are practicing them. It would be useful to go through them before beginning the study of this unit. Also do not forget to glance at the Apendix 22.1, while studying the 'Systematic Position' of the families. This will familiarise you with the usage of the main classification systems of plant taxonomy. However, you are not expected to memorise the contents of the Appendix. Well then, let us move on to the first family of this unit.

Objectives

After studying this unit you should be able to:

- appreciate the immense diversity in angiosperms;
- know the correct botanical name, as well as the name of the Type genus of the families described;
- describe the salient vegetative and floral characters of each of the families dealt with;
- analyse and list the diagnostic features of families discussed here;
- classify each of the family of this unit, according to the different systems of classification;
- list some of the Indian representatives of each family while appreciating their size and distribution;
- prepare a list of locally available economically important plants of each family studied by you;
- realise the importance of vegetation as nature's gift to mankind, and the need to conserve nature for the future well being of mankind.

22.2 RUBIACEAE

The Coffee family
Type genus : *Rubia*

General Information

It is a large family of about 450 genera and 6500 species mainly of tropical or subtropical distribution, but with some temperate and a few arctic species also. In India, this family is represented by 75 genera and 300 species of which some are economically important or cultivated as ornamentals.

Field Recognition Characters

Herbs, shrubs or trees; leaves opposite or whorled, mostly with intra- or inter-petiolar stipules; flowers solitary and large or in dichasial cymes and generally small, bisexual, actinomorphic, fruit a capsule or berry or schizocarpic with small seeds having a well developed endosperm.

Morphological Diversity

The plants show a great diversity in their habits (see Figs 22.1 and 22.2). Many species are trees or shrubs, but herbs also occur. Besides this, at least 4 genera (*Myrmecodia* in Eastern Indo-Malayan areas, *Cuviera* in Africa, *Duroia* in South America, and *Hydnophytum* in East Asia, New Guinea and Fiji) are known for their epiphytic habit, and they also show myrmecophily (a symbiotic association

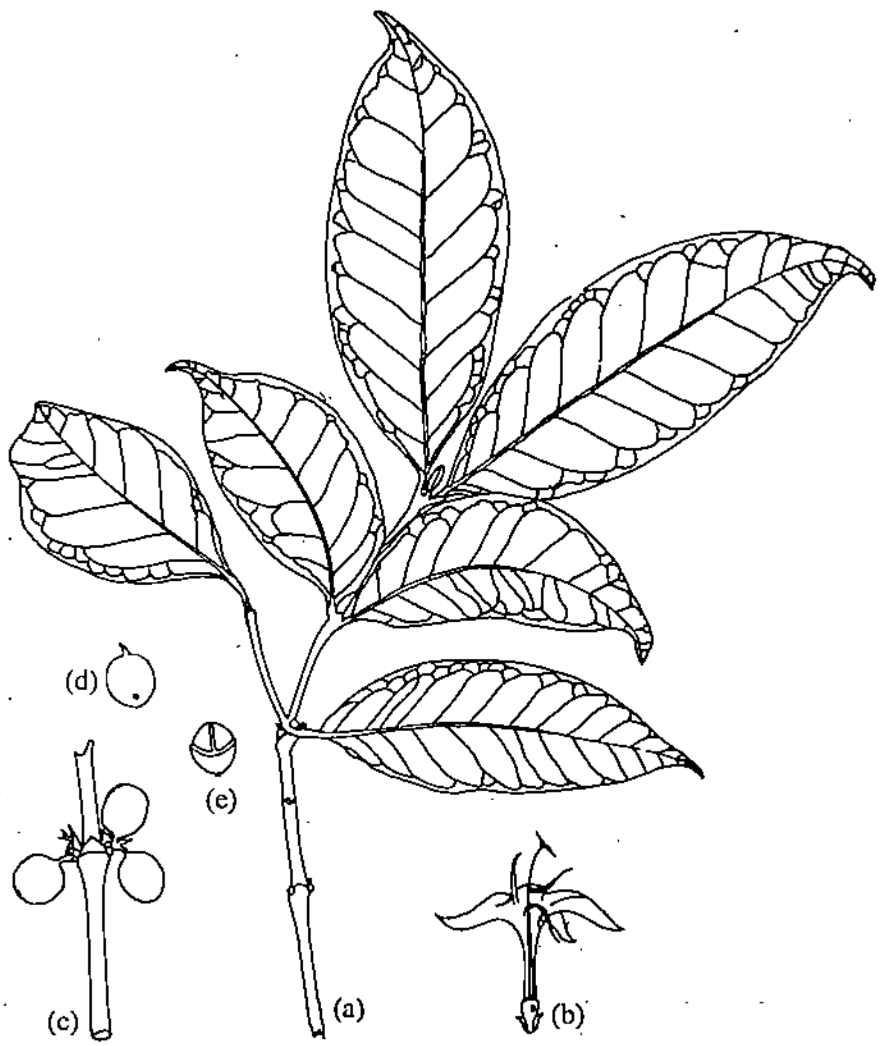

Fig. 22.1: *Coffea arabica*. a) A portion of the vegetative shoot. b) A flower in longitudinal section. c) A node bearing fruits. d) A fruit. e) A fruit with part of the mesocarp removed. (From Purseglove, 1988)

with ants). In these plants, a tuber-like stem develops either at the base of the plant or above the nodes, or just below the inflorescence. This tuber is composed of a mass of corky tissue which is traversed by numerous paths or chambers inhabited by ants. It is believed that the ants protect the flowers from undesirable visitors.

Leaf: The leaves are opposite or whorled and stipulate. The stipules are very characteristic in this family. They may be present between the leaves at the node and are described as inter-petiolar; or they may be in front of the leaf base between the petiole and the stem and are described as intra-petiolar. Besides their position (inter- or intra-petiolar), the stipules also exhibit numerous morphological variations and appear as bristles or spines or they may become leaf-like or even form conical cap-like structures protecting the young buds.

Inflorescence: The inflorescence is either a large, solitary, terminal flower, or a dichasial cyme forming a much-branched cymose panicle. Sometimes these branched inflorescences form dense globose heads with numerous small flowers.

Flower: The flowers are pedicellate, complete, usually actinomorphic, bisexual and epigynous. They are tetra- or pentamerous. The calyx is generally small, of 4 or 5 sepals, gamosepalous or free upto the base. Sometimes, one sepal becomes very large and is brightly coloured (may also be white or yellow or pink) to serve as an attractant for insect-pollinators as in *Mussaenda*. Besides this, in some genera of S. Africa, such as *Alberta* and *Nematostylis*, the sepals enlarge only after fertilisation and help in fruit dispersal.

The gamopetalous corolla of 4 or 5 petals shows valvate, convolute or imbricate aestivation, and this character helps in identifying different groups of genera in the family. Sometimes, the corolla may become zygomorphic.

Androecium: Stamens as many as corolla lobes, and are epipetalous. These alternate with the petals and are generally inserted at or near the throat of the corolla, rarely at the base. Rarely, there may be two whorls of stamens. The anthers dehisce longitudinally.

Gynoecium: The generally bicarpellary (sometimes 1 to many-carpelled), syncarpous gynoecium has an inferior ovary showing epigynous condition, but some genera show a perigynous or occasionally a hypogynous condition also. The placentation is usually axile with 1-numerous ovules in each locule. However, variations in placentation also occur, for example in *Oldenlandia*, peltate or stalked spherical placentae occur, while in *Cinchona* the placenta broadens out to form a T-shaped structure in transeverse section. The style is simple and the stigma capitate or lobed.

Fruit: The fruit is a capsule or a berry or a schizocarp. This feature of the fruit morphology is also used in the classification of the family. In genera like *Galium*, *Anthospermum* and others, the fleshy fruit becomes sticky due to the presence of small, stiff, recurving hairs which help in dispersal by animals. The seeds are sometimes winged, helping in wind-dispersal, e.g., *Cinchona*. The seeds have a small embryo and an abundant endosperm. In *Coffea*, this endosperm becomes cartilaginous and convoluted.

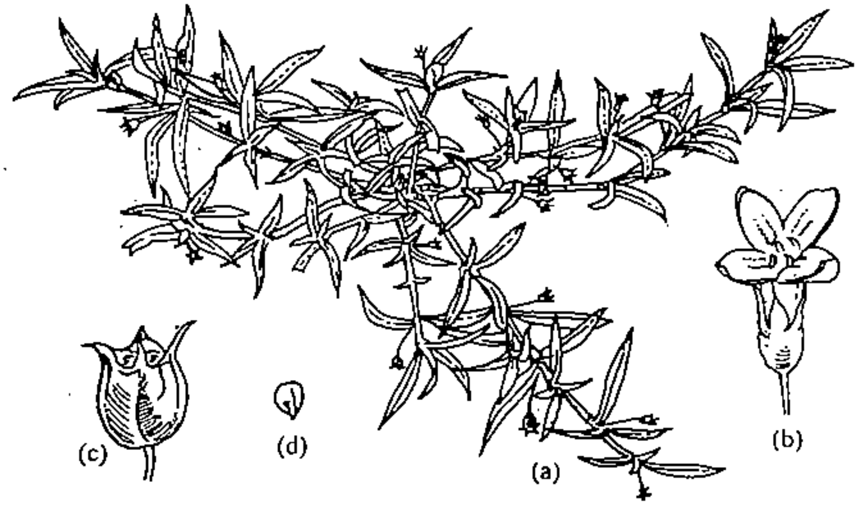

Fig. 22.2: *Oldenlandia corymbosa*. a) A plant with flowers and fruits. b) A flower. c) A capsule, note the remnants of calyx, that are teeth-like structures at the top of the fruit. d) A seed (From Maheshwari, 1966).

Diagnostic Features of the Family

1. Plants herbaceous or woody.
2. Leaves opposite or whorled.
3. Inter-petiolar or intra-petiolar stipules present.
4. Inflorescence of solitary large terminal flower or dichasial cyme.
5. Flowers tetra-or penta-merous and epigynous.
6. Calyx of small sepals or with one enlarged brightly coloured sepal.
7. Gamopetalous corolla with valvate or convolute or imbricate aestivation.
8. Stamens epipetalous and inserted in the corolla tube.
9. Gynoecium bicarpellary, ovary inferior, generally axile placentation.
10. Fruit a berry or capsule or schizocarp.
11. Seeds small with abundant endosperm; sometimes winged also.

Systematic Position

The family Rubiaceae is classified in the Gamopetalae, Series 1 Inferae, Order Rubiales by Bentham & Hooker. This is the first order under Gamopetalae and has 2 families, the Rubiaceae and the Caprifoliaceae.

Engler & Prantl in their classification place the family Rubiaceae in the Sympetalae, Order Rubiales. This order has 5 families: the Rubiaceae, the Caprifoliaceae, the Adoxaceae, the Valerianaceae, and the Dipsacaceae.

In Takhtajan's classification, the family Rubiaceae is classified in Subclass K Lamiidae, and Order 162 – Rubiales with 3 other families. The family Caprifoliaceae is classified in Subclass I Cornidae, Superorder Dipsacanae, and Order 154 Dipsacales. This indicates that according to Bentham & Hooker as well as Engler & Prantl, the Rubiaceae is related to the Caprifoliaceae but according to Takhtajan it is not.

Economic Importance

1. The beverage plant *Coffea* has many species which are cultivated for the fruits that yield coffee. You have studied this in detail in the Unit 18 (Beverages) of this course.
2. After coffee, the genus *Cinchona* with numerous species, is cultivated for its bark which contains quinine and other alkaloids used as anti-malarials.
3. *Cephaelis ipecacuanha* or Ipecac contains alkaloids for treatment of amoebic dysentry.

4. *Uncaria gambier* or Gambier or White cutch is used as a masticatory material, and it contains tannins.
5. A large number of plants of the Rubiaceae are cultivated as ornamentals. Some of the more common ones include: *Gardenia jasminoides, Ixora* species, *Mussaenda* species, *Hamelia* species, *Pentas lanceolata, Portlandia grandiflora, Anthocephalus cadamba.*

Points to Remember

22.3 ASTERACEAE

The Sunflower family, Compositae
Type genus : *Aster*

General Information

The family **Asteraceae** or **Compositae** is considered to be the largest family amongst dicotyledons having about 1100 genera and more than 20,000 species accounting for about 10% of the flowering plants. It has a world-wide distribution and members of this family occur in a variety of habitats. The remarkable success of the family is attributed to the characteristic capitular inflorescence (Figs 22.3 to 22.6) and its wide ecological adaptability. In India about 140 genera and 700 species of this family occur some of which are cultivated as ornamentals in gardens.

Field Recognition Characters

Herbs or shrubs with capitulum inflorescence. Each capitulum has numerous florets on a common receptacle and is surrounded by an involucre of bracts; calyx is modified into pappus, corolla gamopetalous. Androecium with syngenesious anthers. Gynoecium is bicarpellary with a single ovule, fruit is a cypsela.

Fig. 22.3: *Aster salsuginosus*. a) Vegetative portion of the plant. b) A flower bearing stalk. c) A ray floret. d) A disc floret. e) A pappus bristle.

Morphological Diversity

The plants exhibit great diversity in their morphology but are remarkable in their characteristic inflorescence (see Figs 22.3 to 22.6). The majority of the members of this family are herbaceous annuals or biennials; but there are also shrubs and a few trees. Interestingly this variation in morphology can be recognised in different species of *Senecio*. The plants have a well-developed tap root system, but sometimes tuberous roots also occur (e.g., *Dahlia, Helianthus tuberosus*). The stem is generally herbaceous. It is sometimes underdeveloped having a whorl of leaves at the ground level and then a flowering stem grows out from the radical rosette of leaves. The stem becomes suffruticose in the shrubs and woody in the tree members of the family and these are mostly the tropical representatives.

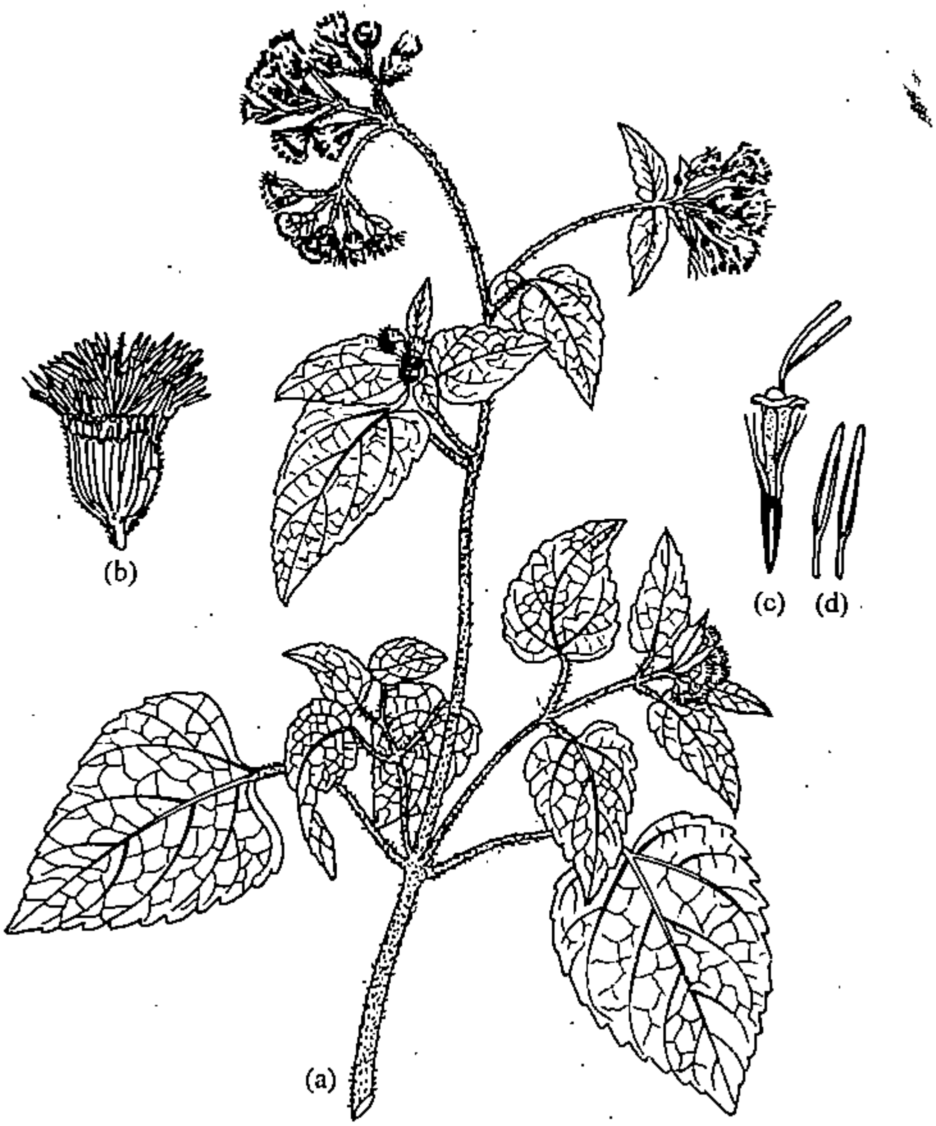

Fig. 22.4: *Ageratum conyzoides*. a) A flowering twig. b) A capitulum. c) A floret in enlarged view. d) Two stamens enlarged.

Leaf: The leaves may form a radical rosette in plants with a scapigerous habit; or they are alternate or opposite or sometimes whorled in their arrangement. The leaves are exstipulate although in some species the leaf bases have auricles or are decurrent (i.e., the base is continuous with the stem epidermis so that the petiole cannot be differentiated). They are simple but show a great diversity in division of the lamina and are rarely truly compound. The stems and leaves contain watery sap in a majority of the plants, but in some members, a milky latex is present. This character helps in classifying the family into 2 subfamilies – viz: the Asteroideae or Tubuliflorae with watery sap, and the Cichoroideae or Liguiflorae with milky latex.

Radical means apparently arising together from the root.

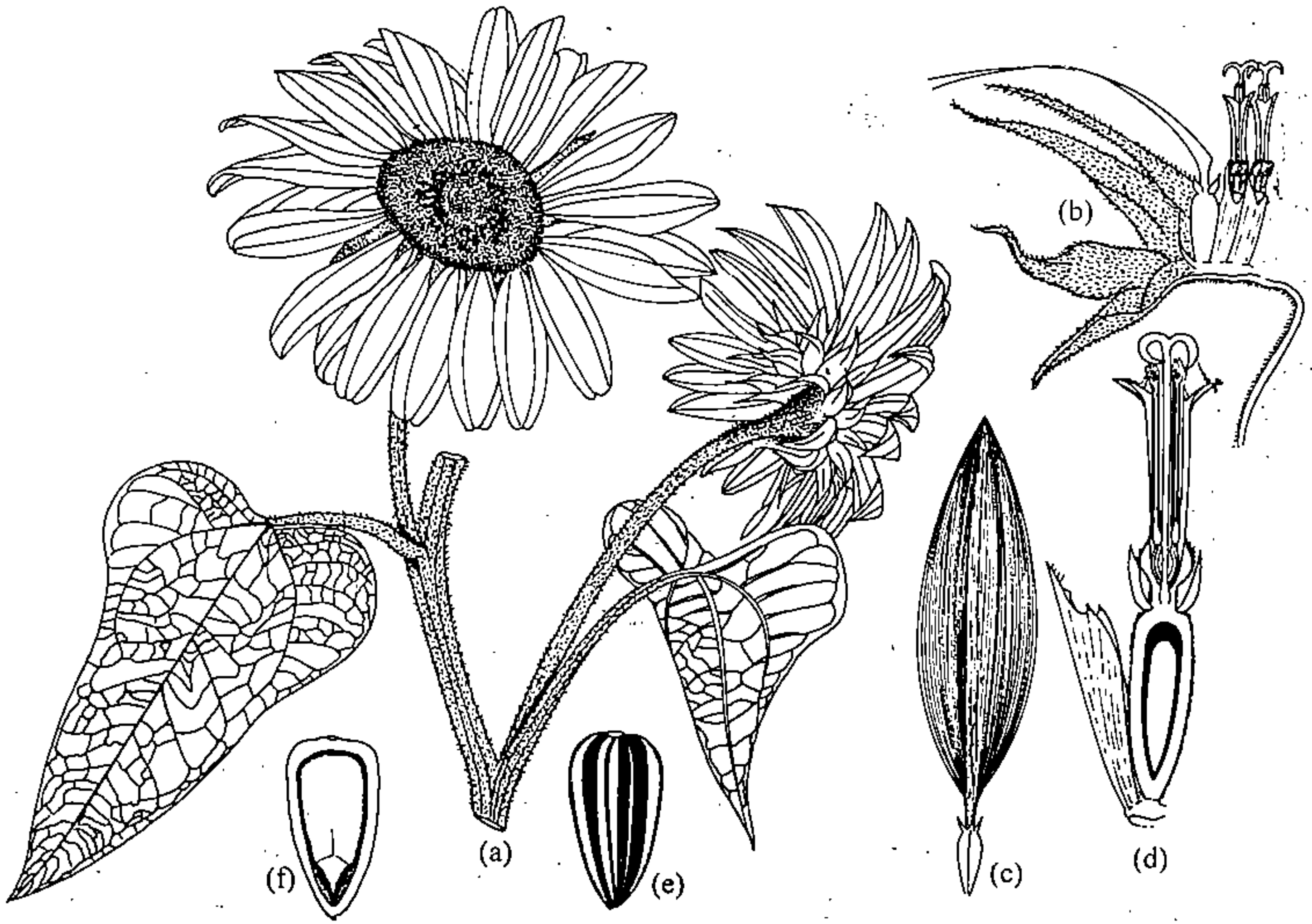

Fig. 22.5: *Helianthus annuus*. a) A flowering twig. b) A portion of the capitulum in longitudinal section. c) A ray floret. d) A disc floret in longitudinal section, in an enlarged view. e) An achene. f) same, in longitudinal section. (Redrawn from Purseglove, 1988).

Inflorescence: The most characteristic feature of the family is its inflorescence. It is called a capitulum which is a special recemose inflorescence having an involucre of bracts surrounding numerous, reduced flowers crowded on a flat receptacle. This involucrate head or capitulum may be solitary or several capitula may be arranged in cymose or racemose inflorescences. The capitulum can be of two types with respect to the sexuality of the florets. If all the florets in a capitulum are of the same kind having all unisexual (of the same sex) or all bisexual florets, then the capitulum is described as *homogamous*. But when there are different types of florets in a single capitulum, some bisexual and the others unisexual or neutral or some male and others female, then the capitulum is described as *heterogamous*. There is also great diversity in both these types with respect to the morphology of the florets in the capitulum. This is the second feature that has been used in the classification of the family into the two Subfamilies Asteroideae or Tubuliflorae (having some or all tubular florets in a capitulum) and Cichoroideae or Liguliflorae (having only ligulate florets in a capitulum). Did you recall the first feature – it is the presence of watery sap or milky latex in the stems and leaves.

The capitulum has a receptacle which develops from the condensed inflorescence axis. On this receptacle the florets are arranged in a definite manner and they are surrounded by the involucre of bracts. The receptacle may be flat, slightly convex or even spindle-shaped and it may be smooth, pitted or hairy or scaly. These characteristics of the receptacle are used for classifying the genera and species in this family.

Flower: Because of the highly elaborate inflorescence, the individual flowers in the family Asteraceae are reduced and are called florets. The florets may be bisexual, unisexual or even neutral serving only as organs for attracting insects for pollination. The florets may be actinomorphic or zygomorphic. The calyx is reduced or modified into a structure called the pappus which persists in the fruit, helping in dispersal. The pappus may consist of hairs or scales (which form an efficient parachute mechanism for wind dispersal), or it may be made up of bristles (for dispersal by animals). Sometimes the pappus is completely absent.

The gamopetalous corolla is made up of 5 petals which either form a tube with 5 equal lobes so that the floret is actinomorphic and tubular (Subfamily Asteroideae or Tubuliflorae); or the corolla is bilabiate having an upper lip of one or 2 segments and a lower lip of 3 or 4 segments or it may be truly ligulate having a small tube at the base and a long showy ligule made up of 2,3,4 or all the 5 segments making the floret typically zygomorphic (Subfamily Cichoroideae or Liguliflorae). The petals show valvate aestivation and are variously coloured.

Androecium: There are 5 epipetalons stamens in the male and bisexual florets. The anthers of the 5 stamens are generally syngenesious forming a cylinder around the style while the filaments are free from one another. The base of each anther is usually extended into a long or short tail while the anther connective grows above the anther lobes as an appendage (Fig. 22.4 d). These features are used for identifying different genera and species within the family.

Gynoecium: The bicarpellary syncarpous gynoecium with an inferior ovary develops in the bisexual or female florets, while in the neutral florets a rudimentary gynoecium may be present. There is a single ovule on a basal placenta. The style is single, long, cylindrical and is surrounded at the base by a small tubular nectary. The style is bifid, i.e., it is divided into 2 stigmatic arms which are papillate. The style may also have pollen collecting hairs below the stigmatic arms and these features also help in distinguishing various tribes, genera and species of the family.

Fig. 22.6: *Carthamus tinctorius*. a) A flowering twig. b) A portion of the flowering twig enlarged to show the capitulum. c) A capitulum in longitudinal section. d) A floret in a magnified view. e) An achene (Redrawn from Purseglove, 1988).

Fruit: The fruit is a cypsela, a one-seeded structure having persistent pappus. Although it is often called an achene in many textbooks, the fruit of Asteraceae is not an achene in the true morphological sense. The achene is defined as "a one-seeded, small, dry, indehiscent fruit developed from one carpel", whereas the cypsela of Asteraceae develops from a bicarpellary gynoecium. Further, an achene generally develops from a superior ovary whereas in Asteraceae the ovary is inferior.

Diagnostic Features of the Family

1. The chief diagnostic feature of the family is its inflorescence called capitulum.
2. Plants mostly herbaceous with watery sap or milky latex.
3. Leaves exstipulate with simple entire or highly divided lamina.
4. Flowers reduced to florets which are crowded together in the capitulum.
5. Involucre of bracts surround the florets in each capitulum.
6. Calyx modified into pappus.

7. Pentamerous, gamopetalous corolla either tubular (actinomorphic) or ligulate (zygomorphic).
8. Stamens epipetalous, anthers syngenesious.
9. Bicarpellary, syncarpous gynoecium with inferior ovary and single ovule on basal placenta.
10. Fruit a cypsela.

Systematic Position

The family Asteraceae has been recognised as a natural unit in all the systems of classification. It is also considered to be the most evolved family of the dicotyledons. It is classified in Gamopetales, Series 1 Inferae, Order 2 Asterales by Bentham & Hooker. This order does not include the family Campanulaceae which is classified in the separate order Campanulales. In the classification of Engler & Prantl, the family Compositae (=Asteraceae) is classified in Sympetalae, Order 10 Campanulatae which has 6 families including Campanulaceae. Takhtajan in his classification, has classified Asteraceae in Subclass J – Asteridae, Superorder Asteranae, and Order 160 Asterales. He classifies the family Campanulaceae in the same Subclass Asteridae but in a different Superorder Campanulanae, and the Order 155 Campanulales.

Economic Importance

1. Edible Plants

   a) *Lactuca sativa* – Lettuce; young leaves eaten as a salad; it is the most widely cultivated salad crop.
   b) *Helianthus tuberosus* – Jerusalem artichoke; the root tubers are edible.
   c) *Cynara scolymus* – Globe artichoke; immature flower heads, fleshy base made up of involucral bracts and the receptacle are boiled and eaten.
   d) *Tragopogon porrifolius* – Oyster plant; taproot is edible.
   e) *Cichorium intybus* – Chicory, stout taproot is roasted and ground into a powder which is used as a coffee substitute or as an admixture with coffee.
   f) *Cichorium endivia* – Endive; used as a salad plant like *Lactuca sativa*.

2. Oil Seeds

   a) *Helianthus annuus* – Sunflower; seeds rich in semi-drying oil used in cooking, preparation of margarine and mixed with linseed oil it is used in paints and varnishes.
   b) *Carthamus tinctorius* – Safflower (Fig. 22.6); oil from the seeds is used in cooking, for illumination, for soap manufacture and in paints and varnishes. It is low in linolenic acid and has excellent colour retention properties and no after-yellowing.
   c) *Guizotia abyssinica* – Niger seed; yellow edible semi-drying oil with little odour and a pleasant nutty taste, it is used like safflower oil.

3. Dyes

   Carthamus tinctorius – Safflower; the dried florets yield a red dye called 'Safflower carmin' used in the preparation of laboratory stains.

4. Medicinal Plants

   a) *Artemisia scoparia* and other species are sources of santonin which is used medicinally as a vermifuge.
   b) *Matricaria chamomilla* – used medicinally as a tonic and for gastric disorders as well as for preparation of skin ointments.
   c) Several species of *Chrysanthemum* especially *C. cinerariifolium* are used as insecticide called pyrethrum.

5. Ornamentals

A large number of plants of the family Asteraceae are cultivated as ornamentals. These include species of *Ageratum, Aster, Calendula, Centaurea, Chrysanthemum, Coreopsis, Cosmos, Dahlia, Gaillardia, Gerbera, Helianthus, Senecio, Tagetes, Tithonia* and *Zinnia*.

6. Latex yielding plants

Parthenium argentatum – Guayule; a minor source of natural rubber. *Taraxacum kok-saghyz* and *Mikania scandens* also yield latex.

Points to Remember

22.4 SAPOTACEAE

The Sapodilla family
Type genus : *Sapota* (now called *Achras sapota*)

General Information

A small family of about 40 genera and 600 species widely distributed in the tropical and subtropical areas of Asia and America as well as in other parts of the world. It is represented in India by 10 genera and about 50 species, the more well-known ones being *Achras sapota* (Sapodilla, cheeku, Fig. 22.7), *Madhuca latifolia* (Fig. 22.8), *Mimusops elengi* and *Manilkara hexandra*.

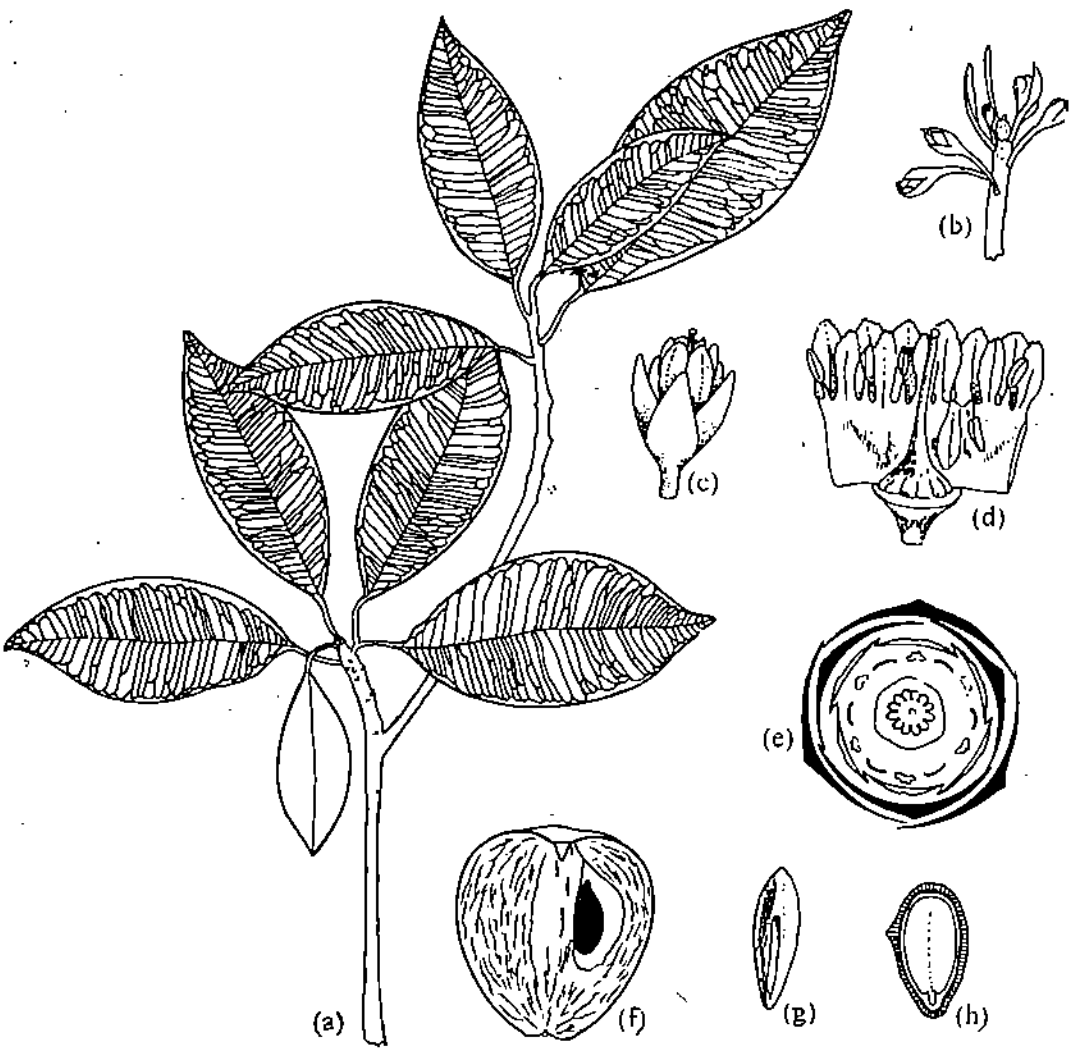

Fig. 22.7: *Achras sapota*. a) A vegetative shoot. b) An inflorescence. c) A flower enlarged. d) The corolla opened out. Note a whorl of petal-like staminodes alternate with the corolla lobes. e) A floral diagram to explain the condition mentioned in d. f) A fruit cut longitudinally. g) A seed seen from the back showing a long hilum. h) A seed in longitudinal section showing the embryo (a,b,d – Redrawn from Purseglove, 1988).

Field Recognition Characters

Small to medium trees; with simple, leathery leaves and milky latex in all parts of the plant. Flowers small, gamopetalous, stamens in 2 or 3 whorls and numerous carpels. Fruit a berry with few seeds.

Morphological Diversity

Plants of the family Sapotaceae are small to medium-sized trees with woody stems. Young shoots are 'tomentose', i.e., covered with rust-coloured epidermal hairs. A characteristic feature of the family is the presence of latex containing cells in the pith and cortex of the stem, in the leaves and also in the fruit.

Leaf: The leaves are alternate, simple, entire and coriaceous (= leathery). They are generally exstipulate, but sometimes stipules may develop. The leaves are covered with unicellular, branched hairs.

Inflorescence: Flowers may be solitary or in cymose inflorescence with small flowers in the leaf axils or on old stems above the scars of fallen leaves.

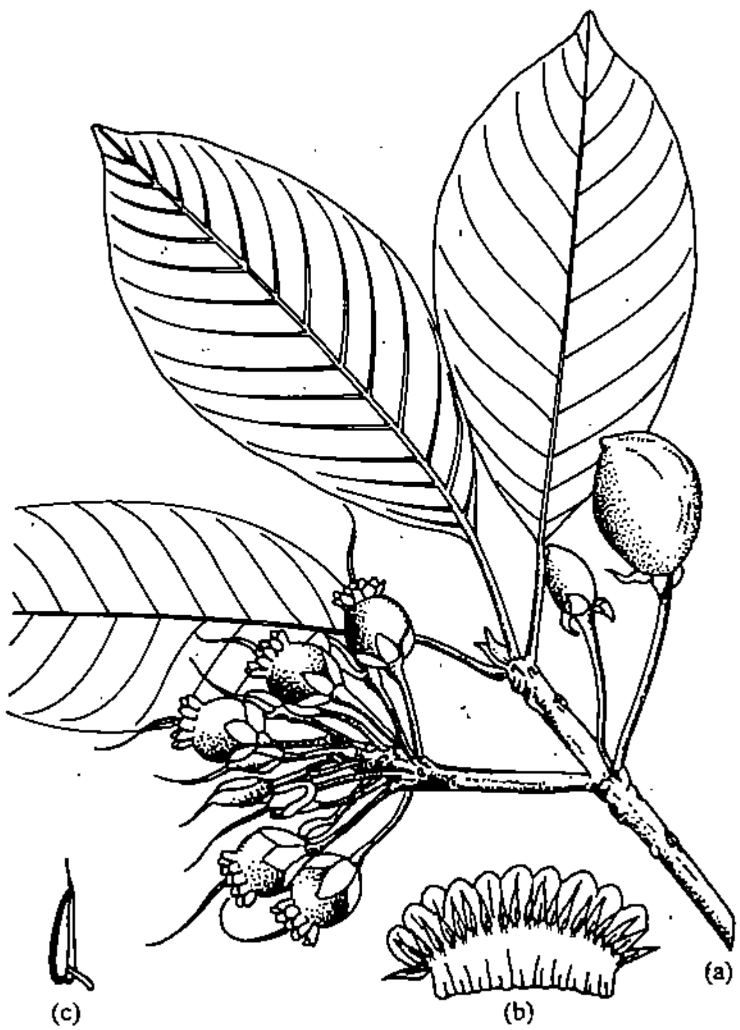

Fig. 22.8: *Madhuca latifolia.* a) Twig bearing flowers and fruits. b) Corolla expanded to show epipetalous stamens. c) A stamen.

Flower: The flowers are bracteate, small, actinomorphic and bisexual. The calyx shows many patterns. There may be 4 or 6 or 8 sepals in two isomerous whorls. Sometimes there are only 5 sepals which are free or slightly united at the base, and show imbricate aestivation. When the calyx is biseriate, the outer whorl shows valvate aestivation and is persistent. The corolla is usually in a single whorl having the same number of petals as the sepals; and alternate with the sepals. Sometimes there may also be 2 isomerous whorls of petals. The corolla shows imbricate aestivation. Special outgrowths from the base of the petals as dorsal appendages and resembling the petals develop in many genera giving the appearance of a many-whorled corolla.

Androecium: There are 2 or 3 whorls of 4-5 each, but usually the inner whorl is of epipetalous stamens. Sometimes the outer whorl may be reduced to staminodes or be completely absent. The anthers show longitudinal dehiscence.

Gynoecium: The carpels are as many, or double the number of stamens in one whorl. The gynoecium is syncarpous with a superior ovary. The placentation is axile and there is only one ovule in each locule. The style is simple and the stigma is inconspicuous. The flowers are protogynous. The gynoecium matures first with the tip of the style and the sticky stigma appearing above the corolla before the latter expands. The young flowers are erect but as they mature they become pendulous.

Fruit: The fruit is a berry in which the outer layers become sclerenchymatous. In large fruits, the outer layer of the epidermis is replaced by cork. The inner pulp of the fruit contains latex cells. In each fruit very few or only one seed develops. The seed is large with a long hilum and a shiny hard testa which contains tannins. The seeds are usually endospermous and oil is stored in the endosperm.

Diagnostic Features of the Family

1. Trees in tropical regions.
2. Simple, coriaceous leaves covered with hairs.
3. Milky latex present in all parts of the plant.
4. Small flowers either solitary or in cymose inflorescence, in the leaf axils.
5. Flowers actinomorphic, gamopetalous and hypogynous.
6. Calyx and corolla in isomerous whorls with imbricate aestivation.
7. Stamens 4-5 each, in 2 or 3 whorls.
8. Carpels numerous, syncarpous, superior ovary with axile placentation, simple style and sticky stigma.
9. Fruit a berry with few seeds.
10. Seeds large with long hilum and shiny testa.

Systematic Position

The family Sapotaceae is classified in the Gamopetalae, Series II Heteromerae, and Order 6 Ebenales by Bentham & Hooker. Besides Sapotaceae, this order also includes the families Ebenaceae and Styraceae. In Engler & Prantl's classification, the family Sapotaceae is classified in Sympetalae and Order 4 Ebenales which has 4 families. Three of these families are also included in the Order Ebenales by Bentham & Hooker while the 4th family is Symplocaceae.

Takhtajan has classified the family Sapotaceae in Subclass G – Dilleniidae, Superorder Primulanae, and Order 74 Sapotales which has only 1 family. The other families are classified in Order 73 Styracales.

Economic Importance

Several plants of this family are important in different ways.

1. The wood of *Sideroxylon* is hard and is a source of useful timber sold as ironwood.
2. The milky latex of *Palaquium gutta*, and some species of *Mimusops* and *Payena* is a source of commercial gutta percha. This substance is hard at ordinary temperature but softens at high temperature. It is an exceedingly poor conductor of electricity. It is used for insulation especially for submarine cables. Gutta percha is also used in dentistry for dental fillings and in the manufacture of golf balls.
3. The latex of *Manilkara bidentata* yields the commercial Balata which is a non-elastic rubber. It is used in machine belting. Balata is also used as a substitute for Chicle, the latex obtained from the Sapodilla plant.
4. Numerous plants are useful for their edible products. The juicy ripe fruits of *Achras sapota* (cheeku) are consumed as a dessert fruit. The latex from this plant is called Chicle and it is used in the manufacture of chewing gum and in dentistry. Fruits of *Manilkara hexandra* (khirni) and *M. kauki* are also edible.

5. *Madhuca latifolia* is extensively exploited in India for Mahua, a butter-like fat, present in the seeds. It is edible and also used in the manufacture of soap. The flowers are used as a vegetable, and an alcoholic beverage is distilled from them. In Africa, *Butyrospermum paradoxa* is exploited in the same way as *Madhuca latifolia* in India. It is called the Shea-butter tree.
6. Several species such as *Mimusops elengi*, *Chrysophyllum cainito* and *Calocarpum sapota* are cultivated for their ornamental value.

Points to Remember

22.5 APOCYNACEAE

The Dogbane family
Type genus : ***Apocynum***

General Information

A family of about 200 genera and 2000 species of mostly tropical and subtropical distribution, but with a few species occurring in the temperate regions also. In India, the family Apocynaceae is represented by about 30 genera and 60 species some of which are commonly cultivated in gardens.

Field Recognition Characters

Herbs, shrubs or trees generally with milky sap; simple exstipulate, opposite or whorled leaves; flowers bisexual, actinomorphic, stamens free, gynostegium and translators absent, ovules many, seeds often comose.

Morphological Diversity

Plants of this family are annual or perennial herbs (e.g., *Vinca rosea*, its other name is *Catharanthus roseus*), shrubs (e.g., *Rauvolfia serpentina*, see Fig. 22.9) or small to large trees [e.g., *Thevetia peruviana* (Fig. 22.10), *Plumeria rubra*, *Alstonia scholaris*]. A few species are woody climbers or lianas and the plants have latex or milky sap. The stem is herbaceous or suffruticose or distinctly woody with bicollateral vascular bundles.

Fig. 22.9: *Rauvolfia serpentina*. a) A flowering twig. b) Flower buds. c) A drupe. d) A seed (Redrawn from Maheshwari, 1966).

Leaf: The leaves are simple, opposite or whorled (*Rauvolfia, Alstonia*) and rarely alternate. They are usually exstipulate but sometimes small inter-petiolar stipules may develop (e.g., *Tabernaemontana*).

Inflorescence: There may be a solitary flower as in *Vinca*, or more commonly the inflorescence is paniculate or umbellate and rarely it may be cymose.

Flower: The flowers are bracteate and bracteolate, pedicellate, bisexual, actinomorphic, hypogynous and generally pentamerous (rarely tetramerous).

The calyx of 5 sepals is usually united to form a tube or sometimes they are united only at the base. The sepals show quincuncial aestivation with the odd sepal posterior. The shape of the calyx as well as the inner glandular surface show many variations.

The gamopetalous corolla has 5 petals. The salverform (e.g., *Vinca*) or funnel-shaped (e.g., *Nerium*, see Fig. 22.11) are the most common types of corolla, but it may be bell-shaped also (e.g., *Allamanda*). The aestivation is generally contorted (hence the classification in the Order Contortae by Engler & Prantl) or sometimes valvate. The inner surface has hairy or membranous outgrowths (forming a corona) which guide the insect to the nectar and thus help in pollination.

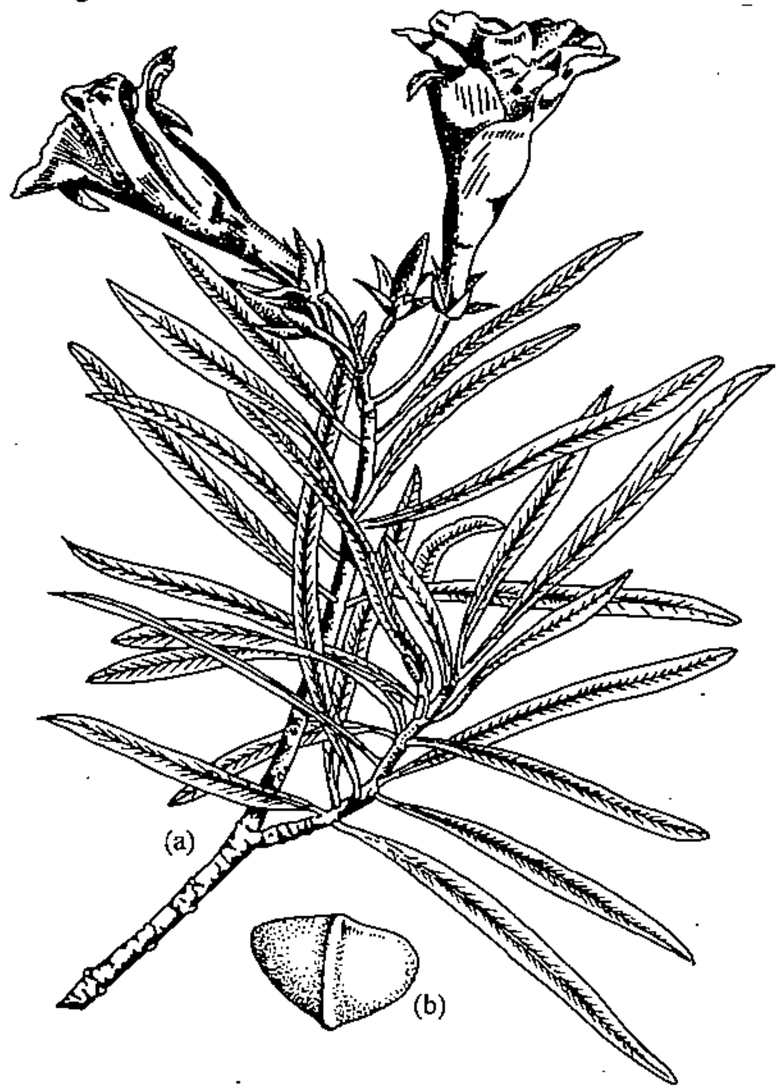

Fig. 22.10: *Thevetia peruviana*. a) A flowering twig. b) A fruit.

The 5, epipetalous stamens have short filaments so that the stamens remain inside the corolla tube. The anthers may be full of pollen or the basal regions may be empty forming tail or spine-like structures which surround the style.

There are two carpels which are usually free at the base but united above in a single style. Each carpel shows marginal placentation. Sometimes the two carpels may unite and the ovary may be unilocular with parietal placentation or it may be bilocular with axile placentation. The ovary is superior and there is a nectariferous disc below the ovary. Sometimes the disc surrounds the ovary making it half inferior or perigynous (e.g., *Plumeria*). There are numerous anatropous, pendulous ovules. The simple style bears a characteristic capitate or dumb-bell shaped stigma. A ring of hairs just below the stigma may be present.

Fruit: Generally 2 separate follicles develop from each ovary, but sometimes the fruit may be a berry or a capsule. The seeds are flat, often with a tuft of hairs (called comose seeds); or the seeds have wing-like outgrowths (e.g., *Allamanda, Plumeria*).

Diagnostic Features of the Family

1. Herbaceous or woody plants with milky sap.
2. Leaves exstipulate, simple opposite or whorled.
3. Flowers solitary or in paniculate inflorescence.
4. Flowers bisexual, pentamerous actinomorphic.
5. Gamosepalous calyx with quincuncial aestivation.
6. Gamopetalous corolla with a distinct tube and contorted aestivation.
7. Five epipetalous stamens inserted in corolla tube, stamens free.
8. Bicarpellary generally superior ovary, free at base. Single style, capitate or dumb-bell shaped stigma.
9. Fruit of 2 separate follicles (rarely a berry or a capsule).
10. Seeds flat and comose or winged.

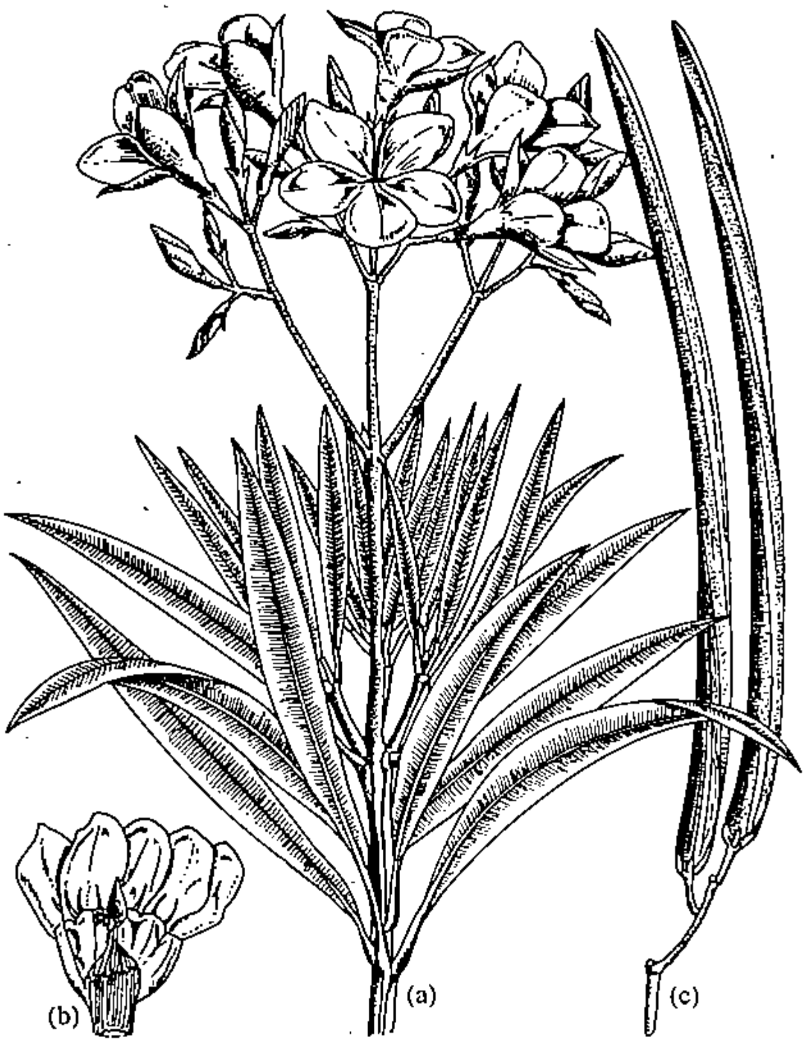

Fig. 22.11: ***Nerium indicum.*** **a) A flowering twig. b) Corolla opened and expanded. c) Two fruits.**

Systematic Position

The family Apocynaceae is classified in the Gamopetalae, Series Bicarpellatae, Order Gentianales by Bentham & Hooker. This order has 6 families (the Oleaceae, the Salvadoraceae, the Apocynaceae, the Asclepiadaceae, the Loganiaceae and the Gentianaceae). In Engler & Prantl's classification, this family and four of the above (excluding the Salvadoraceae) are classified in the Sympetalae, Order Contortae.

Takhtajan in his classification places the family Apocynaceae in the Subclass K – Lamiidae, Superorder Gentiananae and Order 163 – Apocynales.

Thus in Bentham & Hooker's and Engler & Prantl's systems of classification the relationship or affinities of the Apocynaceae, Asclepiadaceae, Gentianaceae and Loganiaceae are accepted. But Takhtajan (1997) merged Asclepiadaceae in Apocynaceae. They are thus united into a single family called Apocynaceae. He classified Gentianaceae with Loganiaceae in Order 161 – Gentianales.

Economic Importance

The common *Vinca rosea* (also called *Catharanthus roseus*) has a large number of alkaloids used in medicine. Similarly, *Rauvolfia serpentina* and other species are important and you have studied about them in Unit-19 of this course. Other medicinal plants of this family include *Holarrhena antidysenterica, Wrightia tinctoria* and *Alstonia scholaris*.

A large number of plants of this family are grown as ornamentals. These include *Vinca rosea, Thevetia peruviana, Nerium indicum, N. odorum, Plumeria acuminata, P. rubra, P. alba, Tabernaemontana divaricata, Allamanda neriifolia, A. cathartica* and *Beaumontia grandiflora. Alstonia scholaris* is commonly planted as an avenue tree and its wood is used for making black-boards, and cheap furniture.

Points to Remember

22.6 ASCLEPIADACEAE

The Milkweed family
Type genus : *Asclepias*

General Information

A family of about 250 genera and 2000 species mainly of tropical and subtropical distribution, but some species also occur in the temperate zone. In India about 53 genera and 250 species occur, some of which are cultivated as ornamentals, some are important as medicinal plants and some are collected for their fibres.

Field Recognition Characters

Perennial, erect shrubs or woody climbers with milky latex; leaves opposite, entire, exstipulate, flowers in cymose or racemose inflorescence, bisexual, actinomorphic; gynostegium present, translators present, corona usually present, fruit of 1 or 2 follicles, seeds comose (see Figs 22.12 and 22.13).

Morphological Diversity

Plants of the family Asclepiadaceae are perennial, erect shrubs or herbaceous/woody climbers or with typical xerophytic morphology having a cactus-like appearance. Many species are similar in appearance to the members of the family Apocynaceae with a herbaceous or suffruticose stem, but sometimes the stem may be fleshy. The stem has bicollateral vascular bundles and laticiferous tubes.

Leaf: The leaves are simple, opposite\decussate, exstipulate, sometimes fleshy and with a waxy layer on the epidermis; or are even reduced to thorns or scales.

Inflorescence: There are two types of inflorescence, cymose or racemose. In the cymose inflorescence, the branching is more pronounced in the axil of one bracteole so that the dichasial inflorescence ultimately becomes monochasial. In the racemose type, the inflorescence may be a simple raceme or an umbel.

Flower: The flowers are bracteate, bracteolate, bisexual, actinomorphic and hypogynous. They show a complex morphological organisation of the androecium and gynoecium. The gamosepalous calyx is deeply divided with 5 equal lobes showing quincuncial aestivation with the odd sepal posterior.

The corolla of 5 petals is gamopetalous and shows various patterns. It may be deeply divided with spreading segments (rotate), or the tube may be long (campanulate corolla). The aestivation is generally contorted as in Apocynaceae but sometimes it may be valvate. Membranous outgrowths in the form of petalloid appendages may arise from the petals or more commonly from the filaments of the stamens forming a corona. This structure helps in pollination by guiding the insects to the nectar.

The five stamens and two carpels arise separately on the floral axis but are organised into a complex structure called the gynostegium which is a characteristic feature of this family.

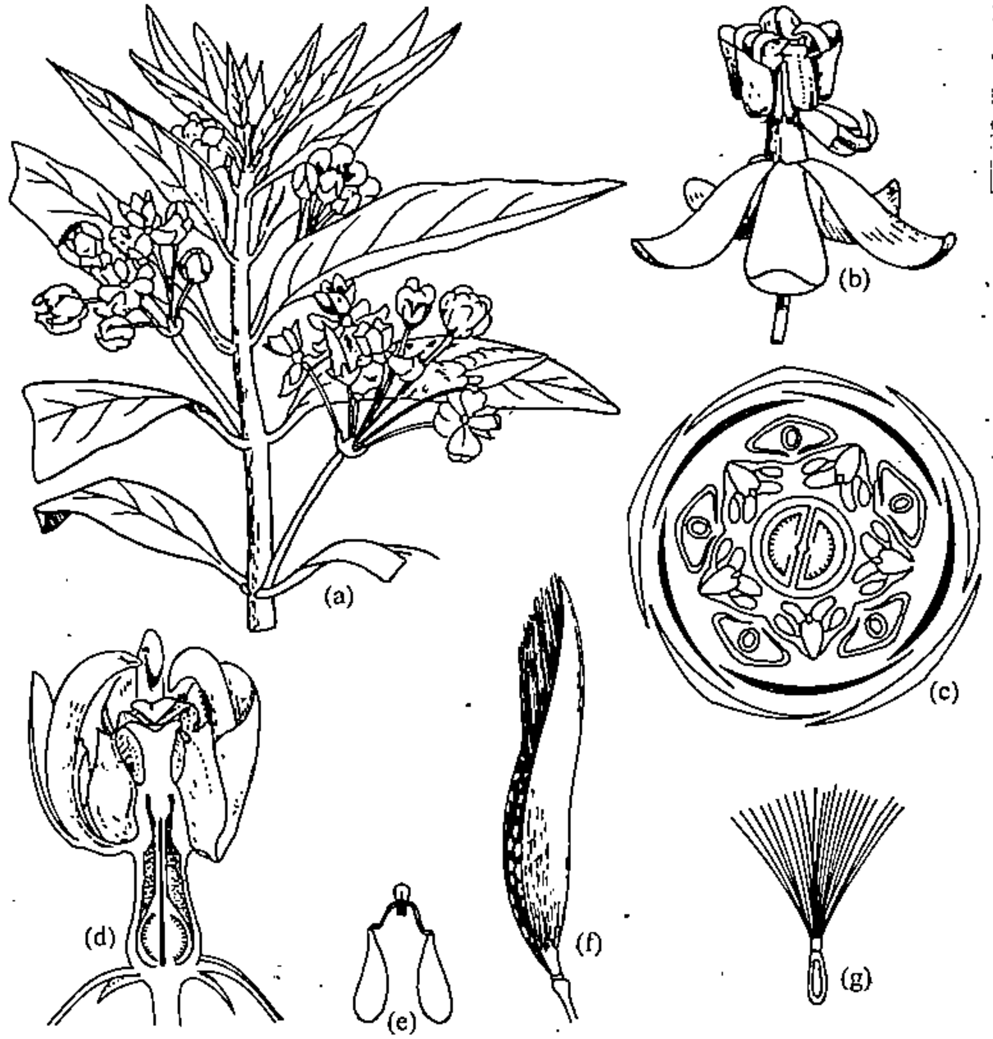

Fig. 22.12: *Asclepias curassavica.* **a) A portion of flowering shoot. b) A flower. c) A floral diagram depicting gynostegium. d) A gynostegium. e) A translator apparatus with pollinia. f) A dehiscing follicle. g) A comose seed.**

The androecium consists of 5 epipetalous stamens with short filaments. In the Subfamily Periplocoideae, the filaments are free and the anthers form spoon-shaped translators containing granular pollen. In the Subfamily Cynanchoideae, the filaments are united into a column and the anthers are united laterally to form a 5-sided blunt cone-like structure which is associated with the style and stigma forming the gynostegium. In this subfamily, the translator mechanism is special, having pollen in special waxy masses called pollinia. Each translator apparatus consists of the gland or adhesive body called the corpusculum from which arise two thread-like structures called retinaculae or caudicles. A waxy mass of pollen in a pollinium is attached to each caudicle. There are 5 corpuscles in the gynostegium, one at each corner of the pentagonal disc, and each translator apparatus has one pollinium from one anther and the other pollinium from another adjacent anther. In this manner, the two anther lobes of each stamen are separated into two pollinia.

The gynoecium is bicarpellary, apocarpous with a superior ovary. The placentation in each carpel is marginal and there are numerous ovules. The two styles are united and are a part of the gynostegium and the stigma is on the disc-like structure of the gynoestegium. The stigmatic surface is on the underside of the disc.

Fruit: A pair of follicles: sometimes only one develops and the other aborts. There are numerous seeds which are usually comose (i.e., having a tuft of hairs) and are wind dispersed.

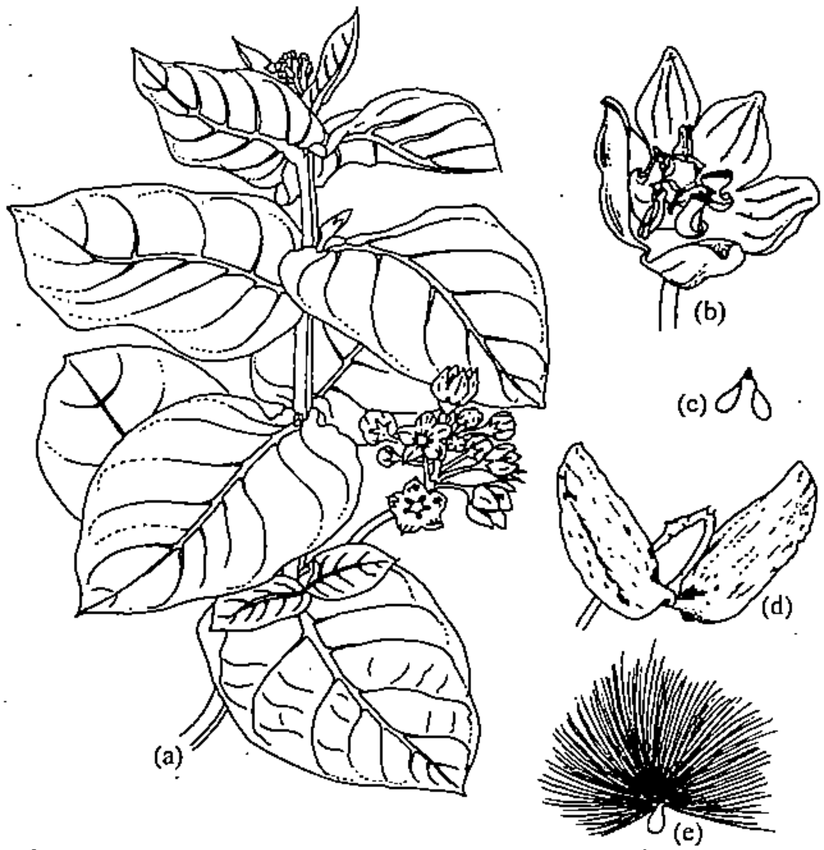

Fig. 22.13: *Calotropis procera.* a) A flowering twig. b) A flower. c) A translator apparatus with two pollinia. d) Two follicles. e) A comose seed. (Redrawn from Maheshwari, 1966).

Diagnostic Features of the Family

The family Asclepiadaceae has many characters which are similar to those of the family Apocynaceae. The two families are closely related, but the family Asclepiadaceae has the following diagnostic features:

1. Herbaceous or woody plants with milky latex.
2. Leaves exstipulate, simple, opposite decussate.
3. Inflorescence cymose or racemose.
4. Flowers bracteate and bracteolate, actinomorphic, bisexual.
5. Gynostegium present.
6. Gamosepalous calyx with quincuncial aestivation.
7. Gamopetalous corolla with contorted aestivation.
8. Five epipetalous stamens with anthers either having spoon-shaped translators or pollinia.
9. Bicarpellary, apocarpous superior ovary. Styles form a part of the gynostegium.
10. Fruit a pair of follicles.
11. Seeds comose.

Systematic Position

The family Asclepiadaceae is closely related to the family Apocynaceae and the two families are classified together in Bentham & Hooker's as well as Engler & Prantl's systems of classification. But Takhtajan (1997) merged Asclepiadaceae in Apocynaceae. They are thus united into a single family called Apocynaceae. You may refer to the systematic position of the family Apocynaceae for information about the systematic position of the family Asclepiadeceae.

Economic Importance

The family Asclepiadaceae includes a large number of plants cultivated as ornamentals. The latex of some plants as well as the fibres of other plants are also of economic value.

1. Ornamental Plants

   Asclepias curassavica (Fig. 22.12)
   Ceropegia woodii
   Stapelia gigantea
   Cryptostegia grandiflora
   Calotropis gigantea

2. Medicinal Plants

   Tylophora indica – for asthma, bronchitis, coughs.
   Sarcostemma acidum – as emetic
   Gymnema sylvestre – as laxative and diuretic.
   Hemidesmus indicus – as blood purifier, and in skin and urinary disease.

3. Latex-yielding Plants

   Cryptostegia grandiflora – latex is used as a rubber substitute .
   Calotropis gigantea and *C. procera* (Fig. 22.13) – the latex is used in the tanning industry.

4. Fibre-yielding Plants

   Asclepias curassavica, Tylophora tenuis, Leptadenia pyrotechnica, Calotropis gigantea – Fibres from their stems are used for cordage, making fishing nets and twines.

SAQ 1

Choose the correct answer from the choices given below:

a) Latex is **not** found in:
   i) Apocynaceae
   ii) Asteraceae
   iii) Rubiaceae
   iv) Sapotaceae

b) Myrmecophily is observed in:
   i) Asteraceae
   ii) Asclepiadaceae
   iii) Rubiaceae
   iv) Sapotaceae

SAQ 2

Assign the following genera to their respective families and mention one economic use of each genus.

	Genus	Family	Economic Use
i)	*Alstonia*	....	....
ii)	*Artemisia*	....	....
iii)	*Carthamus*	....	....
iv)	*Cephaelis*	....	....
v)	*Cinchona*	....	....
vi)	*Cryptostegia*	....	....

vii) *Madhuca* ....
viii) *Palaquium* ....
ix) *Tylophora* ....
x) *Vinca* ....

SAQ 3

Define the following terms and name the families in which they have been described.

a) Capitulum inflorescence

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Family ....

b) Gynostegium

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Family ....

c) Intra-petiolar stipules

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Family ....

d) Protogynous flowers

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Family ....

SAQ 4

The families Rubiaceae and Asteraceae are classified in Series Inferae by Bentham & Hooker due to the inferior ovary. List *two other characters* of the gynoecium by which the two families can be differentiated.

S. No.	Rubiaceae	Asteraceae
i)		
ii)		

SAQ 5

a) Contorted aestivation is used as a character for recognising the Order Contortae by Engler & Prantl. Name two families of this order studied by you.

i) ....

ii) ....

b) What is the systematic position of these families in:

i) Bentham & Hooker classification.

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ii) Takhtajan's classification.

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SAQ 6

a) Name the 2 subfamilies into which the family Asteraceae can be divided.

i) ....

ii) ....

b) List two important characters used for distinguishing these 2 subfamilies.

S. No.	Subfamily (i)	Subfamily (ii) ....
i)		
ii)		

SAQ 7

Compare the system of classification of Engler & Prantl with that of Takhtajan with reference to the systematic position of the family Asteraceae.

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SAQ 8

Describe the important vegetative and floral characters of the family Rubiaceae.

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SAQ 9

Write a note on the economic importance of the family Sapotaceae.

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SAQ 10

List two important features for distinguishing the family Apocynaceae from the family Asclepiadaceae.

i) ....

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ii) ....

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22.7 SOLANACEAE

The Potato family
Type genus : *Solanum*

General Information

The family Solanaceae is mainly distributed in Central and South America and the West Indies where the majority of the genera are found and a large number of them are endemic. Besides this important centre of diversity, members of this family are also found in Europe and Asia. This is a large family with 90 genera and 2000 species, of which about 15 genera and 90 species occur in India and a large number of these are cultivated. Some members are illustrated in Figs 22.14 – 22.18.

Field Recognition Characters

The plants are herbs, shrubs or trees with alternate, exstipulate leaves. The flowers are generally large, bisexual, actinomorphic; the carpels are obliquely placed, with many ovules on a swollen axile placenta; the fruit is a berry or sometimes a capsule.

Morphological Diversity

The plants may be annual, biennial or perennial herbs or shrubs, or even trees, and this diversity in the habit can often be observed within a single genus, e.g., *Solanum* (Fig. 22.14). A constant anatomical character of the stem is the occurrence of bicollateral vascular bundles. There is also a special feature in the branching pattern in the members of this family. There is the congenital fusion of the axillary branch with the main shoot. This is more pronounced in some genera leading to various types of branching patterns especially in the flowering region of the shoot.

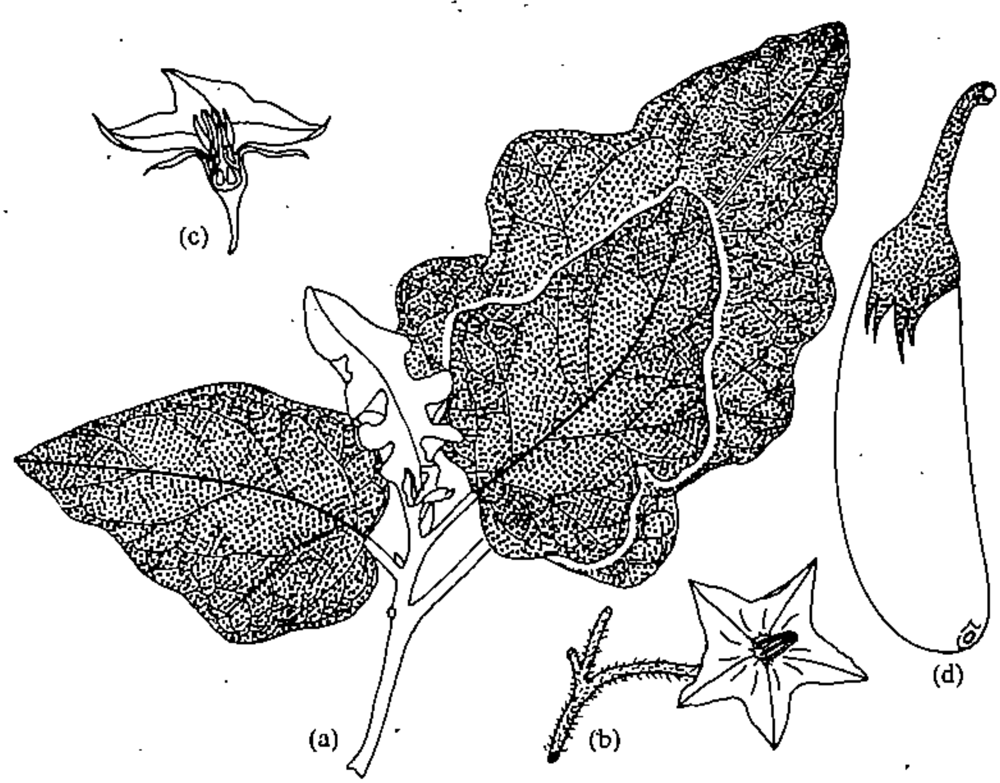

Fig. 22.14: *Solanum melongena*. a) A vegetative shoot. b) A flower. c) A flower cut in longitudinal section. d) A fruit (Redrawn from Purseglove, 1988).

Leaf: The leaves are generally alternate, but in the flowering shoots, they appear almost opposite. A careful examination of the two leaves at a node shows that they are of different sizes, one generally larger than the other. This is due to the congenital fusion of axes. The leaves are exstipulate, simple with an entire or lobed lamina.

Inflorescence: The inflorescence is terminal, or axillary, or it is extra-axillary (due to the congenital fusion of axes). It may consist of a single large flower or it may be cymose with many small flowers.

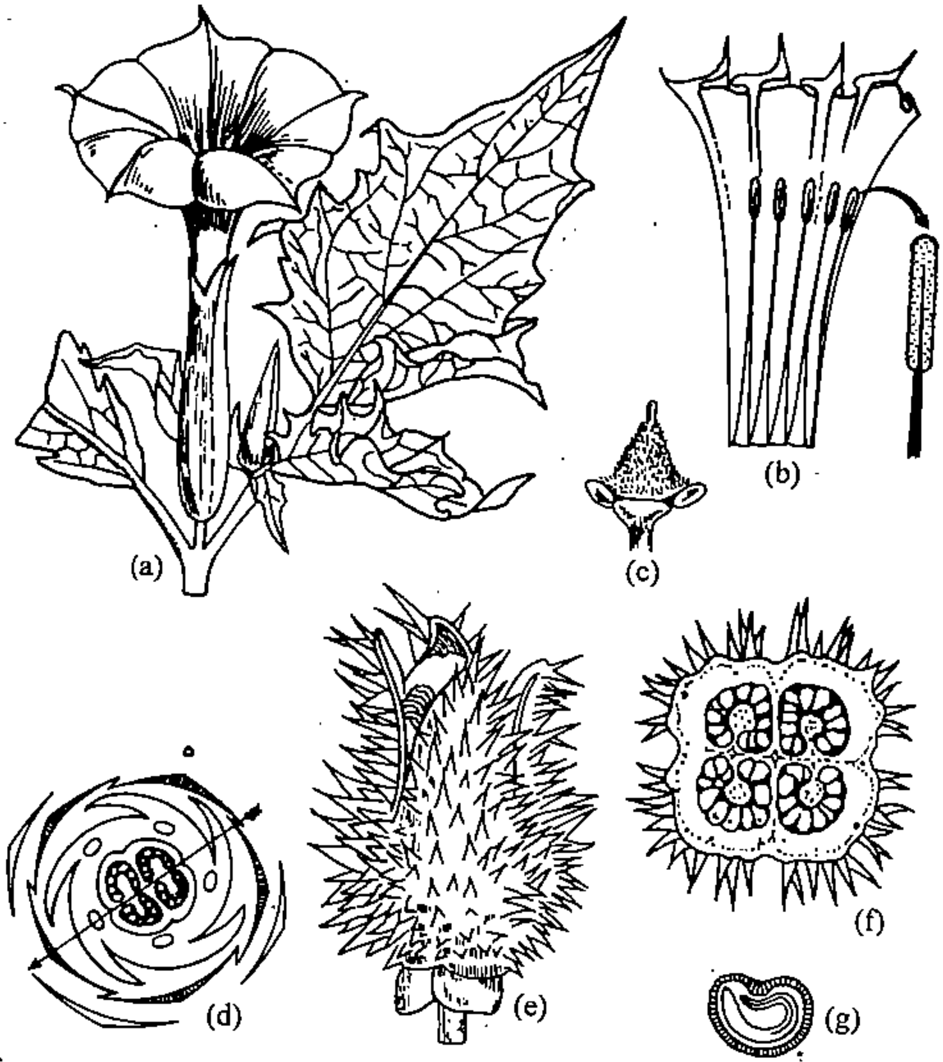

Fig. 22.15: ***Datura stramonium.*** **a) A flowering shoot. b) A corolla cut open. Note the androecium. c) Pistil as seen after removing the petals. d) Floral diagram. The arrow indicates the plane of symmetry. e) A dehiscing capsule. f) A capsule in transverse section. g) A seed.**

Flower: The flowers are ebracteate, complete, bisexual, actinomorphic and hypogynous. The calyx is composed of 5 united sepals which show valvate aestivation. They are persistent and sometimes also accrescent (enlarging with the growing fruit).

The gamopetalous corolla of 5 petals shows different patterns; it is rotate as in *Solanum*, or it is bell-shaped as in *Atropa* or *Datura* (Fig. 22.16), or it may be somewhat zygomorphic as in *Hyoscyamus*. The aestivation may be plicate or even convolute. In a large majority of plants, the corolla is white or pale-coloured.

Androecium: There are 5 epipetalous stamens, but sometimes there may be only 4 (especially in the zygomorphic flowers). They are free, but in *Solanum* the anthers may unite appearing syngenesious. The anthers are dithecous and show longitudinal or poral dehiscence.

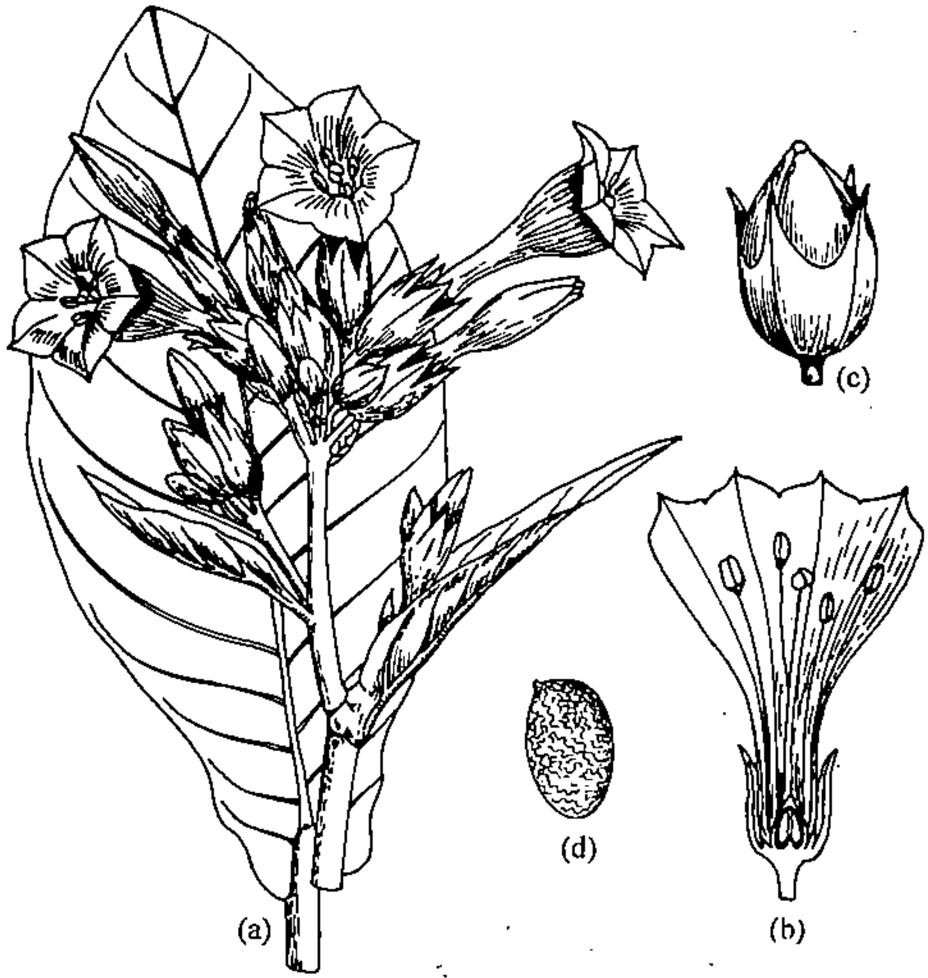

Fig. 22.16: *Nicotiana tabacum.* a) A flowering twig and a leaf in its background. b) A flower cut in vertical section. c) A fruit. d) A seed.

Gynoecium: The gynoecium is bicarpellary, syncarpous with a superior ovary situated on a hypogynous disc. The ovary may be bilocular or falsely 3-5 locular. The placentation is axile, the ovules numerous on intruding placentae. The 2 carpels are obliquely placed with reference to the mother axis, and this is an important feature for identification of the family. (In the floral diagram, the anterior carpel is on the right and the posterior is on the left). The style is simple and the stigma is two-lobed.

Fruit: The fruit is generally a many-seeded berry, but sometimes it is a capsule as in *Datura* (Fig. 22.15) and *Nicotiana* (Fig. 22.16). The calyx persists in the fruit and it is prominent in some plants, e.g., brinjal (Fig. 22.14), and tomato (Fig. 22.17). In *Physalis peruviana,* it (calyx) forms a balloon-like structure around the fruit. There are many seeds each with a straight or curved embryo and this feature along with the partitioning of the ovary serves as an important character for classifying the family into tribes and genera.

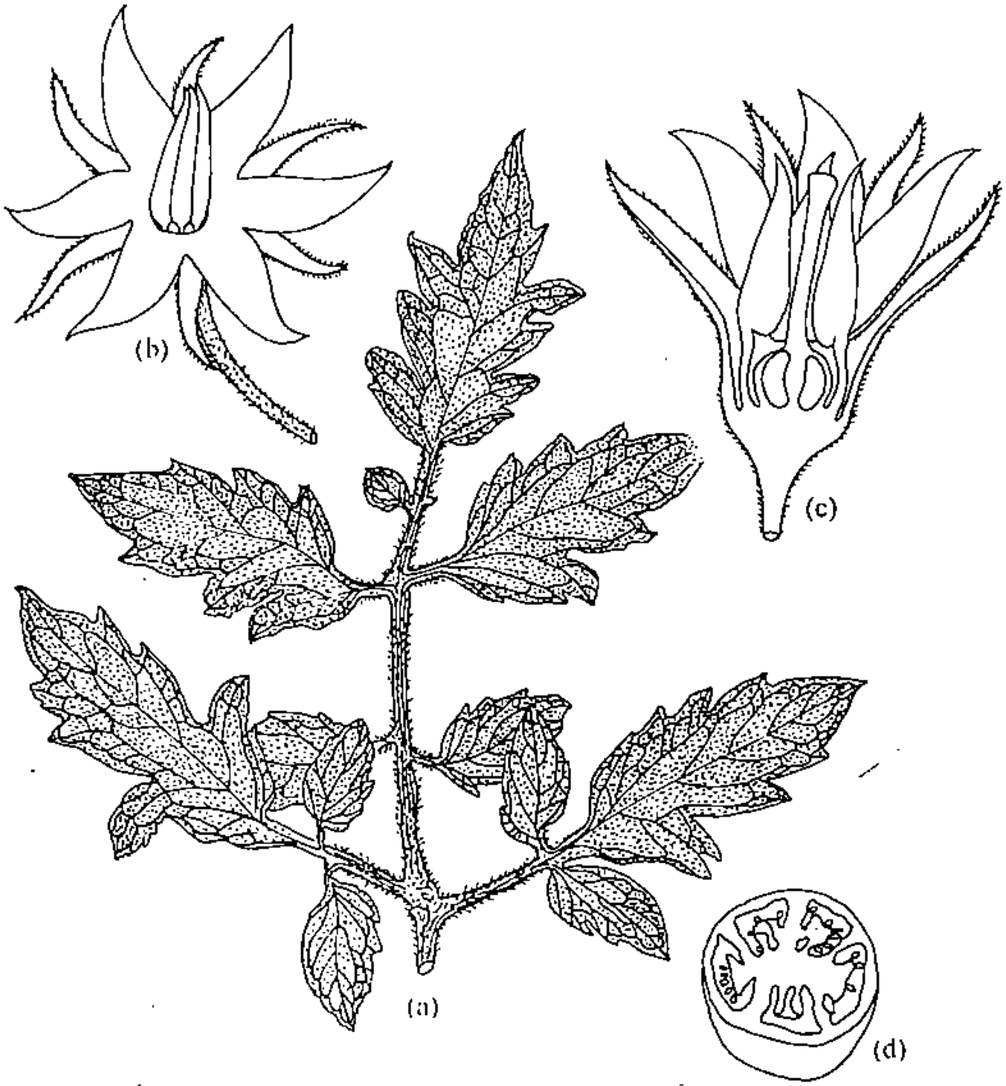

Fig. 22.17: *Lycopersicon esculentum.* a) A vegetative shoot. b) A flower. c) A flower cut in longitudinal section. d) A portion of the fruit cut in transverse section. (Redrawn from Purseglove, 1988).

Diagnostic Features of the Family

1. Herbs, shrubs or trees with bicollateral vascular bundles in the stem.
2. Leaves simple, alternate or subopposite and with extra-axillary inflorescence due to congenital fusion of axes.
3. Flowers complete, hypogynous, bisexual.
4. Calyx 5, united, persistent.
5. Corolla 5, gamopetalous with plicate or convolute aestivation.
6. Stamens equal to or less than the number of petals.
7. Bicarpellary, syncarpous gynoecium.
8. Carpels obliquely placed.
9. Placentation axile and numerous ovules on intruding placentae.
10. Fruit a berry or a capsule with persistent calyx.

Systematic Position

The family Solanaceae is classified in the Gamopetalae, Series III Bicarpellatae and Order 8 Polemoniales by Bentham & Hooker. This Order has 4 other families including Convolvulaceae, and Boraginaceae. In Engler & Prantl's classification, this family is classified in the Sympetalae and Order 6 Tubiflorae which has 20 families including all the families classified in Order Polemoniales by Bentham & Hooker. Takhtajan in his classification, has classified the family Solanaceae in Subclass K – Lamiidae, Superorder Solananae and Order 164 Solanales.

Interestingly, the family Convolvulaceae is classified in Order 165 Convolvulales, and the family Boraginaceae in Order 167 Boraginales.

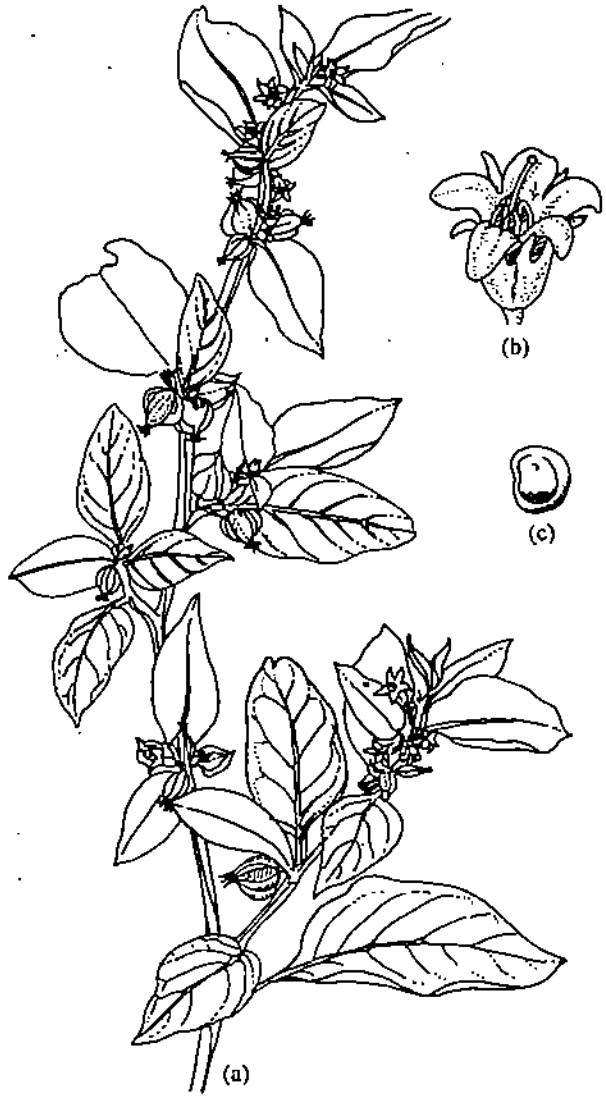

Fig. 22.18: *Withania somnifera.* a) A twig bearing flowers and fruits. b) A flower. c) A berry. (Redrawn from Maheshwari, 1986).

Economic Importance

Plants of the family Solanaceae provide fruits, vegetables, drugs and narcotics. They are also cultivated as ornamentals.

1. Edible Plants

   a) *Solanum tuberosum* – Irish Potato from underground stem tubers. You have studied about this plant in detail in Units 14, and 16 under the starch-yielding plants.

   b) *Lycopersicon esculentum* – Tomato (also see Fig. 22.17), the ripe red fruit is eaten raw as a salad, or used for making sauces or ketchups.

   c) *Solanum melongena* (Fig. 22.14) – Egg plant or Brinjal. The fruit is used as a vegetable.

   d) *Capsicum frutescens* and *Capsicum annuum* – The fruits are used as green pepper or chillies or even pickled or cooked as a vegetable.

   e) *Physalis peruviana* – Cape gooseberry or Raspberry, their fruits are edible.

2. Drugs

   a) *Atropa belladonna* – the alkaloid atropine obtained from its roots, is used to dilate the pupil of the eye and relieve pain. Belladonna plaster is also made for relieving pain.
   b) *Hyoscyamus niger* – Henbane, dried leaves and young flowering shoots are used as a sedative for relieving symptoms of asthma and whooping cough.
   c) *Withania somnifera* – Asgandh (Fig. 22.18), *Datura* – Dhatura (Fig. 22.15) and other plants are used in the Indian system of medicine.

3. Fumitories

   Nicotiana tabacum (Fig. 22.16) and *N. rustica* are two important tobacco-yielding plants (see Fig. 19.13 a,b). You have studied about these in detail in Unit 19.

4. Ornamentals

   Several species of Solanaceae are cultivated as ornamentals. The more well-known plants are:

   Cestrum nocturnum, C. diurnum, Petunia axillaris, Salpiglossis sinuata, Schizanthus pinnatus, S. retusus, Solanum jasminoides, Brunfelsia calycina and *Nicotiana alata.*

Points to Remember

22.8 ACANTHACEAE

The Acanthus family
Type genus : *Acanthus*

General Information

The family Acanthaceae with about 250 genera and more than 2000 species inhabits the warmer parts of the world. It shows four chief centres of distribution: Indo-Malaya, Africa, Brazil, and Central America. Besides these regions, some members also occur in the Mediterranean region, the United States of America and Australia. About 70 genera with 350 species of this family occur in India many of which are commonly cultivated as ornamentals.

Field Recognition Characters

Herbs or shrubs; leaves opposite and decussate (Fig. 22.19), exstipulate; inflorescence with characteristic bracts and bracteoles; flowers bisexual, zygomorphic; fruit a capsule with retinaculate seeds.

Fig. 22.19: *Adhatoda vasica*. A flowering twig. (From Maheshwari, 1966).

Morphological Diversity

Members of the family are herbs or shrubs, and rarely even small trees. Climbing plants, marsh plants and xerophytes are also found. There is abnormal secondary growth in the climbing plants. A characteristic feature is the presence of cystoliths in young stems and leaves. These are visible as streaks or protuberances. They are present in the epidermal cells and are large crystals of calcium carbonate.

Leaf: The leaves are opposite and decussate, exstipulate, usually with an entire margin (Figs 22.19 and 22.20). The cystoliths are conspicous. In the xerophytes, the leaves are reduced and spiny.

Inflorescence: Generally cymose with a dichasial pattern, but spicate and racemose inflorescences are also common in the family. Some genera may have solitary flowers in the axils of the leaves.

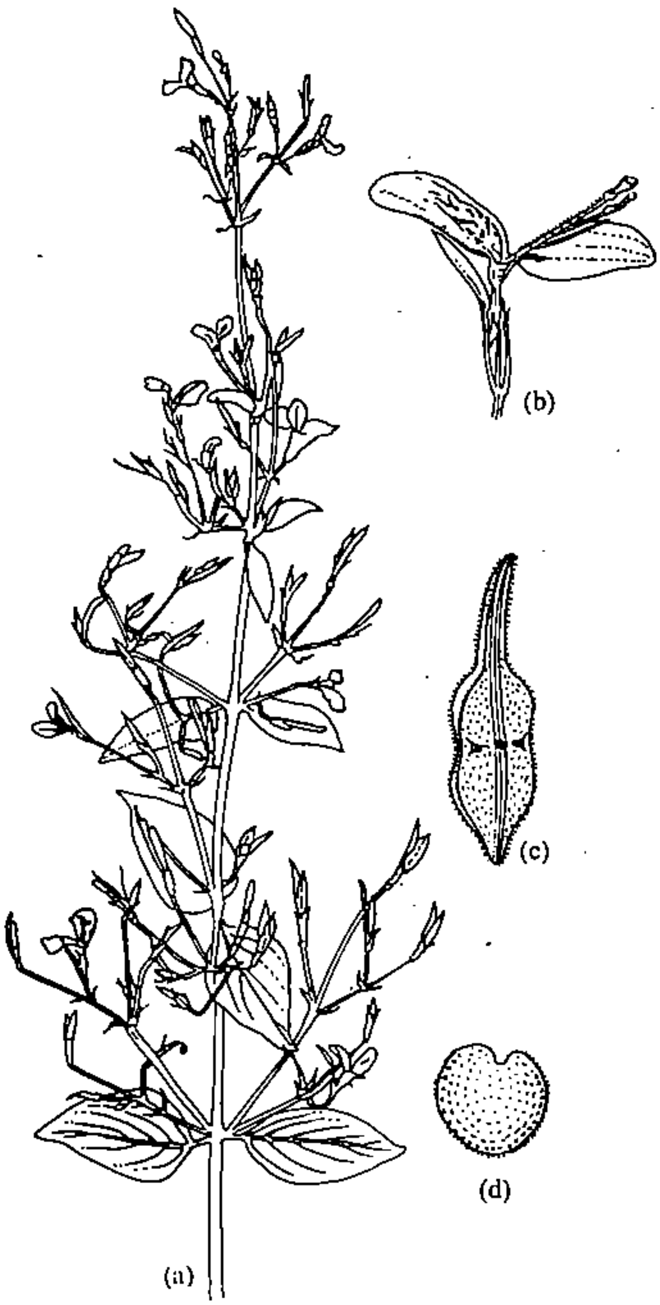

Fig. 22.20: *Peristrophe bicalyculata.* a) Flowering and fruiting twig. b) An open flower. c) A capsule. d) A seed.

Flower: The flowers are bracteate and bracteolate, pedicellate, bisexual, complete, zygomorphic, and usually with a nectariferous disc below the ovary. They are tetra-, or pentamerous.

The calyx is generally small, gamosepalous and made up of 4 or 5 sepals. It may be reduced as in *Thunbergia*, where the large bracteoles protect the developing flower. Sometimes, the sepals are inconspicuous and the bracteoles may be confused as the sepals. The gamopetalous corolla is made up of 5 petals. It forms a long or short, slender tube which then expands into 5 equal lobes or it becomes bilabiate. The upper lip may be more prominent than the lower lip, and it may be densely hairy. In the Subfamily Acanthoideae, the genera can be distinguished into two kinds on the basis of the aestivation of the corolla, which may be contorted or imbricate.

Androecium: Generally there are 4 epipetalous stamens (rarely 5), or only 2 stamens may develop and 2 get reduced to staminodes. The stamens are exserted. In some members of the family, one anther lobe of each stamen is large and the other one is small or is even reduced to a rudimentary structure. The shape, size and exine sculpturing of the pollen grains show considerable diversity and provide useful characters for identifying different genera in the family. Because of this pollen diversity, the family Acanthaceae is classified as a Eurypalynous family by palynologists.

Gynoecium: The gynoecium is bicarpellary, syncarpous with a superior ovary. It is bilocular with axile placentation, having 2-many ovules in two rows in each locule. As the ovary elongates, it develops a long, narrow style, and 2 stigmas.

Fruit: The fruit is a bilocular capsule splitting loculicidally or longitudinally up to the base. Rarely, the fruit may be a one-, or two-seeded drupe. The seeds are small and usually exalbuminous. They have retinaculae or jaculators which are hook-like projections of the funiculus. These structures help in dispersal.

Diagnostic Features of the Family

1. Herbs or shrubs with cystoliths in the young stems and leaves.
2. Leaves opposite, decussate, entire, exstipulate.
3. Inflorescence dichasial cymes or racemose.
4. Bracts and bracteoles prominent.
5. Flowers bisexual, zygomorphic, with nectariferous disc below the ovary.
6. Corolla generally bilabiate, aestivation imbricate or contorted.
7. Stamens 2 or 4, exserted
8. Pollen of diverse morphology.
9. Bicarpellary, syncarpous, bilocular ovary with axile placentation, ovules in 2 rows in each locule.
10. Fruit a bilocular capsule.
11. Seeds with retinaculae or jaculators which help in dispersal.

Systematic Position

The family Acanthaceae is classified in the Gamopetalae, Series Bicarpellatae and the Order Personales by Bentham & Hooker. This order has 8 families; the Scrophulariaceae, the Orobanchaceae, the Lentibulariaceae, the Columellaceae, the Gesneriaceae, the Bignoniaceae, the Pedaliaceae, and the Acanthaceae.

In Engler & Prantl's classification, the Acanthaceae is classified in the Sympetalae and the Order Tubiflorae. This order has 20 families including all the 8 families of the Order Personales of Bentham & Hooker's classification, as well as the families Convolvulaceae, Boraginaceae, Verbenaceae, Lamiaceae, and Solanaceae.

Takhtajan in his classification placed the family Acanthaceae in Subclass K – Lamiidae, Superorder Lamianae, and Order 171 Scrophulariales. This Order has 15 families including many of the families of the Order Personales of Bentham &

Hooker. Thus in all the three systems of classification, the family Acanthaceae is closely related with the family Scrophulariaceae.

Economic Importance

Compared to the large size of the family, few plants of the Acanthaceae are economically important. The majority of the plants of this family are grown for ornamental purposes. These include: *Thunbergia grandiflora; T. alata; T. coccinea; T. laurifolia; Eranthemum nervosum; E. bicolour; E. reticulatum; Jacobinia tinctoria; Barleria montana; B. cristata; B. prionitis; Ruellia tuberosa; R. brittoniana; Justicia gendarussa* and *Crossandra. Strobilanthes* and other related genera show a cyclic pattern of flowering (generally every 12 years) in the Nilgiri Hills of S. India, and when they flower, large amounts of honey is produced by honey bees which pollinate these flowers.

Adathoda vasica is used medicinally in cough syrups, e.g., Glycodin.

Points to Remember

22.9 LAMIACEAE

The Mint or the Sage family, Labiatae
Type genus : *Lamium*

General Information

The family Lamiaceae includes 200 genera and 3200 species with a widespread and interesting distribution pattern. A large number of genera are cosmopolitan, spreading out from the Mediterranean region. There are also members showing restricted distribution in Australia and Tasmania or in South-East Asia, especially in India, Malaysia and China; or in Central and South America. In India there are 64 genera and 380 species of which the sacred tulsi (*Ocimum sanctum*), and spear-mint or pudina (*Mentha spicata*) are very well known.

Field Recognition Characters

Aromatic, herbaceous plants with quadrangular stems; leaves opposite; inflorescence mostly verticillate; flowers zygomorphic; stamens 2 or 4, style gynobasic; fruit of 4 nutlets.

Morphological Diversity

The plants are generally herbs or under-shrubs which are aromatic due to the presence of essential oil glands in the epidermis. This aromatic property along with the characteristic inflorescence has been used since ancient times for identification of the plants of this family. The stems are usually quadrangular with ribbed corners.

Leaf: The leaves are exstipulate, opposite decussate (rarely whorled) and simple. The lamina may be entire or toothed, lobed or even finely dissected. The epidermal cells have numerous essential oil glands which provide the characteristic odour to the plants.

Inflorescence: The majority of the species of this family are characterised by the verticillaster inflorescence. This is a special type of inflorescence in which a dichasial cyme develops in the axil of each leaf at the node. The two cymose inflorescences of each node overlap due to a reduction in the flower stalks. This results in the overlapping of condensed cymes forming a pseudo-whorl or verticel. Such an inflorescence is called a verticillaster. In many species the dichasial cyme shows further overlap of the flowers making the verticillaster more complex. The entire inflorescence at each node becomes a closely condensed unit. Several such verticillasters develop in a racemose manner on successive nodes of the flowering shoot. Sometimes, the inflorescence is a simple raceme with solitary flowers in the axil of each leaf (e.g., *Scutellaria*). Associated with the complexity of the inflorescence is the reduction in the size of the leaves which become bract-like. There is usually a pair of bracteoles above the bract, but sometimes only one develops or both may be suppressed.

Flower: The flowers are bisexual, zygomorphic, hypogynous and usually pentamerous.

Calyx: There are 5 sepals and they are gamosepalous. The calyx may be tubular, funnel or bell-shaped, or sometimes bilabiate. It persists in the fruit. Sometimes, it may be brightly coloured (e.g., *Salvia splendens*).

Corolla: There are 5 petals and they are gamopetalous. The corolla is usually bilabiate having an upper lip and a lower lip showing various patterns in the number of petals in each lip of the corolla. If there are 4 petals in the upper lip, then there is a single petal constituting the lower lip and the corolla is described as 4/1. In this manner the corolla may also be 3/2 or 2/3, 1/4 or even 0/5 where the first figure represents the number of petals constituting the upper lip and the second figure represents the lower lip. This organisation of the bilabiate corolla helps in the identification of different genera within the family. The corolla is variously coloured, but shades of blue predominate.

Androecium: There are generally 4 stamens and they are didynamous (the fifth posterior stamen rarely develops and may be present as a staminode). Sometimes the 2 upper stamens are also reduced to staminodes so that the flower becomes diandrous. In *Coleus* the stamens are monadelphous. They are epipetalous with introrse anthers. The anthers may be widely separated by the development of the connective. In *Salvia* (Fig. 22.21) and other related genera, a lever mechanism is formed by the connective and this assists in cross pollination.

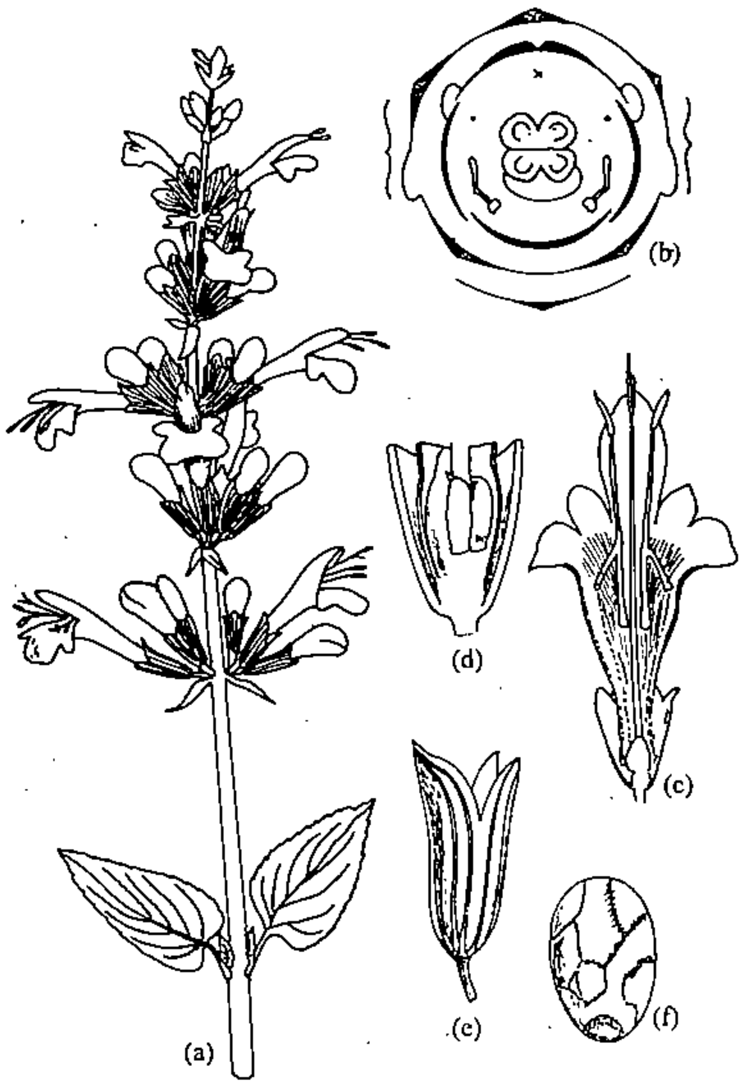

Fig. 22.21: *Salvia* sp. a) A flowering twig. b) Floral diagram. c) A flower opened along the middle line of the anterior petal. d) Base of the flower magnified showing a large nectary developed from the hypogynous disc. e) Calyx in an enlarged view. f) A nutlet.

Gynoecium: The bicarpellary, syncarpous gynoecium develops on a nectariferous disc. The superior ovary becomes quadrilocular by the early development of a deep vertical septum in each carpel. In a mature ovary, each of the 4 portions is nearly independent of the rest. The style is gynobasic and grows out between the carpels in a majority of the genera. This is an important character for identifying the family. The placentation is axile and only one ovule develops in each locule.

Fruit: The fruit is a group of 4 nutlets or achenes each containing one seed. Sometimes the fruit is a drupe. The characters of the fruit, particularly the nutlets are important for classifying the family Lamiaceae into tribes, genera and species. The seeds are small, with little or no endosperm and a somewhat straight embryo.

Diagnostic Features of the Family

1. Aromatic herbaceous plants.
2. Quadrangular stems.
3. Exstipulate leaves with variously dissected laminae.
4. Verticillaster inflorescence.
5. Calyx persistent.
6. Gamopetalous, usually bilabiate flowers, zygomorphic corolla.
7. Epipetalous stamens usually didynamous or diandrous.
8. Bicarpellary, tetralocular ovary with axile placentation.
9. Gynobasic style.
10. Hypogynous ovary on nectariferous disc present.
11. Fruit of 4 nutlets.

Systematic Position

The family Lamiaceae is classified in the Gamopetalae, Series III Bicarpellatae and Order 10 Lamiales by Bentham & Hooker. This has 3 other families including the family Verbenaceae. In Engler & Prantl's classification, the family Lamiaceae is classified in the Sympetalae and Order 6 – Tubiflorae which has as many as 20 families. Takhtajan in his classification has classified the family Lamiaceae in Subclass K Lamiidae, Superorder Lamianae and Order 172 Lamiales. This includes the family Verbenaceae. Thus in all the three systems of classifications of the relationship between the families Lamiaceae and Verbenaceae is accepted.

Economic Importance

A large number of species of this family are useful for the volatile oils they produce. Some plants are used as food and others are cultivated as ornamentals. The more well-known members of the Lamiaceae include the following:

1. *Coleus amboinicus* or Indian Borage. The aromatic leaves are used for flavouring food, especially meat. It is used as a substitute for *Salvia officinalis* (sage) and *Borago officinalis* (Borage).

2. *Coleus parviflorus* and *Plectranthus esculentus* (Hansa potato) produce tubers which are consumed as a substitute for potato in Africa. *Coleus blumei* is commonly cultivated for its brightly coloured leaves as an ornamental.

3. *Hyptis spicigera*: The seeds are used in the same way as *Sesamum indicum* in Africa.

4. Several species of *Mentha* are cultivated as mint plants. *Mentha piperita* or peppermint – An essential oil is extracted from the leaves by steam distillation. It is used in confectionery and in medicine. *Mentha spicata* or spear-mint – the fresh or dried leaves are used for making mint-sauce (chutney) and the oil is used in toothpastes, chewing gum and in medicine. *Mentha arvensis* or Japanese mint – This is the commercial source of menthol.

5. *Majorana hortensis* or sweet majoran. It is used in the perfume, soap, and liquor industries.

6. *Lavendula officinalis* or Lavender. The oil is used in perfumes, soaps, cosmetics, and medicines.

7. *Ocimum basilicum* or Sweet Basil; *Ocimum sanctum* or Sacred Basil or Tulsi, and other species (also see Fig. 22.22) yield oils which are used in the perfume industry and in medicine.

8. *Pogostemon cablin* or Patchouli. The essential oil extracted from the young shoots is one of the best fixatives for heavy perfumes. It is used in soaps, and hair tonics.

9. *Salvia officinalis* or Sage is a culinary herb. *Salvia splendens* or Red Salvia and other species are cultivated as ornamentals.

10. *Thymus vulgaris* or Thyme. The oil Thymol, is used in perfumery; while derivatives of this oil are used in toothpastes, in medicine and as antiseptics.

11. *Rosmarinus officinalis* or Rosemary. The oil is used in perfumery and in medicine.

Fig. 22.22: *Ocimum americanum*. a) A flowering and fruiting twig. b) A flower in an enlarged view. (Redrawn from Maheshwari, 1966)

Points to Remember

22.10 AMARANTHACEAE

The Amaranth family
Type genus : *Amaranthus*

General Information

The family Amaranthaceae is distributed in the tropical and temperate regions of the world. The chief centres of distribution are in tropical America and India. This family has about 65 genera and 900 species of which 17 genera and 50 species occur in India, some of which are cultivated.

Field Recognition Characters

Herbaceous plants with exstipulate, simple leaves; inflorescence dense or congested (Figs 22.23 to 22.26); flowers small with dry, papery perianth lobes which may be spinescent; stamens united at the base into a short tube, gynoecium bicarpellary; fruit frequently a utricle or nutlet, seed with abundant mealy endosperm.

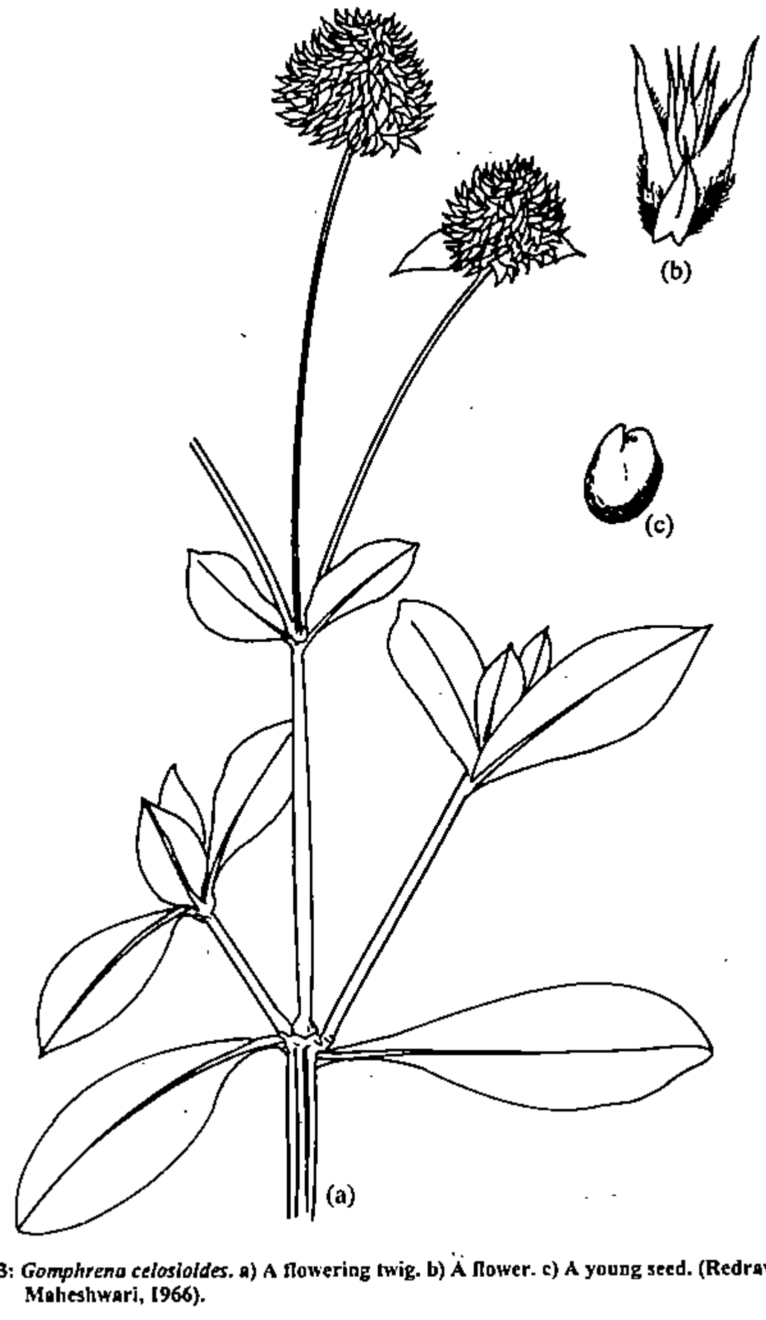

Fig. 22.23: *Gomphrena celosioides*. a) A flowering twig. b) A flower. c) A young seed. (Redrawn from Maheshwari, 1966).

Morphological Diversity

The plants of the family Amaranthaceae are herbs or shrubs, sometimes with prickles or tufts of hairs on younger parts especially in the inflorescence region. The stem may show anomalous secondary growth due to the development of the vascular bundles in several concentric rings.

Leaf: The leaves are alternate or opposite, exstipulate, generally with an entire lamina covered with hairs.

Inflorescence: The inflorescence shows a great diversity (also see Figs 22.23 to 22.26). There may be solitary flowers; or the inflorescence may be cymosely or racemosely organised. It forms a large and dense showy structure. When the inflorescence is highly branched, the lateral flowers usually do not develop. In place of these flowers, prickles or tufts of hairs may develop. These structures persist till the fruit matures and they help in seed dispersal.

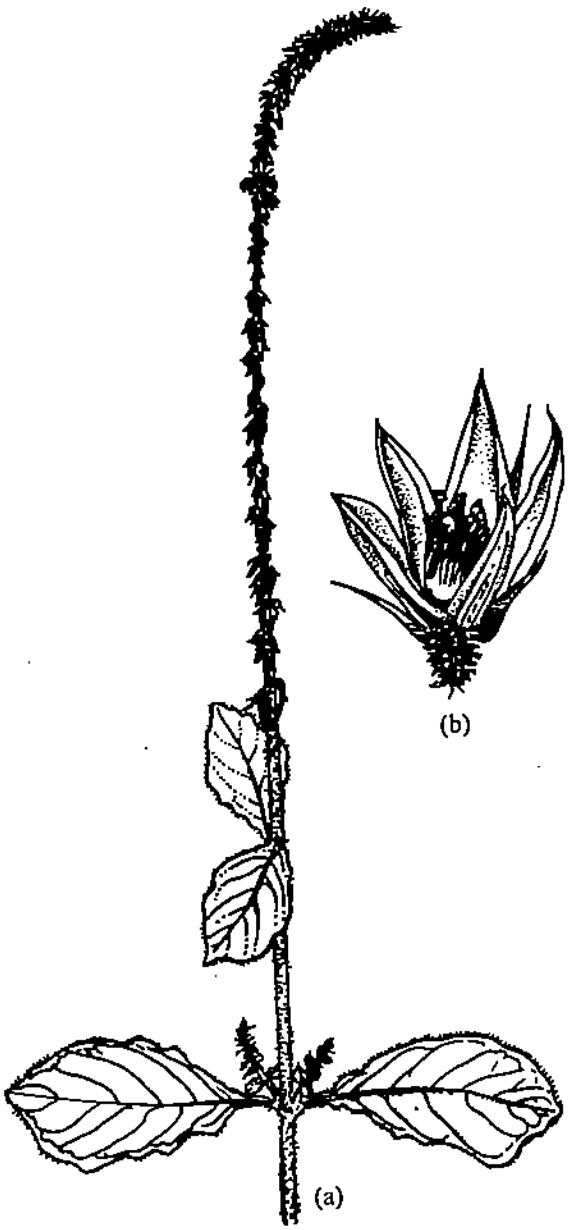

Fig. 22.24: *Achyranthes aspera.* a) A flowering twig. b) A flower. (Redrawn from Maheshwari, 1966).

Flower: The flowers are small and generally bisexual (rarely unisexual, Fig. 22.26) and actinomorphic. The flowers are simple and the perianth does not differentiate into calyx and corolla, i.e., it is homochlamydeous. There is a single whorl of 4 or 5 sepaloid tepals which may be free or united. They are membranous, dry and paper-like, but can become hard and woody when the fruit develops. The tepals show imbricate aestivation.

Androecium: There are 4 or 5 stamens, one opposite each tepal; the stamens are generally united at the base by their filaments to form a membranous tube. This may be simple, lobed or it may have fringed petaloid outgrowths. In many genera the anther is dithecous, but in some it is monothecous. This feature is useful for identifying different groups of genera in the family.

Gynoecium: There are 2 or 3 carpels which are syncarpous. The ovary is superior and unilocular. There is a single ovule (sometimes several in *Celosia*) on a basal placenta. The ovary has 1, 2, or 3 styles each with a terminal stigma.

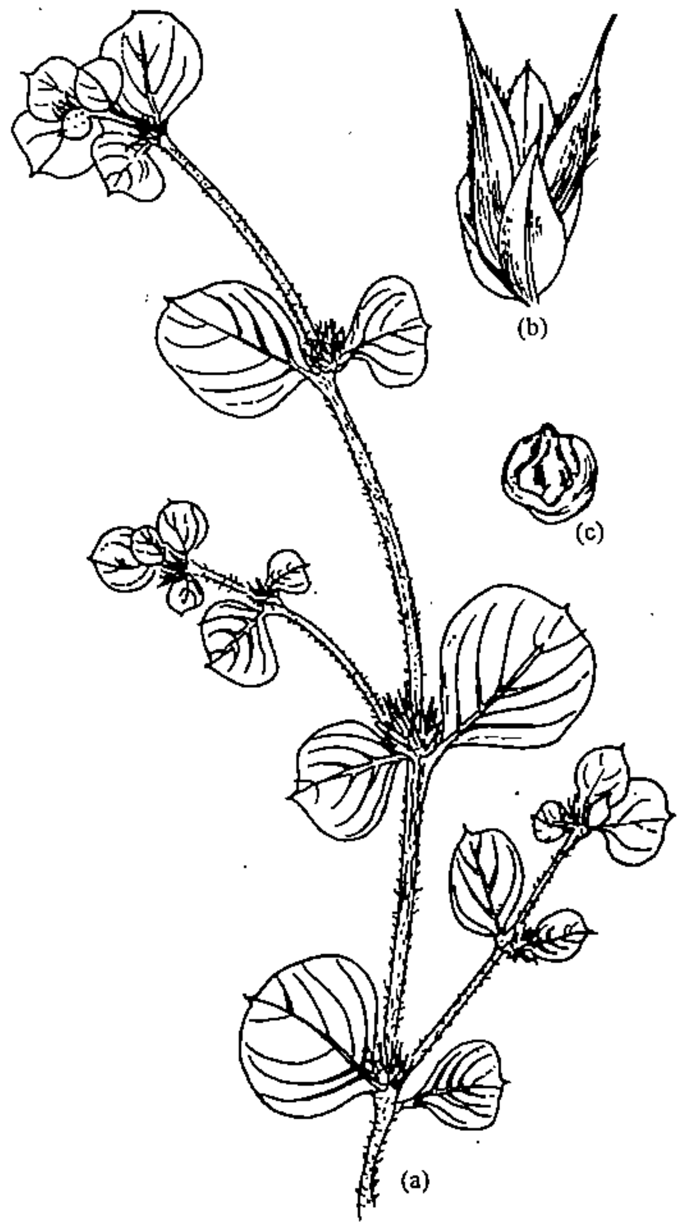

Fig. 22.25: *Alternanthera pungens.* a) A flowering twig. b) A flower. c) A seed. (Redrawn from Maheshwari, 1966).

Fruit: The fruit is usually an utricle with a thin pericarp and one seed; or it is a dry, one-seeded nutlet with a hard pericarp. Sometimes the fruit is a many-seeded berry-like structure. The seeds are lenticular with a rough or shiny testa. The embryo is curved and there is abundant endosperm.

Diagnostic Features of the Family

1. Herbs or shrubs.
2. Stem with anomalous secondary growth.
3. Leaves exstipulate, simple and covered with hairs.
4. Inflorescence diverse in organisation and with prickles or tuft of hairs.
5. Flowers small and simple.
6. Perianth homochlamydeous, generally membranous.
7. Stamens as many as tepals with dithecous or monothecous anthers.
8. Syncarpous gynoecium with superior ovary and generally one (sometimes more) ovules on basal placenta.
9. Fruit an utricle or a nutlet or berry-like.
10. Seed lenticular with curved embryo.

Fig. 22.26: *Amaranthus spinosus.* a) A flowering twig. b) A pistillate flower. c) A staminate flower. d) A developing fruit, also having persistent bracts and calyx. e) A seed.

Systematic Position

The family Amaranthaceae is classified in the Monochlamydeae and Series I Curvembryeae by Bentham & Hooker because of the simple perianth and curved embryo. It is closely related to the family Chenopodiaceae and 6 other families of this Series. Interestingly, the family Caryophyllaceae is classified in Polypetalae, Series Thalamiflorae and Order 4 Caryophyllinae. In Engler & Prantl's classification, the family Amaranthaceae is classified in Archichlamydeae and Order 17 Centrospermae. There are 9 families in this order including Chenopodiaceae and Caryophyllaceae, showing the relationship amongst these families. Takhtajan in his classification has classified the Amaranthaceae in the

Subclass E – Caryophyllidae, Superorder Caryophyllanae, and Order 32 – Caryophyllales which has 21 families. The families Chenopodiaceae, Caryophyllceae and even Cactaceae are included in this order.

Economic Importance

1. Several species of the family Amaranthaceae are cultivated as ornamental plants; a few for food and a large number are weeds of cultivated fields.
2. The more well-known ornamental plants of this family include *Celosia cristata, C. argentea, Gomphrena globosa,* and *Amaranthus* species.
3. Members of the genus *Amaranthus* are also cultivated for food, where the young leaves are eaten as a leafy vegetable or the grains (grain amaranth) are consumed as a pseudocereal.
4. *Achyranthes aspera* is used in the Indian system of medicine. It is also a common weed which can be used as a green manure because of the high content of Potassium it contains.

SAQ 11

Fill in the blanks with the suitable name of the family.

a) Presence of cystoliths in the leaves is observed in the family ....

b) Congenital fusion of the axillary branches with the main shoot occurs in members of the family ....

c) A fruit of 4 nutlets can be observed in the family ....

SAQ 12

Write the name of the Type genus for the following families:

	Family	Type genus
a)	Acanthaceae	....
b)	Lamiaceae	....
c)	Solanaceae	....

SAQ 13

Define the following terms and mention the name of the family in which these terms have been described.

a) Gynobasic style : ....

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Family: ....

b) Jaculator: ....

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Family: ....

c) Obliquely placed carpels: ....

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Family: ....

SAQ 14

Write a note on verticillaster inflorescence.

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SAQ 15

Name the orders in which the following families are classified in the 3 systems of classification.

Family	Bentham & Hooker	Engler & Prantl	Takhtajan
i) Acanthaceae			
ii) Lamiaceae			
iii) Solanaceae			

SAQ 16

List the diagnostic features of the Family Acanthaceae.

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SAQ 17

Describe the vegetative and floral characters of the family Solanaceae.

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SAQ 18

Write a note on the economic importance of the family Lamiaceae.

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Points to Remember

22.11 SANTALACEAE

The Sandalwood family
Type genus : *Santalum*

General Information

The family Santalaceae with about 26 genera and 400 species shows an interesting distribution pattern in tropical and temperate regions of the world. A large majority (about 150) of the species are classified in the largest genus *Thesium* while the remaining genera have few species. The most well known genus *Santalum* with 10 species extends from India through the Malay Archipelago to Australia and the Pacific Islands. Other genera occur only in Australia, some in South Africa and there are also genera occurring in South Europe, Africa and India.

Field Recognition Characters

Semiparasitic shrubs or trees with exstipulate, opposite leaves; Inflorescence of diverse types, flowers small with nectar secreting disc; perianth homochlamydeous; stamens epiphyllous; ovary with central placentation; fruit a nut or drupe; seed without testa; endosperm fleshy, white.

Morphological Diversity

The plants of the family Santalaceae are semiparasites. They are chlorophyllous shrubs or small trees or even herbs. Some of these grow as root parasites (e.g., *Thesium, Santalum*) while others are stem parasites on other angiospermous hosts. They may show normal development of the stem and leaves or they may have a completely altered morphology. The plant may develop a broom-like appearance with numerous branched, green stems having small scale-like leaves.

Leaf: The leaves are exstipulate, alternate or opposite, simple, and glabrous. In *Santalum*, they are bright green, coriaceous and shiny. The reticulate venation may have a solitary midrib or there may be many major veins.

Inflorescence: The inflorescence shows great diversity. There may be a solitary flower in the axil of a leaf, or a simple cyme of 3 flowers due to the development of lateral flowers in the axils of the bracteoles. These solitary flowers or cymose inflorescence may also be arranged in a raceme or a spike, or even a head.

Flower: The flowers are small and usually bisexual; but they may become unisexual by reduction of either the stamens or the carpels. A nectar secreting disc, which is perigynous or epigynous, is an important character of the flower in this family. To put it in other words, the ovary is mostly inferior and embedded in receptacular tissues, or superior and borne on, or is surrounded by a nectar secreting receptacular disc. The flowers have a simple perianth of 4 or 5 tepals. This may be sepaloid and green or petaloid and generally white and it shows valvate aestivation. The perianth is gamophyllous and forms a tube which is adnate to the disc.

Androecium: The stamens are equal in number to, and inserted on the perianth lobes. At the junction of the stamens and the perianth, there are tufts of hairs. The filaments are short and the anthers are dithecous.

Gynoecium: The syncarpous gynoecium is made up of 3-5 carpels. It is unilocular with 1-5, but generally 3 naked ovules on a central placenta. The ovary is generally inferior, but sometimes it is nearly superior (e.g., *Santalum*). The style is terminal with a capitate or lobed stigma.

Fruit: The fruit is indehiscent. It is a nut or a drupe with a single seed. The seed does not have a testa but the white fleshy endosperm is conspicuous.

Diagnostic Features of the Family

1. Semiparasitic, green plants.
2. Leaves simple, exstipulate, alternate or opposite.
3. Flowers small, either solitary, or in cymose or racemose inflorescence.
4. Flowers generally bisexual, sometimes unisexual.
5. Nectar secreting disc present.
6. Simple 4- or 5-lobed gamophyllous perianth adnate to the disc.
7. Tufts of hairs present on perianth at the junction of stamens.
8. Stamens 4 or 5, epiphyllous.
9. Syncarpous gynoecium with central placentation.
10. Fruit a nut or a drupe with a single seed.
11. Seed without testa but with white fleshy endosperm.

Systematic Position

The family Santalaceae is classified in the Monochlamydeae and Series VI – Achlamydosporae by Bentham & Hooker. It is related to Loranthaceae and Balanophoraceae which are classified with it. In Engler & Prantl's classification, the family is classified in the Archichlamydeae and Order 14 – Santalales. This Order has 8 families including Loranthaceae. Takhtajan in his classification has classified the family Santalaceae in Subclass H – Rosideae, Superorder Santalanae, and Order 133 Santalales. There are 9 families in this Order and the relationship between Santalaceae and Loranthaceae is accepted.

Economic Importance

The sandalwood (*Santalum album*) is the most important member of this family. It is one of the finest woods used for carving. The wood is also used in many religious ceremonies. The heartwood of the stem and root contains an essential oil which is used in perfumery and toilet powders. The oil is also used in medicines. Sawdust is used as incense and sandalwood paste is applied on the forehead.

Points to Remember

22.12 EUPHORBIACEAE

The Spurge family
Type genus : *Euphorbia*

General Information

The family Euphorbiaceae is a large family with 300 genera and 5000 species. It is a very interesting and diverse family chiefly distributed in the tropical regions. The majority of the members occur in the Indo-Malayan region and in Brazil. Besides these centres of distribution, members of this family are also found in Europe, Australia and South America. In India, the family Euphorbiaceae is represented by 60 genera and 350 species.

Field Recognition Characters

Herbs, shrubs or trees with milky latex; leaves mostly alternate, stipulate; flowers unisexual, reduced and in special inflorescence called cyathium (e.g., *Euphorbia*) or in cymose or racemose inflorescence; perianth completely absent in the cyathium inflorescence; or homochlamydeous or heterochlamydeous; stamen(s) 1 to many; carpels 3, syncarpous, ovary superior with axile placentation; seed with conspicuous caruncle.

Morphological Diversity

The plants of the family Euphorbiaceae may be herbs, shrubs, or trees. Even in a single genus like *Euphorbia* (with 800 species), the species shows a high degree of diversity. Some species, which inhabit very dry areas, have a typical xerophytic habit and often resemble members of the Cactus family. The Euphorbias are distinguished from the Cacti by the presence of latex in the former. In these plants the stems are fleshy with an outer chlorophyllous photosynthetic zone and an inner parenchymatous storage zone. Many of these also have thorns or spines which are actually modified leaves. Milky latex is present in all parts of the plant.

Leaf: The leaves are generally alternate, but they may be opposite or whorled especially in the upper branches. They are simple with the lamina either entire or deeply cut (see Figs 22.27 and 22.28). The stipules are usually present, but sometimes they are replaced by hairs, glands, or thorns.

Inflorescence: The inflorescence is usually complex and is of many types. In the largest genus *Euphorbia*, the complex inflorescence consists of several small units called cyathia. Each cyathium is a special unit which is actually a cymose inflorescence made up of highly reduced unisexual flowers (see Fig. 22.27). In each cyathium there is a terminal female flower which is naked (i.e., without any perianth). It consists of gynoecium only. Below this terminal female flower there are 4 or 5 bracts which are united to form a cup-shaped involucre. This resembles a gamosepalous calyx. In the axil of each involucral bract there is a scorpioid cyme of highly reduced male flowers. The male flower is naked and consists of a single stamen. Thus *the cyathium which is actually a specialised cymose inflorescence looks like a single bisexual flower.*

In other genera, the inflorescence is either cymose or racemose. Each inflorescence shows a distinct pattern in the arrangement of the male and female flowers. In some, the male flowers are at the base of the inflorescence and the female are above. In others, there may be a solitary, or 2 or 3 female flowers at the apex and the rest are all male flowers in the inflorescence. The reverse condition where the female flowers are at the base and the male towards the apex of the inflorescence also occurs. The ratio between the number of female and male flowers varies and generally there are more male flowers when compared to the female flowers in an inflorescence.

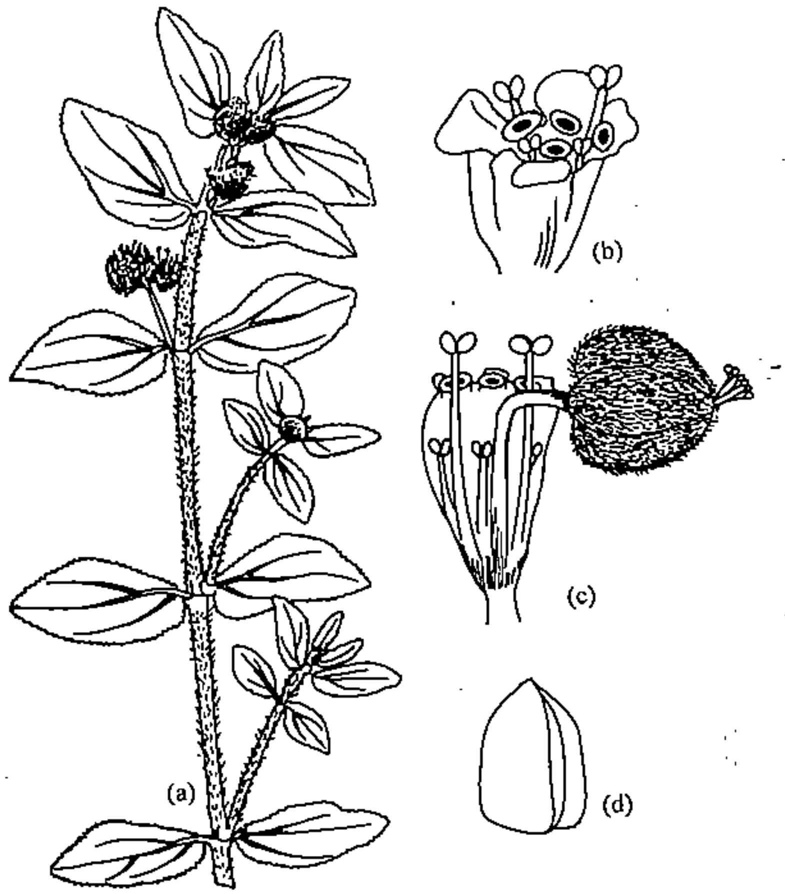

Fig. 22.27: *Euphorbia hirta*. a) A flowering shoot. b) Involucre with glands and staminate flowers. c) An opened cyathium. d) A seed. (Redrawn from Maheshwari, 1966).

Flower: The flowers are unisexual, generally actinomorphic and hypogynous. They exhibit great diversity in form and organisation. In some members, the pentamerous flowers have a distinct calyx and corolla. The more common character is the presence of a single perianth whorl of sepal-like tepals. The cályx is imbricate or valvate and, if present, the corolla is usually polypetalous. In *Euphorbia*, the highly reduced unisexual flowers are completely devoid of perianth.

Androecium: The stamens are 1-many free, or united in various ways. In *Euphorbia*, each male flower consists of a single stamen. In other genera, there may be 5 stamens in a single whorl or there may be 10 stamens in two whorls. The stamens may be numerous (80-100 or more in a single flower) as in *Ricinus* (Fig. 22.29). These are organised into a branched tree-like structure with the anthers borne on the ultimate branches of the dendroid structure. Further, in *Phyllanthus*, *Cyclanthera* the filaments are united and the anthers are continuous in a ring-like structure. This is similar to the androecium in the genus *Cyclanthera* of the family Cucurbitaceae.

Gynoecium: The gynoecium is generally uniformly tricarpellary and syncarpous. The ovary is superior and trilocular. The placentation is axile and there are 1 or 2 ovules in each locule. This character is constant throughout the family and serves as a distinguishing feature. In the genus *Euphorbia*, the gynoecium represents the female flower. The style may be simple or large and sometimes petaloid. Each style is often 2-lobed. The ovules have an integumentary protuberance near the micropyle. It is called a caruncle and it persists in the seed. Fruit is a tricoccus capsule.

Diagnostic Features of the Family

1. Plants with milky latex.
2. Stems with or without spines or thorns.
3. Simple stipulate leaves.
4. Unisexual flowers in diverse types of inflorescences.
5. Special cyathium inflorescence in the genus *Euphorbia*.
6. Perianth absent, or sepaloid, or heterochlamydeous.
7. Stamens 1-many.
8. Tricarpellary, syncarpous, superior ovary with axile placentation.
9. Fruit generally a tricoccus capsule.
10. Seed with caruncle.

Fig. 22.28: ***Hevea brasiliensis*. a) A shoot bearing a dehisced fruit. b) An inflorescence. c) A cut opened male flower. d) A female flower in logitudinal section. e) A seed. (Redrawn from Purseglove, 1988).**

Systematic Position

The family Euphorbiaceae is classified in the Monochlamydeae and Series III – Unisexuales by Bentham & Hooker. They included 8 other families in this Series recognising the unisexual flowers as the important character. In Engler & Prantl's

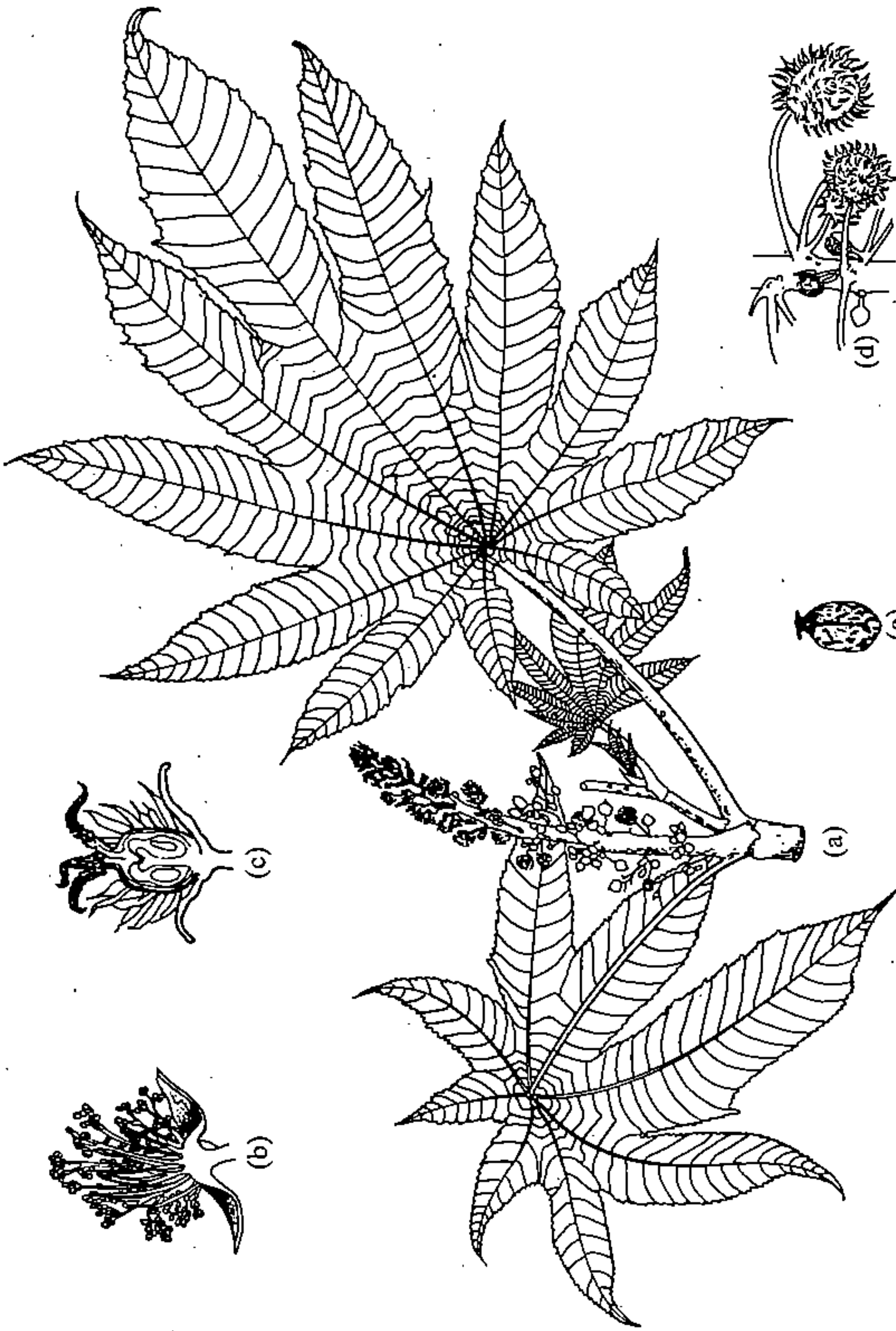

Fig. 22.29: *Ricinus communis*. a) A shoot bearing a young inflorescence. b) A male flower in longitudinal section. c) A female flower in longitudinal section. d) A part of the twig showing developing fruits. c) A seed showing caruncle. (Redrawn from Purseglove, 1988)

classification the family Euphorbiaceae is classified in the Archichlamydeae and Order 23 – Geraniales. This order has 19 other families not including any of the 8 families along with which the Euphorbiaceae is classified in Series Unisexuales by Bentham & Hooker. Takhtajan in his system of classification, classifies the family Euphorbiaceae in Subclass G – Dilleniidae, Superorder Euphorbianae, Order 91 – Euphorbiales. This order has 3 families of which the family Dichapetalaceae is classified with Euphorbiaceae in the Order Geraniales by Engler & Prantl. This suggests that the relationship of the family Euphorbiaceae differs in different systems of classification.

Economic Importance

There are several plants which are economically important. You have studied how Para rubber is obtained from the latex of *Hevea brasiliensis* (Fig. 22.28) in Unit 20.

Also of great importance is the castor seed, botanically it is known as *Ricinus communis* (Fig. 22.29). Seeds of *Aleurites* yield tung oil which is a high quality drying oil used for preparing paints and varnishes. The seeds of *Croton tiglium* are the source of croton oil used medicinally as a purgative. *Euphorbia antisyphilitica* a species of Mexico and South America is the source of candelilla wax.

There are edible plants also in this family. *Manihot esculenta* yields cassava or tapioca. The large root tubers are a source of starch. *Phyllanthus emblica* and *P. acidus* provide fruits rich in vitamin C. The fruits may be eaten raw, or pickled, or made as a preserve in sugar syrup. They are used medicinally also.

Many members of this family are commonly cultivated as ornamental plants. These include *Acalypha hispida, A. wilkesiana, Codiaeum variegatum, Euphorbia milii, E. pulcherrima, E. tirucalli,* species of *Jatropha, Pedilanthus tithymaloides* and *Putranjiva roxburghii.*

The fruits of *Mallotus philippensis* yield kamala dye used in dyeing silk and wool.

The wood of *Bischofia javanica* (Bishop wood) is used for making bridges, boats and rafters.

SAQ 19

Match the items of column I with its appropriate family mentioned in column II.

	Column I		Column II
a)	Caruncle	i)	Amaranthaceae
b)	Central placentation	ii)	Euphorbiaceae
c)	Utricle	iii)	Santalaceae

SAQ 20

Assign the following genera to their respective families and mention one economic use of each.

	Genus	Family	Economic Use
a)	*Celosia*	....	....
b)	*Gomphrena*	....	....
c)	*Mallotus*	....	....
d)	*Phyllanthus*	....	....
e)	*Santalum*	....	....

SAQ 21

Fill in the blanks with the appropriate name of the family.

a) Latex occurs in plants of the family ....
b) Semiparasitic plants occur in the family ....
c) Prickles or tufts of hairs in the inflorescence can be observed in plants of the family ....

SAQ 22

Describe the cyathium inflorescence of genus *Euphorbia*.

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SAQ 23

List the diagnostic features of the family Santalaceae.

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SAQ 24

Describe the important vegetative and floral characters of the family Amaranthaceae.

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SAQ 25

Discuss the systematic position of the family Euphorbiaceae in the 3 systems of classification studied by you.

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SAQ 26

Name any family that is considered to be related to the family Amaranthaceae.

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22.13 SUMMARY

In this unit you have studied eleven more families of dicotyledons. Their diagnostic features are given below:

- **Rubiaceae:** Plants herbaceous or woody. Leaves opposite or whorled. Inter-petiolar or intra-petiolar stipules present. Solitary, large terminal flower or inflorescence dichasial cyme. Flowers tetra- or pentamerous and epigynous. Calyx of small sepals or with one enlarged brightly coloured sepal. Gamopetalous corolla with valvate or convolute or imbricate aestivation. Stamens epipetalous and inserted in the corolla tube. Gynoecium bicarpellary, ovary inferior, generally axile placentation. Fruit a berry or capsule or schizocarp. Seeds small with abundant endosperm; sometimes winged also.

- **Asteraceae:** The most characteristic feature of the family is the special capitular inflorescence. Plants mostly herbaceous with watery sap or milky latex. Leaves exstipulate with simple, entire or highly divided lamina. Flowers reduced to florets which are crowded together in the capitulum. Involucre of bracts surround the florets in each capitulum. Calyx modified into pappus. Pentamerous gamopetalous corolla either tubular or ligulate. Stamens epipetalous, anthers syngenesious. Bicarpellary syncarpous gynoecium with inferior ovary and single ovule on basal placenta. Fruit a cypsela.

- **Sapotaceae:** Trees in tropical regions. Simple leathery leaves covered with hairs. Milky latex present in all parts of the plant. Small flowers either solitary or in cymose inflorescence, in the leaf axils. Flowers actinomorphic, gamopetalous and hypogynous. Calyx and corolla in isomerous whorls with imbricate aestivation. Stamens 4-5 each in 2 or 3 whorls. Carpels numerous,. syncarpous, superior ovary, axile placentation, simple style and sticky stigma. Fruit a berry with few seeds. Seeds large with broad hilum and shiny testa.

- **Apocynaceae:** Herbaceous or woody plants with milky sap. Leaves exstipulate, simple opposite or whorled. Flowers solitary or in paniculate inflorescence. Flowers bisexual, pentamerous, actinomorphic. Gamospealous calyx with quincuncial aestivation. Gamopetalous corolla with a distinct tube and contorted aestivation. Five epipetalous stamens inserted in corolla tube, stamens free. Bicarpellary, generally superior ovary, free at base. Single style, capitate or dumb-bell shaped stigma. Fruit of 2 separate follicles (rarely a berry or a capsule). Seeds flat and comose or winged.

- **Asclepiadaceae:** Herbaceous or woody plants with milky latex. Leaves exstipulate, simple, opposite decussate. Inflorescence cymose or racemose. Flowers bracteate and bracteolate, actinomorphic, bisexual. Gynostegium present. Gamosepalous calyx with quincuncial aestivation. Gamopetalous corolla with contorted aestivation. Five epipetalous stamens with anthers either having spoon shaped translators or pollinia. Bicarpellary apocarpou superior ovary. Styles form a part of the gynostegium. Fruit a pair of follicles. Seeds comose.

- **Solanaceae:** Herbs, shrubs or trees with bicollateral vascular bundles in tl stem. Leaves simple, alternate or subopposite and with extra-axillary inflorescence due to congenital fusion of axes. Flowers complete, hypogynous, bisexual. Calyx 5, united, persistent. Corolla 5, gamopetalou with plicate or convolute aestivation. Stamens equal to or less than the number of petals. Bicarpellary syncarpous gynoecium. Carpels obliquely placed. Placentation axile and ovules numerous. Fruit a berry or a capsule with persistent calyx.

- **Acanthaceae:** Herbs or shrubs with cystoliths in the young stems and leaves. Leaves opposite, decussate, entire, exstipulate. Inflorescence dichasial cymes or racemose. Bracts and bracteoles prominent. Flowers bisexual, zygomorphic, with nectariferous disc below the ovary. Corolla generally bilabiate, aestivation imbricate or contorted. Stamens 2 or 4, exserted. Pollen of diverse morphology. Bicarpellary, syncarpous, bilocula ovary with axile placentation, ovules in 2 rows in each locule. Fruit a bilocular capsule. Seeds with retinaculae or jaculators which help in dispersal.

- **Lamiaceae:** Aromatic herbaceous plants. Quadrangular stems. Exstipulate leaves with variously dissected laminae. Verticillaster inflorescence. Calyx persistent. Gamopetalous, usually bilabiate flowers, zygomorphic corolla. Epipetalous stamens usually didynamous or diandrous. Bicarpellary, tetralocular ovary with axile placentation. Gynobasic style. Hypogynous ovary, nectariferous disc present. Fruit of 4 nutlets.

- **Amaranthaceae:** Herbs or shrubs. Stem with anomalous secondary growth Leaves exstipulate, simple and covered with hairs. Inflorescence diverse in organisation and with prickles or tuft of hairs. Flowers small and simple. Perianth homochlamydeous, generally membranous. Stamens as many as tepals with dithecous or monothecous anthers. Syncarpous gynoecium with superior ovary and generally one (sometimes more) ovule on basal placenta. Fruit an utricle or a nutlet or berry-like. Seed with abundant endosperm.

- **Santalaceae:** Semiparasitic, green plants. Leaves simple, exstipulate, alternate or opposite. Flowers small, either solitary or in cymose or racemose inflorescence. Flowers generally bisexual, sometimes unisexual. Nectar secreting disc present. Simple 4- or 5-lobed gamophyllous perianth adnate to the disc. Tufts of hairs present on perianth at the junction of stamens. Stamens 4 or 5, epiphyllous. Syncarpous gynoecium with central placentation. Fruit a nut or a drupe with a single seed. Seed without testa but with white fleshy endosperm.

- **Euphorbiaceae:** Plants with milky latex. Stems with or without spines or thorns. Simple stipulate leaves. Unisexual flowers in diverse forms of inflorescences. Special cyathium inflorescence in the genus *Euphorbia*. Perianth absent, or sepaloid, or heterochlamydeous. Stamens 1-many. Tricarpellary, syncarpous, superior ovary with axile placentation. Fruit generally a tricoccous capsule. Seed with a cruncle.

TERMINAL QUESTIONS

1. Write a brief account on the economic importance of the family Asteraceae.

2. Compare the families Apocyanaceae and Asclepiadaceae. Mention their similarities as well as differences.

3. A flowering twig is given to you whose inflorescence resembles partly to members of Acanthaceae, and in some ways to Lamiaceae. What specific features would you look for to identify its correct family?

4. 'The family Euphorbiaceae demonstrates a high degree of diversity'. Justify this statement.

22.15 ANSWERS

Self-assessment Questions

1. a) iii) Rubiaceae
   b) iii) Rubiaceae

2.

	Genus	Family	Economic Use
i)	*Alstonia*	Apocynaceae	timber
ii)	*Artemisia*	Asteraceae	medicine
iii)	*Carthamus*	Asteraceae	dye
iv)	*Cephaelis*	Rubiaceae	medicine
v)	*Cinchona*	Rubiaceae	medicine
vi)	*Cryptostegia*	Asclepiadaceae	latex
vii)	*Madhuca*	Sapotaceae	edible, medicine, industrial uses
viii)	*Palaquium*	Sapotaceae	medicine, industrial uses
ix)	*Tylophora*	Asclepiadaceae	medicine
x)	*Vinca*	Apocynaceae	medicine

3. a) *Capitulum inflorescence* – a special type of racemose inflorescence having an involucre of bracts. These bracts surround a large number of reduced flowers called florets. The florets are crowded on a receptacle formed by the highly condensed floral axis.
Family : Asteraceae

b) *Gynostegium* – a special structure formed by association of the androecium and gynoecium. The filaments of the stamens unite to form a column. At the top of this column, the anthers which are united laterally form a 5-sided, blunt cone-like structure. This is associated with the style and stigma. This special structure is called the gynostegium.
Family : Asclepiadaceae

c) *Intra-petiolar stipules* – in many plants, the leaves show an opposite arrangement at the nodes. The leaves may be stipulate. When the stipules are present between the leaf petiole and the stem axis, they are described as intra-petiolar stipules.
Family : Rubiaceae

d) *Protogynous flowers* – flowers in which the gynoecium matures first. The tip of the style with the sticky stigma may appear above the corolla even before the corolla opens and expands.
Family : Sapotaceae

4.

	Rubiaceae	Asterceae
i)	Ovary bilocular	Ovary unilocular
ii)	Ovules 1-many in each locule	Ovule only one
iii)	Placentation axile	Placentation basal
iv)	Stigma capitate or lobed	Stigma bifid

(*write any two*)

5. a) i) Family Apocynaceae
ii) Family Asclepiadaceae

b) i) **Bentham & Hooker's classification**
Gamopetalae
Series Bicarpellatae
Order Gentianales
Two distinct families – Apocynaceae and Asclepiadaceae

ii) **Takhtajan's classification**
Subclass – K Lamiidae
Superorder – Gentiananae
Order 163 – Apocynales
A single family Apocynaceae which includes all genera of Asclepiadaceae also.

6. a) i) Subfamily – Cichoroideae or Liguliflorae
ii) Subfamily – Asteroideae or Tubuliflorae

b)

	Cichoroideae	Asteroideae
i)	Milky latex present in plants.	Milky latex absent, and watery sap present.
ii)	All florets in a capitulum bisexual, zygomorphic and ligulate.	Florets in a capitulum bisexual or unisexual, actinomorphic or zygomorphic and tubular or ligulate.

7.

Engler & Prantl	Takhtajan
Sympetalae	Subclass J Asteridae
Order 10 Campanulatae	Superorder Asteranae
Family Asteraceae	Order 160 Asterales
	Family Asteraceae

8. Refer to Section 22.2

9. Refer to Section 22.4.

10.

	Apocynaceae	Asclepiadaceae
i)	Gynostegium absent	Gynostegium present
ii)	Stamens free	Stamens united with gynostegium
iii)	Anthers distinct	Anthers in the form of translators or pollinia

(*any two*)

11. a) Acanthaceae
    b) Solanaceae
    c) Lamiaceae

12.

	Family	Type genus
a)	Acanthaceae	*Acanthus*
b)	Lamiaceae	*Lamium*
c)	Solanaceae	*Solanum*

13. a) Gynobasic style: When the style arises at the base of the ovary and not at the apex.
    Family : Lamiaceae
    b) Jaculator: A jaculator is a hook-like projection of the funiculus. It helps in dispersal of seeds from the fruit.
    Family: Acanthaceae
    c) Obliquely placed carpels: This refers to the orientation of the 2 carpels with reference to the mother axis of the flower. The anterior carpel is placed on the right and the posterior carpel on the left, as seen in the floral diagram of such a flower. The 2 carpels are not placed vertically or horizontally but obliquely.
    Family : Solanaceae

14. Refer to Section 22.9.

15.

Family	Bentham & Hooker	Engler & Prantl	Takhtajan
i) Acanthaceae	Personales	Tubiflorae	Scrophulariales
ii) Lamiaceae	Lamiales	Tubiflorae	Lamiales
iii) Solanaceae	Polemoniales	Tubiflorae	Solanales

16. Refer to Section22.8

17. Refer to Section 22.7

18. Refer to Section 22.9

19.

	Column I		Column II
a)	Caruncle	ii)	Euphorbiaceae
b)	Central placentation	iii)	Santalaceae
c)	Utricle	i)	Amaranthaceae

20.

	Genus	Family	Economic Use
a)	*Celosia*	Amaranthaceae	Ornamental
b)	*Gomphrena*	Amaranthaceae	Ornamental
c)	*Mallotus*	Euphorbiaceae	Dye, timber
d)	*Phyllanthus*	Euphorbiaceae	Edible, medicinal
e)	*Santalum*	Santalaceae	Essential oil, wood for carving

21. a) Euphorbiaceae
    b) Santalaceae
    c) Amaranthaceae

22. Refer to Section 22.12

23. Refer to Section 22.11

24. Refer to Section 22.10

25. i) **Bentham & Hooker**
    Monochlamydeae
    Series III – Unisexuales
    Family – Euphorbiaceae
    ii) **Engler & Prantl**
    Archichlamydeae
    Order 23 – Geraniales
    Family – Euphorbiaceae
    iii) **Takhtajan**
    Subclass – G Dilleniidae
    Superorder – Euphorbianae
    Order 91 – Euphorbiales
    Family – Euphorbiaceae

26. Chenopodiaceae

Terminal Questions

1. Refer to Section 22.3
2. See Sections 22.5 and 22.6
3. Hint: Study the Sections 22.8 and 22.9 and point out their diagnostic features.
4. See Section 22.12

APPENDIX – 22.1 OUTLINE OF CLASSIFICATION OF THE MAGNOLIOPHYTA

Class MAGNOLIOPSIDA

Subclass A. Magnoliidae

SUPERORDER MAGNOLIANAE

Order 1. Magnoliales
- Family *1. Degeneriaceae*
- *2. Himantandraceae*
- *3. Magoliaceae*

Order 2. Winterales
- Family *1. Winteraceae*

Order 3. Canellales
- Family *1. Canellaceae*

Order 4. Illiciales
- Family *1. Illiciaceae*
- *2. Schisandraceae*

Order 5. Austrobaileyales
- Family *1. Austrobaileyaceae*

Order 6. Eupomatiales
- Family *1. Eupomatiaceae*

Order 7. Annonales
- Family *1. Annonaceae*

Order 8. Myristicales
- Family *1. Myristicaceae*

Order 9. Aristolochiales
- Family *1. Aristolochiaceae*

SUPERORDER LACTORIDANAE

Order 10. Lactoridales
- Family *1. Lactoridaceae*

SUPERORDER PIPERANAE

Order 11. Piperales
- Family *1. Saururaceae*
- *2. Piperaceae*
- *3. Peperomiaceae*

SUPERORDER LAURANAE

Order 12. Laurales
- Family *1. Amborellaceae*
- *2. Trimeniaceae*
- *3. Monimiaceae*
- *4. Gomortegaceae*
- *5. Hernandiaceae*
- *6. Lauraceae*

Order 13. Calycanthales
- Family *1. Calycanthaceae*
- *2. Idiospermaceae*

Order 14. Chloranthales
- Family *1. Chloranthaceae*

SUPERORDER RAFFLESIANAE

Order 15. Hydnorales
- Family *1. Hydnoraceae*

Order 16. Rafflesiales (Cytinales)
- Family *1. Apodanthaceae*
- *2. Mitrastemonaceae*
- *3. Rafflesiaceae*
- *4. Cytinaceae*

SUPERORDER BALANOPHORANAE

Order 17. Cynomoriales
- Family *1. Cynomoriaceae*

Order 18. Balanophorales
- Family *1. Mystropetalaceae*
- *2. Dactylanthaceae*
- *3. Lophophytaceae*
- *4. Sarcophytaceae*
- *5. Scybaliaceae*
- *6. Helosidaceae*
- *7. Langsdorffiaceae*
- *8. Balanophoraceae*

Subclass B. Nymphaeidae

SUPERORDER NYMPHAEANAE

Order 19. Hydropeltidales
- Family *1. Hydropeltidaceae*
- *2. Cabombaceae*

Order 20. Nymphaeales
- Family *1. Nupharaceae*
- *2. Nymphaeaceae*
- *3. Barclayaceae*

SUPERORDER CERATOPHYLLANAE

Order 21. Ceratophyllales
- Family *1. Ceratophyllaceae*

Subclass C. Nelumbonidae

SUPERORDER NELUMBONANAE

Order 22. Nelumbonales
- Family *1. Nelumbonaceae*

Subclass D. Ranunculidae

SUPERORDER RANUNCULANAE

Order 23. Lardizabalales
- Family *1. Lardizabalaceae*
- *2. Sargentodoxaceae*

Order 24. Menispermales
- Family *1. Menispermaceae*

Order 25. Berberidales
- Family *1. Nandinaceae*
- *2. Berberidaceae*
- *3. Ranzaniaceae*
- *4. Podophyllaceae*

Order 26. Ranunculales
- Family *1. Ranunculaceae*

Order 27. Circaeasterales
- Family *1. Kingdoniaceae*
- *2. Circaeasteraceae*

Order 28. Hydrastidales
- Family *1. Hydrastidaceae*

Order 29. Glaucidiales
- Family *1. Glaucidiaceae*

Order 30. Paeoniales
Family *1. Paeoniaceae*
Order 31. Papaverales
Family *1. Papaveraceae*
2. Pteridophyllaceae
3. Hypecoaceae
4. Fumariaceae

Subclass E. Caryophyllidae

SUPERORDER CARYOPHYLLANAE
Order 32. Caryophyllales
Family *1. Phytolaccaceae*
2. Gisekiaceae
3. Agdestidaceae
4. Barbeuiaceae
5. Archatocarpaceae
6. Petiveriaceae
7. Nyctaginaceae
8. Aizoaceae
9. Sesuviaceae
10. Tetragoniaceae
11. Stegnospermaceae
12. Portulacaceae
13. Hectorellaceae
14. Basellaceae
15. Halophytaceae
16. Cactaceae
17. Didiereaceae
18. Molluginaceae
19. Caryophyllaceae
20. Amaranthaceae
21. Chenopodiaceae
SUPERORDER GYROSTEMONANE
Order 33. Gyrostemonales
Family *1. Gyrostemonaceae*
SUPERORDER POLYGONANAE
Order 34. Polygonales
Family *1. Polygonaceae*
SUPERORDER PLUMBAGINANAE
Order 35. Plumbaginales
Family *1. Plumbaginaceae*

Subclass F. Hamamelididae

SUPERORDER TROCHODENDRANAE
Order 36. Trochodendrales
Family *1. Trochodendraceae*
2. Tetracentraceae
Order 37. Cercidiphyllales
Family *1. Cercidiphyllaceae*
Order 38. Eupteleales
Family *1. Eupteleaceae*
SUPERORDER MYROTHAMNANAE
Order 39. Myrothamnales
Family *1. Myrothamnaceae*
SUPERORDER HAMAMELIDANAE
Order 40. Hamamelidales
Family *1. Hamamelidaceae*
2. Altingiaceae
3. Platanaceae
SUPERORDER BARBEYANAE
Order 41. Barbeyales
Family *1. Barbeyaceae*
SUPERORDER DAPHNIPHYLLANAE
Order 42. Daphniphyllales
Family *1. Daphniphyllaceae*
Order 43. Balanopales
Family *1. Balanopaceae*
SUPERORDER BUXANAE
Order 44. Didymelales
Family *1. Didymelaceae*
Order 45. Buxales
Family *1. Buxaceae*
Order 46. Simmondsiales
Family *1. Simmondsiaceae*
SUPERORDER FAGANAE
Order 47. Fagales
Family *1. Fagaceae*
2. Nothofagaceae
Order 48. Corylales
Family *1. Betulaceae*
2. Corylaceae
3. Ticodendraceae
SUPERORDER CASUARINANAE
Order 49. Casuarinales
Family *1. Casuarinaceae*
SUPERORDER JUGLANDANAE
Order 50. Myricales
Family *1. Myricaceae*
Order 51. Rhoipteleales
Family *1. Rhoipteleaceae*
Order 52. Juglandales
Family *1. Juglandaceae*

Subclass G. Dilleniidae

SUPERORDER DILLENIANAE
Order 53. Dilleniales
Family *1. Dilleniaceae*
SUPERORDER THEANAE
Order 54. Paracryphiales
Family *1. Paracryphiaceae*
Order 55. Theales
Family *1. Stachyuraceae*
2. Theaceae
3. Asteropeciaceae
4. Pentaphylacaceae
5. Tetrameristaceae
6. Oncothecaceae
7. Marcgraviaceae
8. Caryocaraceae
9. Pellicieraceae
Order 56. Hypericales
Family *1. Bonnetiaceae*
2. Clusiaceae
3. Hypericaceae
Order 57. Physenales
Family *1. Physenaceae*

Order 58. Medusagynales
Family *1. Medusagynaceae*
Order 59. Ochnales
Family *1. Strasburgeriaceae*
2. Ochnaceae
3. Sauvagesiaceae
4. Lophiraceae
5. Quiinaceae
6. Scytopetalaceae
Order 60. Elatinales
Family *1. Elatinaceae*
Order 61. Ancistrocladales
Family *1. Ancistrocladaceae*
Order 62. Dioncophyllales
Family *1. Dioncophyllaceae*
Order 63. Lecythidales
Family *1. Barringtoniaceae*
2. Lecythidaceae
3. Napoleonaeaceae
4. Foetidiaceae
5. Asteranthaceae
SUPERORDER SARRACENIANAE
Order 64. Sarraceniales
Family *1. Sarraceniaceae*
SUPERORDER NEPENTHANAE
Order 65. Nepenthales
Family *1. Nepenthaceae*
Order 66. Droserales
Family *1. Droseraceae*
SUPERORDER ERICANAE
Order 67. Actinidiales
Family *1. Actinidiaceae*
Order 68. Ericales
Family *1. Clethraceae*
2. Cyrillaceae
3. Ericaceae
4. Epacridaceae
5. Empetraceae
Order 69. Diapensiales
Family *1. Diapensiaceae*
Order 70. Bruniales
Family *1. Bruniaceae*
2. Grubbiaceae
Order 71. Geissolomatales
Family *1. Geissolomataceae*
Order 72. Fouquieriales
Family *1. Fouquieriaceae*
SUPERORDER PRIMULANAE
Order 73. Styracales
Family *1. Styracaceae*
2. Symplocaceae
3. Ebenaceae
4. Lissocarpaceae
Order 74. Sapotales
Family *1. Sapotaceae*
Order 75. Myrsinales
Family *1. Myrsinaceae*
2. Theophrastaceae
Order 76. Primulales
Family *1. Primulaceae*
SUPERORDER VIOLANAE
Order 77. Violales
Family *1. Berberidopsidaceae*
2. Aphloiaceae
3. Bembiciaceae
4. Flacourtiaceae
5. Lacistemataceae
6. Peridiscaceae
7. Violaceae
8. Dipentodontaceae
9. Scyphostegiaceae
Order 78. Passiflorales
Family *1. Passifloraceae*
2. Turneraceae
3. Malesherbiaceae
4. Achariaceae
Order 79. Caricales
Family *1. Caricaceae*
Order 80. Salicales
Family *1. Salicaceae*
Order 81. Tamaricales
Family *1. Reaumuriaceae*
2. Tamaricaceae
3. Frankeniaceae
Order 82. Cucurbitales
Family *1. Cucurbitaceae*
Order 83. Begoniales
Family *1. Datiscaceae*
2. Tetramelaceae
3. Begoniaceae
Order 84. Capparales
Family *1. Capparaceae*
2. Pentadiplandraceae
3. Koeberliniaceae
4. Brassicaceae
5. Tovariaceae
6. Resedaceae
Order 85. Moringales
Family *1. Moringaceae*
Order 86. Batales
Family *1. Bataceae*
SUPERORDER MALVANAE
Order 87. Cistales
Family *1. Bixaceae*
2. Cochlospermaceae
3. Cistaceae
Order 88. Elaeocarpales
Family *1. Elaeocarpaceae*
Order 89. Malvales
Family *1. Tiliaceae*
2. Dirachmaceae
3. Monotaceae
4. Dipterocarpaceae
5. Sarcolaenaceae
6. Plagiopteraceae
7. Huaceae
8. Sterculiaceae
9. Diegodendraceae

10. Sphaerosepalaceae
11. Bombacaceae
12. Malvaceae

SUPERORDER URTICANAE

Order 90. Urticales

Family *1. Ulmaceae*
2. Moraceae
3. Cannabaceae
4. Cecropiaceae
5. Urticaceae

SUPERORDER EUPHORBIANAE

Order 91. Euphorbiales

Family *1. Euphorbiaceae*
2. Dichapetalaceae
3. Aextoxicaceae

Order 92. Thymelaeales

Family *1. Gonystylaceae*
2. Thymelaeaceae

Subclass H. Rosidae

SUPERORDER SAXIFRAGANAE

Order 93. Cunoniales

Family *1. Cunoniaceae*
2. Davidsoniaceae
3. Eucryphiaceae
4. Brunelliaceae

Order 94. Saxifragales

Family *1. Tetracarpaeaceae*
2. Penthoraceae
3. Crassulaceae
4. Saxifragaceae
5. Grossulariaceae
6. Pterostemonaceae
7. Iteaceae
8. Eremosynaceae
9. Vahliaceae

Order 95. Cephalotales

Family *1. Cephalotaceae*

Order 96. Greyiales

Family *1. Greyiaceae*

Order 97. Francoales

Family *1. Francoaceae*

Order 98. Haloragales

Family *1. Haloragaceae*

Order 99. Podostemales

Family *1. Podostemaceae*

Order 100. Gunnerales

Family *1. Gunneraceae*

SUPERORDER ROSANAE

Order 101. Rosales

Family *1. Rosaceae*
2. Neuradaceae

Order 102. Crossosomatales

Family *1. Crossosomataceae*

Order 103. Chrysobalanales

Family *1. Chrysobalanaceae*

SUPERORDER RHIZOPHORANAE

Order 104. Anisophylleales

Family *1. Anisophylleaceae*

Order 105. Rhizophorales

Family *1. Rhizophoraceae*

SUPERORDER MYRTANAE

Order 106. Myrtales

Family *1. Alzateaceae*
2. Rhynchocalycaceae
3. Penaeaceae
4. Oliniaceae
5. Combretaceae
6. Crypteroniaceae
7. Memecylaceae
8. Melastomataceae
9. Lythraceae
10. Punicaceae
11. Duabangaceae
12. Sonneratiaceae
13. Onagraceae
14. Trapaceae
15. Psiloxylaceae
16. Heteropyxidaceae
17. Myrtaceae

SUPERORDER FABANAE

Order 107. Fabales

Family *1. Fabaceae*

SUPERORDER RUTANAE

Order 108. Sapindales

Family *1. Staphyleaceae*
2. Tapisciaceae
3. Melianthaceae
4. Sapindaceae
5. Hippocastanaceae
6. Aceraceae
7. Bretschneideraceae
8. Akaniaceae

Order 109. Tropaeolales

Family *1. Tropaeolaceae*

Order 110. Sabiales

Family *1. Sabiaceae*
2. Meliosmaceae

Order 111. Connarales

Family *1. Connaraceae*

Order 112. Rutales

Family *1. Rutaceae*
2. Rhabdodendraceae
3. Cneoraceae
4. Simaroubaceae
5. Surianaceae
6. Irvingiaceae
7. Kirkiaceae
8. Pteroxylaceae
9. Tepuianthaceae
10. Meliaceae

Order 113. Leitneriales

Family *1. Leitneriaceae*

Order 114. Coriariales

Family *1. Coriariaceae*

Order 115. Burserales

Family *1. Burseraceae*
2. Anacardiaceae
3. Podoaceae

SUPERORDER GERANIANAE

Order 116. Linales

Family *1. Hugoniaceae*
2. Linaceae
3. Ctenolophonaceae
4. Ixonanthaceae
5. Humiriaceae
6. Erythroxylaceae

Order 117. Oxalidales

Family *1. Oxalidaceae*
2. Lepidobotryaceae

Order 118. Geraniales

Family *1. Hypseocharitaceae*
2. Vivianiaceae
3. Geraniaceae
4. Ledocarpaceae
5. Rhynchothecaceae

Order 119. Biebersteiniales

Family *1. Biebersteiniaceae*

Order 120. Balsaminales

Family *1. Balsaminaceae*

Order 121. Zygophyllales

Family *1. Zygophyllaceae*
2. Peganaceae
3. Balanitaceae
4. Nitrariaceae
5. Tetradiclidaceae

Order 122. Vochysiales

Family *1. Malpighiaceae*
2. Trigoniaceae
3. Vochysiaceae
4. Tremandraceae
5. Krameriaceae

Order 123. Polygalales

Family *1. Polygalaceae*
2. Xanthophyllaceae
3. Emblingiaceae

SUPERORDER CORYNOCARPANAE

Order 124. Corynocarpales

Family *1. Corynocarpaceae*

SUPERORDER CELASTRANAE

Order 125. Brexiales

Family *1. Ixerbaceae*
2. Brexiaceae
3. Rousseaceae

Order 126. Parnassiales

Family *1. Parnassiaceae*
2. Lepuropetalaceae

Order 127. Celastrales

Family *1. Goupiaceae*
2. Celastraceae
3. Lophopyxidaceae
4. Stackhousiaceae

Order 128. Salvadorales

Family *1. Salvadoraceae*

Order 129. Icacinales

Family *1. Aquifoliaceae*
2. Phellinaceae
3. Icacinaceae
4. Sphenostemonaceae

Order 130. Metteniusales

Family *1. Metteniusaceae*

Order 131. Cardiopteridales

Family *1. Cardiopteridaceae*

SUPERORDER SANTALANAE

Order 132. Medusandrales

Family *1. Medusandraceae*

Order 133. Santalales

Family *1. Olacaceae*
2. Opiliaceae
3. Aptandraceae
4. Octoknemaceae
5. Santalaceae
6. Misodendraceae
7. Loranthaceae
8. Viscaceae
9. Eremolepidaceae

SUPERORDER RHAMNANAE

Order 134. Rhamnales

Family *1. Rhamnaceae*

Order 135. Elaeagnales

Family *1. Elaeagnaceae*

SUPERORDER PROTEANAE

Order 136. Proteales

Family *1. Proteaceae*

SUPERORDER VITANAE

Order 137. Vitales

Family *1. Vitaceae*
2. Leeaceae

Subclass I. Cornidae

SUPERORDER CORNANAE

Order 138. Hydrangeales

Family *1. Escalloniaceae*
2. Hydrangeaceae
3. Abrophyllaceae
4. Argophyllaceae
5. Corokiaceae
6. Alseuosmiaceae
7. Carpodetaceae
8. Phyllonomaceae
9. Pottingeriaceae
10. Tribulaceae
11. Melanophyllaceae
12. Montiniaceae
13. Kaliphoraceae
14. Columelliaceae

Order 139. Desfontainiales

Family *1. Desfontainiaceae*

Order 140. Roridulales

Family *1. Roridulaceae*

Order 141. Cornales

Family *1. Davidiaceae*
2. Nyssaceae
3. Mastixiaceae
4. Curtisiaceae
5. Cornaceae
6. Alangiaceae

Order 142. Garryales
Family *1. Garryaceae*
Order 143. Aucubales
Family *1. Aucubaceae*
Order 144. Griseliniales
Family *1. Griseliniaceae*
Order 145. Eucommiales
Family *1. Eucommiaceae*
Order 146. Aralidiales
Family *1. Aralidiaceae*
Order 147. Toricelliales
Family *1. Toricelliaceae*

SUPERORDER ARALIANAE
Order 148. Helwingiales
Family *1. Helwingiaceae*
Order 149. Araliales
Family *1. Araliaceae*
2. Hydrocotylaceae
3. Apiaceae
Order 150. Pittosporales
Family *1. Pittosporaceae*
Order 151. Byblidales
Family *1. Byblidaceae*

SUPERORDER DIPSACANAE
Order 152. Viburnales
Family *1. Viburnaceae*
Order 153. Adoxales
Family *1. Sambucaceae*
2. Adoxaceae
Order 154. Dipsacales
Family *1. Caprifoliaceae*
2. Valerianaceae
3. Triplostegiaceae
4. Dipsacaceae
5. Morinaceae

Subclass J. Asteridae

SUPERORDER CAMPANULANAE
Order 155. Campanulales
Family *1. Pentaphragmataceae*
2. Sphenocleaceae
3. Campanulaceae
4. Cyphocarpaceae
5. Nemacladaceae
6. Cyphiaceae
7. Lobeliaceae
Order 156. Goodeniales
Family *1. Brunoniaceae*
2. Goodeniaceae
Order 157. Stylidiales
Family *1. Donatiaceae*
2. Stylidiaceae
Order 158. Menyanthales
Family *1. Menyanthaceae*

SUPERORDER ASTERANAE
Order 159. Calycerales
Family *1. Calyceraceae*
Order 160. Asterales
Family *1. Asteraceae*

Subclass K. Lamiidae

SUPERORDER GENTIANANAE
Order 161. Gentianales
Family *1. Gelsemiaceae*
2. Loganiaceae
3. Strychnaceae
4. Antoniacede
5. Spigeliaceae
6. Gentianaceae
7. Saccifoliaceae
8. Geniostomaceae
9. Plocospermataceae
Order 162. Rubiales
Family *1. Dialypetalanthaceae*
2. Rubiaceae
3. Theligonaceae
4. Carlemanniaceae
Order 163. Apocynales
Family *1. Apocynaceae*

SUPERORDER SOLANANAE
Order 164. Solanales
Family *1. Solanaceae*
2. Sclerophylacaceae
3. Duckeodendraceae
4. Goetzeaceae
Order 165. Convolvulales
Family *1. Convolvulaceae*
2. Cuscutaceae
Order 166. Polemoniales
Family *1. Polemoniaceae*
Order 167. Boraginales
Family *1. Hydrophyllaceae*
2. Boraginaceae
3. Tetrachondraceae
4. Hoplestigmataceae
5. Lennoaceae
Order 168. Limnanthales
Family *1. Limnanthaceae*

SUPERORDER LOASANAE
Order 169. Loasales
Family *1. Loasaceae*
Order 170. Oleales
Family *1. Oleaceae*

SUPERORDER LAMIANAE
Order 171. Scrophulariales
Family *1. Baddlejaceae*
2. Retziaceae
3. Stilbaceae
4. Scrophulariaceae
5. Oftiaceae
6. Globulariaceae
7. Gesneriaceae
8. Plantaginaceae
9. Bignoniaceae
10. Pedaliaceae
11. Martyniaceae
12. Trapellaceae
13. Myoporaceae
14. Acanthaceae

15. Lentibulariaceae

Order 172. Lamiales

Family *1. Verbenaceae*
2. Phrymaceae
3. Cyclocheilaceae
4. Symphoremataceae
5. Avicenniaceae
6. Viticaceae
7. Lamiaceae

Order 173. Callitrichales

Family *1. Callitrichaceae*

Order 174. Hydrostachyales

Family *1. Hydrostachyaceae*

Order 175. Hippuridales

Family *1. Hippuridaceae*

Class LILIOPSIDA

Subclass A. Liliidae

SUPERORDER LILIANAE

Order 1. Melanthiales

Family *1. Tofieldiaceae*
2. Melanthiaceae
3. Japonoliriaceae
4. Xerophyllaceae
5. Nartheciaceae
6. Heloniadaceae
7. Chionographidaceae

Order 2. Colchicales

Family *1. Tricyrtidaceae*
2. Burchardiaceae
3. Uvulariaceae
4. Campynemataceae
5. Scoliopaceae
6. Colchicaceae
7. Calochortaceae

Order 3. Trilliales

Family *1. Trilliaceae*

Order 4. Liliales

Family *1. Liliaceae*
2. Medeolaceae

Order 5. Alstroemeriales

Family *1. Alstroemeriaceae*

Order 6. Iridales

Family *1. Geosiridaceae*
2. Iridaceae

Order 7. Tecophilaeales

Family *1. Ixioliriaceae*
2. Lanariaceae
3. Walleriaceae
4. Tecophilaeaceae
5. Cyanastraceae
6. Eriospermaceae

Order 8. Burmanniales

Family *1. Burmanniaceae*
2. Thismiaceae
3. Corsiaceae

Order 9. Hypoxidales

Family *1. Hypoxidaceae*

Order 10. Orchidales

Family *1. Orchidaceae*

Order 11. Amaryllidales

Family *1. Hemerocallidaceae*
2. Hyacinthaceae
3. Alliaceae
4. Hesperocallidaceae
5. Hostaceae
6. Agavaceae
7. Amaryllidaceae

Order 12. Asparagales

Family *1. Convallariaceae*
2. Ophiopogonaceae
3. Ruscaceae
4. Asparagaceae
5. Dracaenaceae
6. Nolinaceae
7. Blandfordiaceae
8. Herreriaceae
9. Phormiaceae
10. Dianellaceae
11. Doryanthaceae
12. Asteliaceae
13. Asphodelaceae
14. Aloaceae
15. Anthericaceae
16. Aphyllanthaceae

Order 13. Xanthorrhoeales

Family *1. Baxteriaceae*
2. Lomandraceae
3. Dasypogonaceae
4. Calectasiaceae
5. Xanthorrhoeaceae

Order 14. Hanguanales

Family *1. Hanguanaceae*

SUPERORDER DIOSCOREANAE

Order 15. Stemonales

Family *1. Stemonaceae*
2. Croomiaceae
3. Pentastemonaceae

Order 16. Smilacales

Family *1. Luzuriagaceae*
2. Philesiaceae
3. Ripogonaceae
4. Smilacaceae
5. Petermanniaceae

Order 17. Dioscoreales

Family *1. Stenomeridacae*
2. Trichopodaceae
3. Avetraceae
4. Dioscoreaceae

Order 18. Taccales

Family *1. Taccaceae*

Subclass B. Commelinidae

SUPERORDER BROMELIANAE

Order 19. Bromeliales

Family *1. Bromeliaceae*

Order 20. Velloziales
Family *1. Velloziaceae*

SUPERORDER PONTEDERIANAE

Order 21. Philydrales
Family *1. Philydraceae*

Order 22. Pontederiales
Family *1. Pontederiaceae*

Order 23. Haemodorales
Family *1. Haemodoraceae*
2. Conostylidaceae

SUPERORDER ZINGIBERANAE

Order 24. Musales
Family *1. Strelitziaceae*
2. Musaceae
3. Heliconiaceae

Order 25. Lowiales
Family *1. Lowiaceae*

Order 26. Zingiberales
Family *1. Zingiberaceae*
2. Costaceae

Order 27. Cannales
Family *1. Cannaceae*
2. Marantaceae

SUPERORDER COMMELINANAE

Order 28. Commelinales
Family *1. Commelinaceae*

Order 29. Mayacales
Family *1. Mayacaceae*

Order 30. Xyridales
Family *1. Xyridaceae*

Order 31. Rapateales
Family *1. Rapateaceae*

Order 32. Eriocaulales
Family *1. Eriocaulaceae*

SUPERORDER HYDATELLANAE

Order 33. Hydatellales
Family *1. Hydatellaceae*

SUPERORDER JUNCANAE

Order 34. Juncales
Family *1. Juncaceae*
2. Thurniaceae

Order 35. Cyperales
Family *1. Cyperaceae*

SUPERORDER POANAE

Order 36. Flagellariales
Family *1. Flagellariaceae*

Order 37. Restionales
Family *1. Joinvilleaceae*
2. Restionaceae
3. Anarthriaceae
4. Ecdeiocoleaceae

Order 38. Centrolepidales
Family *1. Centrolepidaceae*

Order 39. Poales
Family *1. Poaceae*

Subclass C. Arecidae

SUPERORDER ARECANAE

Order 40. Arecales
Family *1. Arecaceae*

Subclass D. Alismatidae

SUPERORDER ALISMATANAE

Order 41. Butomales
Family *1. Butomaceae*

Order 42. Hydrocharitales
Family *1. Hydrocharitaceae*
2. Thalassiaceae

Order 43. Najadales
Family *1. Najadaceae*

Order 44. Alismatales
Family *1. Limnocharitaceae*
2. Alismataceae

Order 45. Aponogetonales
Family *1. Aponogetonaceae*

Order 46. Juncaginales
Family *1. Scheuchzeriaceae*
2. Juncaginaceae
3. Lilaeaceae
4. Maundiaceae

Order 47. Potamogetonales
Family *1. Potamogetonaceae*
2. Ruppiaceae

Order 48. Posidoniales
Family *1. Posidoniaceae*

Order 49. Cymodoceales
Family *1. Zannichelliaceae*
2. Cymodoceaceae

Order 50. Zosterales
Family *1. Zosteraceae*

Subclass E. Triurididae

SUPERORDER TRIURIDANAE

Order 51. Petrosaviales
Family *1. Petrosaviaceae*

Order 52. Triuridales
Family *1. Triuridaceae*

Subclass F. Aridae

SUPERORDER ARANAE

Order 53. Arales
Family *1. Araceae*
2. Pistiaceae
3. Lemnaceae

Order 54. Acorales
Family *1. Acoraceae*

SUPERORDER CYCLANTHANAE

Order 55. Cyclanthales
Family *1. Cyclanthaceae*

SUPERORDER PANDANANAE

Order 56. Pandanales
Family *1. Pandanaceae*

SUPERORDER TYPHANAE

Order 57. Typhales
Family *1. Sparganiaceae*
2. Typhaceae

UNIT 23 MONOCOT FAMILIES

Structure

23.1 Introduction
Objectives
23.2 Musaceae
23.3 Liliaceae
23.4 Arecaceae
23.5 Poaceae
23.6 Summary
23.7 Terminal Questions
23.8 Answers

23.1 INTRODUCTION

The monocotyledons constitute one of the two major groups of angiosperms. They are mostly herbaceous plants. The stems have closed vascular bundles. Due to the absence of vascular cambium, these plants do not exhibit normal secondary growth as observed in the dicotyledons which you have already read in Unit 8 of Block II of Developmental Biology, LSE-06. However, a few monocotyledons are woody and have tree-like stems (e.g., bamboos and palms). The leaves generally have a basal sheath and show parallel venation. The flowers have a characteristic trimerous organisation. The embryo rarely shows differentiation and has a single (hence the name mono) cotyledon. The endosperm is usually abundant.

The monocotyledons are comparatively fewer than the dicotyledons. They are classified into 7 series and 34 families in Bentham and Hooker's classification. In this system, the monocotyledons are classified after the dicotyledons. In contrast to this, they are classified before the dicotyledons in Engler & Prantl's System. A total of 11 orders and 34 families are recognised in this system. Takhtajan in his system of classification (as revised in 1997) has classified the monocotyledons in class Liliopsida. This is placed after class Magnoliopsida (= dicotyledons). The Liliopsida is divided into 6 subclasses, 16 super orders, 57 orders and 131 families.

In this unit you will study about the characters of 4 important monocot families. These are Musaceae, Liliaceae, Arecaceae (Palmae) and Poaceae (Gramineae). This study follows the same pattern as in the case of the dicotyledon families dealt with in units 21 and 22.

Objectives

After studying this unit, you should be able to:

- know about the families Musaceae, Liliaceae, Arecaceae and Poaceae.
- remember the nomenclatural type of each family name.
- know about the size, distribution as well as the number of genera and species of these families found in India.
- understand the morphological diversity in each family.
- list the diagnostic features of each family and recognise the plants in the field.
- classify each family in 3 systems of classification and know its systematic position.
- list the economically important plants and know about their uses.

23.2 MUSACEAE

The Banana family
Nomenclatural Type: *Musa*

General Information

This is a very small family of monocotyledonous plants. There are two views on the number of genera and species in this family. Engler and Prantl classified 6 genera in this family. These are *Musa* (about 80 species including *Ensete*); *Ravenala* (25 species); *Strelitzia* (4 species); *Heliconia* (30 species); *Lowia* (2 species); and *Orchidantha* (2 species).

On the other hand, taxonomists like Takhtajan, Hutchinson and Cronquist recognise only 2 genera – *Musa* (about 60 species) and *Ensete* (about 20 species). The other genera are classified in Strelitziaceae (*Ravenala* and *Strelitzia*); Heliconiaceae (genus *Heliconia*) or Lowiaceae (*Orchidantha* including *Lowia*). This difference in the size of the family Musaceae in different systems of classification is mainly due to the morphological diversity amongst the plants. Therefore, it would be more appropriate to know about this diversity and follow the suggestion of Engler & Prantl.

In this context of the family Musaceae you should remember two terms; **sensu stricto** and **sensu lato**. These were introduced to you in LSE-07, Block 2, Unit 7. Therefore, the following discussion describes the family Musaceae **sensu lato**.

The members of this family are tropical in distribution. They are found in Asia, Africa and South America. However, there is a large-scale cultivation of the economically important genus *Musa* throughout the warmer parts of the world. *Ravenala, Strelitzia* and *Heliconia* are cultivated in parks and gardens as ornamentals.

Field Recognition

Herbaceous perennials with "tree like" pseudostems or woody palm-like plants; leaves large with oblong blade having a distinct sheath, a stout midrib and parallel venation; inflorescence with characteristic spathe-like bracts; flowers zygomorphic and generally unisexual; male flowers usually with five stamens and one staminode; female flowers with tricarpellary gynoecium and inferior ovary.

Morphological Diversity

The plants of the family Musaceae are generally perennial herbs with an underground rhizome. In the largest genus *Musa*, an aerial pseudostem (growing up to a height of 5 meters) is formed. This is actually made up of large stiff leaf sheaths which are rolled around one another. Therefore, it is not a true stem. The true stem is the underground rhizome, the apex of which is present at the base of the pseudostem. The rhizomatous stem grows out through the cylindrical pseudostem to bear the terminal inflorescence. The plants are herbaceous perennials in *Lowia, Orchidantha* and *Strelitzia reginae* (called Bird of Paradise) also. But *Strelitzia nicolai* and *Ravenala madagascariensis* (called Traveller's tree of Madagascar), are tall woody trees with a palm-like appearance.

Leaf: In *Musa*, the leaves are arranged radially in two rows on the rhizome. This pattern of leaf arrangement also occurs in the other herbaceous perennials. In *Musa*, the leaves appear to arise at the apex of the pseudostem (Fig. 23.1). This is due to the fact that the leaf sheaths are rolled around one another and each new leaf pushes up its convolute blade through the pseudostem. The large blade then expands above the older leaves. In the woody plants like *Ravenala*, the leaves are arranged in two rows forming a crowded crown at the apex of the trunk (Fig. 23.2).

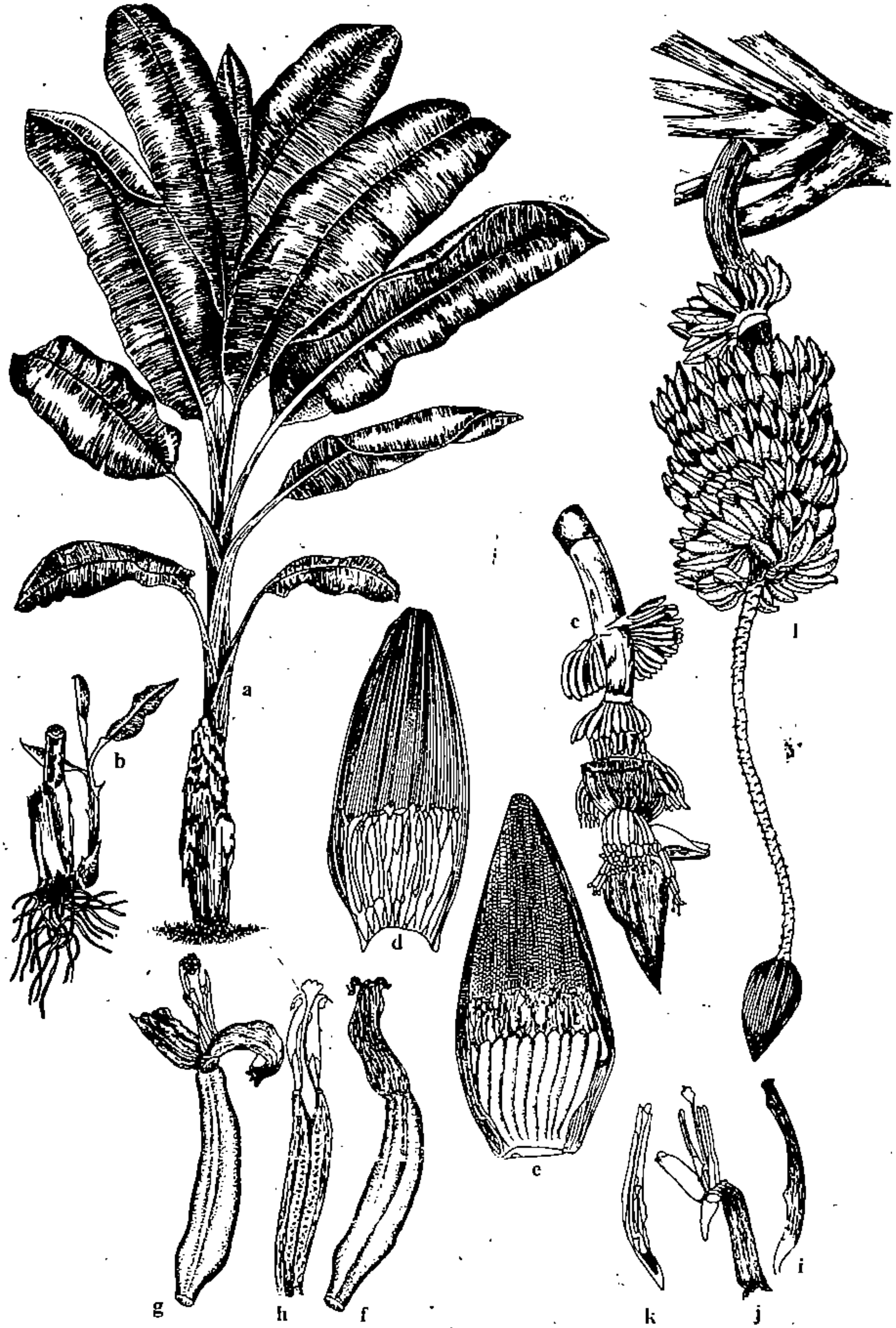

Fig. 23.1: Musa sp. a) Young plant. b) Base of plant with sucker. c) Inflorescence. d) Female flowers and bract. e) Male flowers and bract. f) Female flower. g) Female flower with perianth opened. h) Female flower in longitudinal section. i) Male flower. j) Male flower with perianth opened. k) Male flower in longitudinal section. l) Fruit bunch.

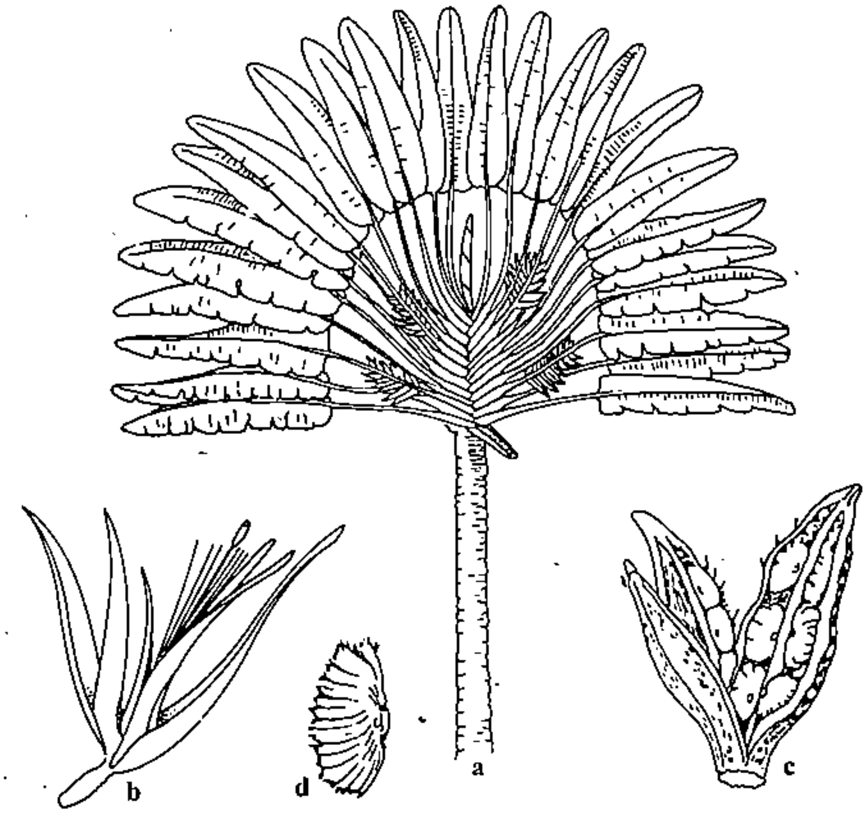

Fig. 23.2: *Ravenala madagascariensis*. a) Plant in flowering stage. b) Open flower. c) Opening capsule. d) Seed with aril.

The leaves are large and consist of a strong sheath which is separated from the oval or oblong blade. The blade has a thick midrib from which numerous parallel veins travel to the margins. There is no anastomosis of the secondary veins (common in dicots), so that the edges of the large blade easily split. Mature leaves are generally torn up to the midrib thus offering very little resistance to wind forces. In *Ravenala madagascariensis* (Traveller's tree), water accumulates in the leaf base. This water has been used for drinking purposes by travellers.

Inflorescence: The inflorescence is terminal in *Musa*: It is a large racemose inflorescence having numerous large bracts. The bracts are spathe-like and brightly coloured. Each bract encloses a large number of unisexual flowers. The flowers towards the apex of the inflorescence are male, while those towards the base are female. Sometimes bisexual flowers may be present in the middle region of the inflorescence. In *Heliconia* (Fig. 23.3) the terminal inflorescence has 2 rows of large bracts. In the axil of each bract, there is a monochasial cyme of the cincinnus type. *Ravenala* and *Strelitzia* have several axilliary inflorescences with large bracts. Each bract has a cincinnus type of monochasial cyme with many (*Ravenala*) or few (*Strelitzia*) flowers. In *Lowia* and *Orchidantha*, the inflorescence is a panicle with large orchid-like flowers.

Flower: The flowers are bracteate, zygomorphic and bisexual in their ontogeny. They become unisexual because either the androecium or the gynoecium does not mature. They are trimerous as in other monocotyledons and they are epigynous. The perianth of the flower consists of two trimerous whorls and the six tepals are generally petaloid. The perianth may also be distinguished into a distinct calyx and corolla. In *Musa*, the 3 outer and 2 inner tepals are united to form a tube, while the sixth is free. They are unequal in size and the inner tepals are smaller and narrower than the outer. In *Ravenala*, the 2 whorls of the perianth show a differentiation into a calyx and corolla. One (median) petal is slightly smaller than all other segments of the perianth. *Strelitzia* has free sepals while 2 lateral petals are united to form a large broadly winged arrow shaped structure which surrounds the stamens. The 3rd or odd petal is very short and broad. In *Lowia* and *Orchidantha* (Fig. 23.4), the sepals are united into a cup-like structure. The two lateral petals are small while the third forms a large spreading labellum. In these genera, the flowers show resupination (this is a change in the orientation of the flower caused by a twist in some portion of the flower axis. This results in the posterior portion of the flower to appear anterior and vice-versa). This is a common feature in the family Orchidaceae.

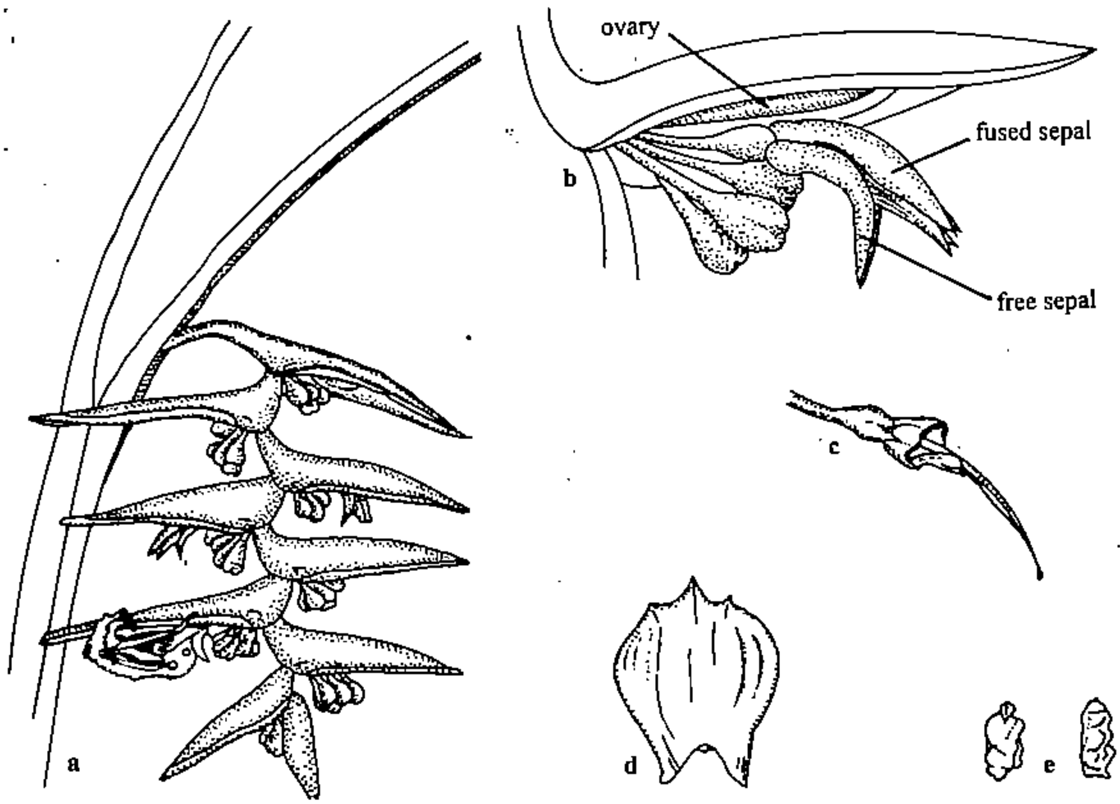

Fig. 23.3: *Heliconia solomonensis.* a) Inflorescence, note pollinating macroglossine bat. b) Cincinnal bract cut away to show flower at anthesis. c) Ovary with style, stigma, and staminode. d) Staminode. e) Pyrenes in ventral and lateral view.

Androecium: There are two trimerous whorls of stamens in each flower. All six stamens are fertile and of equal size in *Ravenala*. In some species of *Musa* (e.g., *M. ensete*), 5 stamens are large and the sixth one and is small, but in all the other genera, only 5 stamens are fertile and the sixth stamen is reduced to a staminode. This staminode becomes petaloid in *Heliconia* and it is completely suppressed in *Lowia* and *Orchidantha*. The anthers are linear, dithecous and show introrse dehiscence. A rudimentary ovary which is generally modified into a nectary is usually present in the male flowers.

Gynoecium: The gynoecium is tricarpellary, syncarpous, with an inferior ovary. The ovary is trilocular and the placentation is axile. There are 1-∞ ovules in each locule. Nectar is secreted in septal glands. The style is simple and the stigma is more or less 3-lobed or capitate. The stamens generally do not develop in the female flowers.

Sometimes in *Musa*, both androecium and gynoecium show normal development and the flowers become bisexual.

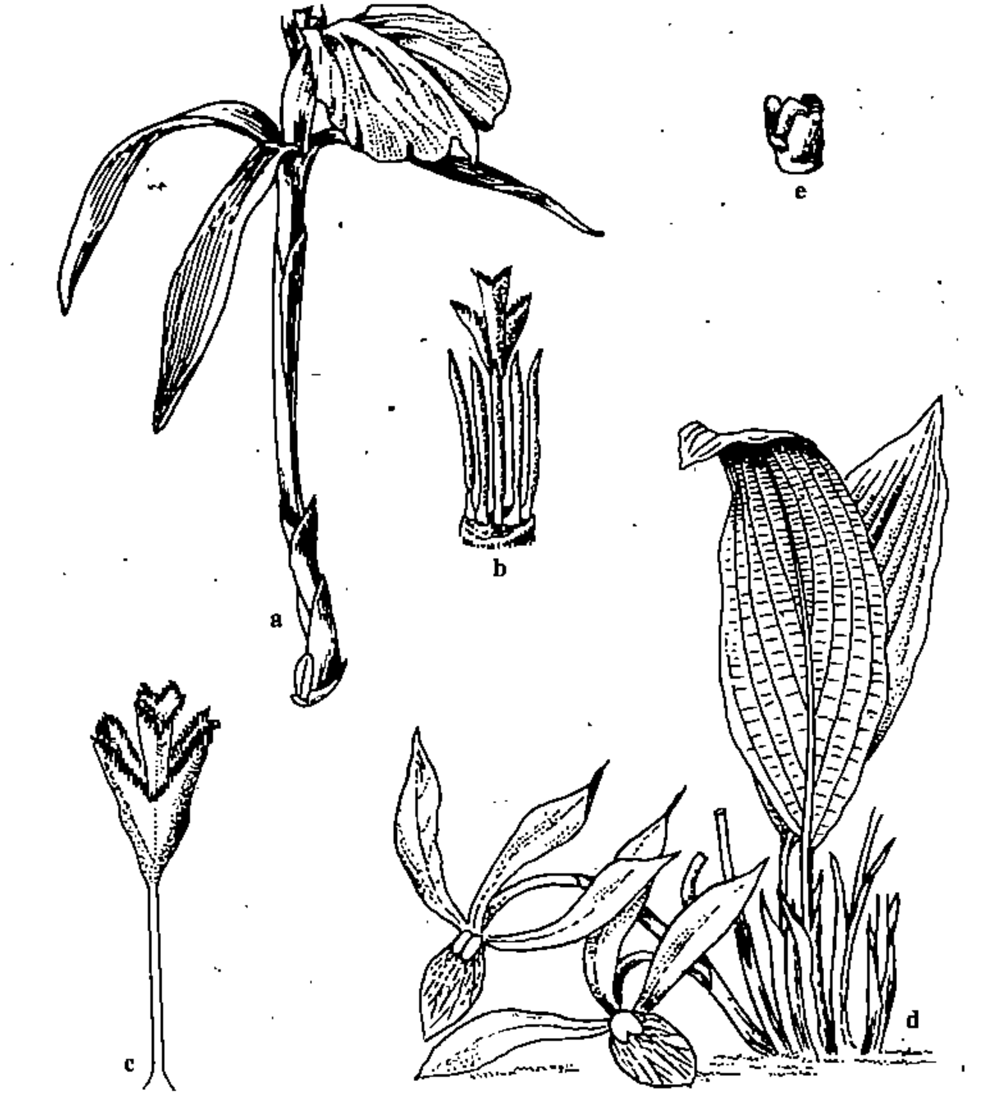

Fig. 23.4: *Orchidantha longiflora.* a) Habit. b) Androecium and stigma, abaxial view. c) Style and stigmatic lobes. d, e) *O. maxillarioides* Flowers and habit. e) Arillate seed:

Fruit: Different kinds of fruit are produced in members of this family. In *Musa*, the fruit is a fleshy berry. In *Heliconia*, it is a schizocarp which opens into 3 one-seeded portions. A capsule develops in *Ravenala*, *Strelitzia*, *Lowia* and *Orchidantha*. This capsule is trilocular and opens loculicidally. In the cultivated edible forms of *Musa*, seeds are not produced. These are mostly triploid hybrids. But in the wild and naturally occurring species of *Musa*, numerous seeds are produced. These seeds are embedded in the fleshy pulp. In *Musa ensete*, the fruit is dry and almost leathery. In *Ravenala*, the seeds are arillate. The aril is shield-like with fimbriate edges and it is brightly coloured. Arillate seeds also occur in *Strelitzia*, *Lowia* and *Orchidantha*. In *Heliconia* no aril is produced. The seeds have a hard and thick testa and a straight embryo. A nutritive tissue called perisperm is present. This is made up of a part of the nucellus, containing reserve food material, and the endosperm. It is used by the embryo at the time of germination.

Diagnostic Features of the Family

1. Monocotyledonous plants.
2. Herbaceous perennials with tree-like pseudostems or woody palm-like plants.
3. Leaves large with a strong sheath, oblong blade, a stout midrib and parallel venation.

4. Inflorescence with characteristic spathe-like bracts.
5. Flowers zygomorphic and generally unisexual.
6. Stamens generally 5.
7. Tricarpellary gynoecium with inferior ovary.
8. Placentation axile.
9. Fruit a berry or a capsule.
10. Seeds with hard thick testa with or without an aril.
11. Perisperm present.

Systematic Position

The family *Musaceae* is not recognised as a separate family in Bentham and Hooker's classification. This group of plants is classified as a tribe Musaeae in the Scifamineae and this is classified in series II Epigynae. In Engler & Prantl's classification, the family Musaceae is recognised as a distinct family. It is classified in Order Scitamineae. There are 3 other families in this order, e.g., Zingiberaceae, Cannaceae, and Marantaceae. In this classification, the family Musaceae contains 6 genera. Interestingly these six genera alongwith plants of the families Zingiberaceae, Cannaceae and Marantaceae were earlier classified together in Scitamineae by Bentham & Hooker.

In Takhtajan's classification, the family Musaceae is classified in subclass - Commelinidae, super order Zingiberanae, and Order Musales (also called Zingiberales). There are 3 families in this order: i) Strelitziaceae (having *Strelitzia* and *Ravenala*); ii) Musaceae (having *Musa* and *Ensete* as 2 distinct genera); and iii) Heliconiaceae (monogeneric with *Heliconia* only). Lowiaceae (having *Lowia* with which *Orchidantha* has been merged) is classified in order Lowidales. Zingiberaceae and Costaceae are classified in order Zingiberales. Cannaceae and Marantaceae are now classified in order Cannales. Interestingly, *Ensete* separated out as a distinct genus by Takhtajan was included in the genus *Musa* by earlier taxonomists.

The description given above is for the family Musaceae as recognised by Engler and Prantl in its wide concept (as Musaceae **sensu lato**) and not in its restricted concept (as Musaceae **sensu stricto**).

Economic Importance

1. The largest genus *Musa* is the most important genus of this family. Many cultivated plants of this genus are important for the edible fruits, called the bananas and the plantains. There are two views on the difference between the bananas and the plantains. According to "The Flora of Hasan District, Karnataka, India" edited by C.J. Saldathha and D.H. Nicolson (Amerinsd Publishing Co. Pvt. Ltd., 1976) "In S. India, the starchy cooking *Musa* is called "banana"; and the sweet dessert type is called "plantain". On the other hand, S.L. Kochhar in his book "Economic Botany in the Tropics" (Macmillan India Ltd., 1981, 1998) writes that "....for the sake of convenience, the cultivated bananas are broadly classified in two groups; the dessert varieties and the cooking varieties. The fruits eaten as a dessert, without any cooking are called "bananas", while the more starchy types with a less pleasant flavour and that need cooking before they can be consumed as a vegetable are called "plantains". From these two contrasting views, we only conclude that there are different types of fruits. Some are sweet (having more sugar) and can be eaten raw, while others are starchy and have to be cooked before they are eaten.

   The cultivated bananas and plantains are the most widely grown of all tropical fruits. There are hundreds of varieties, which differ in size, colour and taste of the fruit. The vast majority of these cultivated varieties are hybrids. They are mostly triploids and therefore, seeds do not develop. The mature fruits are consumed in various ways.

2. Besides the edible fruits, the genus *Musa* is also important for fibre. *Musa textilis* is cultivated for the "Manila hemp" or "Abaca fibre" which is obtained from the leaf sheaths which form the pseudostem. This is a very strong fibre and is used for marine ropes, twine and wrapping paper.

3. The stem of the cultivated bananas is also edible and is cooked as a vegetable. The leaves are used as plates and food is served on these leaves at many religious ceremonies.

4. Several species of *Musa* are cultivated as ornamentals. *Ravenala* is a beautiful palm-like plant. It is cultivated in gardens and parks for its symmetrical appearance. *Strelitzia* has a very beautiful inflorescence with attractive brightly coloured spathe. *Ensete superbum*, *Heliconia metallica*, and *Musa nepalensis* are also cultivated as ornamentals.

Points to Remember

23.3 LILIACEAE

The Lily family
Nomenclatural Type: *Lilium*.

General Information

The family Liliaceae includes about 260 genera and 4000 species. These are world wide in distribution. Some members are found in the north temperate regions. They commonly occur in the Himalayan region, in Scotland and northern England, in North West Europe, in North America and in Japan. There are also genera which are restricted in distribution or are endemic to South America and Australia. Some genera show wider distribution, occurring in tropical, subtropical and temperate regions of both hemispheres. A few are found in the warmer parts of the Old World. In India, there are about 35 genera and 230 species of this family. They are found mainly in the Himalayan region, but there are some well known and very familiar members which are found throughout the country.

In Bentham & Hooker's as well as Engler & Prantl's classification, this large family is divided into as many as 11 sub families. In other systems of classification, the number of subfamilies is even larger. On the other hand, in Takhtajan's classification, many of the subfamilies are treated as separate families which are classified in different orders.

Interestingly, the family Amaryllidaceae is quite similar in its characters with Liliaceae but differs in having an inferior ovary. They are classified as two separate families by most taxonomists. But the American taxonomist, Cronquist merged these two families and called it the Liliaceae. He did not give importance to the position of the ovary.

There is thus diverse opinion about the family Liliaceae. In the following discussion, the suggestion of Bentham and Hooker and Engler & Prantl will be followed to know about the diversity in the family Liliaceae.

Field Recognition

Rhizomatous or bulbous herbs; or shrubs or tree-like woody plants; or woody climbers; or typical xerophytes; branches may be modified into flat-leaf-like cladodes; leaves simple; or reduced to scales or spines; or fleshy with water storing tissue and thick cuticle; inflorescence of solitary terminal flowers, or a simple to branched raceme; or monochasial cymes which may be crowded into umbel-like heads; flowers bisexual, actinomorphic, typically trimerous hypogynous.

Morphological Diversity

The plants of the family Liliaceae show diversity in their morphology. The majority of the members of this family are herbaceous perennials. They may have a sympodial rhizome (*Polygonatum*), monopodial rhizome (*Paris*) or a bulb (e.g., *Lilium*, *Trillium*, *Allium*, *Tulipa*) as the perennating organ. Aerial leafy stems arise from the rhizome. In the bulbous forms, the main aerial stem grows out and it may or may not bear leaves. This generally terminates in an inflorescence. After the development of the aerial stem, new bulbs are formed in the axils of the bulb scales for perennation. Sometimes a corm is formed (e.g., *Colchicum*) at the base of the main axis. This modified stem persists in the soil even after the development of leaves and flowers.

Some members of this family are woody plants. They may have a tree-like habit (e.g., *Dracaena*) with anamolous secondary growth. The stem increases in thickness by the formation of concentric rings of vascular bundles in the ground tissue. *Yucca* is a large shrub or tree-like with a short and thick aerial stem. Typical xerophytic plants of the succulent type are common in the genus *Aloë*. Some species of this genus also show an arborescent habit. In *Yucca* and *Aloë* also, there is anamolous secondary growth as in *Dracaena*.

A much branched aerial stem with modified branches can be observed in *Ruscus* and *Asparagus*. *Ruscus* is shrub-like with the ultimate branches in the form of leaf-like structures called phylloclades. In *Asparagus*, an underground rhizome produces slender herbaceous or woody aerial branches. These may be erect or climbing and the ultimate branchlets are needle-like or narrow flattened cladodes. In *Smilax*, the plants are woody and climbing shrubs.

Leaf: The leaves show diverse morphological forms and patterns of arrangement. In some plants, very few leaves are produced. They are generally basal and may be produced before or after flowering. In the bulbous herbs, the leaves may form a basal rosette and the main aerial stem may or may not bear leaves. If this is leafy, then the leaves are alternate. The rhizomatous perennials have aerial stems which bear alternate leaves. In *Dracaena* the leaves are either in a rossette or in two rows on the woody stem. *Aloë* has large thick fleshy leaves which store water. The climbing *Smilax* has broad dicot-like alternatively arranged leaves. A pair of tendrils is present at the base of each leaf helping the *Smilax* plant to climb. *Gloriosa*, which is also a climbing plant has opposite leaves. It does not have tendrils at the base as in *Smilax*. However, the leaf apex is produced into a tendril-like appendage which helps the plant to climb.

The leaves are arranged in whorls in *Paris* (Fig. 23.5), *Trillium* and other genera. In *Asparagus* and *Ruscus* (Fig. 23.5), the leaves are reduced to scales or spines. Here, the modified branches (cladodes or phylloclades) serve the plant as photosynthetic organs. In general, the leaves are exstipulate, simple, linear and have parallel venation. In *Dracaena*, the leaves are thick and leathery. In *Smilax* the broad coriaceous leaves show reticulate venation (Fig. 23.6).

In some plants, bulbils are formed in the axils of the leaves. These specialised bulbs serve as organs of vegetative reproduction.

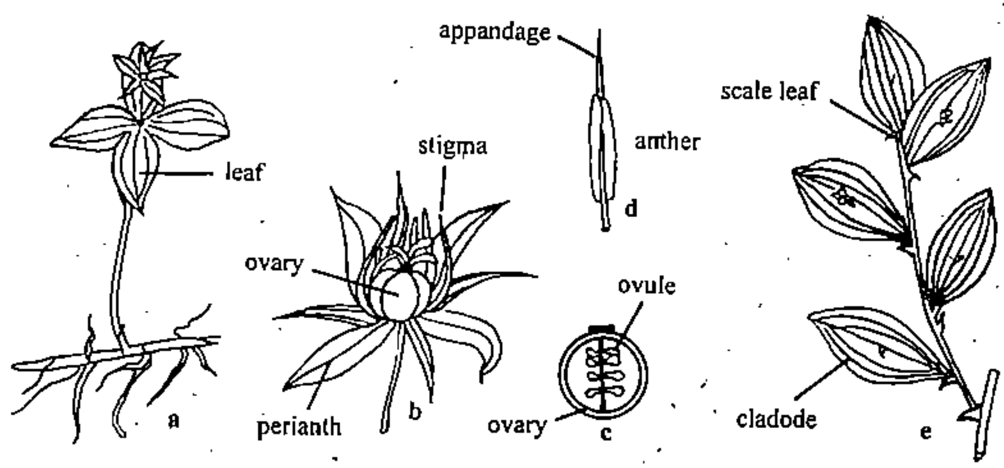

Fig. 23.5: *Paris quadrifolia* (a-d) a) Flowering plant. b) Flower. c) Ovary, longisection. d) Anther. e) Twig of *Ruscus* (*Ruscus aculeata*).

Fig. 23.6: Flowering branch of *Smilax zeylanica*.

Inflorescence: The most common type of inflorescence is racemose (Fig. 23.7). It may be a simple raceme or a panicle produced at the apical end of the aerial shoots. Sometimes the inflorescence is reduced to a solitary terminal flower (e.g., *Tulipa, Lilium*). The solitary flower may be axillary also (e.g., *Gloriosa*). Sometimes the inflorescence may be cymose. In *Hemerocallis*, it is a monochasial cyme. Several such monochasial cymes with short internodes are crowded together to form an umbel-like or head-like complex inflorescence in *Allium* (Fig. 23.8), *Agapanthus* and other genera.

Flower: The flowers are bracteate but generally without bracteoles. Sometimes (e.g., *Lilium*) a single bracteole may develop. The flowers are bisexual, actinomorphic, usually trimerous and hypogynous. Unisexual flowers develop in *Smilax* and *Ruscus*. The flowers may be tetramerous in some genera.

The flowers are large, showy and fragrant attracting insect pollinators. Besides these general features, some genera also have special adaptations to ensure insect pollination. Nectar is secreted in septal glands between the carpels ensuring that insects come in contact with stigma and anthers. Alternatively, the flowers may exhibit protandry so that the anthers dehisce first and this is followed by the lengthening of the style and development of stigmatic papillae.

Fig. 23.7: *Asphodelus tenuifolius*. a) Plant. b) Flower. c) Capsule with stalk. d) Seed.

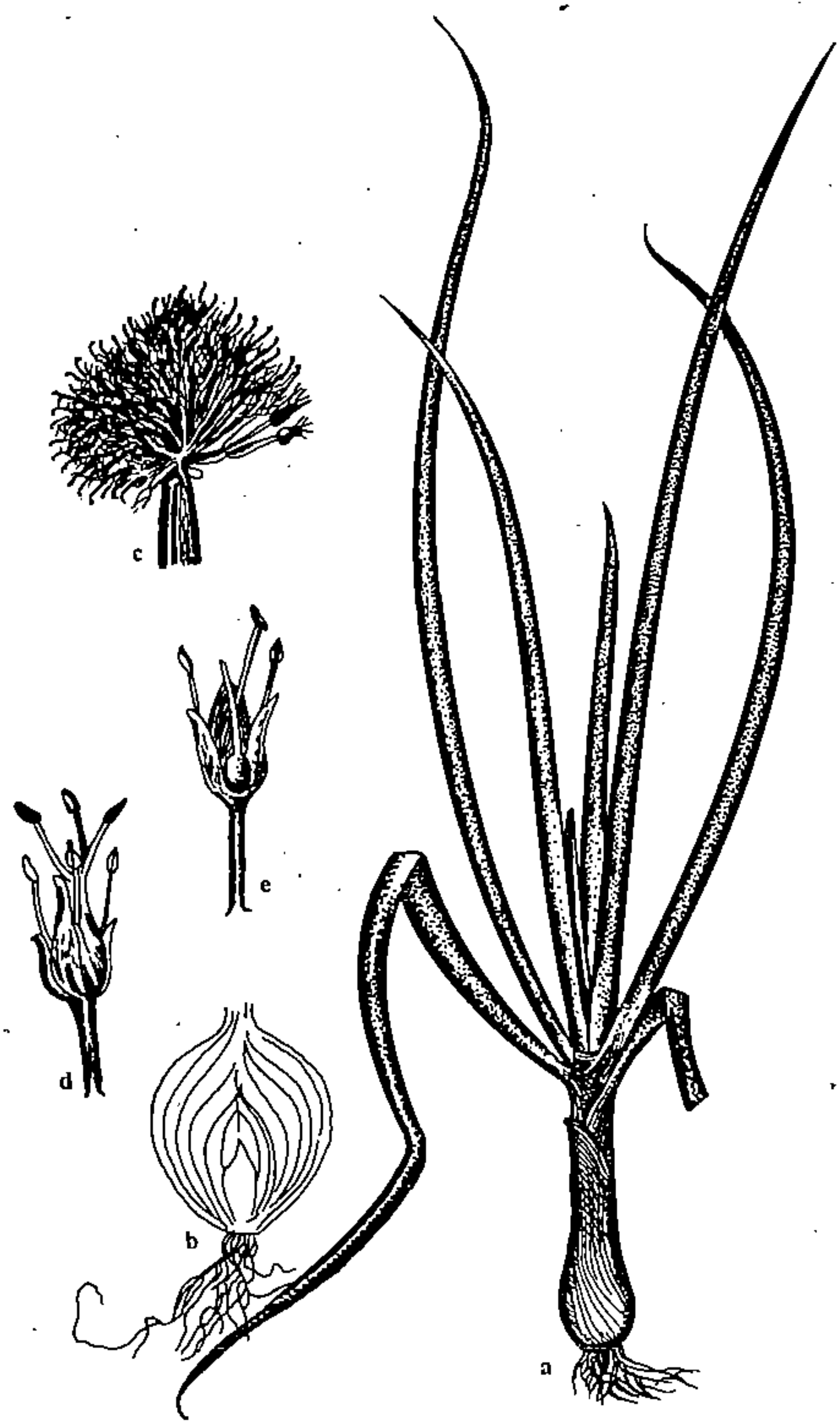

Fig. 23.8: *Allium cepa*. a) Whole plant with bulb. b) L.S. bulb. c) Inflorescence. d) Single flower. e) Flower with part removed.

The most advanced type of adaptation is seen in *Yucca* (Fig. 23.9) where the stigmas are far above the anthers to allow self pollination. The pollination of these flowers is closely associated with the life cycle of a moth called *Pronuba yuccasella*. The flower provides the insect protection to its eggs which are laid in the ovary just below each ovule. In return, the insect pollinates the flower. The development of the insect larvae and the seeds proceeds together. The larvae consume some of the developing seeds and come out through the pericarp to remain dormant as a cocoon in the soil. The adult moth emerges from the cocoon only when the plant flowers again to repeat the life-cycle.

The perianth of the flower has two trimerous whorls. They are usually petaloid or, rarely, the outer whorl is sepaloid. They are free or united and show imbricate or valvate aestivation.

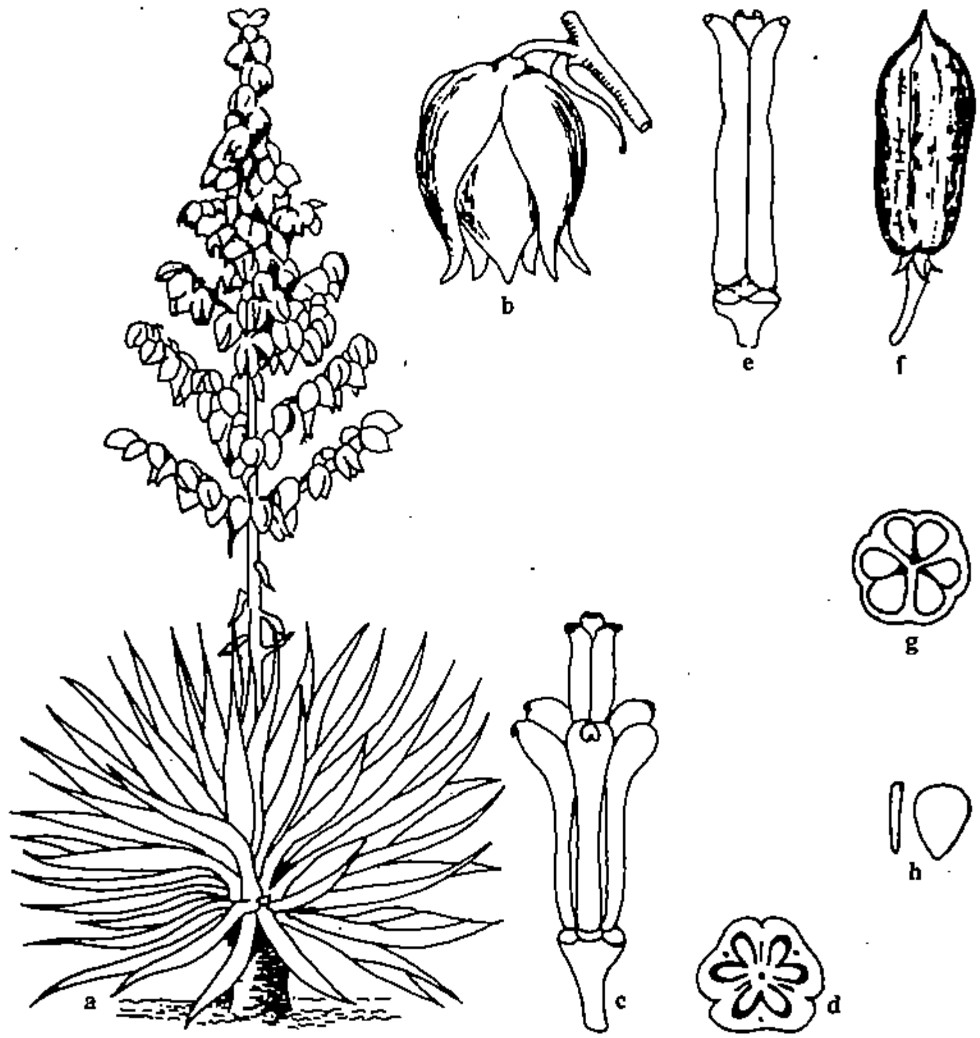

Fig. 23.9: *Yucca gloriosa*. a) Plant (much reduced). b) Flower. c) Stamens and pistil. d) Transverse section of ovary showing septal glands between the three chambers. e) Pistil. f) Fruit. g) T.S. of fruit, which has become six chambered by ingrow of middle wall of each carpel. h) Seeds, edge and surface views.

Androecium: There are generally 6 stamens in two trimerous whorls. Sometimes only 3 are fertile (e.g., *Ruscus*), and the other 3 are sterile. They may be reduced to staminodes or they may be absent. Rarely the number of stamens may be more than 6. The stamens are free or variously connate and are opposite the tepals. The anthers are basifixed and dithecous. They usually show introrse dehiscence.

Gynoecium: The gynoecium is tricarpellary, syncarpous and with a superior ovary. The ovary is trilocular and shows axile placentation. Sometimes the ovary is monolocular and has parietal placentation. The ovules are numerous and are generally present in two rows in each locule.

Nectaries are present in septal glands on the carpellary walls. There is a single style with a 3 [illegible] d or with 3 distinct stigmas.

Fruit: The fruit is usually a trilocular capsule with loculicidal or septicidal dehiscence. Sometimes it is a large berry (e.g., *Smilax, Pogonatum, Asparagus*). The seeds are large and numerous. They have a straight or curved embryo with abundant fleshy or cartilaginous endosperm.

Diagnostic Features of the Family

1. Plants mostly rhizomatous or bulbous herbs, sometimes woody or typical xerophytes.
2. Leaves simple, generally alternate, exstipulate and have parallel venation; sometimes reduced to scales or spines.
3. Inflorescence racemose or cymose or a solitary flower.
4. Flowers ebracteate, bisexual, actinomorphic, hypogynous and trimerous.
5. Flowers scented and with nectar.
6. Perianth in 2 whorls, generally petaloid.
7. Androecium in 2 whorls, one whorl sometimes sterile or reduced to staminodes, rarely absent; anthers basifixed, dithecous, introrse.
8. Gynoecium tricarpellary, syncarpous, ovary superior, placentation axile, ovules numerous.
9. Fruit a capsule or sometimes a berry.
10. Seeds large with abundant endosperm.

Systematic Position

The family Liliaceae is classified by Bentham & Hooker in Series Coronarieae. This series has 7 other families. The family Amaryllidaceae (which has many morphological characters similar to Liliaceae) is classified separately in Epigynae. In Engler & Prantl's classification, Liliaceae is classified in the monocotyledon order – Liliflorae. There are 9 families in this order including Amaryllidaceae.

In both these systems of classification, the large family Liliaceae is divided into 11 sub families. Also, in both systems, Liliaceae is separated from Amaryllidaceae.

Takhtajan in his system of classification has re-organised the classification of this group of plants. As many as 8 subfamilies recognised in the earlier two systems of classification have been recognised as distinct families.

Interestingly, these families are classified in a different orders of subclass A Liliiae. The family Liliaceae is also classified in this subclass and in super order Lilianae. It is classified in order Liliales while the family Amaryllidaceae is classified in order Amaryllidales. Thus, Takhtajan has followed Bentham & Hooker as well as Engler & Prantl in separating Liliaceae from Amaryllidaceae

Allium sativa – Garlic. This is also widely cultivated and the specialised fleshy leaves are called "garlic cloves". These are used as a condiment for flavouring food. It is also used medicinally.

Asparagus officinalis – The young shoots and fleshy roots are eaten as a vegetable or consumed in soups.

2. **Medicinal Plants**

A large number of plants of the Liliaceae are used in different medicines. These include *Aloe vera, A. racemosus, Urginea indica, Scilla hyacinthiana, Yucca gloriosa, Gloriosa superba, Hemerocallis fulva* and *Smilax* species. *Colchium autumnale* yields an alkaloid colchicine which is used by cytogenetists to induce polyploidy.

3. **Fibres**

Fibres are obtained from *Phormium tenax, Sansevieria* species, *Yucca filamentosa.*

4. **Resin**

Xanthorrhoea and Dracaena yield resin which is used in making varnish and sealing wax. *Iphigenia indica* yields a red dye from the flowers.

5. **Ornamentals**

A large number of plants of this family are cultivated as ornamentals. The more well-known include species of: *Agapanthus, Asparagus, Convallaria, Dracaena, Fritillaria, Gloriosa, Hemerocallis, Lilium, Ruscus, Tulipa and Yucca.*

Points to Remember

23.4 ARECACEAE OR PALMAE

The Palm family
Nomenclatural Type: ***Areca.***

General Information

This distinctive family provides one of the tallest palm trees (*Ceroxylon* – 60 meters), the largest woody climber (*Calamus* up to 200 meters), the largest leaf (*Raphia* – 15 meters), one of the largest inflorescence (*Corypha* – 7 meters), and the largest seed (*Lodoicea*) in the plant kingdom.

Corypha gigantic inflorescence terminates the life of trees.

The palms form a characteristic feature of tropical vegetation. They are wide spread in tropical and subtropical regions. This family has about 200 genera and 3000 species occurring in Asia, Africa and tropical America. The palms may be conspicuous along coastlines or on oceanic islands. Some are well-known in cultivation. In India, there are about 28 genera and 90 species. The most common ones are coconut palm, date palm, betel nut palm, toddy palm.

Field Recognition

The palms are large woody plants (Fig. 23.10); the stems are mostly unbranched and columnar, rarely the stem may be reduced or it is thin and reed-like; the stem is generally covered with remains of old leaf sheaths, or it is thorny; the large leaves are characteristic with either a palmate (fan-like) or pinnate (feather-like) shape; the leaves are present as a crown at the apex of the stem. The large paniculate inflorescence subtended by a spathe; flowers are small and unisexual, the fruit is a berry or a drupe.

Morphological Diversity

The majority of the palms are large trees with a tall woody stem. This cylindrical stem grows erect and its diameter varies in different species. A single stem may attain a height up to 60 meters (e.g., *Ceroxylon*). Interestingly, there is no secondary growth, but sometimes there is an increase in the diameter of older stems. This increase is brought about in two ways; (a) There is an expansion of parenchymatous tissue in which the vascular bundles are present; (b) There is an increase in the cell cavity and wall thickness of the sclerenchyma fibres supporting the vascular bundles. The primary root is short-lived and adventitious roots develop near the base of the stem. Several kinds of aerial roots i.e. stilt or prop root, spine root, and pneumatophores are found in family. These support the tall columnar stem.

Sometimes the stem is very short (e.g., *Phoenix acaulis*, *Phytelephas macrocarpa*) or the plant may have a bushy habit. This is due to the formation of numerous erect stems from horizontal suckers near the base of the main stem. In *Calamus* (Rattan or Cane), the stems are long, slender, and climb on surrounding vegetation. A single climbing stem may attain a length of about 200 meters.

Fig. 23.10: Growth forms. a) *Roystonea regia*, large tree palm with well-defined crownshaft. b) *Washingtonia filifera*, stem partially covered with persistent marcent leaves. c) *Dypsis lutescens*, caespitose habit. d) *Calamus* sp., climber with cirrate leaves.

Most palms are unbranched. Branching which is rare is observed in *Hyphaene thebaica* (doum palm). Here the axillary bud grows into a branch like the main stem. Sometimes branching may occur due to injury of the terminal bud (e.g., *Phoenix sylvestris* or wild date palm) (Fig. 23.11).

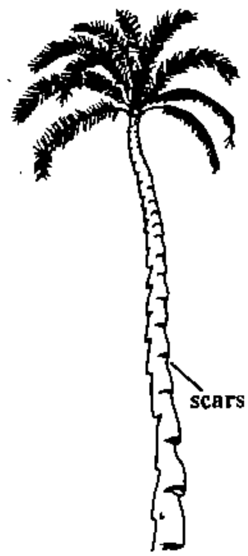

Fig. 23.11: *Phoenix sylvestris*, stem with scars from incisions on the leaf sheaths for drawing sugary sap.

Leaf: The leaf is the most characteristic feature of the palms. There are a few leaves generally forming a crown at the apex of the stem. They are often very large (e.g., A single leaf may be 15 meters long in *Raphia farinifera*). Two types of leaves can be easily recognised in palms. Some palms have palmate (fan-shaped) leaves while others have pinnate (feather-shaped) leaves. At the base of the leaf is a sheath which firmly fixes the leaf to the stem. The sheath has many bundles of fibres forming a dense mat around the younger leaves. These may persist after the decay of the softer tissues. In *Calamus*, the sheath is a stipule-like structure called ochrea.

Fan palms have palmate leaves.

Feather palms have pinnate leaves

A stout axis continues as the main axis of the large leaf. The lamina is entire or dissected. In the fan palm, the lamina is entire in the bud and it is folded. As it opens and expands, the lamina may get torn along the folds to a greater or lesser degree. The folding of the lamina and tearing of the pinnae are also observed in the feather palms.

The leaves show xerophytic characters. There is a thick glossy cuticle. As the leaf emerges, it is almost vertical to escape excessive radiation and transpiration. The leaf is rarely arranged perpendicular to the incident rays of light.

The petiole, leaves and stems may have thorns or recurved spikes.

Inflorescence: A few palms are monocarpic, where a single large terminal inflorescence is produced after many years of vegetative growth. In *Corypha umbraculifera* (Talipot palm) the inflorescence is about 7 meters long. After the fruits are formed, the plant dies. Other palms have axillary inflorescences which are produced at regular intervals. In these palms, the plants do not die after flowering and fruiting.

The entire inflorescence may be enclosed in a large spathe or each branch of the large inflorescence may have a spathe. The inflorescence may be a simple or a compound spike or a large panicle. The numerous flowers are sessile or sometimes embedded in the fleshy axis. In such cases the inflorescence is called a spadix (e.g., male inflorescence of *Borassus*). Both male and female flowers may be present on the same inflorescence. Generally, there are few female flowers towards the base of the inflorescence and numerous male flowers towards the apex. Sometimes the plants are dioecious (e.g., *Phoenix dactylifera* or date palm, *Borassus flabellifer* or palmyra palm). The inflorescence has a sweet smell (Fig. 23.12).

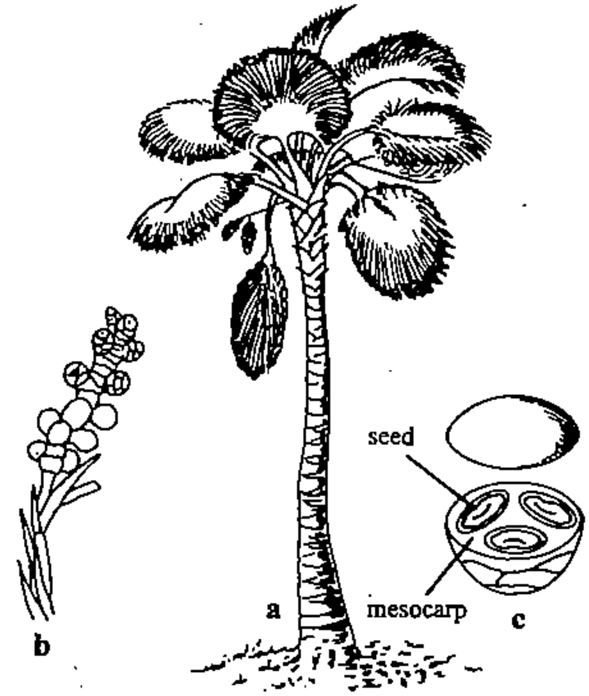

Fig. 23.12: *Borassus flabelliformis*. a) Habit. b) Female inflorescence. c) Fruit cut transversely.

Flower: The flowers are small in comparison to the large inflorescence. They are typically trimerous, actinomorphic, unisexual (rarely bisexual) and hypogynous. The perianth of the flower has 2 trimerous whorls which are similar to each other. The outer whorl is generally smaller than the inner. Each tepal is tough, leathery or fleshy. It is green to yellow or whitish and persistent. The aestivation is imbricate or valvate in the outer whorl. The inner whorl is valvate in the male flowers and imbricate in the female flowers.

There are generally six stamens, but sometimes there are only 3 in one whorl. Rarely, there are numerous stamens in a single flower. Filaments are free and short. The anthers are dithecous and show introrse dehiscence. Large amounts of pollen are produced and many palms are wind-pollinated.

Gynoecium: The gynoecium is tricarpellary. It may be apocarpous (e.g., *Phoenix*) or syncarpous (e.g., *Borassus*, *Areca*). The ovary is superior and trilocular or unilocular. The placentation may be axile (trilocular) or parietal (unilocular). When the gynoecium is apocarpous, each carpel has a single ovule on basal placenta. Sometimes 2 of the 3 carpels with their ovules abort during development of the fruit, so that the mature fruit contains only one seed (e.g., *Cocos nucifera* or coconut). The style is generally absent and there are 3 sessile stigmas.

Fruit: The fruit is a fleshy berry (e.g., *Phoenix dactylifera*) or a fibrous drupe (e.g., *Cocos nucifera*) (Fig. 23.13). The fleshy pericarp of the fruit in the date palm contains sugar and encloses a single cylindrical seed. In the fibrous drupe, the mesocarp is made up of bundles of small fibres while the endocarp is hard and woody. In some palms (e.g., *Calamus*, *Metroxylon* or Sago palm) the exocarp is covered with dry woody scales. The fruit varies greatly in size in different palms. The seed also shows diversity in shape and size corresponding with the fruit, e.g., in *Lodoicea maldivica* (double coconut or coco-de-mer) the fruit requires about 5 years to mature and contains a single large bilobed seed. Each fruit may weigh 13-22 kgs.

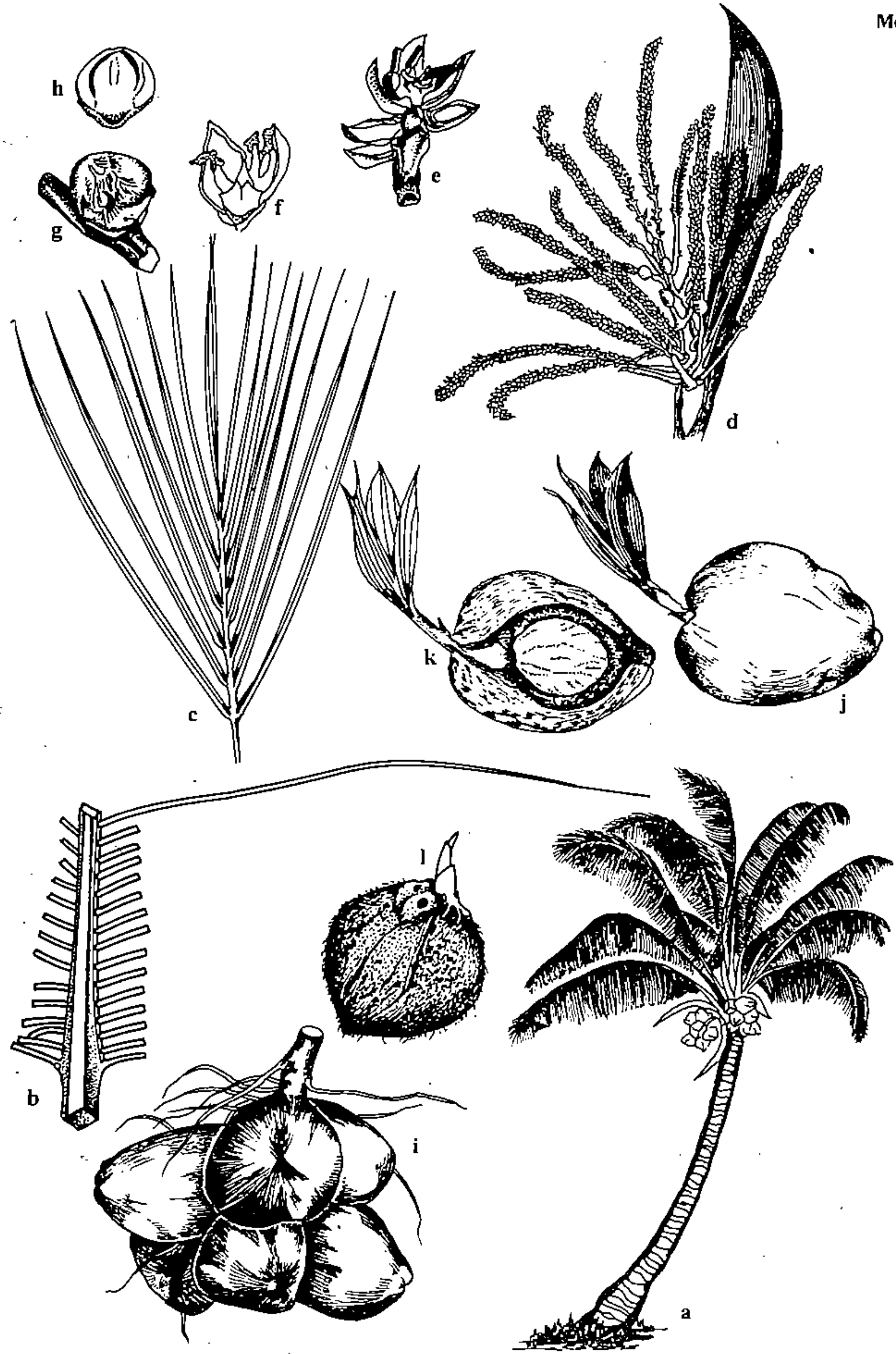

Fig. 23.13: Arecaceae: *Cocos nucifera*. a) Palm. b) Portion of leaf rachis. c) Tip of leaf. d) Inflorescence. e) Male flower and bud. f) Male flower opened. g) Female flower. h) Female flower in L.S. I) Inflorescence with fruit. j) Germinating fruit. k) Germinating fruits L.S. l) Germinating fruit with mesocarp removed.

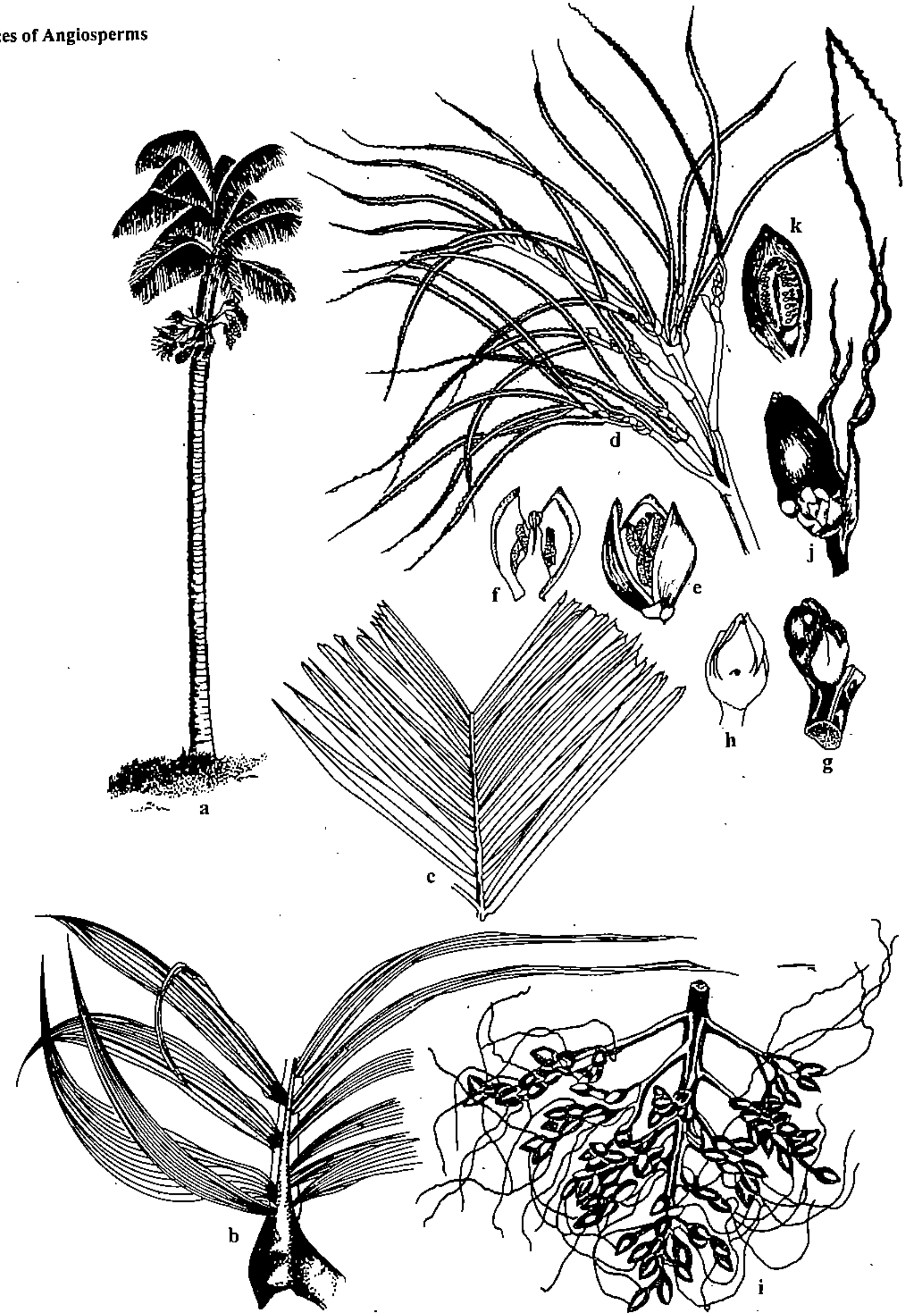

Fig. 23.14: Arecaceae: *Areca catechu*. a) Palm. b) Base of leaf. c) Tip of leaf. d) Inflorescence. e) Male flower f) Male flower in L.S. g) Female flower. h) Female flower in L.S. i) Fruit bunch. j) Fruit. k) Fruit in L.S.

The seed has a large endosperm and a very small embryo. The endosperm may be soft forming a fleshy substance which stores oil and other food material (e.g., coconut). The endosperm may also be hard (e.g., date) or ruminate (e.g., betel nut, Fig. 23.14) or it may be very thick and hard (e.g., vegetable ivory).

Diagnostic Features of the Family

1. Large woody plants generally with unbranched columnar stem.
2. Stem covered with leaf sheaths.
3. Thorns or spines may be present on stem, petiole, or leaf.
4. Leaves very large, fan or feather shaped.
5. Inflorescence very large, subtended by sheaths, sweet smelling.
6. Plants monoecious or dioecious, flowers small, unisexual.
7. Perianth not differentiated into calyx and corolla; tepals tough leathery or fleshy, persistent.
8. Stamens six, filaments free.
9. Tricarpellary gynoecium, ovary superior.
10. Fruit a berry or a drupe.
11. Seeds with abundant endosperm and small embryo.
12. Endosperm soft or hard.

Systematic Position

The family Palmae (Arecaceae) is classified in the monocotyledon Series – Calycinae by Bentham & Hooker. In Engler & Prantl's classification, the family is classified in the Order Principes. Takhtajan in his classification has classified the family Arecaceae in subclass – Arecidae, super order Arecanae, and Order Arecales.

Economic Importance

The palms provide a wide range of economic products. Many of them have multiple uses, unlike other economic plants. They provide edible products, fats, waxes, fibres, raw material for furniture and many other articles. In many tropical areas, the palms serve as life supporting systems for mankind, providing several products for daily needs. The more important and well-known palms and some of their uses are listed here.

1. *Cocos nucifera* – Coconut palm. This is a feather palm. It is said to have more than 1000 uses because every part of the plant is useful. It provides food, beverage, oil, medicine, fibre; timber, thatching material, fans, mats, brushes, brooms, fuel, domestic utensils, decorative articles and many more. It has been called "Kalpavriksh" or "tree of life" in ancient Indian literature.

2. *Phoenix dactylifera* – Date plam. The edible fruits are rich in sugar (60-70% of the fleshy pericarp is sugar). They may be eaten fresh, dried or used in bakery and confectionery. The stem and spathes may be tapped for obtaining palm wine or toddy.

3. *Phoenix sylvestris* – This is a fan palm which is tapped for its sap. The sap contains 12% sucrose and can be converted into jaggery and palm sugar. The sap is also fermented to prepare an alcoholic beverage called toddy. For this, the inflorescence is tapped and up to 20 litres of sap can be obtained from a single plant. The mature fruit is edible. The columnar stem is made up of durable wood which is used in various ways. Fibres are obtained from the leaf stalks.

4. *Metroxylon rumphii, M. sagus* – Sago palms. These are feather palms. They are monoecious and monocarpic palms. A large terminal inflorescence is produced when the palm is 10-15 years old. The trunk of this palm is cut before flowering and large quantities of starch are

removed. This starch is washed and dried to produce edible flour. Small granules called pearl sago are prepared from this flour.

5. *Nypa fruticans* – Nipa palm. This is an acaulescent feather palm. The palm is tapped for sugary sap which contains about 17% sucrose. It can be fermented to produce toddy or the toddy may be distilled to produce arrack. Vinegar is also produced from the sap. The sap may be evaporated to produce molasses-like sugar called "gula malacca".

6. *Arenga pinnata* – Sugar palm. This is a monoecious, monocarpic feather palm. A large quantity of starch is stored in the trunk. This is converted into sugar when the palm begins to flower. The peduncle of the male inflorescence is tapped to produce about 2.5 litres of sap per day. This tapping can be carried out for 2-3 months. The juice is boiled to produce sticky sugar or jaggery. Sago may be obtained if the stem is tapped before the onset of flowering.

7. *Caryota urens* – Fish-tail palm or Toddy palm. This is a monoecious, monocarpic feather palm. The inflorescence is tapped for the sap which is converted into toddy or sugar.

8. *Hyphaene thebaica* – Doum palm. This is a branched, dioecious fan palm. The sweet fleshy mesocarp of the fruit is edible. It is also used in medicine. The hard seeds are used as a substitute for vegetable ivory. The terminal meristem may be tapped for toddy.

Large scale cultivation of the oil palm has been undertaken in several states of In_a by the Department of Biotechnology. This shall help the nation to become self-sufficient in edible oil production.

9. *Elaeis guineensis* – Oil palm. This is a very important fan palm. It provides the highest yield of vegetable oil per unit area for any crop. Two distinct oils called palm oil and palm-kernel oil are obtained from this palm. Both are very important in the world trade in vegetable oils. Palm oil is obtained from the fleshy mesocarp of the fruit. The mesocarp contains 45-55% oil. This oil is light yellow to orange-red in colour. It is edible and is also used industrially for the manufacture of soap, candles, railway axles, and other products.

   Palm-kernel oil is obtained from the kernel or endosperm. It resembles coconut oil and is nearly colourless. It is edible and is used in confectionery and bakery products, and in ice-creams. It is also used in the manufacture of soaps and detergents.

10. *Copernicia cerifera* – Carnauba wax palm. This fan palm produces the most important vegetable wax which covers the leaves. The young leaves are cut and dried. The wax is removed from the surface and it is melted. It is very hard and has a high melting point. The wax is used in the manufacture of furniture, car and floor polishes. It is also used in the manufacture of paints, varnishes, carbon paper, gramophone records, ointments and lipstics.

11. *Areca catechu* – Betelnut palm. This is a fan palm. The hard dried endosperm of the ripe and unripe seeds is widely used as a masticatory. It is chewed with betelpepper leaf or alone. This habit of chewing betel is widespread and can cause cancer of the mouth. The betelnut is also commonly used in religious ceremonies and in medicine.

12. *Phytelephas macrocarpa* – Vegetable Ivory or Ivory nut palm. This is a dioecious feather palm. The non-ruminate endosperm is made up of very hard and durable cellulose. It is used as a substitute for true ivory and is called vegetable ivory. It can be carved like true ivory. It is also used for making chessmen, billiard balls, dice, buttons, and door knobs. It can be easily coloured with dyes.

13. *Lodoicea maldivica* = *Lodoicea seychellarum* – Double Coconut or Coco-de-mer. This fan palm produces the largest seed in the plant kingdom. This is believed to be the palm on which the "Garuda" bird lived. The shells are used as vessels for collecting water, alms, etc. The leaves supply plaiting material for mats and other articles.

14. *Calamus rotang* – Rattan or Cane palm. This is a climbing dioecious feather palm. The long stems are used for making cane furniture, walking sticks, polo sticks, ski sticks, swinging bridges, baskets and mats.

15. *Ornamental palms* – Many palms are grown for their elegant sturcture and they are important ornamental plants in many gardens. A few of the more common ornamental palms are:

Roystonea regia	-	Cuban Royal palm or Bottle palm
Caryota urens	-	Fish-tail palm
Corypha umbraculifera	-	Talipot palm
Livistona chinensis	-	Chinese fan palm
Arenga pinnata	-	Sugar palm
Hyphaene thebaica	-	Egyptian Doum palm
Lodoicea maldivica or *L. seychellarum*	-	Coco-de-mer

Points to Remember

23.5 POACEAE OR GRAMINEAE

The Grass family
Nomenclatural type: ***Poa***

General Information

The Poaceae constitute a natural and homogenous family of monocotyledonous plants. The grasses are widely distributed throughout the world and they grow wherever plants can survive. This is one of the very large families of flowering plants having about 550 genera and 10,000 species. The grasses can be found from the Equator to the poles, and from the sea level to the snowline on the mountains. They can occur on wet as well as dry places, in brakish or fresh waters or even in deserts. Grasses prefer open lands and are not common in dense forests. They may form dominant communities like the savanna, prairies, steppes and meadows.

Civilisations, developed when man learnt about agriculture. The grasses were the first plants to be cultivated by man. These plants are quite distinct in their characters and differ from the rest of the plant kingdom. This interesting group of plants is represented in India by about 240 genera and 1200 species, and are found throughout the country.

Field Recognition

The grasses are mostly herbaceous plants with a fibrous root system; the aerial stems are terete and the internodes are generally hollow; the leaves are alternate; each leaf consists of a sheath, a lamina and a ligule. The lamina shows parallel venation. The inflorescence is made up of complex spikelets; each spikelet has sterile bracts and paired fertile glumes, flowers are reduced and generally bisexual. The perianth is represented by lodicules. There are generally 3 stamens with versatile anthers. The gynoecium generally has 2 feathery styles; the fruit is a grain or caryopsis which you have already read in Unit 11 of Block 3A.

Although the grasses are distinct from other plants, they do show a superficial resemblance with the sedges (members of the family Cyperaceae). These two groups of plants can be distinguished as follows:

Box 23.1: Differences in Poaceae and Cyperaceae.

Poaceae (grasses)	Cyperaceae (sedges)
1. Stems terete i.e. circular in cross-section.	1. Stems 2-sided i.e. triangular in cross-section.
2. Internodes generally hollow.	2. Internodes solid.
3. Leaves alternate and 2-ranked.	3. Leaves 3-ranked.
4. Flowers in spiklets and enclosed in pairs of fertile glumes.	4. Flowers in spikelets but in the axils of single fertile glumes.

Morphological Diversity

Most grasses are herbaceous plants, but a few (especially the bamboos) are woody. The herbaceous grasses may be annual or perennial. They have a well-developed fibrous and adventitious root system. In the perennial grasses, the lower internodes are short and numerous branches arise from the lowermost leaf ı. These branches or tillers grow erect giving a tufted appearance to the plant. the economically important grasses **like wheat** (Fig. 23.16), **the tillers crease the grain production per plant**. This is due to the fact that each tiller ɪrminates in an inflorescence. From the base of the tillers, adventitious roots ɪrise to support the tufted grass (Fig. 23.15).

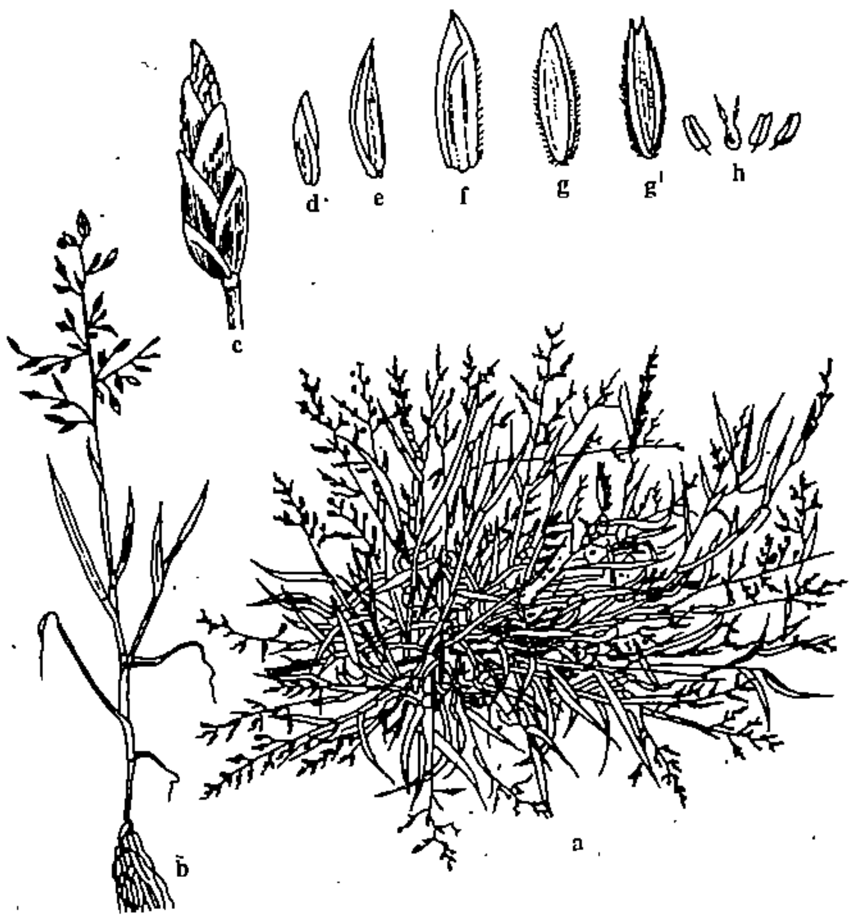

Fig. 23.15: ***Poa annua*. a) Portion with panicles. b) Flowering culm. c) Spikelet. d) Lower involucral glume. e) Upper involucral glume. f) Floral glume. g & g') Outer and inner view of palea respectively. h) Anthers, ovary and stigmas.**

The perennial grasses may also have an underground rhizome. This is sympodial in nature and is formed by the lower nodes of the aerial branches. Erect aerial shoots arise from this sympodial rhizome. Sometimes, a stoloniferous rootstock is formed and aerial shoots arise from this rootstock. The woody bamboos grow in clumps. The clumps expand continually by the formation of new shoots on the periphery. There is a big underground rhizome from which the erect perennial woody stems arise. A single bamboo stem may attain a height of 30 meters and a diameter of 25 cms. They are thus the largest members of the grass family.

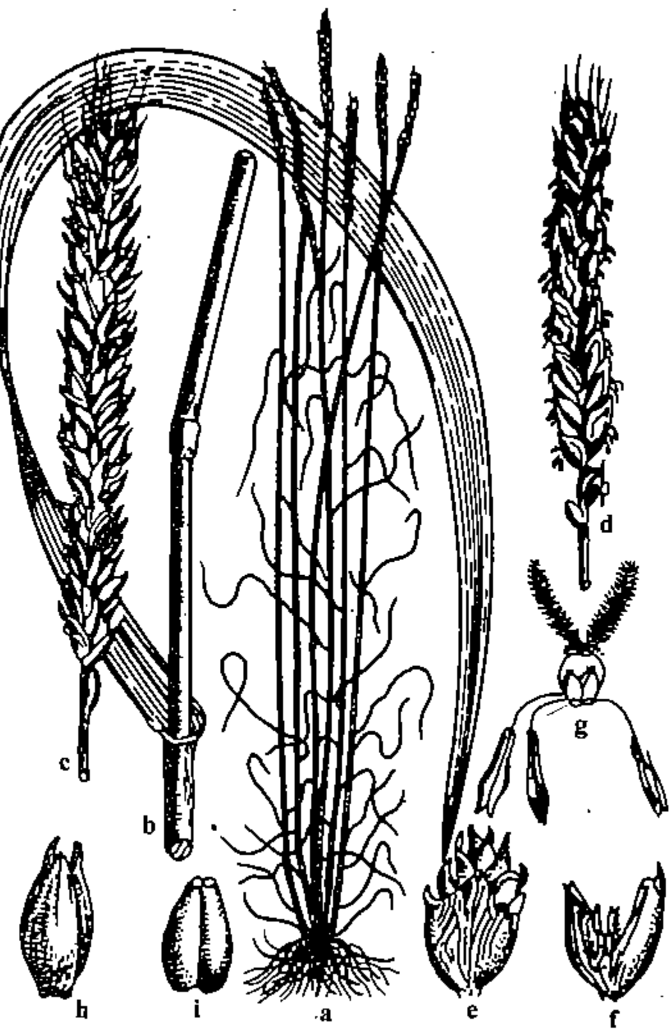

Fig. 23.16: *Triticum aestivum*. a) Flowering plant. b) Culm with leaf. c, d) Spikes, e) Spikelet. f) A flower enclosed by lemma and palaea. g) Flower. h) Caryopsis enclosed in glumes. i) Caryopsis.

The aerial stems of the grasses are called culms and they do not generally branch. In some tropical grasses and in bamboos, branching of the culm does occur. Each culm has well-marked nodes and internodes. The internodes towards the base are shorter while those towards the apex are longer. The internodes are generally hollow because the parenchymatous (ground) tissue, in which the vascular bundles are embeded, breaks down easily. But in *Zea mays* (maize) (Fig. 23.18), *Saccharum officinarum* (sugarcane) (Fig. 23.17) and other grasses, the internodes are solid. Here the parenchymatous tissue does not break down.

The stems are terete (i.e. circular in cross-section). An intercalary meristematic zone of special cells is present above each node in many grasses. This enables elongation of the internode. It also enables the grass stem to become erect after it is bent downwards by external forces. The culms remain rigid due to the development of sclerenchymatous tissue beneath the epidermis and around the vascular bundles. In many grasses (e.g., sugarcane), a root band containing the root primordia or root initials of adventitious roots is also present just above each node.

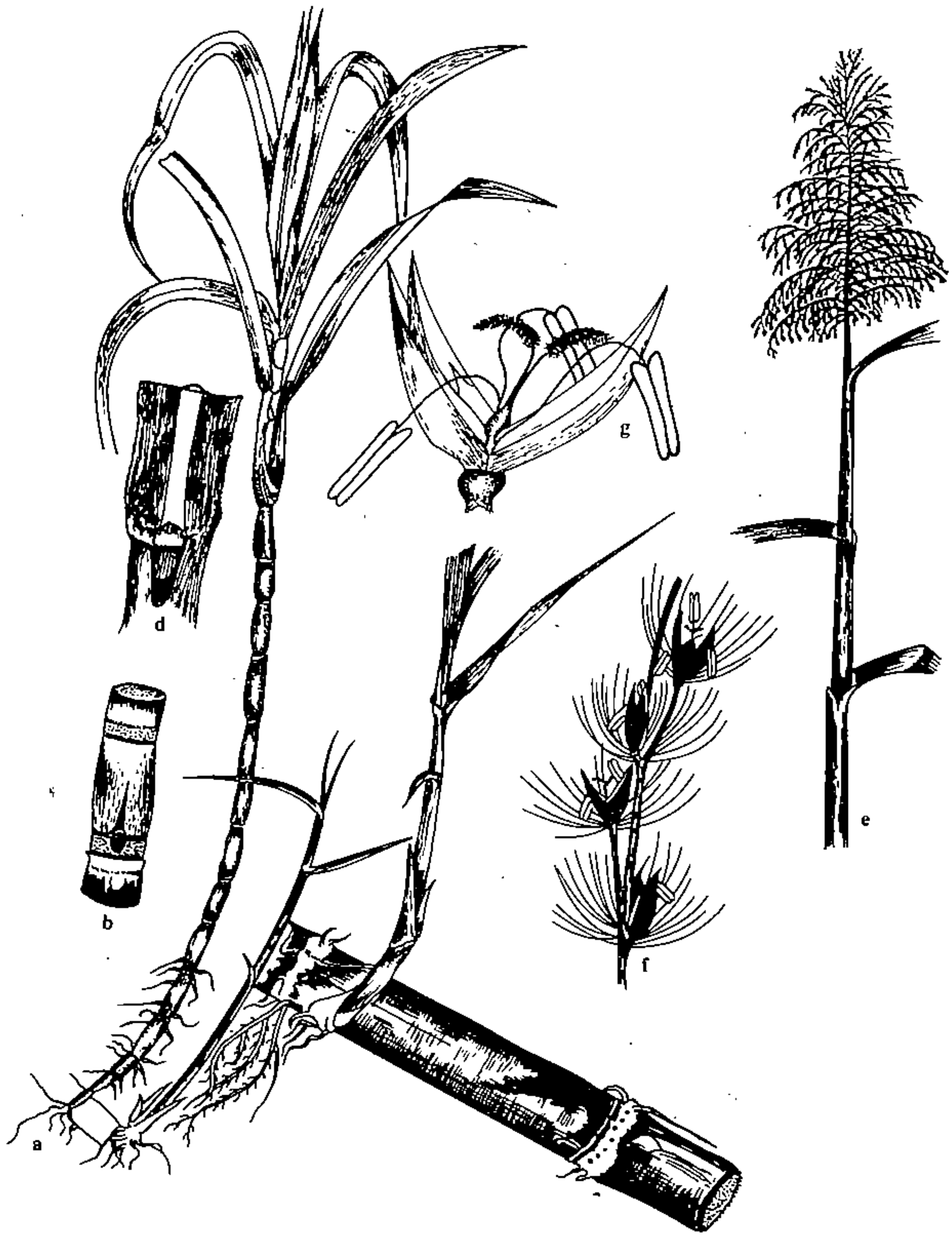

Fig. 23.17: *Saccharum officinarum.* **a)** Young plant growing from sett. **b)** Portion of stem. **c)** Sett showing early growth. **d)** Base of lamina. **e)** Inflorescence. **f)** Portion of inflorescence. **g)** Spikelet.

Leaf: In Poaceae, the leaves are alternate and arranged in 2 rows. (This is also called a distichous arrangement or a 1/2 phyllotaxy. (In the Cyperaceae, the leaves are 3 ranked showing a 1/3 phyllotaxy). The lower leaves may appear crowded because of the shorter internodes. Each leaf has a basal sheath. The edges of this leaf sheath overlap on the opposite sides of the culm. They surround the internode and form a closed or open tube. This sheath protects the internode. The sheath is followed by the lamina or blade. However, in many bamboos and a few other grasses, a petiole separates the sheath from the blade. A special structure called ligule, is generally present at the junction of the sheath and the blade. This is generally a membranous (sometimes a hairy) outgrowth at the apex of the sheath. The lamina or blade is usually long and narrow. It may be linear or linear-lanceolate and it generally tapers to a fine point. The margins of the blade may be entire, serrate or sharply toothed. The leaves show parallel venation.

The stomatal mechanism in the grasses is very distinct and characteristic. The two guard cells are elongated. They are bulbous at the two ends and straight in the middle. The middle portion of each guard cell has strong unevenly thickene walls. The bulbous ends of the guard cells are thin walled. Increase or decrease pressure at the bulbous ends of the guard cells result in opening or closing of tl stomatal aperature.

In many xerophytic grasses, the leaf blades are often folded or rolled up. This folding or rolling up of the leaf is brought about by the parenchyma cells betwe the veins. When the atmosphere is moist, these parenchyma cells are turgid and the blade is expanded. In dry conditions, these parenchyma cells become flaccid and the blade rolls up. When the blade is rolled up the stomata are completely enclosed. This checks transpiration.

Inflorescence: The inflorescence is usually terminal on the culm and it is a complex structure. It consists of special units called spikelets. Several spikelets are arranged in dense (compact) to loose panicles, or in spikes or in racemes. In *Triticum aestivum* (wheat) (Fig. 23.16) and other grasses, the inflorescence is a spike of spikelets at the apex of each tiller. *Oryza sativa* (rice) (Fig. 23.21), *Saccharum officinarum* (sugarcane) (Fig. 23.17) and many other grasses have a terminal panicle of spikelets. The flowers are unisexual and the plants are monoecious in *Zea mays* (maize) (Fig. 23.18). Here, the terminal male inflorescence is a panicle of spikelets. It is called a tassel. The female inflorescence is a modified or specialised spike of spikelets and is called the cob. The floral axis is thickened. This female inflorescence appears in the axil of a leaf near the centre of the culm. It is actually terminal and it is produced on a short compact lateral branch. This special branch develops in the axil of the leaf. On a single maize plant, there is only one male inflorescence but 2 or even 3 female inflorescences generally develop.

Each spikelet consists of a condensed axis called the rachilla. At the base of this axis, there are one or two bract like structures called glumes. They do not bear any flowers. Their main function is to protect the developing flowers in the spikelet. Above these glumes there are 1 or more pairs of fertile glumes. A flower is enclosed in each pair of fertile glumes. Each pair of fertile glumes consists of an outer or lower fertile glume called lemma and an inner or upper glume called palea. The lemma is usually more prominent than the palea. The lemma may or may not have a spine-like projection called the awn. This may be a terminal prolongation of the apex of the lemma. Sometimes, the awn is attached to the dorsal side of the lemma. The palea is usually membraneous and smaller than the lemma. The lemma is generally convex and the palea concave so that they make a compact pair enclosing the flower (Fig. 23.19).

This basic pattern of spikelet organisation is common throughout the family (Fig. 23.20). Each spikelet may have only one (e.g., *Agrostis, Coix, Hordeum, Oryza*) or 2 to many flowers (e.g., *Bromus, Festuca, Eleusine, Triticum,* bamboos). The highly reduced flowers are also called florets.

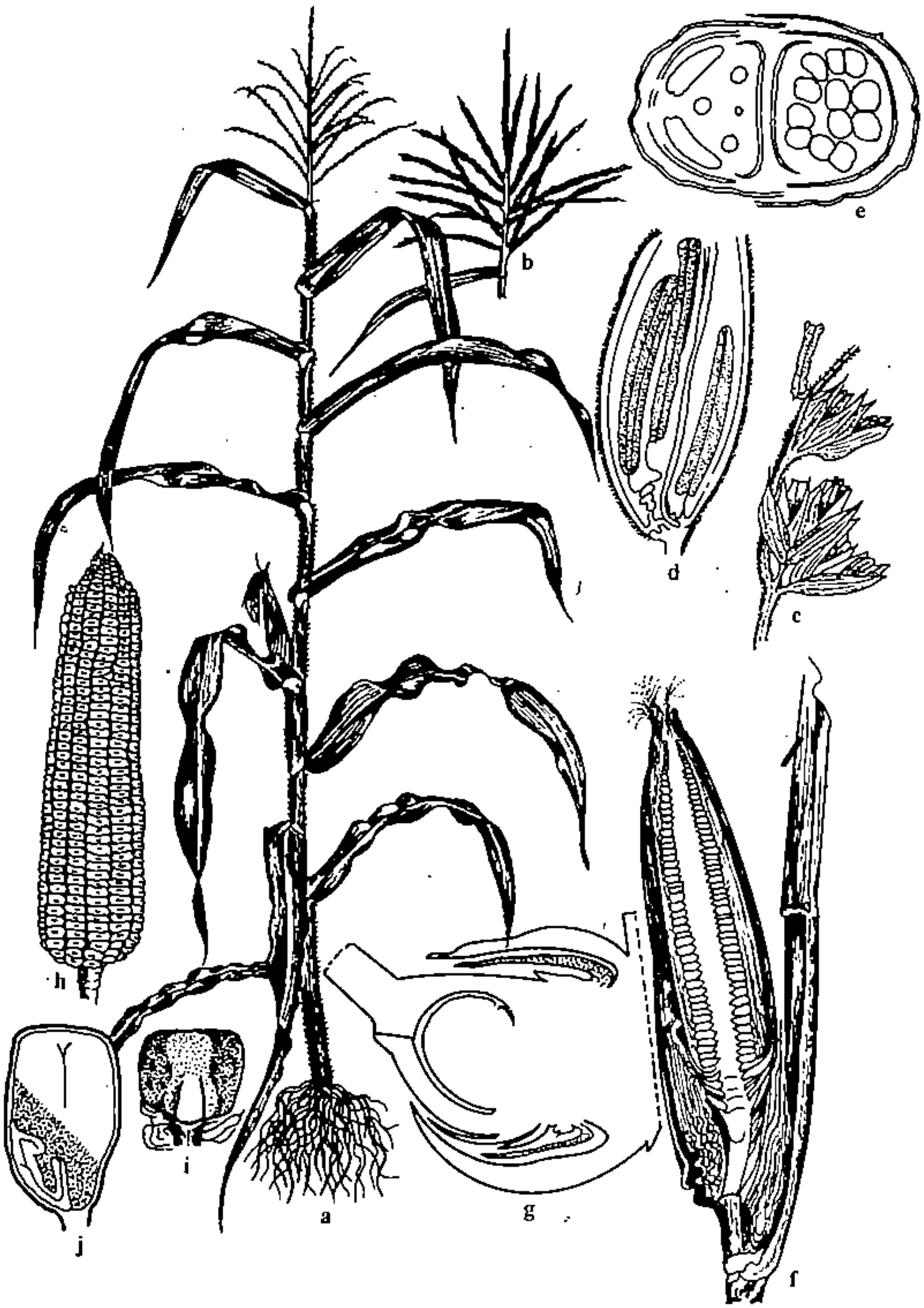

Fig. 23.18: *Zea mays.* a) Plant. b) Male inflorescence. c) Male spikelets. d) Male spikelet in longitudinal section. e) Male spikelet in transverse section. f) Female inflorescence in longitudinal section. g) Female spikelet in longitudinal section (much enlarged); h) Ear. i) Caryopsis. j) Caryopsis in longitudinal section.

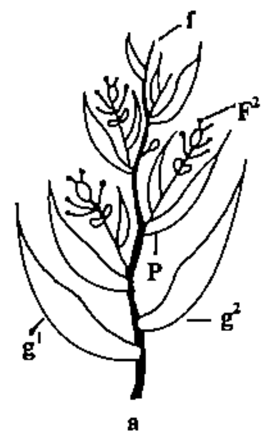

Fig. 23.19: Diagram of a spikelet of a grass as it would appear if the internodes between each set of organs were elongated. g¹) lower and g²) upper barren glume. P) fertile glume and p) pale of the second oldest flower. F²) f) a barren flower represented only by the axis and pale. Above it a single glume and the termination of the axis (rachilla) (a) of the spikelet.

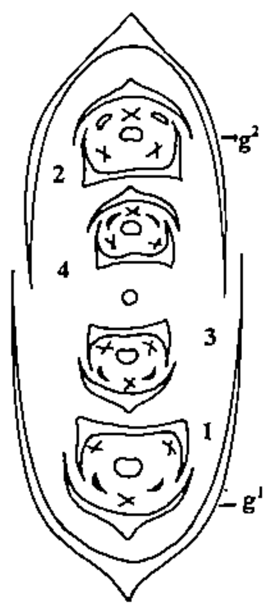

Fig. 23.20: Diagram of a spikelet of a grass. The two barren glumes – g¹, lower, g², upper – embrace f flowers of which 1 is the lower most and 4 the upper most.

Agrostologist, is a taxonomists who specialise in the study of grasses

Flowers: The flowers are very simple. They are small, inconspicuous, zygomorphic, hypogynous and usually bisexual. In some grasses the flowers are unisexual (e.g., *Zea mays*) and sometimes there are both bisexual and unisexual flowers in the same inflorescence (e.g., *Andropogon, Erianthus, Paspalum, Panicum, Digitaria*). A true perianth is absent, and according to some agrostologists the flowers are naked. However, each flower has generally 2 (sometimes 1 or 4) minute membraneous or scaly structures called lodicules. They are present at the base of the flower between the lemma and the palea. Many botanists consider the lodicules to represent the perianth of the flower. In a few grasses (e.g., *Anthoxanthum*) the lodicules are completely absent and the flower is actually naked. The lodicules help to separate the lemma and the palea so that the anthers and stigmas protrude out. This is similar to the swell. Pressure is thus exerted at the base of the lemma and palea, separating the two laterally and exposing the reproductive organs. When the lodicules are absent, the lemma and palea do not separate laterally. In such grasses, the reproductive organs protrude out through the apex of the fertile glumes.

Flowering occurs annually in many of the perennial grasses, but in bamboos and some other grasses flowering is variable. Some bamboos flower and bear fruits at short intervals without dying. Others flower sporadically after intervals of a few to 40 years. There are also monocarpic bamboos which produce a very large number of flowers only once in their lifetime. Such monocarpic bamboos die after fruit formation (e.g., *Arundinaria amabilis, Oxytenanthera abyssinica*).

Most grasses have chasmogamous flowers (those which open and the reproductive organs protrude out through the lemma and palea). These may be self or cross-pollinated. Some grasses have cleistogamous flowers (closed flowers in which the reproductive organs are never exposed). These are always self-pollinated.

Androecium: There are generally three stamens in a single whorl in the flower. However in some grasses (e.g., *Festuca, Uniola*), there is only one stamen. In genera like *Anthoxanthum* and *Coleanthus*, there are two stamens in the flower. Most bamboos, rice and in a few other grasses, there are two alternating trimerous whorls of stamens in each flower. Rarely there may be more than six stamens.

Each stamen has a long delicate filament and a dithecous anther. The anthers are versatile and show introrse dehiscence. Each anther produces abundant fine granular and smooth pollen.

Gynoecium: There are two views on the organisation of the gynoecium in the Poaceae. Some agrostologists believe that the gynoecium is monocarpellary. Others suggest that the gynoecium is either bi-or tri-carpellary and syncarpous. The superior ovary is always unilocular and has a single ovule on a basal placenta. There are usually two (sometimes 1 or 3) styles each with a much-branched plumose (feathery) stigma. In *Zea mays*, the long silky stigmas are very prominent.

Fruit: The fruit is very characteristic in this family. It is a dry indehiscent fruit called a caryopsis. This is a one-seeded fruit in which the pericarp (fruit wall) is completely fused with the testa (seed coat). The seed contains a small straight embryo on one side near the base. The major part of the seed consists of the starchy endosperm. Sometimes the fruit is utricle (one-seeded hard dry indehiscent fruit with a thin pericarp). Here the seed has a well-developed testa which is not fused with the pericarp. The seed can be removed from the fruit (e.g., *Eleusine coracana* or finger millet) (Fig. 23.22). In some bamboos, the pericarp is very hard forming a small nut-like fruit. In a few grasses (e.g., *Hordeum vulgare* or barley) the glumes are fused with the caryopsis.

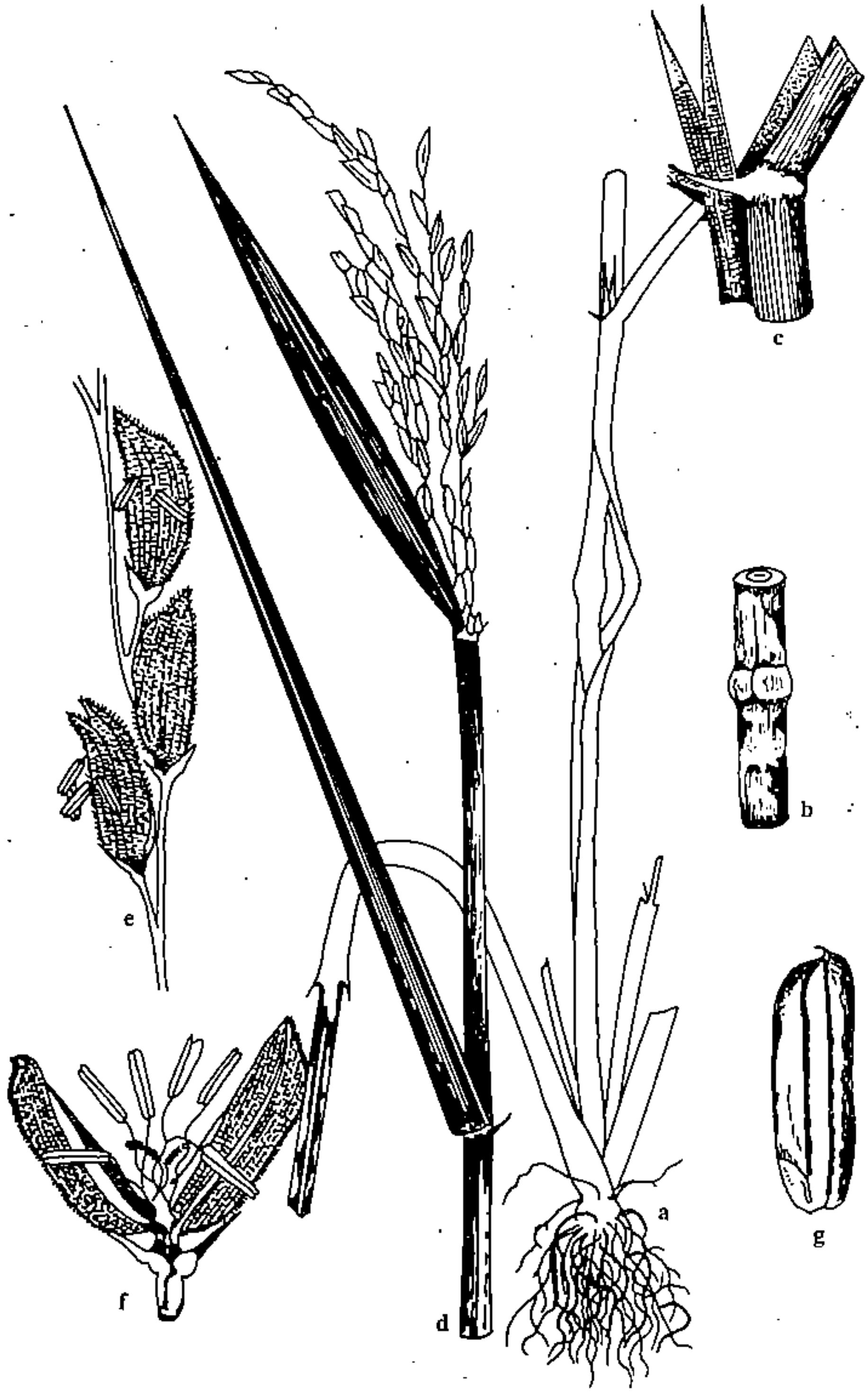

Fig. 23.21: *Oryza sativa*. Rice. a) Base of plant. b) Portion of stem with sheath node. c) Base of lamina with ligule and auricles. d) Emerging inflorescence. e) Portion of inflorescence. f) Open spikelet. g) Caryopsis.

Diagnostic Features of the Family

1. Plants generally herbaceous with a fibrous root system.
2. Tufted habit or with underground rhizome.
3. Aerial stems or culms are terete.
4. Internodes usually hollow.
5. Leaves distichous, with a basal sheath, a ligule and a long narrow lamina.
6. Venation parallel and stomata characteristic with buliform guard cells.
7. Inflorescence made up of spikelets having sterile and pairs of fertile glumes.

8. Flowers small, inconspicuous having a perianth of 0-3 minute membranceous lodicules.
9. Stamens 3 with versatile anthers.
10. Superior ovary with single ovule and 2 styles with feathery stigmas.
11. Fruit a caryopsis.
12. Seed with small embryo and abundant starchy endosperm.

Fig. 23.22: *Eleusine coracana*. a) Flowering shoot. b) Base of plant. c) Spikelets. d) Lemma and palea in transverse section. e) Fruit.

Systematic Position

The family Poaceae is classified in – Glumaceae of the monocotyledons by Bentham and Hooker. This is the last series with Gramineae as the last family in this system of classification. The family Cyperaceae is also classified with Gramineae. In Engler & Prantl's classification, the family Graminae is classified in Order Glumiflorae of the monocotyledons. This order also includes the family Cyperaceae. Takhtajan in his classification has classified the family Poaceae in subclass B - Commelinidae, super order Poanae and order – Poales. In this system of classification, the family Cyperaceae is classified in Super Order Juncananae and Order – Cyperales of subclass Commelinidae.

Economic Importance

The family Poaceae is economically the most important family of flowering plants. The cereals are the most important grasses which have been used as staple diet by man since the dawn of civilization. Besides providing food for man, grasses are also used for feeding animals. They are important for production of alcoholic beverages and other products.

Some of the important and well known grasses used by man are listed here.

1. **Cereals and Millets**

   There are six major cereals consumed by man:

   a) *Triticum aestivum* – wheat
   b) *Oryza sativa* – rice
   c) *Zea mays* – maize
   d) *Hordeum vulgare* – barley
   e) *Avena sativa* – oats
   f) *Secale cereale* – rye

   Besides these, there are other edible grasses with small seeds. They are called millets. These include:

   a) *Eleusine coracana* – Fingermillet, ragi
   b) *Pennisetum typhoides* – pearl or bulrush millet
   c) *Sorghum vulgare* – sorghum or jowar
   d) *Setaria italica* – Italian millet
   e) *Echinochloa frumentacea* – Japanese barnyard millet.
   f) *Panicum miliaceum* – Common millet

   You have been provided detailed information about cereals and millets in Block III A, Unit 11.

2. **Fodder Grasses**

   The green herbage and dried fodder from grasses provide the basic food for man's domestic and many wild animals. Grass is the cheapest of all livestock feed. Naural grasslands or planted pastures have different species of grasses. Some widely used fodder grasses include species of *Digitaria, Eragrostis, Echinochloa, Lolium, Cenchrus, Cynodon, Chrysopogon, Heteropogon, Panicum, Paspalum, Poa, Setaria, Sorghum* and *Sporobolus*. Some of these grasses may also be grown for decorative purposes and in sports fields.

3. **Sugar**

   The genus *Saccharum* has many economically important cultivated varieties. These are the most important source of cane sugar. Thus the sugarcane is one of the most valuable crops of the family Poaceae.
   A detailed account of this grass has been provided in Block III A, Unit 16.

4. **Bamboos**

These tall arborescent grasses are classified in about 45 genera and more than 250 species. The largest number of bamboo species are found in the Indo-Malaysian region. There are numerous uses of bamboos. They may be used for construction purposes. Houses, huts, rafts, bridges and other structures are made of bamboo. They are used for scaffolding, as poles or for making ladders, baskets, brushes and many more articles. Bamboo pulp is an important raw material in the paper industry. Besides, these uses, young shoots of some bamboo species are edible. Bamboo foliage is used as fodder for elephants and bamboos are also grown as wind-breakers and to check soil erosion.

The bigger bamboos are obtained from species of *Bambusa, Dendrocalamus, Arundinaria, Gigantochloa, Melocanna, Ochlandra, Oxytenanthera* and other genera.

5. **Essential Oils**

Lemon-grass oil is used in perfumery and cosmetics as well as a flavouring substance. It is obtained from the leaves of the grasses *Cymbopogon citratus* and *C. flexuosus*. Other species of this genus are also important e.g., citronella grass – *C. nardus*, gingergrass – *C. caesius*, rosha grass – *C. martini*. They also yield essential oils.

Vetiveria zizanioïdes yields oil of vetiver (khus). This is obtained from the roots. It is used in perfumery, cosmetics, soaps and for flavouring purposes. The roots are also woven into mats which when wet, cool and make the atmosphere fragrant.

6. **Miscellaneous Uses**

Several grasses are used for packing and thatching purposes and as building material. Fibres obtained from grasses are used for making ropes and as raw material for paper making. Stems of *Arundo donax* and *Phragmites karka* are used for making musical pipes and other articles. The panicles of *Thysanolaena maxima* are used for making brooms.

Many grasses are widely used in soil conservation because their fibrous root systems act as efficient soil binders. This prevents soil erosion.

Several grasses are important components of the landscape. These include golf courses sportsfields, lawns and other open spaces. Some grasses are also cultivated as ornamentals. *Coix lachryma – jobi* (job's tears or adlay) produces hard nut like fruits which show many variations in their size and colour. They are used as beeds for making necklaces. They are also used as poultry feed and for edible purposes. A beer like alcoholic beverage is also prepared from these fruits.

SAQ

1. Assign the following genera to their respective families and mention one economic use of each.

Genus	Family	Use
a) *Arundinaria*		
b) *Borassus*		
c) *Calamus*		
d) *Cymbopogon*		
e) *Dracaena*		
f) *Ravenala*		
g) *Strelitzia*		
h) *Yucca*		

2. Subclass Liliidae in Takhtajan's classification **does not** include:

   a) Arecaceae
   b) Liliaceae
   c) Musaceae
   d) Poaceae

3. List 3 families other than those mentioned above which are also classified in subclass Liliidae.

   a)
   b)
   c)

4. Write the botanical name of the following plants.

	Common name	**Botanical name**
a)	Bird of Paradise	
b)	Citronella grass	
c)	Date palm	
d)	Job's tears	
e)	Traveller's tree	
f)	Vegetable Ivory	

5. a) What is meant by a monocarpic plant?

   ....
   ....
   ....

   b) List three examples.

   i)
   ii)
   iii)

6. Define the following terms and name the family in which each has been described.

   a) Culm ....
   ....
   ....

   Family ....
   ....
   ....

   b) Phylloclade ....
   ....
   ....

   Family ....
   ....
   ....

c) Pseudostem ....

....

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Family ....

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23.6 SUMMARY

- This unit defines the monocotyledons plants and describes in detail four selected families. These are Arecaceae, Liliaceae, Musaceae and Poaceae.
- The nomenclatural type of each family, its size and distribution as well as information on the number of genera and species occurring in India have been mentioned.
- The diagnostic characters for recognising the plants of these families have been listed.
- Information on the systematic position of each family has been provided. This helps us to compare the different systems of plants classification.
- The economically important plants are listed for each family to help us understand the value of plants for human welfare.

23.7 TERMINAL QUESTIONS

1. Mention the systems of classification in which the following terms are used. Name one family which you have studied for each.

Term	System of classification	Family
a) Arecidae		
b) Calycinae		
c) Poanae		
d) Coronarieae		
e) Glumiflorae		
f) Liliiflorae		
g) Principes		
h) Zingiberales		

2. a) Differentiate Family Musaceae **sensu lato** from Family Musaceae **sensu stricto.**

   b) Write a note on the systematic position of Family Musaceae in 3 systems of classification.

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....

3. List the diagnostic features of Family Poaceae.

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....

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....

4. Describe the vegetative and floral structures of:

   a) Family Arecaceae

   ....

   ....

   b) Family Liliaceae

   ....

   ....

5. Write a note on the economic importance of:

   a) Family Musaceae

   ....

   ....

   ....

   ....

   b) Family Poaceae

   ....

   ....

   ....

   ....

6.

a) Based on your study of Block III (Economic Botany) and Block IV (Flowering Plants) and with the help of books in your study centre, prepare a list of the botanical names of all the plants (including Plant products) used by you and your family. Assign each plant to its botanical family. Recognise the most useful part of the plant and mention its use.

b) Collect 25 plants from your neighbourhood. Record the important characters of each plant (use Unit IV as a guide for recording this information). From these observations, you should be able to assign some of the plants to the families studied by you. Press the plants in newspapers to prepare herbarioum specimens. With the help of the botany teachers at your study centre, identify the plants you have collected. Write out a detailed report on this project.

23.8 ANSWERS

Self-assessment Questions

1.

	Genus	Family	Use
a)	*Arundinaria*	Poaceae	Bamboo for construction etc.
b)	*Borassus*	Arecaeae	Palm sugar or jaggery or toddy.
c)	*Calamus*	Arecaceae	Cane for furniture etc.
d)	*Cymbopogon*	Poaceae	Essential oils.
e)	*Dracaena*	Liliaceae	Resin, ornamental.
f)	*Ravenala*	Musaceae	Ornamental.
g)	*Strelitzia*	Musaceae	Ornamental
h)	*Yucca*	Liliaceae	Fibres, medicine, ornamental

2. a) Arecacae b) Musaceae c) Poaceae

3. List any three families from the Systematic Position of Family Liliaceae.

4.

	Common name	Botanical name
a)	Bird of Paradise	*Strelitzia reginae*
b)	Citronella grass	*Cymbopogon nardus*
c)	Date palm	*Phoenix dactylifera*
d)	Job's tears	*Coix lacryma-jobi*
e)	Traveller's Tree	*Ravenala madagascariensis*
f)	Vegetable Ivory	*Phytelephas macrocarpa*

5. a) A monocarpic plant is one which flowers and fruits only once in its life itme. Flowering occurs after many years of vegetative growth and the plant dies after formation of fruits.

   b) i) *Metroxylon rumphii* - Sago palm
      ii) *Arenga pinnata* - Sugar palm
      iii) *Caryota urens* - Fish tail palm
      iv) *Arundinaria amabilis*
      v) *Oxytenanthera abyssinica*

6. a) Culm
   Aerial stem of a grass plant. It has well marked nodes and internodes. The internodes towards the base the shorter while those towards the apex are longer.
   Family – Poaceae

   b) Phylloclade
   A modified stem usually flattened and leaf like serving the plants as a photosynthetic organ. E.g., *Ruscus*.
   Family – Liliaceae

   c) Pseudostem
   A false stem, made up of leaf sheaths which are rolled around one another, e.g., *Musa*.
   Family – Musaceae

Terminal Questions

1.

	Term	System of classification	Family
a)	Arecidae	Takhtajan	Arecaceae
b)	Calycinae	Bentham & Hooker	Arecaceae (Palmae)
c)	Poanae	Takhtajan	Poceae
d)	Coronarieae	Bentham & Hooker	Liliaceae
e)	Glumiflorae	Engler & Prantl	Poaceae
f)	Liliiflorae	Engler & Prantl	Liliaceae
g)	Principes	Engler & Prantl	Arecaceae
h)	Zingiberales	Takhtajan	Musaceae

2. a) Family Musaceae **sensu lato** refers to the definition of the family in a broad context. This includes other genera besides *Musa*.

   Family Musaceae **sensu stricto** refers to the definition of the family in a restricted context. This excludes several genera, but retains the genus *Musa*.

   b) Refer to Section – Systematic Position of Musaceae.

3. Refer to Section – Diagnostic features of Poaceae.

4. a) Refer to Section – Morphological Diversity of Arecaceae.

   b) Refer to Section – Morphological Diversity of Liliaceae.

5. a) Refer to Section – Economic Importance of Musaceae.

   b) Refer to Section – Economic Importance of Poaceae.

UNIT 24 SOME UNUSUAL PLANTS

Structure

24.1 Introduction
Objectives
24.2 Carnivorous Plants with Unusual Modes of Nutrition
24.3 Saprophytic Plants
24.4 Parasitic Plants
24.5 Some Plant Curios
24.6 Seed and Fruit
24.7 Some Special Monocots
24.8 Summary
24.9 Terminal Questions
24.10 Answers

24.1 INTRODUCTION

In this course of Plant Diversity II, you have read about the structure, function and reproductive biology of seed plants and also about their importance in the welfare of human kind.

The vast array of flowering plants on earth could be possible due to their capacity to colonize and exploit practically every conceivable habitat on the earth. Beginning at about 125 to 145 million years ago, angiosperms have diversified so greatly that not only hundreds of thousands of species but thousand of types now exist.

They range from gigantic Redwood to tiny *Wolffia*, woody to herbaceous, perennial to biennial to annual, temperate to tropical, desert habitat to mesic to rainforest to aquatic, autotrophic to partial parasitic to fully parasitic, epiphytic to subterranean to endophytic. These evolutionary changes involved multifarious adaptations through mutation, structural modifications and developmental plasticity. Those which have the capacity to endure mutation that alter their growth and development emerge as fittest to survive. You know that plants are immobile and thus cannot escape from harsh environmental conditions. They, therefore, experiment with nature for survival through modifications in anatomy and morphology. Their various adaptations for a particular type of environment have determined where they will survive and where they will be outcompeted by organisms that are better adapted.

By definition all flowering plants have roots, stem and leaves, but some plants come close to exceptions. Some of the examples given in this chapter are interesting because they are completely leafless and stemless. **Some flowering plants are more dramatic** because these plant lacks all these basic organs for most of its life; but they are angiosperms.

Some plants in the bromeliad family are nearly rootless. In the coastal deserts South of Lima, Peru, fog is frequent but rain never falls. Because soil is always dry, roots will be of little use. *Tillandsia straminea* of the region is a small herbaceous vine that lies on top of the soil. Plants absorb moisture through leaves made wet by fog and they derive minerals from wind blown dust that dissolves on the moist leaf surface. The plants are not anchored to the soil but roll over the coastal dunes as the wind blows them. Such a life style would be impossible for a tree or bush because large plants could not absorb enough water and minerals without root.

The diversity in the angiosperms is enormous. It is appropriate if we end this brief survey of the plant kingdom with a short account of some unusual or interesting plants that have always fascinated people, botanist and non-botanist alike.

Objectives

After studying this unit you will be able to

- appreciate the range of diversity in higher plants,
- list various saprophytes, parasites and describe specially carnivorous plants,
- admire various plant curios in the plant world.

24.2 CARNIVOROUS PLANTS WITH UNUSUAL MODES OF NUTRITION

The idea of carnivory in plants has always intrigued people because it is difficult to believe that delicate objects like plants can trap and devour insects or animals. About 370 species of flowering plants belonging to 12 genera and 5 families have developed extraordinary adaptations for capturing animals for a supplement diet are *Nepenthes*, *Sarracenia* (pitcher plants), *Darlingtonia* (Cobra plant), *Dionaea* (Venus flytrap), *Drosera* (Sundew) and *Utricularia* (bladderwort).

All these carnivorous plants are capable of normal photosynthesis and of absorption of minerals from the soil. Living on the impoverished soils, they capture insects primarily as an alternative source for nitrogen, phosphorous, potassium and other minerals.

Types of Traps found in insectivorous plants

- **Active traps** (Involves rapid plant movement)
  - **Closing traps** (e.g., Venus flytrap)
  - **Trap doors** (e.g., Bladderworts)
- **Passive traps** (Involves no rapid movement)
  - **Pitfall traps** (e.g., Pitcher plants)
  - **Adhesive traps** (e.g., Sundews)

24.2.1 Bladderworts (*Utricularia* spp.)

This worldwide genus has approximately 180 species inhabiting ponds and lakes. It belongs to the family Lentibulariaceae. It consists mostly of free floating water plants with submerged leaves that are modified into bladder-shaped structures with a diameter of 0.3 to 5 mm. The bladder is a one-way door. Fluids are absorbed during the resting stage to fill the bladder with air. There are sensitive hairs located at the edge of the trapdoor, and when stimulated they cause the valve to move due to a sudden inrush of water (1/460th of a second), pulling in the aquatic organism, and then the door swings into the closed position. Digestive enzymes are secreted by the surrounding tissue, and prey are digested within several days. If prey are not captured, the trap resets within 30 minutes. When a bladderwort is lifted from the water, on which it floats, there is a fine crackling sound as the trapdoors are triggered.

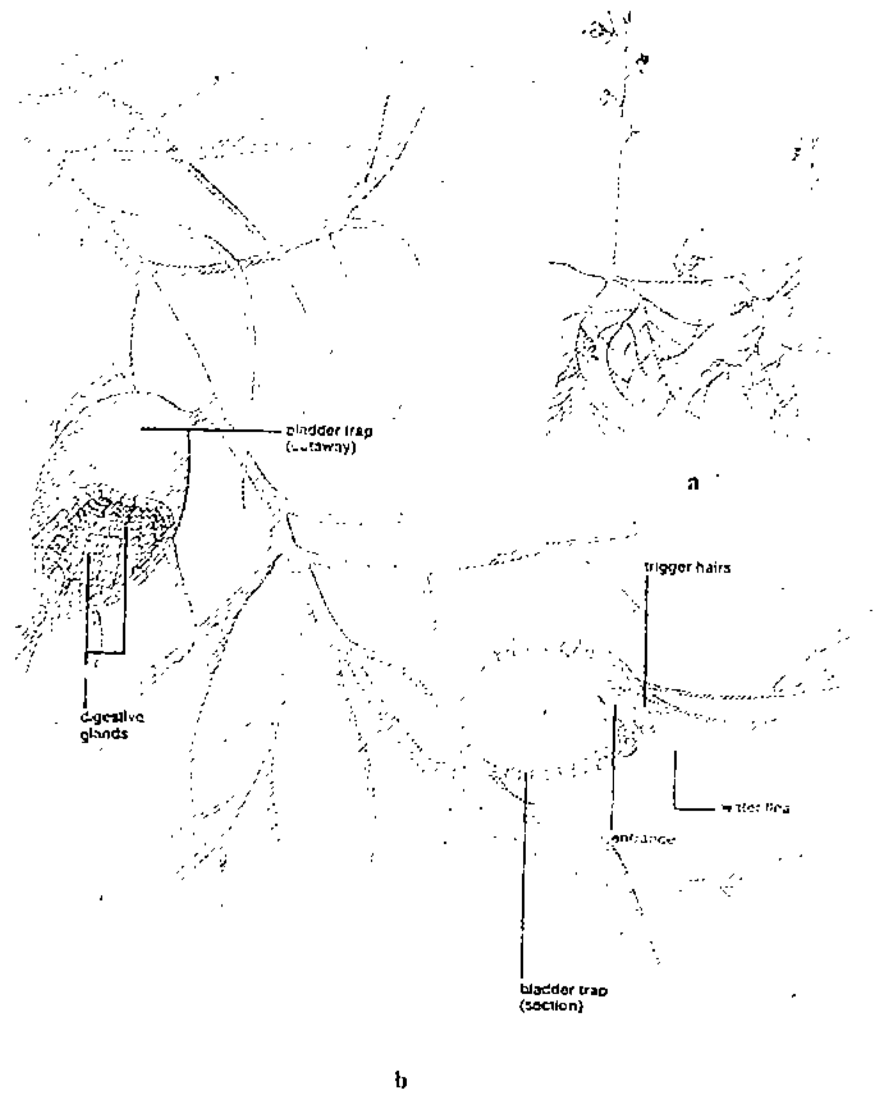

Fig. 24.1: a) *Utricularia* (bladderwort). b) Bladder trap is cut to show the digestive glands. c) Section of bladder to slow entrance and trigger hairs.

24.2.2 Venus Flytrap (*Dionaea* spp.)

The Venus flytrap, *Dionaea muscipula*, is a small terrestrial plant having rosettes of six to eight leaves bearing traps 1-3 cm (0.4-1.2 in) long. The trap is formed at the end of the leaf, the leaf stalk forming a hinge and the remainder of the leaf tissue two lobes. The edges of the lobes are equipped with a number of long spines. The spines of opposite lobes intermesh when the leaf closes. Located in a triangle on each lobe are three stiff hairs. These are about 1.5 mm long and serve to trigger off the closing of the leaf. An insect when brushes against one of the hairs, an electric charge is created but trap remains open. The hinge is activated only when a second hair movement increases the potential charge to a fixed discharge level. The electric discharge, then activates the hinge and moves across the leaf as fast as nerve impluse though there is no specialized nervous tissue. The venus's fly trap may have developed this double action trigger to avoid fruitless closing of the trap by raindrop. Once triggered the trap closes very quickly within one fifth of a second.

If no prey is caught, the trap opens within an hour. The venus flytrap are brightly coloured due to anthocyanin pigment which in turn attract insects to the plant.

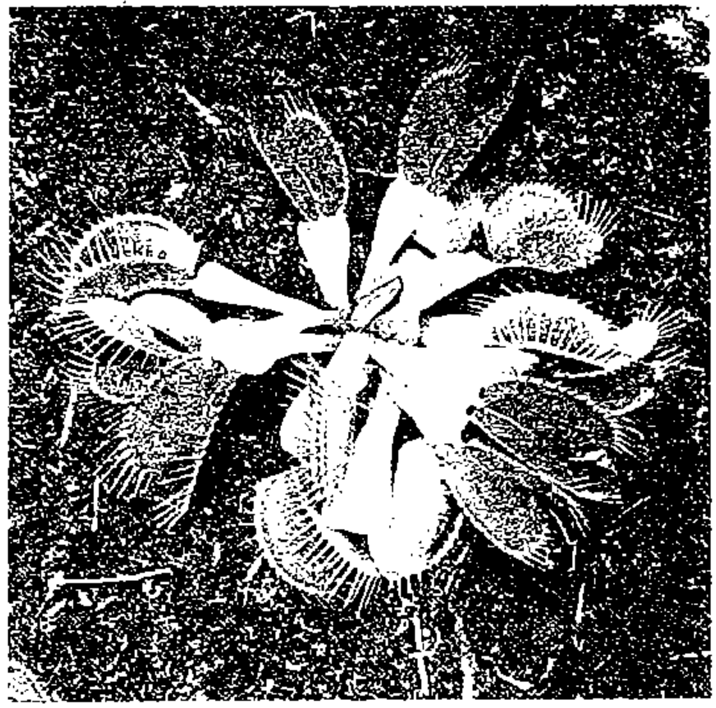

Fig. 24.2: Venus flytrap – spectacular carnivore, with open and closed traps. The inner surfaces of the leaf lobes carry bright red digestive glands.

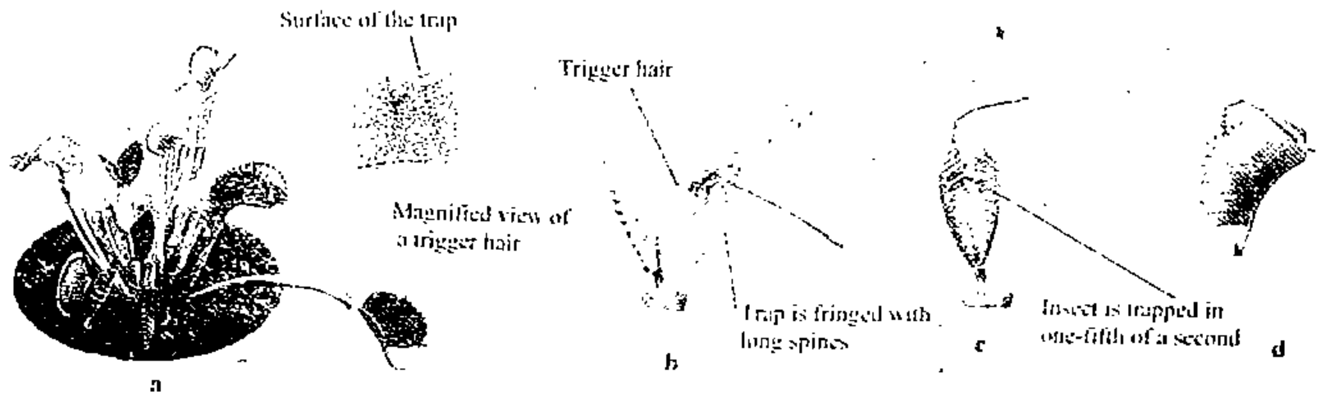

Fig. 24.3: Working of Venus flytrap. a) Full plant. b) An insect lands on a leaf touching the sensitive trigger hairs. c) The leaf closes trapping the insects by interlocking the spines. d) The trap is fully closed in 30 minutes and digestion begins.

24.2.3 Sundews (*Drosera* spp.)

The traps of the sundews, *Drosera,* the butterworts *Pinguicula* and the rainbow plant *Byblis* all use a sticky mucilage to snare insects. The blade of leaf is circular in some spp., elongated in others and is set with curious tentacles; these are emergences containing vascular bundles and ending in swollen reddish heads which secrete a sticky glistening fluid.

Flies and other insects mistaking it for honey are held by it. The tentacles are exceedingly sensitive to continued pressure even by the lightest bodies; the result is to cause an inward and downward movements of the head of the tentacle, finally placing the fly upon the blade of the leaf. At the same time the stimulus passes to the surrounding tentacles, causing them also to bend downward to the same point. The victim or insect is thus smothered, and now the glandular heads of the tentacles secrete a ferment which acts upon the prey and digestive enzyme digest the prey. Afterwards the tentacles expand once more and recommence the secretion of the sticky fluid. *Drosera* is able to live in very poor soil.

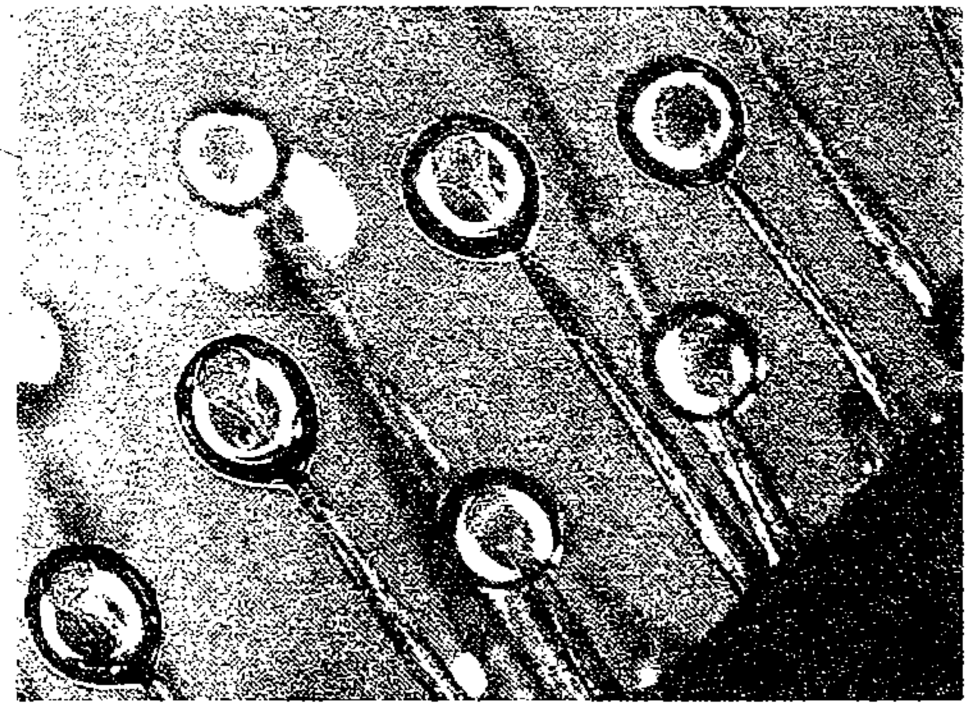

Fig. 24.4: *Drosera sp.* The stalked glands in close-up, a sticky fluid is visible which is highly viscous and sugary.

Fig. 24.5: Sundews (Drosera sp.) with a fly trapped, the sticky fluid sticks to the prey.

24.2.4 Pitcher Plants (*Nepenthes* spp., *Sarracenia* spp.)

Pitcher plants capture their prey by means of modified, cup-shaped leaves or 'pitchers' which contain digestive fluid. Insects are induced to land inside the pitcher where they lose their footing and fall into the pond of fluid below. Pitchers are often brightly coloured and attract insects. Leaves are modified into vases of various shapes and sizes; with or without umberella like flaps over the mouth. Some pitchers are formed at the terminal portion of a leaf. Plants release distinct odour to attract insects. There are nectar secreting glands at the rim of the pitcher. Seduced insects fall into the fluid at the bottom and small slippery walls prevent their climbing up. Even if they are successful in climbing up to rim, stiff downwardly projected hairs prevent further passage. Eventually they die and are digested by the plants with the help of digestive enzymes and bacteria. Why do plants have to eat animals? Obviously these plants grow in soils lacking few essential nutrients. The nutrient deficit is made up by eating insects. Experimental studies have shown that when these plants are grown under standard conditions with all essential nutrients, these plants turn out to be 'nonviolent', and do not require to develop any traps or eat animals.

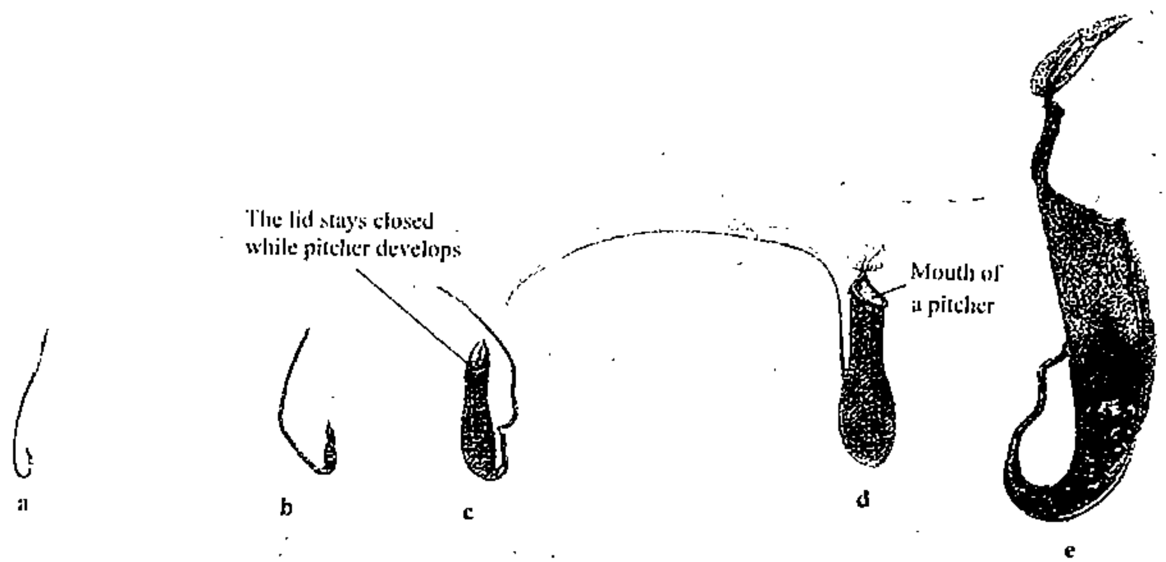

Fig. 24.6: Development of pitcherplant a) A young leaf tip extends into a tendril b) An upturned swelling appears at the end. c) The swellings develop into a pitcher d) The lid opens when the pitcher is mature. e) Pitcher plants where a portion of pitcher is removed so insects can be seen.

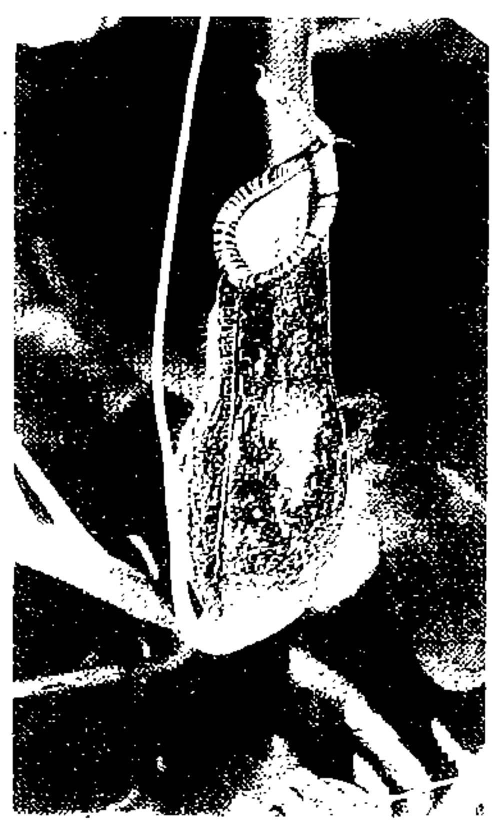

Fig. 24.7: A brightly coloured pitcher plant.

The biggest prey that the largest of tropical pitchers, *Nepenthes* can hold is a small rodent or a bird. However, some spiders can live in easy association with some pitchers. One species of spider regularly spins its web at the mouth of the pitcher.

Nepenthes khasiana is the only species found in India (Meghalaya) which is also endemic. Its pitcher measures upto 12cms.

Despite this prodigious digestive capacity there are some insects which are able to live within the pitchers. Larvae of the mosquito *Wyeomyia smithii* live in the pitcher of *Sarracenia purpurea* and the adult have no difficulty aligning on the walls or flying out of the pitcher.

SAQ 1

Match the botanical names of the following species by their common names.

1)	*Dionaea*	a)	Pitcher plant
2)	*Drosera*	b)	Bladderwort
3)	*Utricularia*	c)	Venus flytrap
4)	*Nepenthes*	d)	Sundew

24.3 SAPROPHYTIC PLANTS

Nearly all angiosperms are autotrophic (i.e., they have chlorophyll and can synthesize their food in the presence of sunlight), but there are a number of plant species that have lost their chlorophyll pigment and, therefore, depend on non-autotrophic mode of nutrition.

These are about 400 species of non-chlorophyllous parasitic angiosperms. They derive their nutrition through mycorrhizal association with fungi and are known as saprophytes. These plants make use of organic compound and the water of living plants by actually penetrating the host plant. Parasites exhibit a wide range of structural modification and adaptation for their successful survival

All the mycorrhizal associations perhaps the most amazing are the strange and unusual flowering plants that are also intimately connected with fungus-root partnership and are called in botanical circles as "mycotrophic wild flowers or fungus flowers". Since they live parasitically on fungi that are in turn parasitic on the roots of trees, they are termed as epiparasites (a parasite on a parasite). Unlike true root parasites like *Orobanche,* they can be compared to mushroom since they are also non-chlorophyllous and fleshy but unlike them they are true vascular plants with flowers and seeds. Since many of these mycotrophic wild flowers are non-photosynthetic, they were once thought to be saprophytic (i.e. surviving on nutrients from decaying organic matter in the soil). Now we know that these species are getting their organic nutrients from the forest trees growing in the vicinity through a microscopic channel of mycorrhizal soil fungi. This type of food exploitation by these unusual plants shows the height of adaptations which angiosperms have reached.

In saprophytes (non photosynthetic plants) the organic carbon is obtained from the cellulosic cell walls. However, higher plants are unable to do this themselves but fungi in a mycorrhizal association with roots of the saprophytic vascular plants can break down cellulose and transfer the carbon compounds to the plants.

Most of these species belong to Monótropaceae (the Indian pipe family) or the closely related Ericaceae (heath family). The world's second largest plant family Orchidaceae has also been found to channelise its food source with several mycotrophic species.

Some 'fungus flowers' are cream-beige coloured and fleshy like fungus e.g. *Monotropa uniflora* (Indian pipe), *Hemitomes congestum* (gnome plant), *Pityopus californicus* (pinefoot) and *Pleuricospora fimbriolata* (fringed pinesap). Several of these 'fungus flowers' have been reported from the shady coniferous forests of the Pacific coastal states of America. Another ghostly white plant is the rare phantom orchid (*Cephalanthera austinae*). Many a times these fungus flowers are mistaken for the fruiting body of a fungus.

Other mycotrophic flowers are quite colourful. *Pterospora andromedea* and *Hypopitys monotropa* (American pine sap, the name 'pinesap' may refer to the fact that these plants commonly grow under pines or other conifers and 'sap' their juices.) are pinkish red. *Sarcodes sanguinea* is brilliant red and called brilliant red snow plant, *Allotropa virgata* has the striking red and white striped resembling pepper stick, *Corallorhiza maculata* and *C. striata* are lovely coral root orchids. One character is common in all these wild flowers that they develop from a mass of fungal hyphae and tree roots deep in the ground and in *Corallorhiza* this fleshy mass resembles a clump of soft corals.

SAQ 2

Describe some saprophytic plants. Why are these plants called mycotrophic? If these plants resemble mushrooms, then why have they been classified into angiosperms?

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24.4 PARASITIC PLANTS

Plants that live at the cost of other plants partially (hemiparasites) or fully (holoparasites), are known to be successful parasites. An organism (a plant species in this case) need to be capable of recognising its host and successfully attacking and penetrating host's tissues to suck nutrients with the help of suitable specialized structures (haustoria). An haustorium is an absorbing organ which penetrates the host's tissue and gets closely connected with xylem or phloem or both share such relationship that the host cell form plasmodesmata with the cells of parasite. The parasite should be able to stick to hosts body (root, stem or leaf) for a longer duration to complete its mission and should be able to reproduce much faster as compared to its host. An obligate parasite severely affects the growth and development of host. A partial parasite follows a startegy of "live and let the host also live".

Ironically largest flowers and smallest flowers are found as parasites only.

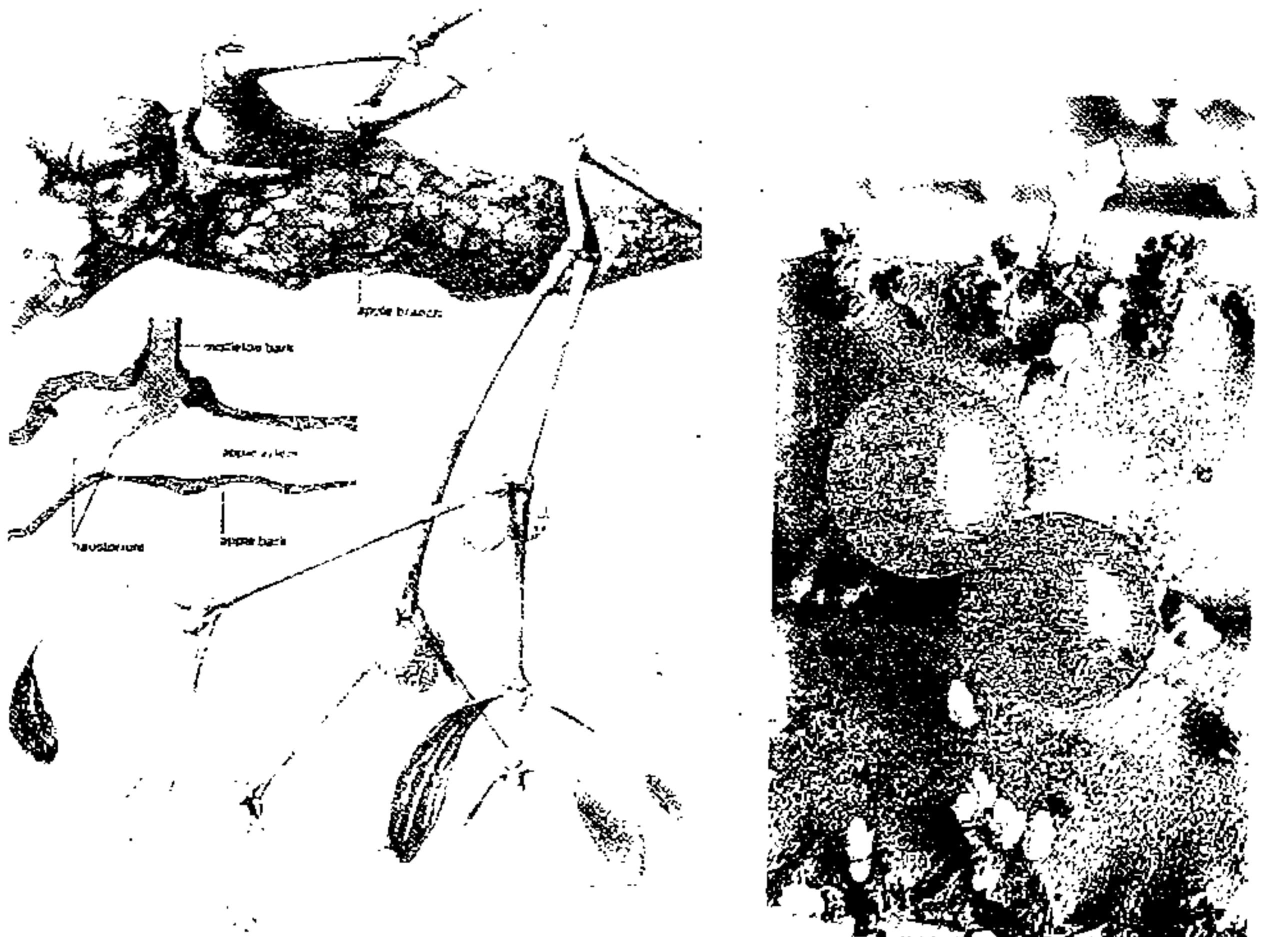
24.4.1 Stem Parasites

These are the types which can be termed as true epiphytic holo-parasites because they grow on stem, leaf or on aerial parts of the plant.

Parasitism has also evolved in many families of flowering plants. Some of the important stem parasite genera in the new and old world are mistletoes. *Viscum, Phoradendron, Arceuthobium* belong to the family Viscaceae, and *Loranthus* to the Loranthaceae, Dodder (*Cuscuta*) of the family Cuscutaceae.

The legendary mistletoe was known for centuries before Christian era. In some parts of Europe the midsummer gathering of mistletoe is still associated with the burning of bonfires, a remnant of sacrificial ceremonies performed by ancient priest or druids. Mistletoe was once believed to have magic powers as well as medicinal properties. It was used as a cure for sterility and as an antidote for poisons. Later, the custom developed in England (and, still later, the United States) of kissing under the mistletoe, an action that once was believed to lead inevitably to marriage.

The mistletoe *Viscum album* has been found to grow on *Acer, Alnus* and *Salix* and other deciduous trees. Different species of mistletoe typically grow on different host trees and shrubs. Desert mistletoe (*Phoradendron californicum*) commonly grows on *Acacia greggie*. Desert mistletoes produce juicy bright red berries that provide food and water to numerous birds during winter months. The seeds of mistletoes are transported from one bush to other by birds. In fact the word is derived from two Germanic words: Mista (dung) and tan (twig) referring to birds droppings on branches or stem.



b)

Fig. 24.8: a) *Viscum album* showing sticky fruits which cling to the birds beak. The portion of apple tree where misletoe had connected itself to the host through haustorium b) *Viscum minimum* tropical misletoe with red fruit.

Fig. 24.9: *Arceuthobium* sp. only the flowers are visible out of the host tree.

The leafless flowering dwarf mistletoes depend entirely on the host tree for nourishment. They are lethal parasites of conifers such as pine, spruce, fir and hemlock. Pine or dwarf mistletoe (*Arceuthobium*) is specially interesting because it grows only on different species of pines and produces white berries. Because the sap within the berries develops considerable hydrostatic pressure causing them to explode when they are ripe. Seeds only three milimeters long may shoot up to 49 feet (15 m) laterally, with an initial velocity of about 62 miles (100 km) per hour. *Arceuthobium minutissimum* occurs on *Pinus wallichiana* and is found in Jammu and Kashmir.

Another very interesting endophytic holoparasitic mistletoe is *Tristerix aphyllus* that infects some of the cacti like *Trichocereus chilensis* in Centre Chile. A bird deposits seeds of *T. aphyllus* onto a cactus and once the seed germinates, seedling roots which are filamentous, hairlike pass through stomata into highly cytoplasmic cells of the cactus cortex. The rest of the seedling outside the host dies. The whole plant body of the mistletoe is thus nothing more than a filamentous web of parenchyma, no organs not even vascular tissue. At the time of flowering, nodules emerge out of epidermis of cacti and form flowers. They also die as soon as the fruit is ripe. Although at first glance it appears to be bizarre, an understanding of its special habitat reveals that its anatomy and development are quite logical and adaptive to the environment in which they grow.

Another common stem parasite is dodder or witches hair (*Cuscuta*), a member of family Cuscutaceae. *Cuscuta* is non-photosynthetic and an obligate parasite that is completely dependent on its host for water and nutrients. At maturity dodders resemble tangled masses of orange sphagetti-like strands twining over shrubs. They produce white flowers that resemble miniature morning glory.

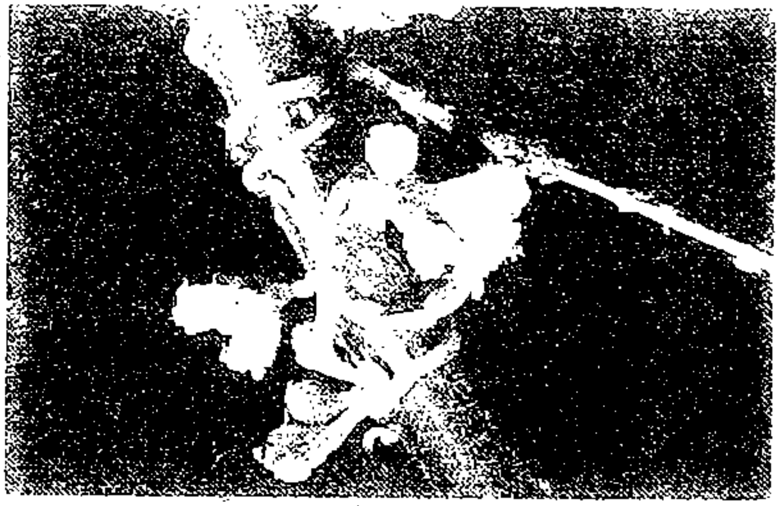
Dodder absorbs water, minerals and carbohydrates from host through haustoria that penetrate the host's tissue. The haustoria here are modified adventitious roots. Dodder is said to contain some chlorophyll in the buds, fruits and stems, but the amount of food manufactured in these is of little significance to the survival of the plant. Dodder produces seed that drops to the ground and germinates the next growing season if a suitable host is present. If no suitable host is present, the seed may remain dormant for five years.

Dodder seedlings must attach to a suitable host within a few days of germinating or they die. The young seedling is sensitive to touch and yellowish stem gropes in the air until it makes contact with a plant. The contact is made firm by one or more coils about the stem. If this plant happens to contain foods suitable to the dodder then a secondary stimulus is aroused which causes root like branches haustoria to form and penetrate the stem. The basal part of the parasite soon shrivels away so that no soil connection exists. Dodder has been shown to spread the yellow disease pear decline, aster yellows, tomato big bud. Thus dodder is capable of transmitting plant diseases in field or garden area.

Mistletoes have been collected by people for various reasons. European mistletoe is a symbol of strength and good fortune, as a powerful and magical cure all medicine. However, the kissing tradition at Christmas appears to be of recent in origin and has gained tremendous popularity in North America.

A similar appearing dodder of many Carribean island is *Cassytha filiformis*. This dodder belongs to the family Lauraceae and entirely different from the genus *Cuscuta*. This is a good example of **convergent evolution in which a single genus in each family has developed a parasitic mode of life.**

The other extreme of endophytic holo-parasite belonging to the family Rafflesiacae is a tiny stem endoparasite named *Pilostyles thurberi* native to the southwestern United States and Mexico. Like *Rafflesia* it has no roots, stems or leaves. It is completely dependent upon the sweet-smelling, desert shrub called dyeweed (*Psorothamnus emoryi*) belonging to pea family (Fabaceae) for water and other vital nutrients. The only visible parts are tiny reddish-brown, unisexual, fleshy flowers, 2-3 mm in diameter when fully opened, and appear somewhat like the scars left by acne or head of an ordinary straight pin.



a

b

Fig. 24.10: Cuscuta spp. a) Dodder with flower. b) Magnified haustoria.

24.4.2 Root Parasites

Some of the strangest and most beautiful flowers on earth come from root parasites. There are several fascinating families in both old and new world regions including Rafflesiaceae, Broomrape family (Orobanchaceae), Lennoa family (Lennoaceae), Sandalwood family (Santalaceae) and Balanophora family (Balanophoraceae). They are different from mycotrophic flowers as they do not channelise their nutrient absorption through fungal net work instead they have a direct association with plant roots. This is truly an amazing symbiotic association for survival.

Rafflesiaceae is a strange and little known family of parasitic flowering plants scattered throughout tropical and subtropical regions of the world. One member of the family, *Rafflesia arnoldii* (the infamous "stinking corpse lily") produces the largest individual flower on earth, and is truly a wonder of the plant kingdom. Unlike most flowering plants, it has no leaves or stems and grows endophytically as a holo-parasite within the woody roots of its host vine *Tetrastigma*, a relative of grape (*Vitis*). A large flower bud resembling a pale orange cabbage breaks through the bark of the host vine and expands into an enormous blossom upto 3 feet (0.9 m) in diameter and weighing up to 25 pounds (11 kg). The gigantic unisexual flower has five fleshy red lobes (sepals) spattered with raised white spots with an odour reminiscent of a stinking corpse.

Box 24.1: *Rafflesia arnoldii*

It has been called the "giant panda of the plant world" because this rare and endangered species only occurs in the rainforests of Sumatra and Borneo in the Malay.

The chances of its seed finding a host vine are slim and the massive deforestation of rain forests further decreased the odds of this remarkable event. Recently the governments of Indonesia and Malaysia have realised the marketable curiosity value of this plant and ecological preserves are being established to conserve them in-situ.

SAQ 3

Make a list of some stem parasites.

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24.5 SOME PLANT CURIOS

24.5.1 Tallest Flowering Plant

The tallest tree is cone-bearing tree native to California, the coast redwood (*Sequoia sempervirens*). The tallest living redwood on record stands 367 feet, 62 feet taller than the Statue of Liberty. The record for the tallest tree of all time has been debated by botanists for centuries. The amazing flowering Australian tree (*Eucalyptus regnans*) is 18 feet in diameter and 435 feet tall, it was reported by William Ferguson making it the tallest (perhaps longest) dead tree. The trees of *E. regnans* are measured well over 300 feet but the tallest tree known to the standing at present is 322 feet (Monograph on *Eucalyptus* by Stan Kelly, Vol I, 1977).

24.5.2 Most Massive Living Tree

Giant sequoia (*Sequoiadendron giganteum*) have the world longevity record. The greatest authenticated age of a giant sequoia, was nearly 3,200 years. Although it may fall short of the world's oldest, the giant sequoia has the undisputed record for the world's most massive living thing. The largest tree, named General Sherman, is 272 feet tall with a massive trunk 35 feet in diameter and 109 feet in circumference at the base. Even more remarkable is the fact that a point 120 feet in the air the trunk of General Sherman is still 17 feet in diameter. It has been estimated to contain over 600,000 board feet of timber, enough to build 120 average sized houses. The trunk of General Sherman alone weighs nearly 1400 tons.

Another conifer species called the Montezuma bald cypress (*Taxodium mucronatum*) occasionally grows into a huge tree. One enormous specimen of this tree grows in the churchyard of Santa Maria de Tule near Oaxca Mexico called "El Gigante" by the locals, it is one of the most massive of all living things, with a trunk circumference of 140 feet – larger than General Sherman – giant sequoia. The trunk of this tree is 50 feet in diameter. This tree was once thought to be 10,000 years old, but botanists now consider it to be a youngster of only 1500 to 2000 years.

The Indian banyan (*Ficus benghalensis*) also have enormous trunks upto 100 feet or more in circumference, but do not grow tall.

Box 24.2: The great banyan tree.

One of the largest trees on record grew at the Indian Botanic Garden, Calcutta. It is listed in the **Guinness Book of World Records (1985)** as the world's largest (spreading) tree crown, with 1000 prop roots and covering an area of four acres. The canopy of some banyans provides shade for entire villages. Alexander the Great reportedly camped with an army of 7000 soldiers under a banyan. The Hindus regard the banyan as sacred, for it is said that Buddha sat under its shade for six years while he developed his philosophy of the meaning of existence. The striking heart-shaped leaves of the banyan tree tremble in the slightest breeze like a cottonwood – a legendary tribute to the divine meditations of Buddha. The English name "banyan" comes from the "banias", or Hindu merchants who set up markets in the shade of these enormous trees.

24.5.3 The Hardest, Heaviest and Lightest Wood

At least a dozen species of flowering trees called "ironwoods" hold the title of world's heaviest wood. Wood is composed of dead cells of a tree trunk, particularly the inner xylem tissue when the bark is removed. Certainly one of the world's heaviest and hardest ironwoods is the Caribbean tree called lignum vitae (*Guaiacum officinale*), with a specific gravity of 1.37. The name lignum vitae means "wood of life", owing to the medicinal properties of the sweet-smelling resin. The density and high resin content of the wood make it extremely resistant to friction and abrasion and account for its remarkable self-lubrication properties. Under certain conditions it actually wears better than iron. By way of contrast, cork bark from the European cork oak (*Quercus suber*) has a specific gravity of 0.24; and the tropical American balsawood tree (*Ochroma pyramidale*) is one of the world's softest and lightest woods with a specific gravity of only 0.19.

24.5.4 Smallest Flowering Plants

The duckweed family (Lemnaceae) contains about 36 species of minute flowering plants, floating at the surface of ponds, swamps and quiet streams. They are distributed throughout the world, particularly in warm temperature and tropical region. They are greatly reduced flowering plants, without leaves or stems and with only the remnants of vascular tissue in some species. The family contains four genera based upon the presence or absence of roots and the shape of their plant body. Members of the genus *Wolffia* are the ultimate in reduction of a flowering plant consisting of tiny, rootless spheres only 1mm long (or less). The common name "water meal" is often used for *Wolffia* sp. because they look and feel like small mealy particles in the water.

It is a small enough to slip through the eye of an ordinary sewing needle and at least 5000 plants could be packed into a thimble. Each plant produces a microscopic flower inside a small cavity that develops on the upper side of the plant. The minute flower consists of a single pistil and stamen. Since the stigma is generally receptive before the anther is matures, the flower typically requires cross-pollination. After pollination the ovary develops into a tiny one seeded fruit called a utricle which is also the world's smallest fruit. The fruit is about the size of a cuboidal grain of ordinary table salt (0.3 mm long) and weighs about 70 micrograms.

The world's smallest flowering plant also has one of the most rapid rates of vegetative reproduction. The Indian species *Wolffia microscopica*, can produce a smaller daughter plant in its basal reproductive pouch by budding every 30-36 hours. One plant could theoretically give rise to about one million plants (1 followed by 30 zeros) in four months. They are quite palatable and have about 40% protein (dry weight) similar to soybean. *Wolffia* is a plausible food source for people. In Thailand *W. globosa* is known as Khai-nam (water eggs) and is eaten by people.

The record for the fastest growth of an individual goes to a tropical species of bamboo that reaches 100 feet in three months. Growth increments of three feet a day have been recorded-an astonishing 0.0002 miles per hour.

Two of the smallest species are *Wolffia angusta* an Australian species and worldwide tropical species *W. globosa*. The entire plant body of these two species is less than one mm long (less than 1/25th of an inch) and it is difficult to say which is the smaller of the two, but perhaps *W. globosa* may be slightly smaller. An average individual plant is 0.6 mm long (1/42 of an inch) and 0.3 mm wide (1/85 of an inch). It weighs about 150 micrograms (1/90,000 of an ounce) or the approximate weight of two ordinary grains of table salt.

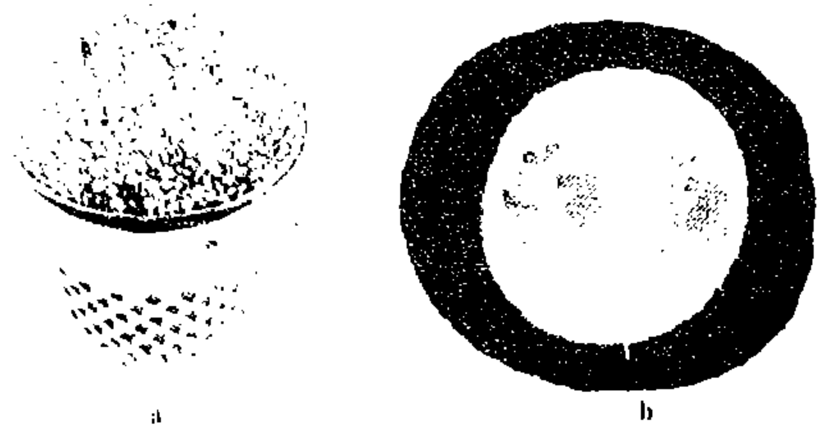


Fig. 24.11: a) Wolffia sp. in a thimble. b) Two plants can easily fit in single typed letter O.

24.5.5 Largest Leaf

Victoria amazonica (giant water lily or Royal water lily) of Nymphaeaceae of monocots bears world's largest known leaves.

This hydrophyte grows in tropical South American fresh water bodies. The more or less circular floating leaves are attached by thick, rope-like stalk to rootstocks. The leaves are 2-3 m in diameter. The leaf can easily support weight of a new born baby to a maximum of 40-75 kg if the load is evenly distributed. The edge of the leaf is turned upto a height of several cm, and on the lower side the ribs projects and are armed with spines. It was discovered in 1801 and brought to general notice in 1837.

Fig. 24.12: *Victoria amazonica* leaf showing notches.

In mid 1800 it was introduced as the 'Giant Water-Platter'. Initially named *Victoria regia* in honor of the Queen of England, its name was later changed to *V. amazonica*. It is native to equatorial Brazil where it grows in calm water along the river Amazon, in ox-bow lakes (former river channels) and in flooded grasslands. Its huge glossy green leaves grow to seven feet in diameter, with a pronounced maroon lip around the circumference. The lip is notched in two places to drain rainwater. Whole plant of *Victoria* is covered with flesh-piercing spines, only the roots, flowers and the upper sides of the leaves are spine free. The lush, 12-inch flower opens at night, heralded by a fruity fragrance described as reminiscent of pineapple.

A second recognised species *Victoria cruziana*, is found in the cooler waterways of Argentina and Paraguay. It has smaller leaves (only four to six feet), a higher lip that is generally green, and is obviously more cold tolerant.

24.5.6 Largest Inflorescence among the Flowering Plants

Amorphophallus titanium, belonging to arum family, is the largest flower in terms of sheer bulk but technically it is an inflorescence. It is found only in equatorial tropical rain forests of Sumatra, Indonesia. It is also known as the Titan Arum, Bunga Bangkai or 'Corpse flower' or 'Devil's tongue' or kurbi. It was discovered in Sumatra by Italian botanist Odoardo Beccari in 1878.

Thousands of true flowers are hidden inside the base of the spadix (the fleshy central column). A single stalk grows several feet tall (12 feet in cultivation, in wild it can reach up to 20 feet) and as thick as a person's thigh before branching into compound leaf. The single huge umbrella-like frilly structure enclosing the spadix is called the spathe and is itself quite 'titanic'. The unfurled spathe resembles an upturned fluted bell with a maroon interior. Male and female flowers are separate. A fully opened flower emits a repulsive smell (hence its Indonesian common name) bunga bangkai meaning corpse flower.

The Bolivian bromeliad, *Puya raimondii* produces one of the largest flower clusters or inflorescences. The individual flower stalk may be over 30 feet tall, bearing more than 8,000 white blossoms. This enormous flower stalk is rivalled by some species of *Agave*. According to Charles E. Hubbuch, Director of Plant Collections at the Fairchild Tropical Garden in Coral Gables, Florida, the talipot palm (*Corypha umbraculifera*) of India has the largest inflorescence of any plant. The huge inflorescence may be 10 meters (over 30 feet) tall with millions of flowers.

Fig. 24.13: *Amorphophallus titanium*.

In cultivation it can reach over 12 feet high and 6 feet across, in wild it can attain the height of 20 feet and 15 feet across.

Ultimate size for mature *Amorphophallus titanium*

Inflorescence height	7 to 12 feet
Leaf height	20 feet
Leaf width	15 feet
Tuber	120 to 160 pound

24.5.7 Largest Flower in the World

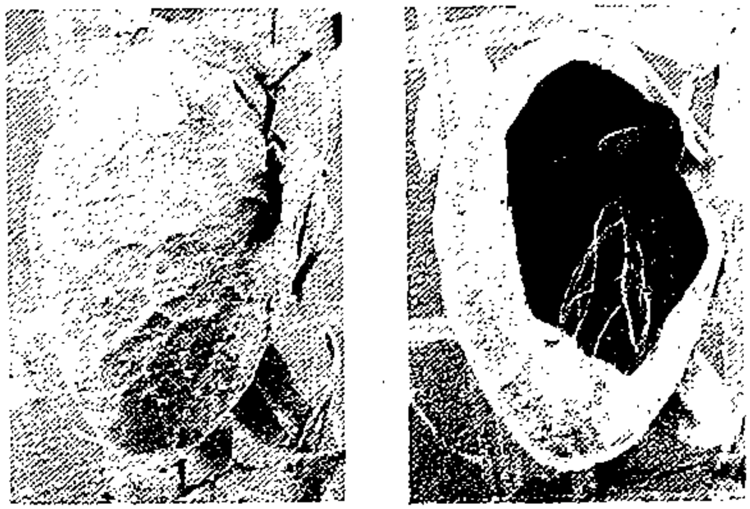
In true sense *Rafflesia arnoldii* of family Rafflesiaceae also a 'stinking corpse flower' is compatriot of 'Titan Arum'. Though not as large as *Amorphophallus titanium*, it is a single flower, not an inflorescence. Again a native of rainforests of Sumatra and Borneo. *Rafflesia* sp. grows wild in Thailand, Malaysia, Indonesia and Philippines. The plant is an endophytic holoparasite on roots of *Cissus* vines. *Rafflesia* bud erupts from the host vine as a dark lump and slowly swells for some 9 months before opening. Flowers last less than a week. They are prettiest for the first day or two, after that flesh darkens and finally collapses. The large, pink, with or without white protruding spots, five lobed flowers are pollinated by carrion flies. It grows up to 91 cms (36 in) in width, with petals 3 cms (1 in) thick and 46 cms (18 in) long, and weighs as much as 7 kg (15 lb.).

In India a close relative of the *Rafflesia* known as *Sapria himalayana* is present. This species was discovered by Griffith in Mishmi hills in eastern himalaya. The flower of this species is 35 cm in diameter and is highly endangered today.

Fig. 24.14: *Rafflesia arnoldii*.

24.5.8 Flower Pot Leaves

Dischidia rafflesiana (Asclepiadaceae) is an epiphytic climber found in Assam. The pitchers or flowerpots are modifications of leaves but it has nothing to do with insect catching. It usually contains a lot of debris, largely carried into it by nesting ants. Most of these contain rain water, so that perhaps they act as humus collectors and water reservoirs. The inner surface is waxy, so that the water cannot be absorbed by the pitcher itself, but must be taken up by the adventitious root which grows out from the stem nodes and ramifies within the cavity. The roots grow down into soil when detached from parent plant and this helps in vegetative propagation.



(a) b

Fig. 24.15: *Dischidia* sp. provides ants' a nest box b) a clumps of roots which absorbs nutrients from ants' dropping.

24.5.9 Window Leaves

In Kalahari desert of South Africa there are atleast three plant species belonging to carpetweed family Aizoaceae that use unique adaptations suitable to dry and sandy habitat. The two genera, *Lithops* and *Conophytum* (Living stones) are notable for the way they mimic the stones among which they grow. The chlorophyll bearing part of the plants is below ground level; the plants consist of a few swollen leaves the upper surface of which is transluscent allowing light to pass down into the lower part of the leaf where the chlorophyll is found. *Lithops* and *Conophytum*, may survive many years of drought, finally flowering soon after the first rainfall. This arrangement which keeps most of the plant buried and away from drying winds, allows the plant to thrive under circumstances that most other plants could not tolerate.

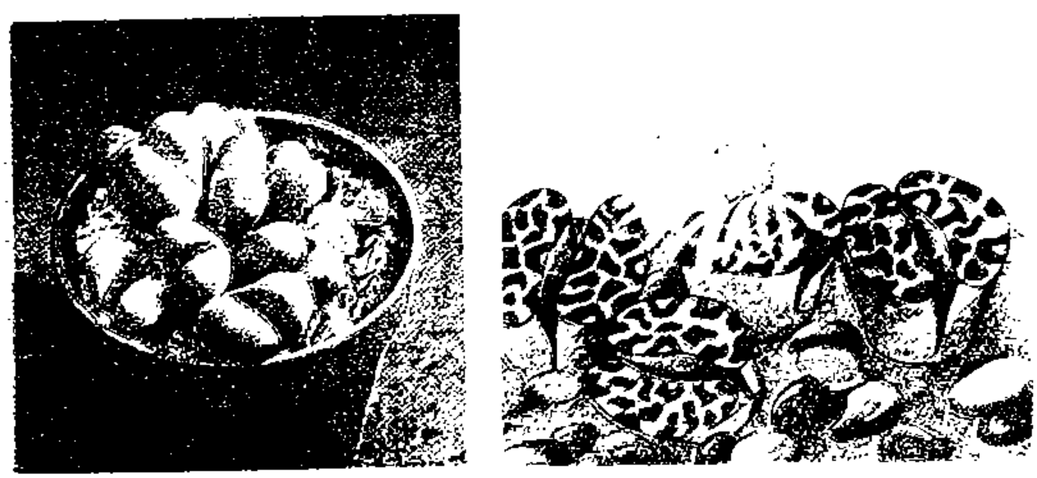


Fig. 24.16: *Lithops rubra* which mimics the stone and are translucent.

24.5.10 Baobab

Adansonia digitata, Bombacaceae, is the baobab. Its height is not great, but the trunk may reach 9 m in thickness. The trunk is barrel-like and may reach a diameter of 9 meters (30 feet) and a height of 18 m. The large, gourdlike, woody fruit contains a tasty mucilaginous pulp. A strong fibre from the bark is used locally for rope and cloth. The trunks are often excavated to serve as water reserves or temporary shelters. One of the largest trees in the world is estimated to be more than 2000 year old.

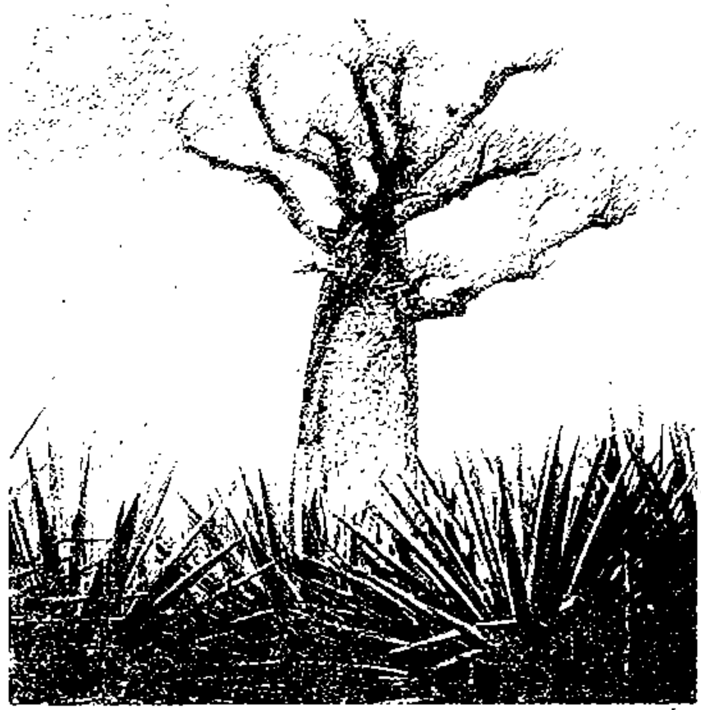


Fig. 24.17: *Adansonia digitata.*

24.5.11 Stinging Nettle

Urtica = Latin from urotoburn or sting, dioica :di = two oecos = house i.e. sexes on separate plant.

Many of the most successful weed species are plants with well developed defences against large herbivores. In addition to preventing the plants from being eaten, these defences also inhibit animal movements. The common stinging nettle (*Urtica dioica*) employs sophisticated stinging hairs that act like a hypodermic syringe and squirts a mixture of acid, histamine and other substances that irritate the skin and cause reddening, itching and swelling. Any animal receiving such a mixture subcutaneously will probably cease feeding and retreat. The plant can form large colonies in orchards, farmyard, old pastures, ditches and waste places. In the tree nettle, *Urtica ferox* which is native to New Zealand the stings can be fatal.

Fig. 24.18: Stinging nettle.

24.5.12 The Botanical Jewels

There are some botanical gems that rival some of natural jewelleries in value and beauty. Certainly the rarest and most valuable botanical jewel is the legendary "coconut pearl" that occasionally forms inside a coconut (*Cocos nucifera*). It is difficult to place a monetory value on a genuine coconut pearl, but the odds of finding one in a coconut are certainly less than one in a million. To put it another way, if you cracked open and thoroughly examined one coconut every 15 minutes during a normal eight hour work day, it would take roughly 80 years to go through a million coconuts. In his classic six-volume work entitled 'Herbarium Amboinense', the distinguished 17^{th}-18^{th} century naturalist Georg Eberhard Rumphius described and illustrated exquisite coconut pearls, often mounted in jewelled settings of gold and silver, owned by Malaysian dynasties.

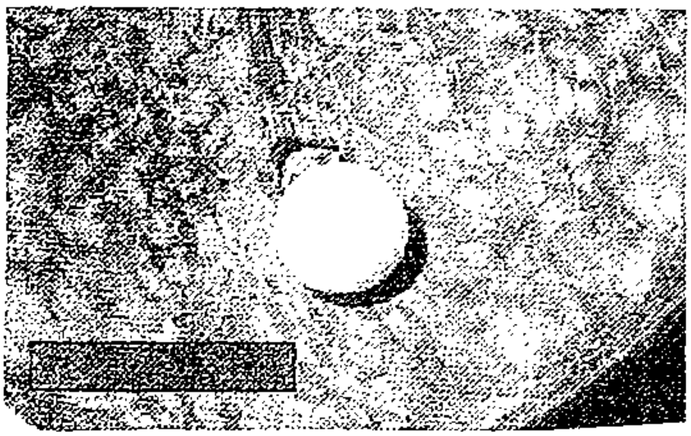


Fig. 24.19: Coconut fruit with coconut pearl.

24.6 SEED AND FRUIT

Seed and fruit characteristics vary greatly among the angiosperms. The size of seed vary from those of the epiphyte orchids, which average about 1.2 million per gram, to those of the double coconut, *Lodoicea seychellarum* (*L. maldivica*) which weigh on an average 15 – 20 kg. It takes 10 years to ripen. The distribution of these enormous plants is correspondingly limited. They are found on two islands in Seychelles.

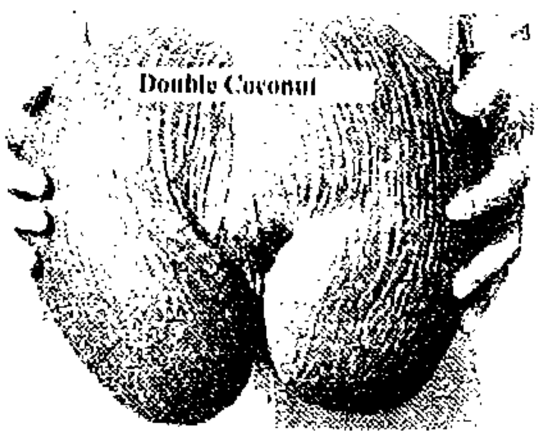


Fig. 24.20: *Lodoicea seychellarum.*

SAQ 4

Write notes on the following

1. Largest tree

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2. Smallest flowering plant

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3. Largest inflorescence

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4. Largest leaf

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24.7 SOME SPECIAL MONOCOTS

Three important tropical monocot families are agave families, Agavaceae, the bromelid family Bromeliaceae and the banana family Musaceae.

***Agave* and *Yucca* species** are found from the southern United States down into South America. Many species of *Agave* have very long life cycles, growing from 60 to 100 years before flowering and dying hence their common name of "Century Plants". *Yucca* has a special pollination mechanism involving the moth *Pronuba*. The moth lays its eggs in the ovary of the *Yucca* flower, and then deposits pollen, previously collected from another plant, on the stigma. It thus ensures that enough ovules develop both to feed its caterpillars and to perpetuate the yucca, which can only be pollinated by the moth. Neither the moth nor the yucca can survive without the other.

Ravenala madagascariensis

The traveller's tree (family Musaceae) usually grows in Oasis of deserts, so-called because the water that accumulates in the woody leaf bases of fan like arranged leaves has been used for drinking in cases of necessity. It may be taken out by piercing the base with knife. The plant has a true sub-aerial stem, which bears large 2-ranked leaves giving it a peculiar fan-like appearance.

Fig. 24.21: *Ravenala madagascariensis.*

24.8 SUMMARY

In this unit you have studied about extreme variation in stem, leaf and flower.

- Plants are autotrophic but some are carnivorous, saprophytic and parasitic. Some plants live on insects and are able to grow on poor-mineral-deficient habitats. They have different mechanisms to catch their prey.
- The seeds being an important part of the plants show a great deal of variation in size, structure, shape, nutrients and mode of dispersal.
- Some special monocot *Yucca* and *Ravenala* have special features.

24.9 TERMINAL QUESTIONS

1. Make a list of carnivorous plants and describe any one of them.

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2. Write short notes on stem parasites.

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3. Write short account on carnivorous plant.

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4. Give a short account of five plant curious of your choice.

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24.10 ANSWERS

Self-assessment Questions

1. 1-c, 2-d, 3-a, 4-b.
2. Refer to Section 24.3.
3. Refer to Subsection 24.4.1 and 24.4.2.
4. See Section 24.5: Some Plant Curios.

Terminal Questions

1. See Section 24.2.
2. See Subsection 24.4.1.
3. See Section 24.2.
4. See Section 24.5.

FURTHER READING

1. Takhtajan, A 1997, Diversity and Classification of Flowering Plants. Columbia University Press, New York.

Acknowledgement

The sites http://daphne.palomar.edu/ and http://www.ftg.org/ are acknowledged for some Figures used in Unit 24.

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