M.Sc. Previous Year

Botany, MB-04

TAXONOMY AND DIVERSITY OF SEED PLANTS

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Published by Registrar, MP Bhoj (Open) University, Bhopal in 2020

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E-28, Sector-8, Noida - 201301 (UP)
Phone: 0120-4078900 • Fax: 0120-4078999
Regd. Office: A-27, 2nd Floor, Mohan Co-operative Industrial Estate, New Delhi 1100 44
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INTRODUCTION

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Plant taxonomy is the science that finds, identifies, describes, classifies, and names plants. Principally, the term 'Plant Taxonomy' is closely allied to plant systematics, and there is no sharp boundary between the two. In practice, 'Plant Systematics' involves relationships between plants and their evolution, especially at the higher levels, whereas 'Plant Taxonomy' deals with the actual handling of plant specimens. The precise relationship between taxonomy and systematics, however, has changed along with the goals and methods employed. The classification of plants results in an organized system for the naming and cataloging of specimens, and also the scientific ideas about inter-relationships between plants. The set of rules and recommendations for formal botanical nomenclature, including plants, is governed by the International Code of Nomenclature (ICN).

The term Gymnosperms means naked seeds. Gymnosperm seeds are often configured as cones. These plants do not have flowers and hence the seeds do not form inside any specialized structure like the ovary seen in the other group of plants, i.e., angiosperms. Rather, the seeds develop in on the surface of the reproductive structures of the plants and are visible as cones on maturity. The seeds can sometimes be found on short stalks too. Gymnosperms have an evolutionary significance and show some unique features. Their characteristic feature is the absence of flowers and presence of naked, open seeds. As they do not have flowers, consequently, fruits are also absent in these group of plants. The main source of pollination and dispersal is wind. These are generally medium to tall trees, with a few shrub species also present. *Sequoia* is a gymnosperm which is one of the tallest tree species. The plant body shows differentiation and is divided into leaves, stem, and roots. The leaves are generally needle-like with a thick cuticle and sunken stomata, generally seen in conifers. This feature helps in the reduction of water loss due to transpiration. The root system present in the gymnosperms is taproot system. In some plants, these roots have an association with fungi and form mycorrhiza, for example *Pinus*. In a few other species like the *Cycas* plant, the roots are in the form of specialized roots called coralloid roots and are associated with nitrogen-fixing cyanobacteria. These plants are also vascular, with both xylem and phloem being present.

Angiosperms, also called flowering plants, have seeds that are enclosed within an ovary (usually a fruit), while gymnosperms have no flowers or fruits, and have unenclosed or 'naked' seeds on the surface of scales or leaves. The characteristics that differentiate angiosperms from gymnosperms include flowers, fruits, and endosperm in the seeds. The angiosperms or flowering plants are all plants with flowers and fruit and are the most recently evolved of all plant groups. They are also the most diverse and abundant plants throughout the globe and have come to dominate many of the world's forests. Angiosperms can be defined as vascular plants with seeds, fruit, and flowers for reproduction. Angiosperms have a unique relationship with animals that other plants do not. Many angiosperm species rely on the interaction between animals and their flowers for reproduction. As insects, birds or other animals move from one flower to another feeding on nectar, they commonly distribute pollen from flower to flower as they go which leads to plants being pollinated and seeds to be produced. Animals can also play a role in the dispersal of many angiosperm species by feeding on the fruit of the plant and carrying the seeds to new locations.

NOTES

This book, *Taxonomy and Diversity of Seed Plants*, has been designed keeping in mind the Self-Instruction Mode (SIM) format and follows a simple pattern, wherein each Unit of the book begins with the Introduction followed by the Unit Objectives. The content is then presented in a simple and easy-to-understand manner, and is interspersed with Check Your Progress questions to reinforce the student's understanding of the topic. A list of Questions and Exercises is also provided at the end of each Unit. The Summary, Key Terms and Further Reading further act as useful tools for students and are meant for effective recapitulation of the text.

SECTION 'A' (GYMNOSPERMS)

UNIT 1 GYMNOSPERMS AND FOSSILS

NOTES

Structure

1.0 INTRODUCTION

The term Gymnosperms means naked seeds. These plants do not have flowers and hence the seeds do not form inside any specialized structure like the ovary seen in the other group of plants, i.e., angiosperms. Rather, the seeds develop in on the surface of the reproductive structures of the plants and are visible as cones on maturity. The seeds can sometimes be found on short stalks too.

Gymnosperms have an evolutionary significance and show some unique features. Their characteristic feature is the absence of flowers and presence of naked, open seeds. As they do not have flowers, consequently, fruits are also absent in these group of plants.

The main source of pollination and dispersal is wind. These are generally medium to tall trees, with a few shrub species also present. Sequoia is a gymnosperm which is one of the tallest tree species. The plant body shows differentiation and is divided into leaves, stem, and roots. The leaves are generally needle-like with a thick cuticle and sunken stomata, generally seen in conifers. This feature helps in the reduction of water loss due to transpiration. The root system present in the gymnosperms is taproot system. In some plants, these roots have an association with fungi and form mycorrhiza, for example Pinus. In a few other species like the Cycas plant, the roots are in the form of specialized roots called coralloid roots and are associated with nitrogen-fixing cyanobacteria. These plants are also vascular, with both xylem and phloem being present.

A fossil is the preserved remains or traces of organisms (plants, animals, etc.) that lived in the distant past. The convention is that a fossil must predate recorded human history. While there is no defined date, typically something must be older than 10,000 years to be considered a fossil. The oldest fossils in the fossil record date from 3.5 billion years ago, however it was not until around 600 million years ago that complex, multi-cellular life began was first preserved in the fossil record. There are two main types of fossils; body and trace. Body fossils include the remains of organisms that were once living, while trace fossils are the signs that organisms were once present. Trace fossils represent a data source that reflects animal behaviors, and they do not require the preservation of hard body parts. Many traces date from significantly earlier than the body fossils of the animals suspected to have made them.

In this unit, you will study about classification of gymnosperms, fossil records, process of fossilization and types of fossils in detail.

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1.1 UNIT OBJECTIVES

After going through this unit, you will be able to:

- Understand the classification of gymnosperms
- Discuss about fossil records
- Explain the process of fossilization and types of fossils

1.2 INTRODUCTION TO GYMNOSPERMS

Gymnosperms (Gymnos = Naked + Sperm = Seeds) derived from Greek word, are heterogeneous group of plants including many fossil records and living genera. The seed plants are usually classified into two major groups: gymnosperms and angiosperms based on the presence of protecting structure, i.e., ovary, around the ovules at the time of pollination. The gymnosperms bear naked ovules, i.e., the ovules are borne directly on the sporophyll modified leaves or an equivalent structure, and are exposed. In some of the gymnosperms, overlapping scales and sporophylls may protect the ovules but they are freely exposed at pollination. In the angiosperms, the ovules develop within an ovary. This distinction between naked and enclosed ovules and later seeds is of considerable importance. It is one of the most threatened group of plant kingdom and around forty percent of the taxa belonging to this group is at the verge of extinction. According to Christenhusz *et al.* (2011) a total of 1026 species in 83 genera and 12 families are reported as living members of gymnosperms. According to Singh and Srivastava (2013) there are 46 genera of 12 gymnosperms families in India. There are eight order of living members of gymnosperms, i.e., *Cycadales*, *Ginkgoales, Welwitschiales, Gnetales, Ephedrales, Pinales, Araucariales* and *Cupressales*. Amongst all *Cycadales* and *Ginkgoales* represents the ancient groups and considered as living fossils.

General Characters of Gymnosperms

- Gymnosperms are woody and evergreen and trees, shrubs or lianas in habit.
- No gymnosperm are herbaceous in habit.
- Gymnosperms have tap root, xylem consists of presence of tracheids, xylem parenchyma and rays in xylem but no vessels (except in *Ephedra*, *Welwitschia* and *Gnetum*), phloem consists of sieve cells but no companion cells (in lieu of companion cells albuminous cells are present), bordered pits are present, exothecium is present in anther, during male gametophyte development prothalial cells are formed, ovules are orthotropous and unitegmic, and often there is delay in pollination and fertilization leading to free nuclear division and a development of proembryo and haploid endosperms (double fertilization is absent as in the angiosperms).
- Ovule is naked, orthotropous (except in *Podocarpaceae* where anatropous ovule is present) and unitegmic (except in *Ephedra* two integuments; *Welwitschia* and *Gnetum* three integuments).
- Monosporic development of female gametophyte (except in *Welwitschia* and *Gnetum*). Archegonia is absent in *Gnetum* and *Welwitschia* (archegonium intial functions as an egg cell).

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- No neck canal cell is present in gymnosperms.
- Cell wall between ventral canal nucleus and egg cell is not distinct in many genera.
- Endosperm is haploid in nature and forms before fertilization (in *Gnetum* endosperm is formed after fertilization). Double fertilization is absent in gymnosperms (except in *Ephedra*).
- Some of the gymnosperms attain a height up to 100 metres, for example Sequoia sempervirens (nearly 112 metre, the tallest living tree). The smallest gymnosperms is *Zamia pygmaea*, a cycad. Its fronds are only 4 or 5 cm long.
- From the economic point of view, gymnosperms are highly important in forestry and horticulture. They yield timber, resins, essential oils, drugs and edible nuts. The newspaper industry is almost completely dependent on the wood of conifers for its paper requirements.
- The radicle forms the tap root. The tap root system is exarch and diarch to polyarch.
- The stem is branched but generally un-branched in *Cycas*. In *Cycas* revolute (Pant, 1973) the stem sometimes shows branching.
- In stem the vascular bundles are conjoint, collateral, open and endarch. They are usually arranged in a ring.
- Cambium is present, and the plants show secondary growth.
- The xylem is composed of xylem parenchyma and tracheids with bordered pits. Vessels are absent (except in *Gnetales*).
- Gymnosperms resemble pteridophytes in the absence of vessels and wood fibres.
- Phloem consists of sieve tubes and phloem parenchyma as in pteridophytes. Companion cells are absent.
- The wood may be scanty, loose with wide medullary rays, i.e., manoxylic (for example *Cycadales*) or may be compact with narrow medullary rays, i.e., pycnoxylic (for example *Coniferales*).
- The leaves are of two types, i.e., foliage and scaly leaves. They are large (megaphyllous) and pinnately compound as in *Cycas*, or small (microphyllous) and needle-like as in Pinus.
- Usually the leaves are arranged in a spiral manner except in *Cupressaceae* and Gnetales where their arrangement in cyclic. Author reported forking of rachis and leaflets in *Cycas circinalis*.
- Presence of transfusion tissue is an important feature of the leaf of gymnosperms. It was first discovered by Frank (1864) in Taxus.
- The leaf in most genera contains a single vein. Venation, however, is parallel in *Agathis*, reticulate in Gnetum and dichotomous in Ginkgo.
- Resin canals occur in the leaves of all conifers. Mucilage ducts are present in cycads while latex tubes are present in Gnetum.
- The reproductive parts are generally arranged in the form of compact and hard cones or strobilli. The cones are unisexual. Hermaphrodite cone in certain members occurs sometimes as an abnormality. Male cones are usually smaller and short-lived than female cones in certain genera (for example *Cycas*), however, reproductive structures are not present in the form of compact cone-like structures.

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- In male cones, several microsporophylls are arranged on the central axis, each possessing several microsporangia containing microspores or pollen grains. The microsporophyll's may-be broad (for example *Cycas*) or peltate (for example *Dioon*, *Taxus*).
- Sporangial development is similar to eusporangiate ferns.
- Only one (*Cycas*) or two (Pinus) prothallial cells are present in the male gametophyte.
- The ovules are covered by one or rarely two integuments, and are orthotropous. The integument consists of an outer fleshy, a middle stony and an inner fleshy layer. It surrounds the nucelus. An outer structure, forming an aril, is often present in Taxus.
- Each ovule opens with a mouth opening or micropyle.
- The ovules are not enclosed inside the ovary. Instead, they are born naked on the leafy sporophylls, and hence the name gymnosperms (Gymnos-naked; sperma-seed) is given.
- Double fertilization, a feature unique to angiosperms, is absent in gymnosperms. Khan (1943) and Friedman (1990, 1991), however, reported double fertilization in Ephedra.
- The pollination is direct, i.e., the pollen grains come in contact with the ovule directly. At the time of pollination a 'pollination drop' is secreted by the ovule in almost all gymnosperms.
- Gymnosperms are wind-pollinated. Insect pollination, common in angiosperms, is nearly absent in gymnosperms.
- The female gametophyte or endosperm in post-fertilization stages remains haploid in gymnosperms. It is however, triploid in angiosperms.
- Embryo development is meroblastic, i.e., develops from a small part of zygote. The embryo is straight and embedded in the endosperm (except in *Bennettitales*).
- Several members show polyembryony (for example *Pinus*).
- Due to the absence of ovary, the true fruits are lacking.
- The mature and ripened ovule forms the seed. The integuments of ovule form the seed coat.
- Cotyledons vary from one to many (2 in *Cycas*, but 2-14 in *Pinus*) in number.
- Polyploidy is rare in gymnosperms. It is, however, common in Ephedra.
- The diploid or sporophytic phase is dominant and independent in the life cycle while the haploid or gametophytic phase is dependent and reduced.
- Members of *Cycadofilicales, Bennettitales* and *Cordaitales* are altogether extinct and occur only as fossils, while that of *Cycadales*, *Ginkgoales* and *Coniferales* are living as well as extinct. Members of *Gnetales* are living. However, some pollen as that of Ephedra and Welwitschia from Permian period, have been reported by Delevoryas (1963).
- Amongst the living or extant gymnosperms, Ginkgoales and *Cycadales* are very ancient. They have a very long fossil history, and due to this they are called 'living fossils'.
- Gymnospermous genera found commonly under cultivation are *Cycas*, *Biota, Thuja, Araucaria, Ginkgo, Agathis, Cunninghamia* and *Taxodium*.
- Plants show alternation of generations. The scheme representing the reproductive cycle of a gymnospermous plant has been generalized by Foster and Gifford.

At the time of shedding, number of cells present in mature pollen grains differs (Refer Table 1.1).

Table 1.1 *List of Number of Cells Present in Mature Pollen Grains of Gymnospermous Genera at the Time of Shedding*

No. of Cells Present in Mature Pollen at the Time of Shedding	Genera
1	*Taxus*, *Cryptomeria* and *Cupressus*
2	*Taxodium*
3	*Cycas*, *Welwitschia* and *Gnetum*
4	*Pinus* and *Ginkgo*
5	*Ephedra* and *Cedrus*
Multiple	*Podocarpos* and *Araucaria*

Similarities between Gymnosperms and Pteridophytes

They exhibit sporophyte as dominant and independent phase of life cycle. Sporophyte plant body is divided into root, stem and leaf. Vascular bundle is composed of xylem and phloem where xylem is composed tracheids, parenchyma and rays and vessels are absent whereas in phloem companion cells are absent and archegonia is present (except in *Welwitschia* and *Gnetum*).

Dissimilarities between Gymnosperms and Pteridophytes

Tap root is present in gymnosperms whereas in pteridophytes adventitious root is present. Gymnosperms exhibits monostelic stelar arrangement whereas multiple setelic arrangement is found in the members of pteridophytes *viz*., *protostele, actinostele, siphonostele, solenostele, dictyostele* and *polystele*, presence of secondary growth is a common feature of gymnosperms whereas it is often absent in pteridophytes. In many pteridophytes *viz*., *Isoetes* and *Botrychium* secondary growth is present but it is not extensive as in gymnosperms. Bordered pits are present in gymnosperms whereas scalariform pits are present in pteridophytes. Sieve cells are shorter and have large diameter in gymnosperms whereas longer and exhibit less diameter in pteridophytes. Callose deposition have also been reported from *Psilotum*, Lycopods and the ferns. All gymnosperms are heterosporous whereas pteridophytes are homo as well as heterosporous, for example *Selaginella*, *Isoetes*, *Stylites*, *Marsilea*, *Pilularia*, *Regnellidium*, *Salvinia* and *Azolla*. Anemophily is more frequent in gymnosperms except in *Ephedra aphylla*, *E. campylopoda*, *Gentum* and *Welwitschia*. Water is not necessary for fertilization. In gymnosperms female gametophyte is dependent on sporophyte and retained inside the megaspore and bears naked seeds.

Dissimilarities between Gymnosperms and Angiosperms

Vegetative reproduction is limited in gymnosperms. They are perennial and slow growing. Absence of xylem vessels and companion cells in gymnosperms. Presence of both manoxylic (well-developed pith and cortex and less secondary xylem; low strength; not used as timber) and pycnoxylic wood (well-developed secondary xylem and low pith and cortex; high strength; mostly used as timber) in gymnosperms. Pollination in gymnosperms is anemophilous whereas in angiosperms it is entomophilous, hydrophilous and zoophilous. Naked, orthotropus and unitegmic ovules are present in gymnosperms (in angiosperms uni or bitegmic ovules are present) and pollen grains enters through micropylar end. In most of the gymnosperms the germination pollen grain rests on nucleus except in *Gnetum*, *Tsuga*, *Abies*, *Pseudotsuga*,

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Torreya and Caytoniales where pollen germination begins away from nucellus. Style, stigma and ovary are absent in gymnosperms. Archegonium is present in gymnosperms and the development of female is monosporic except in *Gnetum* and *Welwitschia* where archegonia is absent and development of female gametophyte is tetrasporic (in angiosperms uni-, bi-, or tetrasporic development of female gametophyte took place). Double fertilization is absent in gymnosperms and haploid endosperm is present (in angiosperms double fertilization occurs and triploid endosperms is formed). Cleavage polyembryony is a common feature of gymnosperms and free nuclear division took place in zygote (except in *Gnetum*, *Sequoia* and *Welwitschia*) whereas in angiosperms division is followed by wall formation in zygote (except in *Paeonia*) and cleavage polyembryony is absent.

Distribution of Gymnosperms

Gymnosperms are distributed in both the hemispheres. Forty genera are restricted to Northern Hemisphere while twenty nine genera are restricted to Southern Hemisphere. Some of the widely distributed genera of Northern Hemisphere are *Cupressus, Juniperus*, *Abies*, *Larix*, *Picea*, *Pinus* and *Taxus* and only one genera, i.e., *Podocarpus* is widely distributed in Southern Hemisphere. Twelve gymnospermous genera are distributed in both the hemispheres. Endemism is commonly occur in gymnosperms and few of the examples with their native place is listed in Table 1.2.

Table 1.2 *Name of Genera and Their Area of Distribution*

S. No.	Genera (Family)	Area Restricted to
1	*Bowenia* (Stangeriaceae)	North-Eastern Australia
2	*Stangeria* (Stangeriaceae)	Southern Africa
3	*Chigua* (Zamiaceae)	Colombia
4	*Macrozamia* (Zamiaceae)	Australia
5	*Microcycas* (Zamiaceae)	Cuba
6	*Lepidozamia* (Zamiaceae)	Eastern Australia
7	*Ginkgo* (Ginkgoaceae)	South-Western China
8	*Wollemia* (Araucariaceae)	South-Eastern Australia
9	*Cephalotaxus* (Cephalotaxaceae)	Eastern Asia
10	*Athrotaxis* (Cupressaceae)	Tasmania
11	*Cryptomeria* (Cupressaceae)	Eastern Asia
12	*Cunninghamia* (Cupressaceae)	Eastern Asia
13	*Diselma* (Cupressaceae)	Tasmania
14	*Neocallitropis* (Cupressaceae)	New Caledonia
15	*Papuacedrus* (Cupressaceae)	New Guinea
16	*Platycladus* (Cupressaceae)	Eastern Asia
17	*Sequoia* (Cupressaceae)	Western North America
18	*Sequoiadendron* (Cupressaceae)	Western North America
19	*Taiwania* (Cupressaceae)	Eastern Asia
20	*Thujopsis* (Cupressaceae)	Japan
21	*Cathaya* (Pinaceae)	China
22	*Nothotsuga* (Pinaceae)	China
23	*Pseudolarix* (Pinaceae)	China
24	*Falcatifolium* (Podocarpaceae)	Islands near Australia
25	*Halocarpus* (Podocarpaceae)	New Zealand
26	*Microcachrys* (Podocarpaceae)	Tasmania
27	*Parasitaxus* (Podocarpaceae)	New Caledonia
28	*Sciadopitys* (Sciadopityaceae)	Japan
29	*Austrotaxus*	New Caledonia
30	*Pseudotaxus*	China

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1.2.1 Classification of Gymnosperms

George Bentham and Joseph Dalton Hooker published '*Genera Plantarum* (1862-1883)' and had divided Phanerogamia (plants with seeds) into three classes, i.e., as follows:

- Dicotyledoneae
- Gymnospermae
- Monocotyledoneae

In Gymnospermae they have included three families. In 1883, Eichler reclassified Phanerogamae (seed bearing plants) into two divisions, as follows:

- Gymnospermae
- Angiospermae

In 1911, Bessey classified Spermatophytes (seed bearing plants) into three phylum, as follows:

- Cycadophyta
- Strobilophyta
- Anthophyta (flowering plants)

Phylum: Cycadophyta

Class: Pteridospermae

Cycadineae

Bennettitineae

Cordaitineae

Phylum: Strobilophyta

Class: Pinoideae

Phylum: Anthophyta

Class: Monocotyledoneae

Dicotyledoneae

In 1920, Prof. Birbal Sahni (Father of Paleobotany in India) divided gymnosperms into two groups:

- **Phyllosperms:** Reproductive structures are borne on leaves or structures other than stem, for example *Pteridospermales, Cycadales* and *Bennettitales.*
- **Stachysperms:** Reproductive structures are borne on stem, for example *Cordaitales, Ginkgoales, Taxales* and *Coniferales* (Refer Figure 1.1).

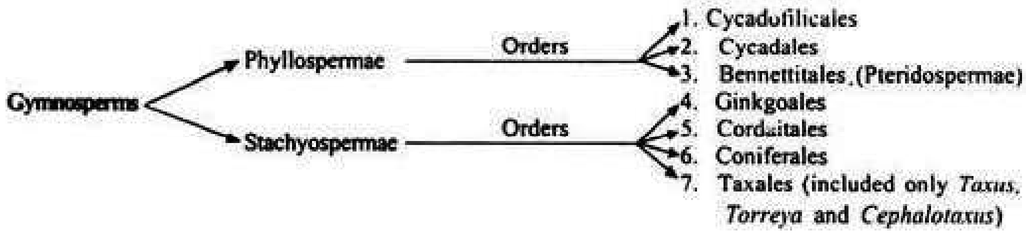

Fig. 1.1 *Classification Proposed by Prof. Birbal Sahni*

In 1935, Chamberlain followed same classification as proposed by Sahni and named the two groups as:

- Cycadophytes, for example *Cycadofilicales, Bennettitales* and *Cycadale*s.
- Coniferophytes, for example *Cordaitales, Ginkgoales, Coniferales* and *Gnetales* (Refer Figure 1.2).

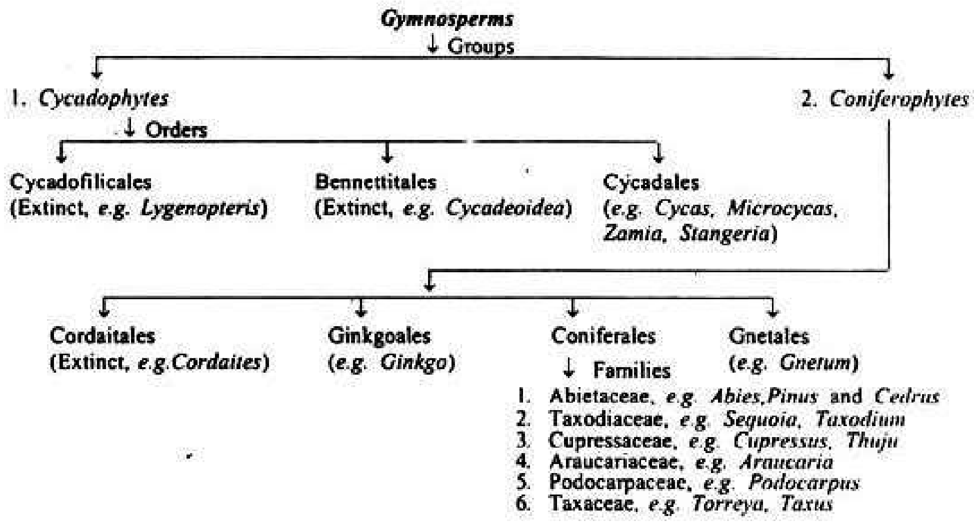

Fig. 1.2 *Classification Proposed by Prof. Birbal Sahni in 1935*

In 1936, Engler classified the division Embryophyta Siphonogamia (plants producing embryo and pollen tube) into two subdivisions (i) Gymnospermae and (ii) Angiospermae.

Gymnospermae

Class: Cycadofilicales

Cycadales

Bennettitales

Ginkgoales

Cordaitales

Coniferales

Gnetales

Angiospermae

Class: Monocotyledoneae

Dicotyledoneae

In 1948, Arnold divided Gymnosperms into three phylum:

- Cycadophyta, for example *Pteridospermales, Cycadeoidales (Bennettitales)* and *Cycadales*.
- Coniferophyta, for example Cordaitales, Ginkgoales, Taxales and *Coniferales*.
- Chlamydospermophyta, for example *Ephedrales* and *Gnetales*.

In 1957, Pant followed Arnold's classification and proposed a system of classification as follows (Refer Figure 1.3):

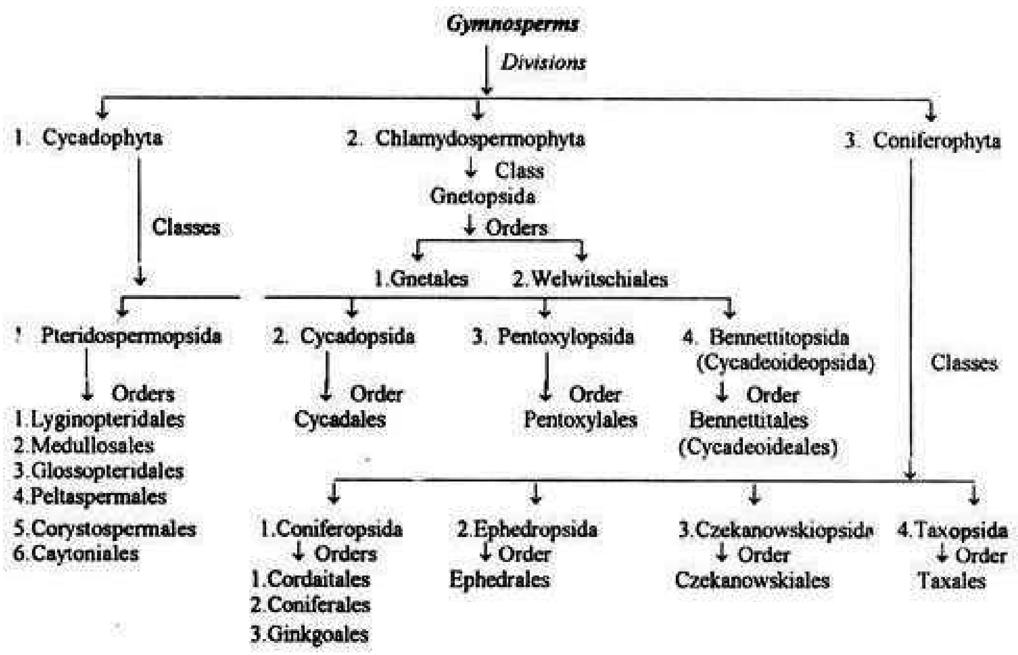

Fig. 1.3 An Outline of Pant's (1957) Scheme of Classification of Gymnosperms

In 1966, Cronquist, Takhtajan and Zimmermann had divided subkingdom Embryobiotina into following division and classes (Refer Figure 1.4):

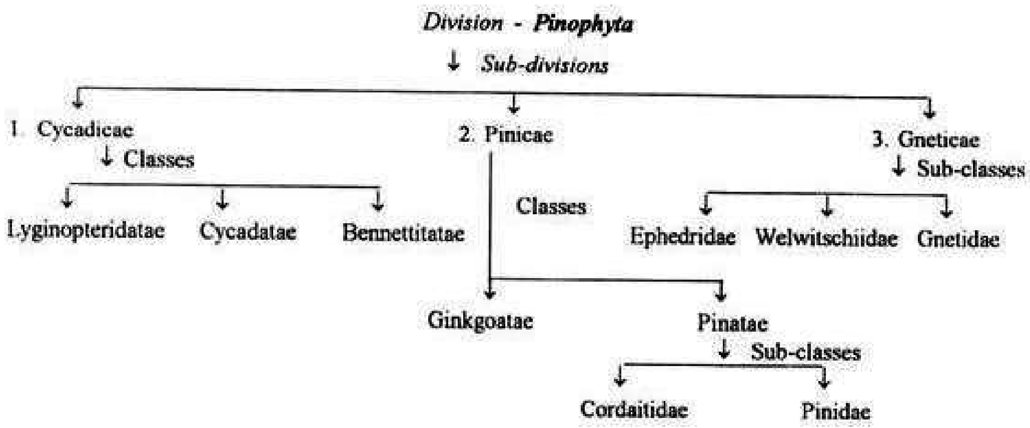

Fig. 1.4 Classification Proposed by A.Cronquist, A. Takhtajan & W.Zimmermann (1966)

Bierhorst (1971) divided Gymnosperms into following three classes:

1. Cycadopsida includes following Six Orders:

- Pteridospermales
- Caytoniales
- Cycadeoidales
- Cycadales
- Pentoxylales
- Glossopteridales

2. Coniferopsida includes following Five Orders:

- Cordaitales
- Protopityales
- Ginkgoales
- Coniferales
- Taxales

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3. Gnetopsida includes following Three Orders:

- Ephedrales
- Gnetales
- Welwitschiales

Classification Proposed by Sporne (1974)

Sporne (1974) adopted classification of Pilger and Melchior (1954) and recognized following three classes and nine orders:

- Cycadopsida: Pteridospermales, Bennettitales, Pentoxylales and Cycadales
- Coniferopsida: Cordaitales, Coniferales, Taxales and Ginkgoales
- Gnetopsida: Gnetales

Classification Proposed by Taylor (1981)

Taylor (1981) divided gymnosperms into six major divisions (Progymnospermophyta, Ptendospermophyta, Cycadophyta, Cycadeoidophyta, Ginkgophyta and Coniferophyta) as under:

1. Division Progymnospermophyta (Progymnosperms)
2. Division Pteridospermophyta (Seed ferns)
    - Lyginoptendales
    - Medullosales
    - Callistophytales
    - Calamopityales
    - Caytoniales
    - Corystospermales
    - Peltaspermales
    - Glossoptendales
3. Division Cycadophyta (Cycads)
4. Division Cycadeoidophyta (Cycadeoids)
5. Division Ginkgophyta (Ginkgophytes)
6. Division Coniferophyta
    - Cordaitopsida (Cordaites)
    - Coniferopsida (Conifers)
        - o Voltziales
        - o Coniferales
        - o Taxales

According to Taylor (1981) Gnetales, Vojnovskyales and Pentoxylales are the problematic gymnosperms.

Classification Proposed by Stewart (1983)

Stewart (1983) classified the gymnosperms mainly on the basis of the evidences available from the fossil records.

He divided gymnosperms into three classes (Progymnospermopsida, Gymnospermopsida and Gnetopsida) as under:

1. Progymnospermopsida
   - Aneurophytales
   - Archaeopteridales
   - Protopityales
2. Gymnospermopsida
   - Pteridospermales
   - Cycadales
   - Cycadeoidales
   - Caytoniales
   - Glossoptendales
   - Pentoxylales
   - Czekanowskiales
   - Ginkgoales
   - Cordaitales
   - Voltziales
   - Coniferales
   - Taxales
3. Gnetopsida (Gnetum, Ephedra, Welwitschia)

Classification Proposed by Sandra Holmes (1986)

Holmes (1986), in her book entitled 'Outline of Plant Classification', divided gymnosperms into three classes (Cycadopsida, Gnetopsida and Coniferopsida) but also described some fossil ancestors in a separate class Progymnospermopsida.

An outline of her classification is under mentioned:

Division Spermatophyta:

Sub-division Gymnospermae

Class Cycadopsida (Cycadatae)

Order Lyginoptendales (Cycadofilicales, Pteridospermales)

Order Caytoniales

Order Bennettitales

Order Pentoxylales

Order Cycadales

Order Nilssoniales

Class Gnetopsida (Gnetatae, Chlamydospermae)

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Order Welwitschiales

Order Ephedrales

Order Gnetales

Class Coniferopsida

Order Ginkgoales

Order Cordaitales

Order Coniferales (Pinales)

Order Voltziales

Order Taxales

Class Progymnospermopsida:

Fossils which are now thought to be nearer to gymnosperms although not of full gymnospermous status. It includes,

Order Pityales

Order Aneurophytales

Order Protopityales

Classification Proposed by Gifford and Foster (1989)

Gifford and Foster (1989) raised the major groups to the rank of Divisions and divided gymnosperms into following seven divisions:

- Progymnospermophyta
- Pteridospermophyta
- Cycadophyta
- Cycadeoidophyta
- Ginkgophyta
- Coniferophyta
- Gnetophyta

Classification Proposed by Kramer and Green (1990)

Recently, Kramer and Green (1990; see Kubitzki, 1990) divided gymnosperms as under (Refer Figure 1.5):

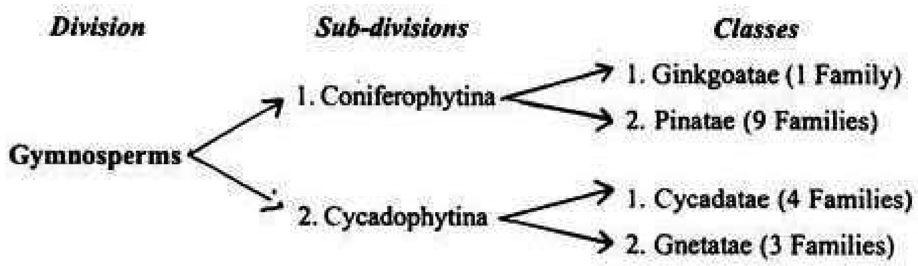

Fig. 1.5 *Classification Proposed by Kramer and Green (1990)*

Progymnosperms (Extinct Group) are ancestors to gymnosperms and found in the period of Devonian-Pennsylvanian period. The members of this group exhibit anatomy similar to gymnosperms, pycnoxylic wood, bifacial cambium, tracheids with circular bordered pits and reproduction is by spores similar to that of pteridophytes. Reproductive structure is a fertile leaf and fusiform sporangia were born on lateral or adaxial surface. Taxa exhibited homo- as well as heterospory. It is divided into Archaeopteridales, Anuerophytales and Protopityales. In 1960, Beck had discovered a leaf, *viz. Archaeopteris macilenta* and a stem *Callixylon zalesskyi* from Upper Devonian beds in New York State. *Archaeopteris* (Refer Figure 1.6A) are bipinnate and bear one or two rows of adaxial fusiform sporangia. In longitudinal radial section of C*allixylon* exhibits horizontal bands of pits separated by unpitted bands (Refer Figure 1.6B).

Phylogenetically *Archaeopteris* is considered as an intermediate between pteridophytes and phanerogams due to arborescent habit, megaphyllous leaves, secondary growth and heterosporous reproduction. It may have been evolved parallel to the pteridosperms and coniferophytes or was ancestral to some of them.

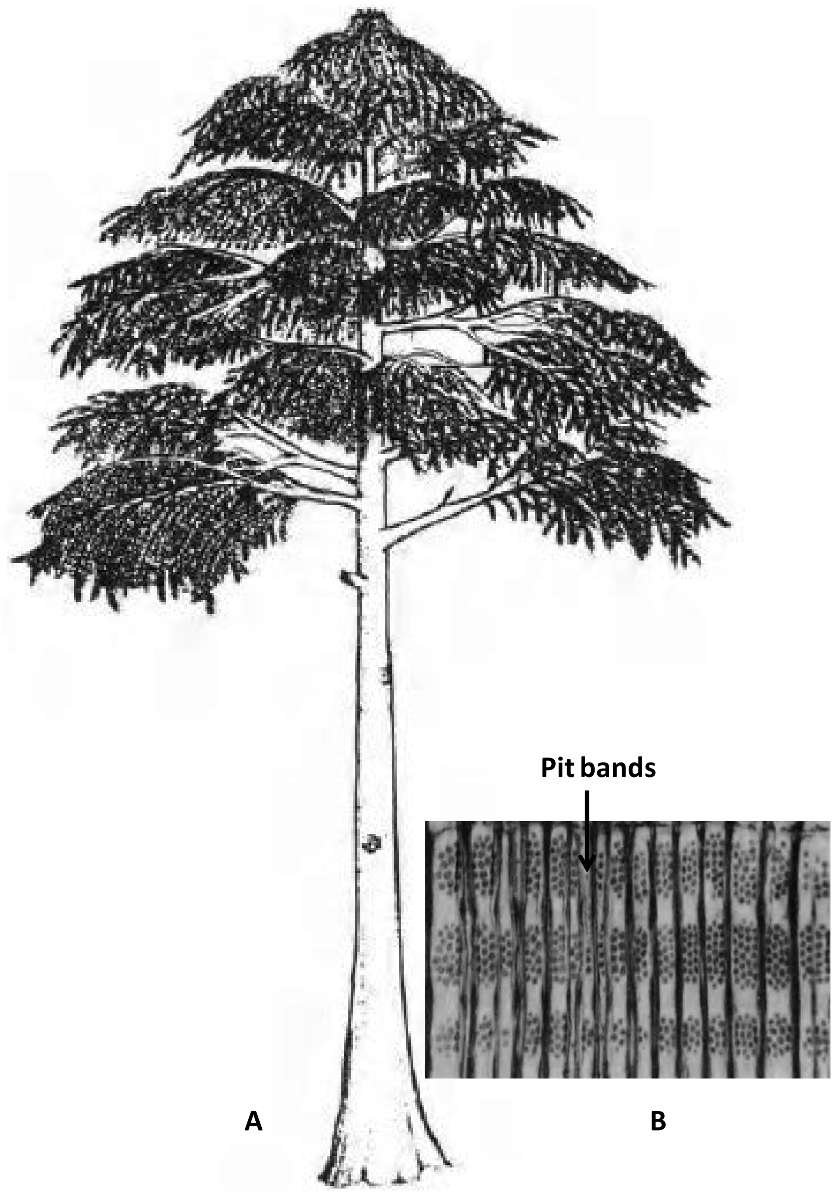

Fig. 1.6 *A. Archaeopteris sp. (After Beck, 1962); B. Longitudinal Section of Callixyon with Tracheids showing Bands of Pits.*

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Pteridosperms or Seed Ferns, is an extinct group, exhibits fern like leaves and gymnospermous seed habit. In 1887, Williamson recognized the carboniferous plants exhibiting anatomical characters of cycads and ferns. Later In 1899, Potonie named this Cycadofilices. Due to the discovery between the association of these fern-like leaves (characteristic feature of pteridophyte) with true seed structures (characteristic feature of spermatophyte) the name Pteridospermae was proposed by Oliver and Scott (1904) and the members of this group exhibit protosteles to eusteles, mostly mesarch xylem and rarely exarch is present, manoxylic (thin walled tracheids and more parenchyma) wood, slender stem, bifacial activity of cambium, large and fern-like leaves often multipinnate, reproductive structures are present on modified leaves and haplocheilic stomata. Examples of paleozoic pteridosperm are *Calamopityales, Buteoxylonales, Lyginopteridales, Mudullosales, Callistophytales* and *Glossopteridales*. Examples of mesozoic pteridosperm are *Caytoniales, Corystospermales, Petriellales* and *Peltaspermales*.

Lyginopteridales (Upper Carboniferous)

***Lygniopteris oldhamia* (Stem):** A climbing plant with long, branched, and radially symmetrical stem bearing large leaves. In transverse section stem shows large central parenchymatous pith with mesarch siphonostele and outer thick walled cells and inner cortex (Refer Figure1.7). Cambium is present. The parenchymatous pith consists of scattered thick walled cells known as sclerotic nests. Capitate glands are present in every plant part (except roots). In tangentially longitudinal section these bands forms a net like structure and the cortex is termed as *Dictyoxylon* cortex.

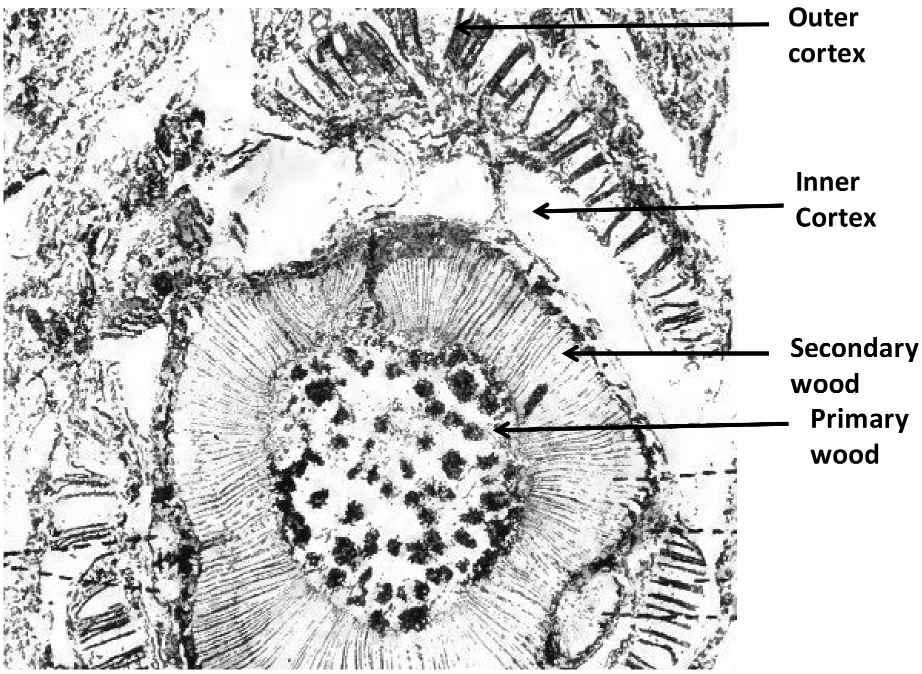

Fig.1.7 *Transverse Section of Lygniopteris Oldhamia Stem*

***Sphenopteris hoenighausi* (Leaf):** Rachis is forked and bipinnate having two or three pinnate leaves (Refer Figure 1.8).

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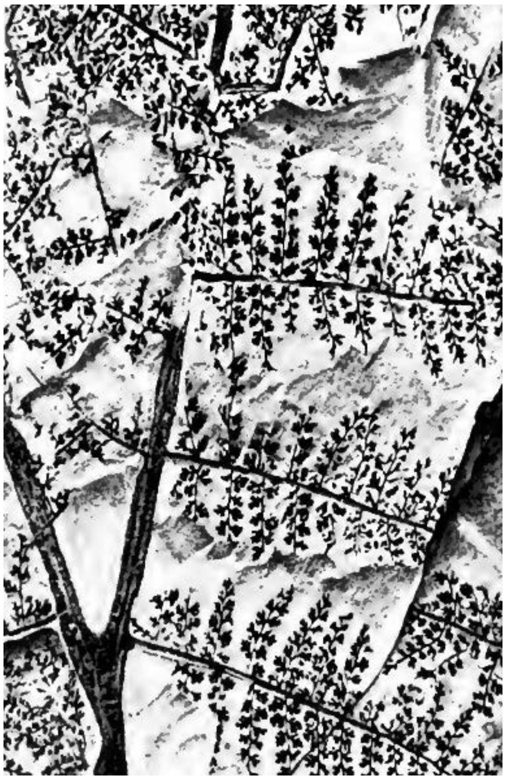

Fig. 1.8 Sphenopteris hoenighausi after Potonie

***Kaloxylon* (Root):** Roots are abundant, adventitious and some are aerial. Anatomically outer cortex consist of two or three tier of parenchymatous cells and inner mucilaginous thick walled cortex with exarch condition.

***Crossotheca* (Microsporangium):** Fertile pinnules bears six or seven bilocular microsporangia (Refer Figure 1.9). Sporangia is devoid of annuli. Spores have triradiate markings.

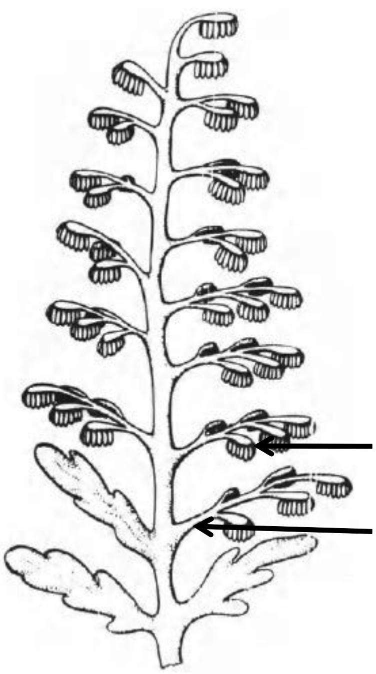

Fig. 1.9 Crossotheca Exhibiting Microsporangia (After Andrews 1961)

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***Lagenostoma lomaxii* (Seed):** It was enclosed in a cup like structure (cupule), integument is incompletely fused, a pollen chamber sealing device (Refer Figure 1.10) (lagenostome) is present. Pollen are small, trilete and borne in clusters of sporangia. Tent pole (beak like structure at the micropylar end of female gametophyte) like structure was present (Refer Figure 1.11).

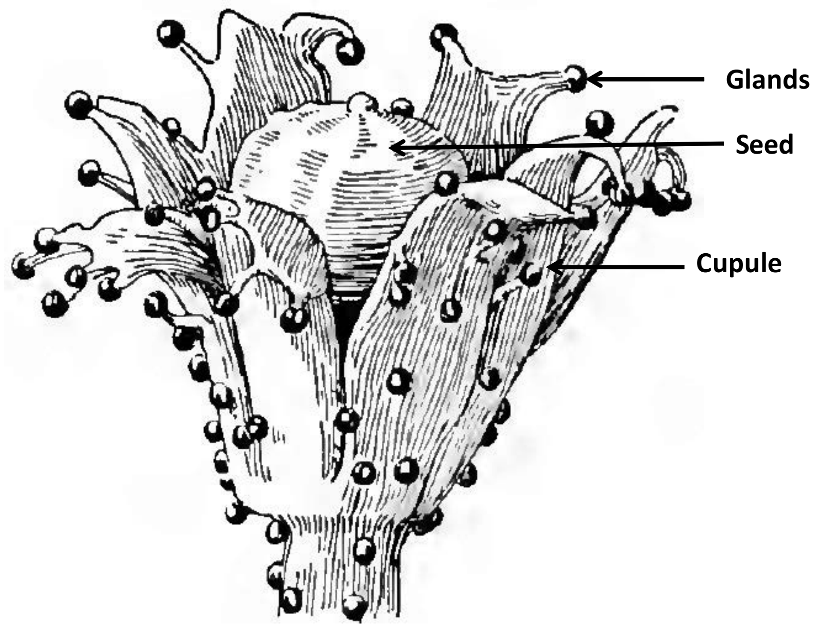

Fig. 1.10. *Lagenostoma lomaxii: Seed with Glands and Cupule*

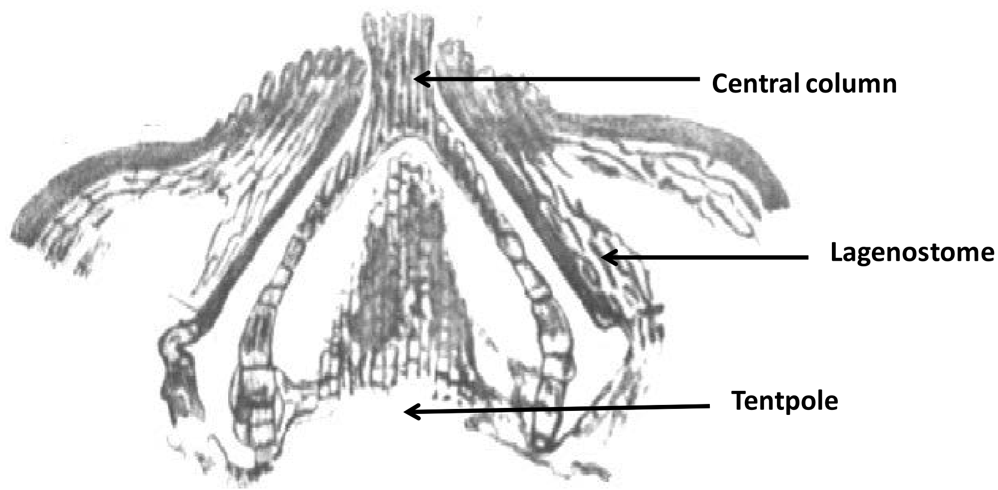

Fig.1.11 *Longitudinal Section of Apex of Lagenostoma lomaxii (After Oliver and Scott, 1905)*

Glossopteridale: Leaf morphogenus *Glossopteris* appeared in the permian period of Gondwana including India. Earlier it was considered in the cycads but after the discovery of seed bearing megasporophylls glossopterids were classified under seed ferns. Glossopterids were arborescent plants and had alternately arranged leaves. Sediments suggests that glossopterids were deciduous.

***Glossopteris* (Leaf):** It is lanceolate to tongue shaped, entire, midrib is made up of multiple veins and reticulate venation (Refer Figure 1.12). Vascular bundles in leaves are exarch to mesarch surrounded by thick walled bundle sheath. Stomata were borne in rows.

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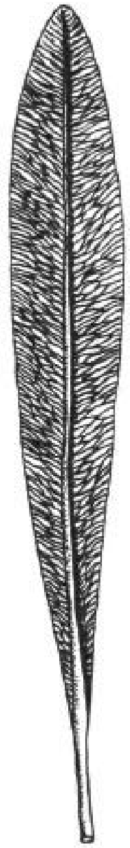

Fig. 1.12 Glossopteris Leaf Showing Nearly Reticulate Venation and Prominent Midrib

***Gangamopteris* (Leaf):** *Gangamopteris* is distinct from *Glossopteris* in large size and absence of midrib.

***Agathoxylon* (=*Araucarioxylon*) (Stem):** It is pycnoxylic wood with growth rings. Multiseriate pits are present on the radial walls of tracheids and xylem rays are uniseriate.

***Vertebraria* (Root):** Secondary growth is present, exarch primary xylem, secondary xylem appears as wedge shaped and surrounded by the periderm. The cavities present between the radiating arms of protoxylem suggests the nature as root which flourished in the semi aquatic environment. Uniseriate vascular rays are present in the pycnoxylic wood of *Vertebraria*.

***Eretmonia* (Pollen Organ):** Pollen organs were stalked with triangular distal lamina. Two branches arises from on the adaxial surface bearing *Arberiella* type sporangia. Sporangia bears bisaccate pollen grains.

***Scutum* (Ovulate Organ):** Ovulate organs were attached either in the axil of bract or to its upper surface. The megasporophyll was bilaterally symmetrical, two sided pedicellate cupule borne on the midrib of a leaf. Open megasporophyll revealed ovule on one surface and bracts (interpreted as microsporophylls), that is why it was initially considered as a bisexual reproductive structure.

Lidgettonia and *Denkania* consists of a stalked fertile head or capitulum. In *Lidgettonia,* capitulum was stalked and peltate consisting of rows of six to seven ovules. In *Denkania,* rows of pedicels attached to the adaxial surface of leaf was present. Single ovule is present in a terminal cupule. In *Dictyopteridium* ovules are surface attached while in *Ottokaria,* the ovulate organ was attached to the leaf of *Gangamopteris* (Refer Figure 1.13).

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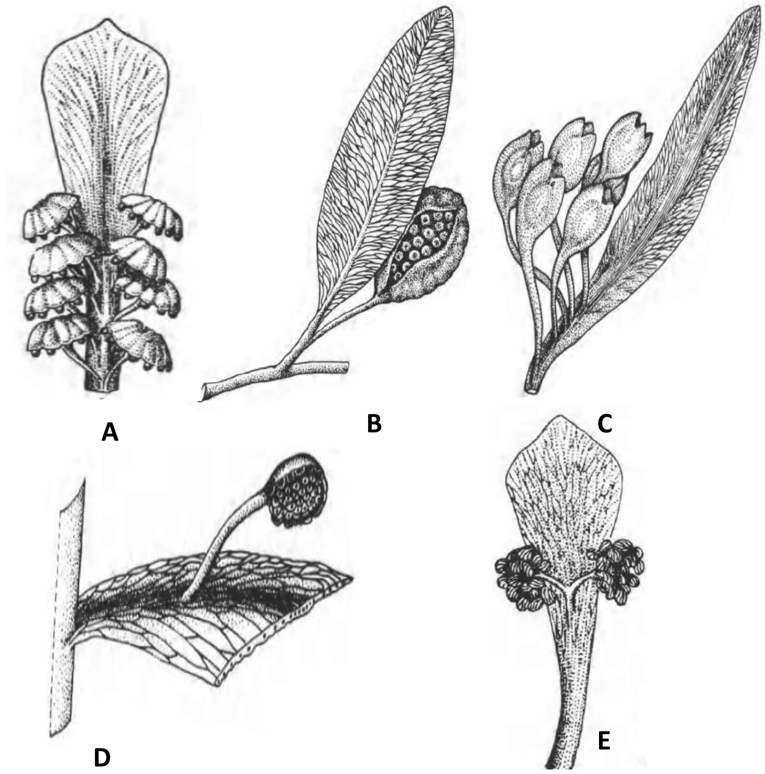

Fig. 1.13 Ovulate Organs (Female Fructifications) of Glossopterids; A. Lidgettonia mucronata; B. Dictyopteridium sp.; C. Denkinia indica; D. Ottokaria bengalensis; E. Pollen Organ of Eretmonia

Cycads consists of manoxylic wood, well developed pith and cortex, long tracheids with large diameter, large pinnate frond-like leaves, circinate vernation is present in the leaves (*Cycas*), haplocheilic stomata, reproductive structures borne on modified leaves, motile gametes is present and swim freely in water and dicotyledonous embryo. The orders present in this group are Cycadales and Bennettitales (Cycadeoidales).

Epidermal characters established the significant clue regarding the relationship between the two orders. In 1913, Thomas and Bancroft compared the two epidermal characters of the orders and in 1931, Florin demonstrated presence of two types of stomata based on origin of guard and subsidiary cells.

- **Haplocheilic Stomata:** In this type of stomatal development, stomata mother cell divides once and give rise to guard cells. No subsidiary cells are formed.
- **Syndetocheilic Stomata:** In this type of stomatal development, stomata mother cell divides thrice. First and second division give rise to subsidiary cells and the third division give rise to guard cells.

Bennettitales or Cycadeoidales (Extinct Order): Dates back from Triassic to Cretaceous period, abundant in Mesozoic era (Age of Cycads), plants monoecious (for example *Cycadeoidea*) or dioecious (for example *Williamsonia*), manoxylic wood, persistent cambium, pinnately compound leaves, syndetocheilic stomata, mono- or bisporangiate strobili, synangium, platyspermic and stalked ovules, inter-seminal scales or bracts are present, exalbuminous seeds and dicotyledonous embryo. In 1868, *Williamsonia gigas* was described as *Zamia gigas* by Williamson. It was discovered from Yorkshire coast from Jurassic. The first complete reconstruction from India was discovered by Prof. Birbal Sahni (1932) from Upper Gondwana beds of Rajmahal Hills of Bihar was *Williamsonia sewardiana* **(**Refer Figure 1.14).

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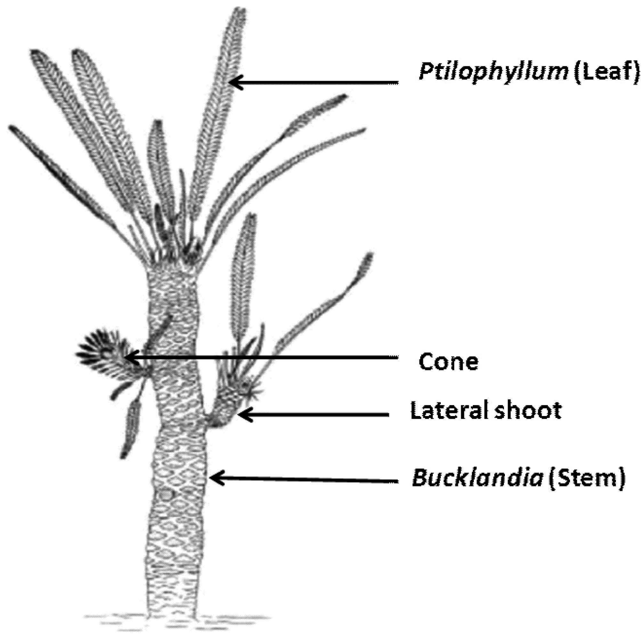

Fig.1.14 *Reconstruction of Williamsonia sewardiana*

Williamsonia sewardiana was 2 meter tall tree with presistant helical arranged leaf bases. Crown of *Ptilophyllum* type of pinnate leaf was present at the distal end of trunk. Short lateral stalks bears ovulate cones along with leaves. Cone was covered with hairy bracts and borne on long peduncles. *Bucklandia* were the stems with large leaf scars (Refer Figure 1.15).

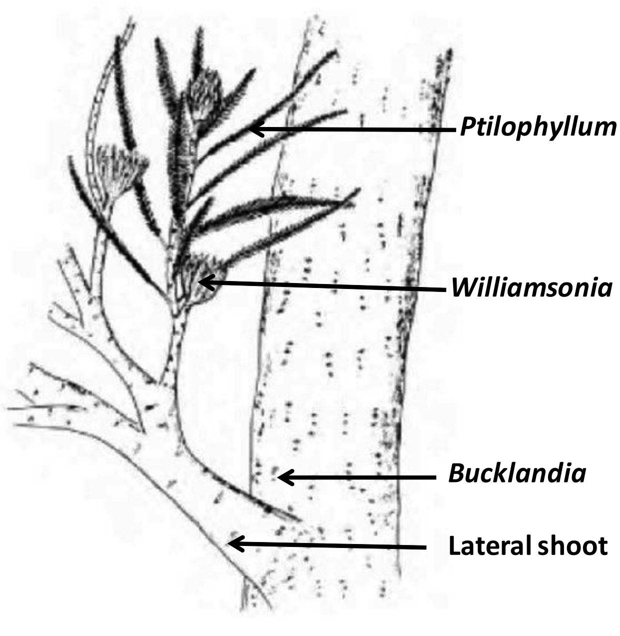

Fig. 1.15 *Lateral Shoot of Williamsonia showing Ovulate Structure*

Williamsonia (Ovulate structure) were monosporangiate cones was cup shaped and up to 15 cm in diameter. Interseminal scales and numerous small seeds were present in the dome shaped receptacle of *Williamsonia* cone. Micropylar tube extend above the level of scales. A whorl of bracts is present surrounding the seed bearing receptacle that gives flower like appearance to the *Williamsonia*.

Williamsoniella was a bisporangiate cone consists of a whorl of wedge-shaped and pinnate microsporophylls. Interseminal scales and seeds were present on the reduced receptacle of cone. Synangiate pollen sacs, like that of Bennettitales, consisting of monosulcate and smooth walled pollen is present (Refer Figure 1.16).

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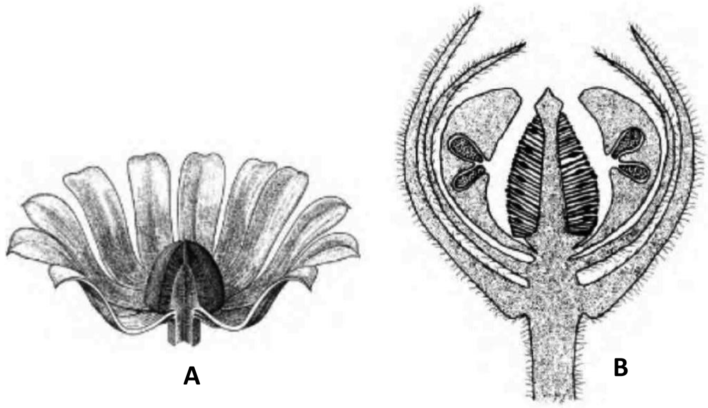

Fig. 1.16 *A. Williamsonia; B. Williamsoniella*

Cycadales (living and extinct both taxa are present): Fossil taxa dates back from Upper Triassic to Jurassic, plants dioecious, unbranched stem, manoxylic wood, many cambia present in concentric rings, diploxylic leaf trace, pinnately compound leaves, stomata haplocheilic, monosporangiate strobili, multiciliate spermatozoids, sessile ovules, endospermic seeds and dicotyledonous embryo, for example *Cycas* (Refer Figures 1.17 and 1.18). In *Microcycas calocoma* more than 200 archegonia is present in the female gametophyte. *Zamia pygmea* is the smallest known gymnosperm. At present there are fifteen species (Source thirteen species listed in Cycads of India and two new species discovered from Andaman and Nicobar) of *Cycas* reported from India *viz., C. annaikalensis*, *C. circinalis*, *C. beddomei* (endemic to Seshachalam Biosphere Reseve and Cuddapah district of Andhra Pradesh), *C. nayagarhensis* (endemic to Nayagarh district of Odisha), *C. indica*, *C. nathorstii*, *C. pectinata*, *C. orixwnsis*, *C. sainathii*, *C. seshachalamensis*, *C. sphaerica*, *C. swamyi*, *C. zeylanica*, *C.pschannae* (reported from Andaman and Nicobar Islands, India) and *C. dharmrajii* (reported from Andaman and Nicobar Islands, India).

Fig. 1.17 *Cycas Revolute*

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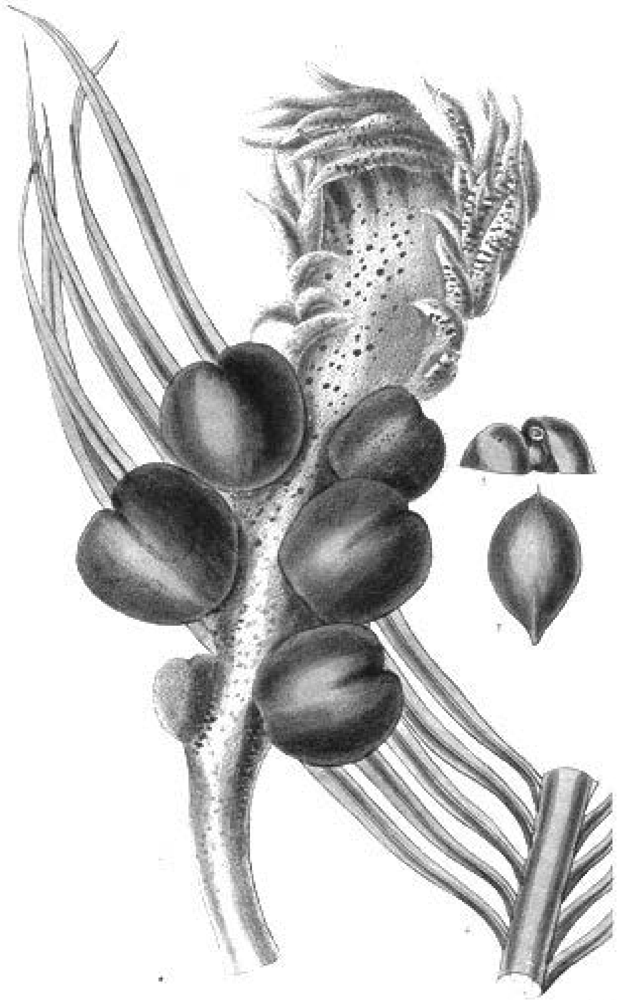

Fig. 1.18 *Cycas Revoluta Sporophyll*

Voltziales group is often called as transition conifers, present between late paleozoic and mesozoic era. They exhibits monopodial branching, leaves are acicular while leaves present on the fertile branches exhibits bifurcate tips. Leaves possess haplocheilic stomata present on both the surface (amphistomatic). In 1951, Florin classified it into two families as (i) Lebachiaceae- older Voltziales and (ii) Voltziaceae- younger Voltziales.

Coniferales (Living and Extinct Both Taxa are Present): It dates back from Carboniferous period to present, mostly evergreen and few deciduous conifers are *Larix*, *Pseudolarix*, *Metasequoia* and *Taxodium distichum*, either monoecious or dioecious, wood is pycnoxylic, presence of multiseriate bordered pits on tracheids, resin canals are present in pith and cortex, haplocheilic stomata, cones are unisexual and compound, male gametes are non-motile, seeds are endospermic and embryo contains two or more cotyledons. The tallest tree belongs to this group, i.e., *Sequoia semipervirens* (Californian redwood) family Taxodiaceae. *Dacrydium laxifolium* is the samllest known conifer. The only parasitic gymnosperm belongs to Podocarpaceae is *Parasitaxus usta* (*Podocarpus ustus*) and its host is *Falcatifolium taxoides* (*Dacrydium taxoides*). Some of the conifers found in India are shown in Figure 1.19.

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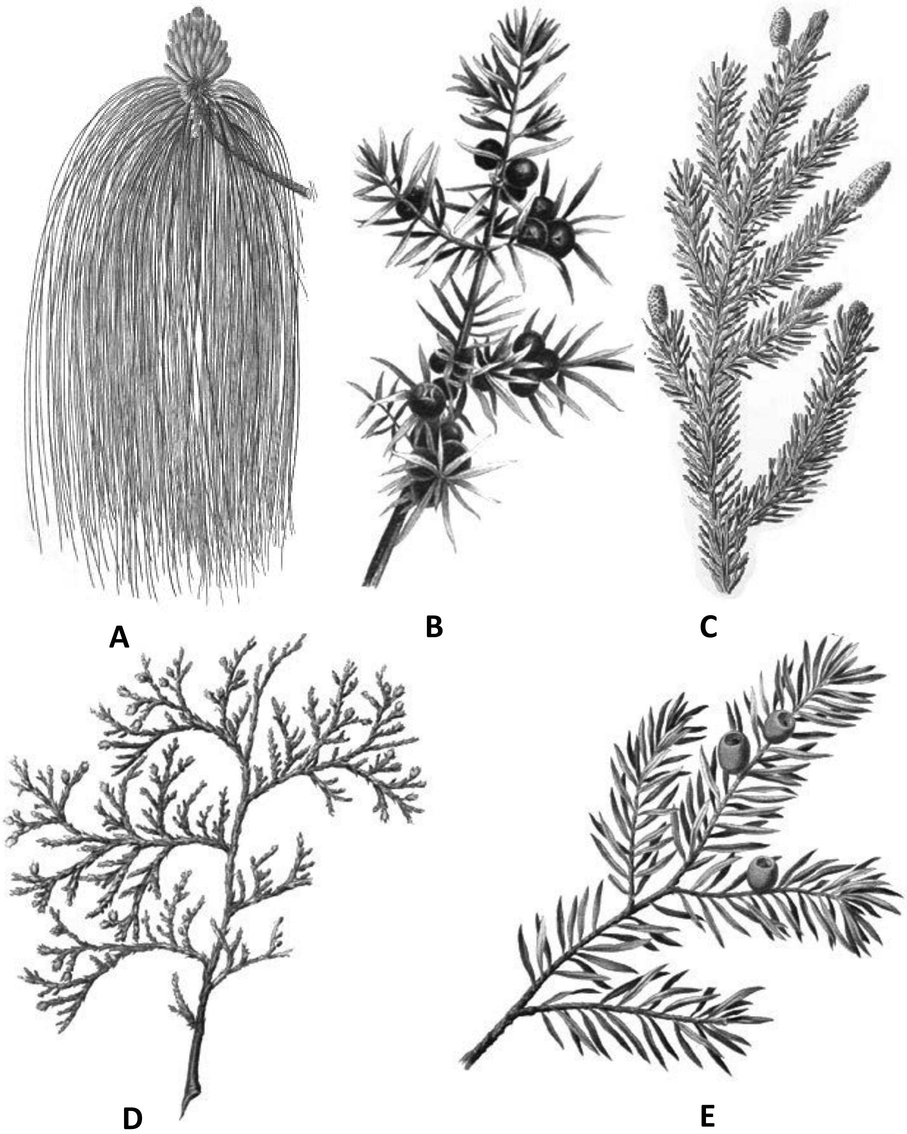

Fig. 1.19 Twigs of Some Conifers; A. Pinus roxburghii; B. Juniperus communis; C. Picea orientalis; D. Thuja occidentalis; and E. Taxus baccata

Taxales: Commonly known as yew (for example *Taxus baccata*, appeared in late triassic or early jurassic. Plants are mostly dioecious or sometimes monoecious evergreen and profusely branched. Leaves are acicular or narrow arranged spirally. Leaves are opposite and decussate and scale like on fertile shoots. Tunica is absent on the stem apex. Wood are pycnoxylic and resin canals are absent. Dicotyledonous embryo is present.

Welwitschiales, Monotypic Living Taxa, *Welwitschia mirabilis*: Dioecious, Turnip like underground stem bearing two strap shaped leaves. vessels are present, two persistent leaves with continuously growing at base, syndetocheilic stomata, archegonia is absent, tetrasporic development of female gametophyte and winged seeds. Some researchers considered the two leaves in *Welwitschia* as a cotyledonary leaves and a mature plant as a seedling with developed sexual organs thus suggested the Neoteny (a phenomenon in which juvenile features are retained in adults) in the genera. Although Martens (1977) proven that neoteny is not present in the genera but it is a handicapped plant, i.e., it has lost its apical bud. Fertilization in *Welwitschia* is remarkable, after pollination the pollen germinates at the base of the mycropylar tube or into pollen chamber. The pollen tubes grows downwards towards the fertilization bulb where fertilization occurs and syngamy took place. Fertilization bulb is the swollen tip of embryo sac tube or prothallial tube which contains female nuclei (Refer Figure 1.20).

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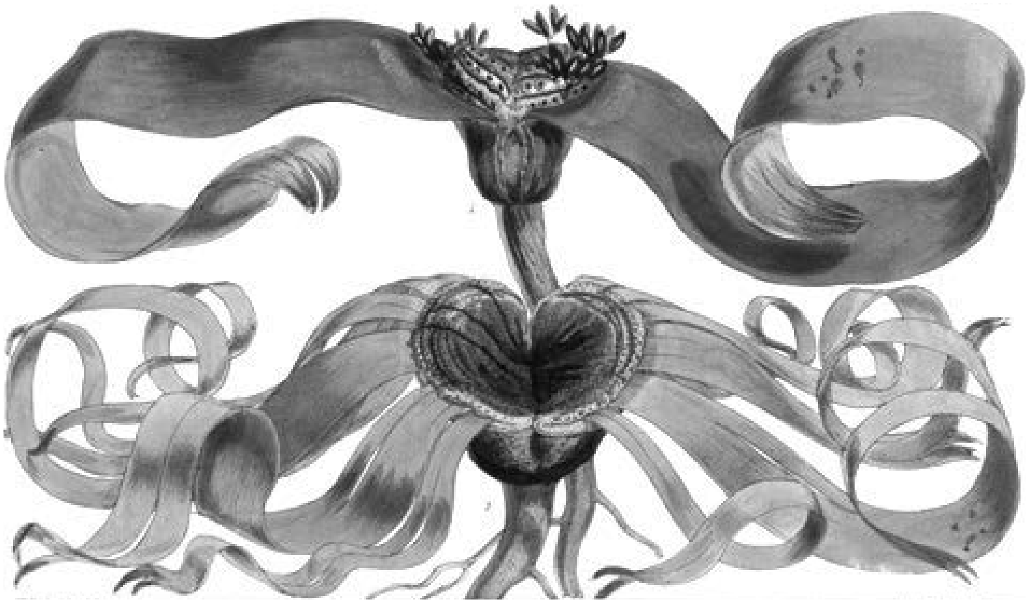

Fig. 1.20 *Welwitschia mirabilis*

Christenhusz *et al.* Classification of Living Gymnosperms

In 2011, Christenhusz *et al*., proposed another classification of living genera of gymnosperms based on molecular and morphological characters. They have divided gymnosperms into following subclasses:

1. Cycadidae

Cycadales

Cycadaceae: Living genera present in India is *Cycas*

Zamiaceae: Living genera present in India are:

- *Bowemia*
- *Dioon*
- *Encephalartos*
- *Lepidozamia*
- *Microcycas*
- *Macrocycas*
- *Stangeria*
- *Zamia*

2. Ginkgoidae

Ginkgoales

Ginkgoaceae: Living genera present in India is *Ginkgo*

3. Gnetidae

Welwitschiales

Welwitschiaceae: Living genera in India is *Welwitschia* (native of Africa)

Gnetales

Gnetaceae: Living genera present in India is *Gnetum*

Ephedrales

Ephedraceae: Living genera present in India is *Ephedra*

4. Pinidae

Pinales

Pinaceae: Living genera present in India are:

- *Abies*
- *Cedrus*
- *Larix*
- *Picea*
- *Pinus*
- *Pseudotsuga*
- *Tsuga*

Araucariales

Araucariaceae: Living genera present in India are:

- *Agathis*
- *Araucaria*

Podocarpaceae: Living genera present in India are:

- *Afrocarpus* (Gondwana Conifer)
- *Nageia* (Gondwana Conifer)
- *Podocarpus*

Cupressales

Sciadopityaceae: No genera of this order is present in India.

Cupressaceae: Living genera present in India are:

- *Callitris*
- *Calocedrus*
- *Chamaecyparis*
- *Cryptomeria*
- *Cunninghamia*
- *Cupressus*
- *Fitzyroya*
- *Juniperus*
- *Metasequoia*
- *Platycladus*
- *Squoiadendron*

- *Sequoia*
- *Taiwania*
- *Taxodium*
- *Tetraclinis*
- *Thuja*
- *Thujopsis*
- *Widdringtonia*

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Taxaceae: Living genera present in India are:

- *Amentotaxus*
- *Cephalotaxus*
- *Taxus*

List of genera present in India was taken from Singh, N.P. and Srivastava, R.C. 2013. Gymnosperms of India. A Check List. Botanical Survey of India, Kolkata.

Economic Importance of Gymnosperms

Gymnosperms are evergreen, woody and have symmetrical appearance. *Cycas, Ginkgo* (male plant), *Thuja, Araucaria, Juniperus, Pinus, Cupressus, Cryptomeria, Thujopsis, Abies, Piceae* and *Pseudostuga* are some of the gymnosperms used for landscaping in gardens and for ornamental purpose as bonsai and as floral decorations. Various species of gymnosperms are popular as Christmas trees but before World War II, *Juniperus virginiana* was preferred traditional Christmas tree.

The pycnoxylic wood of gymnosperms provides the commercially important timber. The wood of gymnosperms have soft texture due to high cellulose content. Xylem fibres are absent in most part of the gymnospermous wood. Very hard wood was obtained from *Larix decidua, Agathis* and *Taxus* while soft wood obtained from *Picea* and *Pinus*. Generally gymnospermous wood lacks strength and durability therefore these are used for the manufacturing of furniture, cabinet, flooring and building purpose, etc. Logs of *Agathis angustifolia* and *A. cunninghamia* were used for manufacturing plywood. *Cupressus semipervirens* wood is one of the preferred woods used for the construction of Christ cross. *Cupressus semipervirens* and *Cedrus libani* was used for making coffins and mummy cases by Egyptians. *Libocedrus decurrens* wood oil contains carvacrol and hydrothymoquinone (exhibits antifungal property) which contributes to the fragrance and durability of wood. *Juniperus plicata* contains thujalicins (antimicrobial property) in woods. Amongst Indian gymnosperms *Cedrus deodara* produces most valuable and strongest timber due to presence of fragrance and oils exhibiting antimicrobial properties. *Picea* wood from Romania is used for making bodies of violin and sounding boards of pianos. In China and Japan, *Ginkgo* wood is made for making Chess boards and men. *Pinus*, *Picea*, *Abies* and *Tsuga* are used worldwide for making paper and boards.

Woods of *Cedrus deodara* and *Juniperus virginiana* contains resin ducts that yield essential oils that are of commercial importance in histological works and used in oil emersion technique. *Juniperus communis* and *Dacrydium franklini* were used as flavouring agent in liquor and scenting soaps, respectively. *Gnetum ula, Araucaria bidwilli* and *Torreya nucifera* seeds were used for edible purpose because of their fatty acids.

Various *Cycas* species and *Gnetum* leaves are cooked and eaten as vegetables. Kaffir bread is made from *Encephalartos* pith whereas as cycad sago is obtained from *Cycas revoluta* (Sago Palm). *Ginkgo biloba* seeds were roasted and eaten by the Chinese and Japanese. Chilgoza are the pine nuts obtained from *Pinus gerardiana*. Spruce beer is obtained by fermenting the leaf extract of *Picea abies*.

Ephedrine, pseudoephedrine and oxazolidone are the pharmaceutically important drugs obtained from *Ephedra*. Toxol is another drug obtained from *Taxus brevifolia* having anticancerous property produced by an endophytic fungus present in the phloem known as *Taxomyces andreanae*.

Resins are the organic exudates produced from the gymnospermous woods used in paints, varnishing, water proof coating, printer ink ingredient, adhesives, fireworks and linoleum sheets, which makes them invaluable for industries. Hard resins having high melting temperature are known as copal whereas resins having low melting point is known as oleoresins. Copal is obtained from *Agathis australis* (Kauri copal), *Agathis alba* (Manila copal) while sandarac is obtained from *Tetraclinis articulata* and *Callitris* species. Oleoresins are obtained from *Pinus palustris* and *P. caribaea* (Turpentine), *Abies balsamea* (Canada balsam) and *Larix decidua* (Venice Turpentine). Tanins obtained from *Tsuga canadensis*, *Larix decidua*, *Picea alba* and *Phyllocladus trichomanoides* are used in petroleum and leather industries.

'Check Your Progress'

1. What is progymnosperms?
2. Define pteridosperms.
3. Distinguish between haplocheilic stomata and syndetocheilic stomata.
4. What is voltziales group?
5. What are coniferales?
6. Explain artifacts.

1.3 GEOLOGICAL TIME SCALE

In 1669, Nicolaus Steno described two principles about relationships of different rock units as:

- Sedimentary rocks are laid down in a horizontal fashion.
- Younger rocks were deposited on top of older ones.

In 1795, James Hutton described that there is a uniformity in the frequency and magnitude of natural geological processes known as 'principle of uniformitarianism'. The aforementioned idea and principles laid down the foundation of geological timescale. After the formation of Earth, ca. 4600mya ago, there were different events took place during the course of time. The time period is divided into various divisions, *viz.* Eons, Era, Periods, Epochs and Ages. Major events in the pasts delimits one division from the other. Table 1.3 enumerates list of various geological time divisions.

NOTES

Table 1.3 *Geological Time Scale*

Eon	Era	Period		Epoch	Age	Years (Ma)
	Cenozoic	Quaternary		Holocene		-0.012
				Pleistocene	Calabrian	0.012-1.8
					Gelasian	1.8-2.58
		Tertiary	Neogene	Pliocene	Piacenzian	2.58-3.6
					Zanclean	3.6- 5.33
				Miocene	Messinian	5.33-7.24
					Tortonian	7.24-11.63
					Serravallian	11.63-13.82
					Langhian	13.82-15.97
					Burdigalian	15.97-20.44
					Aquitanian	20.44-23.03
			Paleogene	Oligocene	Chattian	23.03-27.82
					Rupelian	27.82-33.9
				Eocene	Priabonian	33.9-37.8
					Bartonian	37.8-41.2
					Lutetian	41.2-47.8
					Ypresian	47.8-56.0
				Paleocene	Thanetian	56.0-59.2
					Selandian	59.2-61.6
					Danian	61.6-66.0
		Cretaceous		Late	Maastrichtian	66.0-72.1
					Campanian	72.1-83.6
					Santonian	83.6-86.3
					Coniacian	86.3-89.8
					Turonian	89.8-93.9
					Cenomanian	93.9-100.5
				Early	Albian	100.5-113
					Aptian	113-125
					Barremian	125-129.4
					Hauterivian	129.4-132.9
					Valanginian	132.9-139.8
					Berriasian	139.8-145.0
		Jurassic		Late	Tithonian	145.0-152.1
					Kimmeridgian	152.1-157.3
					Oxfordian	157.3-163.5
				Middle	Callovian	163.5-166.1
					Bathonian	166.1-168.3
					Bajocian	168.3-170.3
					Aalenian	170.3-174.1
				Early	Toarcian	174.1-182.7
					Pliensbachian	182.7-190.8
					Sinemurian	190.8-199.3
					Hettangian	199.3-201.3

NOTES

Mesozoic	Triassic	Late		Rhaetian	201.3-208.5
				Norian	208.5-227
				Carnian	227-237
		Middle		Laninian	237-242
				Anisian	242-247.2
		Early		Olenkian	247.2-251.2
				Induan	251.2-251.9
Paleozoic	Permian	Lopingian		Changhsingian	251.9-254.14
				Wuchiapingian	254.14-259.1
		Guadolupian		Capitanian	259.1-265.1
				Wordian	265.1-268.8
				Roadian	268.8-272.95
		Cisuralian		Kungrian	272.95-283.5
				Artinskian	283.5-290.1
				Sakmarian	290.1-295.0
				Asselian	295.0-298.9
	Carboniferous	Pennsylvanian	Late	Gzhelian	298.9-303.7
				Kasimovian	303.70307.0
			Middle	Moscovian	307.0-315.2
			Early	Bashkirian	315.2-323.2
		Missisisppian	Late	Serpukhovian	323.2-330.9
			Middle	Visean	330.9-346.7
			Early	Tournaisian	346.7-358.9
	Devonian		Late	Famennian	358.9-373.2
				Frasnian	373.2-382.7
			Middle	Givetian	382.7-387.7
				Eifelian	387.7-393.3
			Early	Emsian	393.3-407.6
				Pragian	407.6-410.8
				Lochkovian	410.8-419.2
	Silurian		Pridoli		419.2-423.0
			Ludlow	Ludfordian	423.0-425.6
				Gorstian	425.6-427.4
			Wenlock	Homerian	427.4-430.5
				Sheinwoodian	430.5-433.4
			Llandovery	Teychian	433.4-438.5
				Aeronian	438.5-440.8
				Rhuddanian	440.8-443.8
	Ordovician		Late	Hirnantian	443.8-445. 2
				Katian	445.2-453.0
				Sandbian	453.0-458.4
			Middle	Darriwilian	458.4-467.3
				Dapingian	467.3-470.0
			Early	Floian	470.0-477.7

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Phanerozoic			Early	Floian	470.0-477.7
				Tremadocian	477.7-485.4
		Cambrian	Furongian	Age 10	485.4-489.5
				Jiangshanian	489.5-494
				Paibian	494-497
			Epoch 3	Guzhangian	497-500.5
				Drumian	500.5-504.5
				Age 5	504.5-509
			Epoch 2	Age 4	509-514
				Age 3	514-521
			Terreneuvian	Age 2	521-529
				Fortunian	529-541

Precambrian			
Eon	Era	Period	
Proterozoic	Neoproterozoic	Ediacaran	541-635
		Cryogenian	635-720
		Tonian	720-1000
	Mesoproterozoic	Stenian	1000-1200
		Ectasian	1200-1400
		Calymmian	1400-1600
	Paleoproterozoic	Statherian	1600-2800
		Orosirian	1800-2050
		Rhyacian	2050-2300
		Siderian	2300-2500
Archean	Neoarchean		2500-2800
	Mesoarchean		2800-3200
	Paleoarchean		3200-3600
	Eoarchean		3600-4000
Hadean			4000-4600

1.3.1 Fossils

Fossils are the evidence from the past in the form of preserved living plants or animals or other material (Refer Figure 1.21). They indicate environment of past, relative time of deposition and other activities. Broadly fossils are classified into two broad categories, i.e., Macrofossils and Microfossils. Macrofossils are those which can be seen through naked eyes whereas microfossils are microscopic in nature. The details provided by the macrofossils are scanty but they are displayed in museums. Microfossils provides more details as they remain intact and a whole lot of features is preserved in the form of microscopic details. The process of fossil formation is known as fossilization and the study of fossils is known as paleontology.

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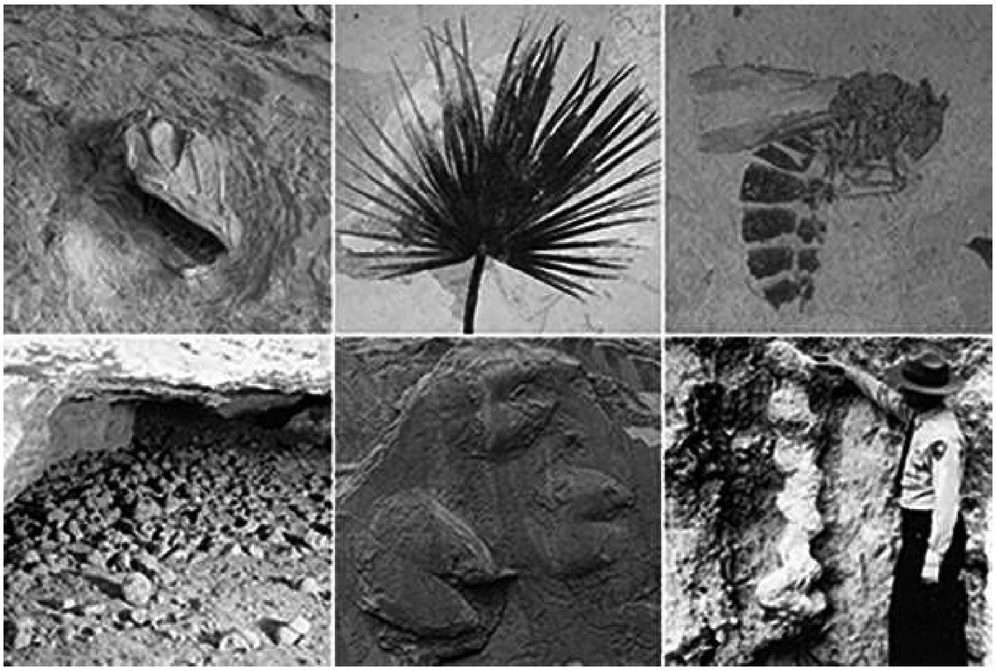

Fig. 1.21 Some Fossils

Taphonomy: It is the study of period between death of an organism and the discovery of fossil. Taphonomy encompass the processes between death and subsequent burial of the organism in the sediment (biostratinomy) and physical and chemical changes occur after burial (diagenesis).

Biostratinomy: Dead remains of an organism, if not buried quickly, are subjected to various processes such as weathering due to wind, water and other abiotic factors. The large sized organisms are subjected to fragmentation and leads to the deposition in various forms or sometimes moved to distant places depending upon the size of plant part and the driving force of the factor. All that happen to a fossil before deposition is studied under biostratinomy.

Diagenesis (Informally Fossilization): The process of preservation of direct or indirect information of an organism from the past is known as fossilization. The process of fossil formation is affected by the nature of material to be preserved and the biotic and abiotic factors in the surroundings. For example spores of plants are resistant and chemically inert in nature thus they are more favored for the fossilization whereas soft tissues are tend to be less favored as they are more susceptible to the decay from biological activity of microbes and oxidation due to presence of oxygen. The process of fossilization is hindered by biological activity of microbes, decaying of tissues and weathering. The fossils are found in sedimentary rocks only not in igneous and metamorphic rocks.

Methods of Preservation

- **Freezing:** Preservation of organism or part of organisms in the ice.
- **Encasement:** Entrapment of organisms or part of organisms in resins or oil seeps or tar or in sediment.
- **Permineralization or Petrification:** Mineral ions from surroundings get deposited in the pore and spaces of the skeleton or wood. Through permineralization the original skeletal information is preserved. During permineralization the mineral ions get deposited into the pores and fossil contains deposited ions along with the original material. Permineralization leads to formation of petrified fossils.

- **Carbonization:** In carbonization, volatile compounds present in the fossils are lost during the course of time and only carbon film or structure remains behind. Fine details are preserved during carbonization. The process occurs in anaerobic or oxygen deficient and high organic environments such as coal swamps. Carbonization leads to the formation of compressions.
- **Recrystallization:** The original structural material recrystalizes into more stable form. For example aragonite an original skeletal material of a gastropod recrystalizes into more stable calcite. The original materials is transformed into another form and the physical as well as chemical details were lost.
- **Replacement:** The original structural material is replaced by the new minerals such as Calcium carbonate ($CaCO_3$), Quartz (SiO_2) and Pyrite (FeS_2). Replacement leads to the formation of Molds (External and Internal), Casts and Impressions.

Types of Fossils

Impression: The plant parts falls on semi-solid surface of clay and the impression of the plant part gets imprinted on the clay when the clay solidifies, the imprinted information gets permanently fixed. External features are preserved in this type fossils (Refer Figure 1.22).

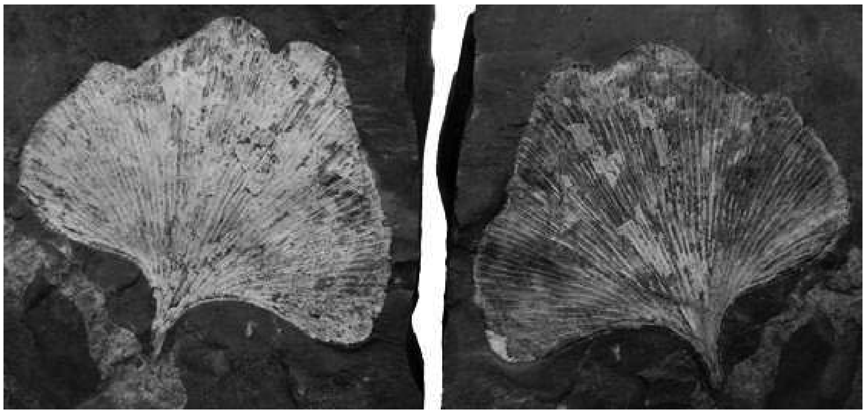

Fig. 1.22 *Impression Fossil*

Compression: The actual plant material is remained intact during the process of impressions and compressed by the pressure of the above lying strata of sediments. These types of fossils are well preserved and external and chemical properties of the fossils can be studied (Refer Figure 1.23).

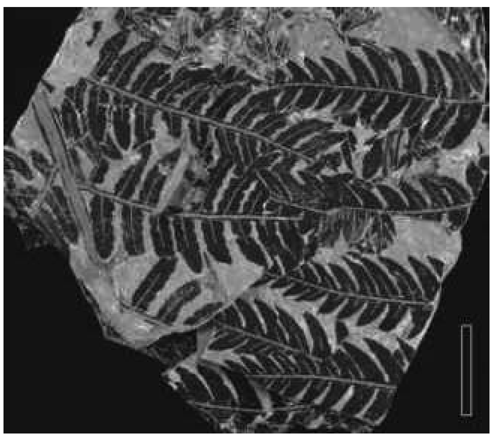

Fig. 1.23 *Compression Fossil*

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Molds: A hollow space or cavity left after the decay of original material (Refer Figure 1.24).

Fig. 1.24 *Molds Fossil*

Cast or Incrustations: These are the most common type of fossils. The dead part of the organism gets covered up by sand or mud and during the course of time dead part degrades leaving a hollow cavity. The cavity made by the decayed dead part is filled up by the minerals and original structural material is replaced.

Amber: These are the fossil containing tree resins stabilized after the evaporation of volatile compound.

Petrified Fossils: Formed due to permineralization of mineral ions and are best preserved. Petrified fossils are best Provides important internal as well as external details. Physical deformities does not occur in the fossils due to molecule by molecule deposition of mineral ions in the voids of structural materials such as wood (Refer Figure 1.25).

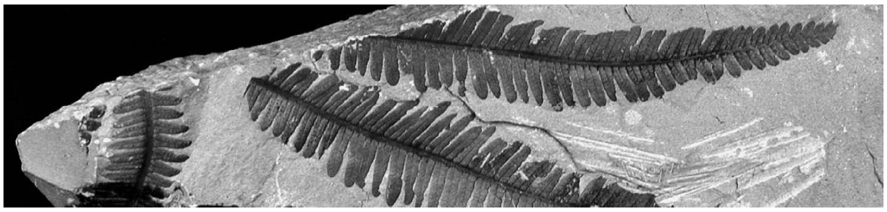

Fig. 1.25 *Petrified Fossils*

Trace Fossils: These are the indirect evidences of the organisms such as tracks, foot prints, burrows, feces, etc. (Refer Figure 1.26).

Fig. 1.26 *Trace Fossils*

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Pseudofossils: These are the inorganic structure having appearance of a biological remain (Refer Figure 1.27).

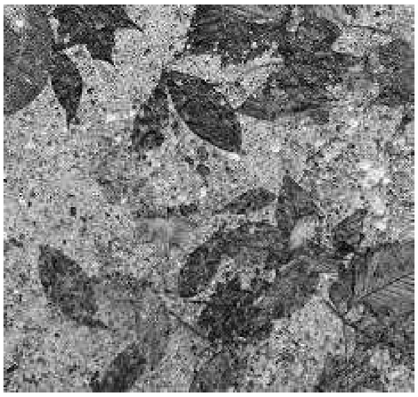

Fig. 1.27 *Pseudofossils*

Artifacts: During the process of fossilization some features are generated that leads to the preservation of fossils specimens.

Fossil DNA or Ancient DNA: DNA of the past discovered in the fossil beds or fossils or ancient specimens.

Evolution and historical discoveries in the field of paleobotany occurs in the past which includes fossil of Rhodophyta is *Rafatazmia chitrakootensis* from Chitrakoot, Uttar Pradesh, India of Proterozoic eon (Precambrian). The fossil dates back to 1600mya. Another fascinating discovery was *Cooksonia hemispherica*- first vascular plant record from Lower Devonian or Upper Silurian period. Table 1.4 enumerates some of the major events in the history of gymnosperms.

Table 1.4 *Major Discoveries in the Evolution of Gymnosperms*

S.No.	Era/Period	Time (mya)	Event
1	Late Devonian	385-359	Earliest seed plant arise.
2	Middle Pennsylvenian	310	Earliest conifers, cycads and *Ginkgo* evolved from Cordaitales. Carboniferous period referred as Age of ferns (369-280mya).
3	Permian	299-251	Divergence of Ginkgoales.
4	Middle Permian	271-260	First evidence of Gnetophytes.
5	Upper Triassic	235-202	First appearance of Bennettitales.
6	Triassic	228-225	First appearance of Podocarpaceae (*Rissikia media*).
7	Lower Jurassic	202-176	First appearance of *Ginkgo* Jurassic period referred as Age of cycads (201-145mya).
8	Jurassic	197-190	First appearance of Cupressaceae (*Austrohamia minuta*).
9	Jurassic	190-183	First record of Taxacaeae (*Paleotaxus rediviva*) and Araucariaceae.
10	Jurassic	156-151	First record of Pinaceae (*Eathiestrobus mackenziei*).
11	Lower Cretaceous	130	First appearance of *Pinus* (*P.yorkshirensis*).
12	Cretaceous	125-112	Earliest record of Gnetales leaves (*Drewia potomacensis*).
13	Cretaceous	89-86	First record of Sciadopityaceae (*Sciadopitys*).

1.3.2 Mass Extinctions

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Mass extinction is the loss of huge number of biological species at a time. In our earth's history there has been a total of nine mass extinction. Out of nine mass extinction four occurred during precambrian times. The following are the list of precambrian mass extinctions:

- Paleoproterozoic (1800-2300mya)
- Sturtian (725-670mya)
- 3 Marinoan/Gaskiers (640-580mya)
- Ediacaran (540mya)

After precambrian there were five major mass extinctions listed as follows:

- Cambrian-Ordovician
- Devonian
- Permian
- Triassic
- Cretaceous- Tertiary

Several researchers and scientist across the world belief that currently we are experiencing sixth mass extinction.

First Mass Extinction: First mass extinction occurred during Proterozoic eon during which billions microbial life forms become extinct. Most researchers consider extinction of microbes insignificant to count as a mass extinction. First mass extinction also known as 'Great oxidant event' or snow ball earth' was caused by the first global ice age. Whole planet was frozen at the beginning of 2300mya killing most of the microbial life and end around 1800mya. Apart from low temperature, low level of methane and increased oxygen in atmosphere were the other two factors influencing the first mass extinction.

Second Mass Extinction: Second mass extinction was also occurred during Proterozoic eon around 725mya-670mya. During 1600mya to1200mya complex multicellular eukaryotes (survived during first mass extinction) diverged and proliferated. Around 800mya many photosynthetically active eukaryotes proliferated resulted into the reduced level of carbondioxide and elevated level of oxygen. Around 850-820mya the pre-Pangean supercontinent occupied the tropical regions and starting to break apart due tectonic movement plate movement which resulted into mantle subduction and extensive volcanism happened. Around 730mya percentage of methane and carbondioxide decreased while oxygen level increased in the atmosphere. The temperature of Earth atmosphere decreased to such an extent resulting into the onset of second ice age (Sturtian global ice age) around 725mya and lasted until 670mya.

Third Mass Extinction: Third mass extinct was also a result of third ice age known as 'Marinoan' around 640mya to 580mya.

Fourth Mass Extinction: Fourth mass extinction occurred around 540mya to 510mya and very little is known about this mass extinction after fourth mass extinction there was an explosion of life. During this mass extinction the most of trilobite species were wiped out.

Fifth Mass Extinction (Cambrian-Ordovician Extinction): Fifth mass extinction occurred from 510mya to 440mya and considered as second most devastated mass extinction in terms of animal life. Like previous mass extinction global cooling and glaciation due to movement of Godwana supercontinent over to North Pole. During this period dense skeletal species were evolved.

Sixth Mass Extinction (Devonian): During devonian age evolution of bony fishes into amphibians and insects took place due to global ice age resulted from the impact of bright meteorite (bolide). It was estimated that around seventy percent of all taxa were disappeared.

Seventh Mass Extinction (Permian): Seventh mass extinction was most devastated and resulted into the loss of nearly ninety five percent of all species. The reason behind this mass extinction were meteorite impact, volcanic eruptions and glaciation followed by global warming.

Eighth Mass Extinction (Triassic): Triassic mass extinction happened due to asteroid impacts and volcanic eruptions. Breaking of Pangea (supercontinent) continental flood and flood basalts resulted into the elevated level of carbondioxide and decreased level of oxygen and global cooling resulting from sunlight blocking by debris (due to asteroid impact and volcanic eruptions) in the atmosphere.

Ninth Mass Extinction (Cretaceous-Tertiary): Cretaceous mass extinction resulted into extinction of approximately eighty five percent species. Dinosaurs became extinct along with other species. Asteroid impact near Yucatan Peninsula of Mexico and volcanic eruptions were two main reason behind this mass extinction. Ferns and phanerogams were spared and quickly diversified after this mass extinction.

Reasons of Mass Extinction

- **Glaciation and Global Cooling:** Decrease in the Earth's temperature resulted into cold planet thus triggering glaciation and lowering of sea level. Catastrophic events such as volcanism, plate tectonics, meteorite impact and sometimes biological factors like evolution of photosynthetic organisms appears to be the responsible agents. Glaciation causes lowering of sea level while global warming result into raised sea level. The history of Earth includes repeated events of glaciation and global warming. Melting of glaciers releases chemicals, gasses, metals in the oceans.
- **Gamma Rays:** These are the shortest wavelength of all waves in electromagnetic spectrum and are highly penetrating. Gamma rays have capability to destroy DNA and cells. They are produced in the universe during supernova and merger of binary stars. It has estimated that our planet was struck 8 to 10 times since its formation. Gamma ray burst is one of the factors of Cambrian-Ordovician mass extinction.
- **Global Anoxia:** Anoxia is a condition of significant reduction in the oxygen levels. During Devonian mass extinction and Permian mass extinction global anoxia plays an important role in the devastation of species. Numerous meteorites strikes and volcanic eruptions can cause global anoxia in the atmosphere whereas phytoplanktonic bloom results into decreased level of oxygen in aquatic ecosystems.
- **Volcanism:** Volcanic eruption releases ashes and dust into the atmosphere and one of the reason of global anoxia. Enormous volcanic dust and ashes blocks the sunlight and contribute towards the global glaciation by lowering the temperature.
- **Asteroid Impact:** It was believed that extinction of dinosaurs during cretaceous mass extinction was due to the asteroid impact on Earth. Another extinction due to asteroid impact was that of mammoths around 12.9 mya ago.
- **Disease:** Selective mass extinction of particular species is caused by pathogens such as bacteria, fungi or viruses. Due to sudden change in the environment conditions or vectors or hosts response the pathogenicity of these microbes and causes epidemics.

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Plate Tectonic Theory

Tectonics means large scale movement of lithospheric plates. Lithospheric plates are divided by natural boundaries such as ridges and trenches. Everything about plate tectonic theory starts from continental drift theory proposed by Alfred Wagner (1922) (Refer Figure 1.28). According to Wegner, before Mesozoic era a large supercontinent exists known Pangea and a large ocean known Panthalassa. During Mesozoic era, the continents starts to break apart into two land masses: (i) Laurentia (North) and (ii) Gondwanaland (South) separated by a newly emerged sea known as Tethys. The driving force needed for the movement of such large crustal plates, explained by the Wegner was not satisfactory. Arthur Holmes proposed the thermal convection currents were possibly the driving force behind the continental drifts. In 1960's, Hess (1962) and Deitz (1961) published the sea spreading theory based on the mantle convention currents as driving force. India was a part of Gondwana land.

There are many evidences behind this theory and the important one for botany students is the distribution of Glossoperis leaves across all the continents of world. Glossopteris were discovered from southern South America, Southern Africa, Madagascar, India, Antarctica and Australia. At present these continental plates are far separated by geographical boundary of oceans but distribution of Glossopteris around all part of the world suggests that all these continents were once a part of big landmass.

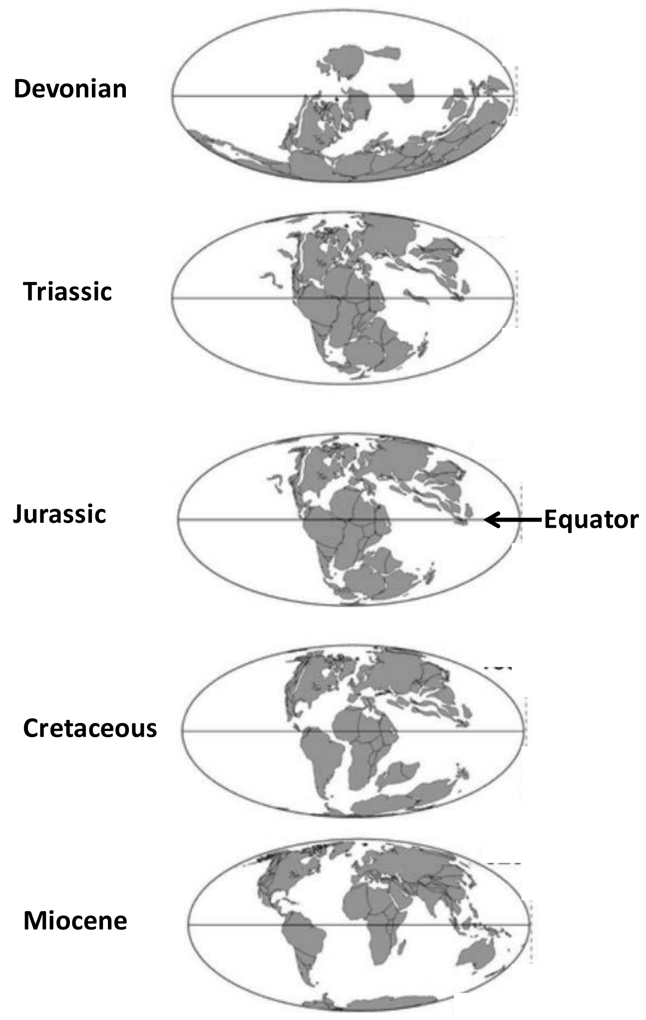

Fig. 1.28 *Wegner's Continental Drift Theory*

NOTES

'Check Your Progress'

7. What are fossils?
8. Distinguish between microfossils and macrofossils.
9. What is taphonomy?
10. Define diagenesis.
11. What are amber?
12. Explain mass extinction.
13. When did first mass extension occur?

1.4 SUMMARY

- Gymnosperms (Gymnos = Naked + Sperm = Seeds) derived from Greek word, are heterogeneous group of plants including many fossil records and living genera.
- The seed plants are usually classified into two major groups: gymnosperms and angiosperms based on the presence of protecting structure, i.e., ovary, around the ovules at the time of pollination.
- The gymnosperms bear naked ovules, i.e., the ovules are borne directly on the sporophyll modified leaves or an equivalent structure, and are exposed.
- Gymnosperms are woody and evergreen and trees, shrubs or lianas in habit.
- No gymnosperm are herbaceous in habit.
- Ovule is naked, orthotropous (except in *Podocarpaceae* where anatropous ovule is present) and unitegmic (except in *Ephedra* two integuments; *Welwitschia* and *Gnetum* three integuments).
- Monosporic development of female gametophyte (except in *Welwitschia* and *Gnetum*). Archegonia is absent in *Gnetum* and *Welwitschia* (archegonium intial functions as an egg cell).
- Endosperm is haploid in nature and forms before fertilization (in *Gnetum* endosperm is formed after fertilization). Double fertilization is absent in gymnosperms (except in *Ephedra*).
- Some of the gymnosperms attain a height up to 100 metres, for example Sequoia sempervirens (nearly 112 metre, the tallest living tree). The smallest gymnosperms is Zamia pygmaea, a cycad. Its fronds are only 4 or 5 cm long.
- From the economic point of view, gymnosperms are highly important in forestry and horticulture. They yield timber, resins, essential oils, drugs and edible nuts. The newspaper industry is almost completely dependent on the wood of conifers for its paper requirements.
- The reproductive parts are generally arranged in the form of compact and hard cones or strobilli. The cones are unisexual. Hermaphrodite cone in certain members occurs sometimes as an abnormality.
- Male cones are usually smaller and short-lived than female cones in certain genera (for example *Cycas*), however, reproductive structures are not present in the form of compact cone-like structures.

- In male cones, several microsporophyll's are arranged on the central axis, each possessing several microsporangia containing microspores or pollen grains. The microsporophyll's may-be broad (for example *Cycas*) or peltate (for example *Dioon*, *Taxus*).
- Pollination in gymnosperms is anemophilous whereas in angiosperms it is entomophilous, hydrophilous and zoophilous.
- Naked, orthotropus and unitegmic ovules are present in gymnosperms (in angiosperms uni or bitegmic ovules are present) and pollen grains enters through micropylar end.
- Archegonium is present in gymnosperms and the development of female is monosporic except in *Gnetum* and *Welwitschia* where archegonia is absent and development of female gametophyte is tetrasporic (in angiosperms uni-, bi-, or tetrasporic development of female gametophyte took place).
- Double fertilization is absent in gymnosperms and haploid endosperm is present (in angiosperms double fertilization occurs and triploid endosperms is formed).
- Cleavage polyembryony is a common feature of gymnosperms and free nuclear division took place in zygote (except in *Gnetum*, *Sequoia* and *Welwitschia*) whereas in angiosperms division is followed by wall formation in zygote (except in *Paeonia*) and cleavage polyembryony is absent.
- Progymnosperms (extinct group) are ancestors to gymnosperms and found in the period of Devonian-Pennsylvanian period.
- The members of this group exhibit anatomy similar to gymnosperms, pycnoxylic wood, bifacial cambium, tracheids with circular bordered pits and reproduction is by spores similar to that of pteridophytes.
- Phylogenetically *Archaeopteris* is considered as an intermediate between pteridophytes and phanerogams due to arborescent habit, megaphyllous leaves, secondary growth and heterosporous reproduction.
- Pteridosperms or seed ferns or extinct group, exhibits fern like leaves and gymnospermous seed habit. In 1887, Williamson recognized the carboniferous plants exhibiting anatomical characters of cycads and ferns.
- *Kaloxylon* (Root) are abundant, adventitious and some are aerial. Anatomically outer cortex consist of two or three tier of parenchymatous cells and inner mucilaginous thick walled cortex with exarch condition.
- Glossopteridale, the leaf morphogenus *Glossopteris* appeared in the permian period of Gondwana including India. Earlier it was considered in the cycads but after the discovery of seed bearing megasporophylls glossopterids were classified under seed ferns.
- Glossopterids were arborescent plants and had alternately arranged leaves. Sediments suggests that glossopterids were deciduous.
- *Gangamopteris* (Leaf), *Gangamopteris* is distinct from *Glossopteris* in large size and absence of midrib.
- *Agathoxylon* (=*Araucarioxylon*) (Stem), is pycnoxylic wood with growth rings. Multiseriate pits are present on the radial walls of tracheids and xylem rays are uniseriate.
- *Vertebraria* (Root) the secondary growth is present, exarch primary xylem, secondary xylem appears as wedge shaped and surrounded by the periderm.

- The cavities present between the radiating arms of protoxylem suggests the nature as root which flourished in the semi aquatic environment. Uniseriate vascular rays are present in the pycnoxylic wood of *Vertebraria*.
- *Eretmonia* (Pollen Organ) are the pollen organs were stalked with triangular distal lamina. Two branches arises from on the adaxial surface bearing *Arberiella* type sporangia. Sporangia bears bisaccate pollen grains.
- Haplocheilic Stomata is the type of stomatal development, in which the stomata mother cell divides once and give rise to guard cells. No subsidiary cells are formed.
- Syndetocheilic Stomata is the type of stomatal development, in which the stomata mother cell divides thrice. First and second division give rise to subsidiary cells and the third division give rise to guard cells.
- *Williamsonia sewardiana* was 2meter tall tree with presistant helical arranged leaf bases. Crown of *Ptilophyllum* type of pinnate leaf was present at the distal end of trunk. Short lateral stalks bears ovulate cones along with leaves.
- Coniferales (living and extinct both taxa are present), dates back from Carboniferous period to present, mostly evergreen and few deciduous conifers are *Larix*, *Pseudolarix*, *Metasequoia* and *Taxodium distichum*, either monoecious or dioecious, wood is pycnoxylic, presence of multiseriate bordered pits on tracheids, resin canals are present in pith and cortex, haplocheilic stomata, cones are unisexual and compound, male gametes are non-motile, seeds are endospermic and embryo contains two or more cotyledons.
- Taxales is commonly known as yew (for example *Taxus baccata*, appeared in late triassic or early jurassic. Plants are mostly dioecious or sometimes monoecious evergreen and profusely branched.
- Leaves are acicular or narrow arranged spirally. Leaves are opposite and decussate and scale like on fertile shoots. Tunica is absent on the stem apex. Wood are pycnoxylic and resin canals are absent. Dicotyledonous embryo is present.
- Welwitschiales, monotypic living taxa *Welwitschia mirabilis* is dioecious, turnip like underground stem bearing two strap shaped leaves. vessels are present, two persistent leaves with continuously growing at base, syndetocheilic stomata, archegonia is absent, tetrasporic development of female gametophyte and winged seeds.
- Gymnosperms are evergreen, woody and have symmetrical appearance. *Cycas, Ginkgo* (male plant), *Thuja, Araucaria, Juniperus, Pinus, Cupressus, Cryptomeria, Thujopsis, Abies, Piceae* and *Pseudostuga* are some of the gymnosperms used for landscaping in gardens and for ornamental purpose as bonsai and as floral decorations.
- Various species of gymnosperms are popular as Christmas trees but before World War II, *Juniperus virginiana* was preferred traditional Christmas tree.
- The pycnoxylic wood of gymnosperms provides the commercially important timber. The wood of gymnosperms have soft texture due to high cellulose content. Xylem fibres are absent in most part of the gymnospermous wood.
- Woods of *Cedrus deodara* and *Juniperus virginiana* contains resin ducts that yield essential oils that are of commercial importance in histological works and used in oil emersion technique.
- *Juniperus communis* and *Dacrydium franklini* were used as flavouring agent in liquor and scenting soaps, respectively. *Gnetum ula, Araucaria bidwilli* and *Torreya nucifera* seeds were used for edible purpose because of their fatty acids.

NOTES

- Various *Cycas* species and *Gnetum* leaves are cooked and eaten as vegetables. Kaffir bread is made from *Encephalartos* pith whereas as cycad sago is obtained from *Cycas revoluta* (Sago Palm).
- *Ginkgo biloba* seeds were roasted and eaten by the Chinese and Japanese. Chilgoza are the pine nuts obtained from *Pinus gerardiana*. Spruce beer is obtained by fermenting the leaf extract of *Picea abies*.
- Ephedrine, pseudoephedrine and oxazolidone are the pharmaceutically important drugs obtained from *Ephedra*. Toxol is another drug obtained from *Taxus brevifolia* having anticancerous property produced by an endophytic fungus present in the phloem known as *Taxomyces andreanae*.
- Fossils are the evidence from the past in the form of preserved living plants or animals or other material.
- Broadly fossils are classified into two broad categories, i.e., Macrofossils and Microfossils.
- Macrofossils are those which can be seen through naked eyes whereas microfossils are microscopic in nature. The details provided by the macrofossils are scanty but they are displayed in museums.
- Microfossils provides more details as they remain intact and a whole lot of features is preserved in the form of microscopic details.
- The process of fossil formation is known as fossilization and the study of fossils is known as paleontology.
- Taphonomy is the study of period between death of an organism and the discovery of fossil. Taphonomy encompass the processes between death and subsequent burial of the organism in the sediment (biostratinomy) and physical and chemical changes occur after burial (diagenesis).
- Diagenesis (Informally Fossilization) is the process of preservation of direct or indirect information of an organism from the past is known as fossilization.
- The process of fossil formation is affected by the nature of material to be preserved and the biotic and abiotic factors in the surroundings.
- Impression, the plant parts falls on semi-solid surface of clay and the impression of the plant part gets imprinted on the clay when the clay solidifies, the imprinted information gets permanently fixed. External features are preserved in this type fossils.
- Compression is the actual plant material is remained intact duringo the process of impressions and compressed by the pressure of the above lying strata of sediments.
- Cast or incrustations are the most common type of fossils. The dead part of the organism gets covered up by sand or mud and during the course of time dead part degrades leaving a hollow cavity. The cavity made by the decayed dead part is filled up by the minerals and original structural material is replaced.
- Amber are the fossil containing tree resins stabilized after the evaporation of volatile compound.
- Trace Fossils are the indirect evidences of the organisms such as tracks, foot prints, burrows, feces, etc.
- Artifacts refers to the process of fossilization in which some features are generated that leads to the preservation of fossils specimens.

- Mass extinction is the loss of huge number of biological species at a time. In our earth's history there has been a total of nine mass extinction.
- First mass extinction occurred during Proterozoic eon during which billions microbial life forms become extinct.
- Second mass extinction was also occurred during Proterozoic eon around 725mya-670mya.
- Third mass extinct was also a result of third ice age known as 'Marinoan' around 640mya to 580mya.
- Fourth mass extinction occurred around 540mya to 510mya and very little is known about this mass extinction after fourth mass extinction there was an explosion of life.
- Fifth mass extinction occurred from 510mya to 440mya and considered as second most devastated mass extinction in terms of animal life.
- Sixth Mass Extinction (Devonian) specifies that during devonian age evolution of bony fishes into amphibians and insects took place due to global ice age resulted from the impact of bright meteorite (bolide).
- Seventh mass extinction was most devastated and resulted into the loss of nearly ninety five percent of all species.
- Eighth Mass Extinction (Triassic), triassic mass extinction happened due to asteroid impacts and volcanic eruptions.
- Ninth Mass Extinction (Cretaceous-Tertiary), cretaceous mass extinction resulted into extinction of approximately eighty five percent species.
- Glaciation and Global Cooling decrease in the Earth's temperature resulted into cold planet thus triggering glaciation and lowering of sea level.
- Gamma rays are the shortest wavelength of all waves in electromagnetic spectrum and are highly penetrating.
- Tectonics means large scale movement of lithospheric plates. Lithospheric plates are divided by natural boundaries such as ridges and trenches.

1.5 KEY TERMS

- **Progymnosperms:** Progymnosperms (extinct group) are ancestors to gymnosperms and found in the period of Devonian-Pennsylvanian period.
- **Pteridosperms:** Pteridosperms (seed ferns) (extinct group) exhibits fern like leaves and gymnospermous seed habit.
- **Fossils:** Fossils are the evidence from the past in the form of preserved living plants or animals or other material.
- **Macrofossils:** Macrofossils are those which can be seen through naked eyes.
- **Microfossils:** Microfossils are the fossils that are microscopic in nature.
- **Amber** are the fossil containing tree resins stabilized after the evaporation of volatile compound.
- **Mass extinction:** Mass extinction is the loss of huge number of biological species at a time. In our earth's history there has been a total of nine mass extinction.

1.6 ANSWERS TO 'CHECK YOUR PROGRESS'

NOTES

1. Progymnosperms (extinct group) are ancestors to gymnosperms and found in the period of Devonian-Pennsylvanian period.
2. Pteridosperms (seed ferns) (extinct group) exhibits fern like leaves and gymnospermous seed habit.
3. In Haplocheilic type of stomatal development, stomata mother cell divides once and give rise to guard cells. No subsidiary cells are formed, whereas in syndetocheilic stomata type of stomatal development, stomata mother cell divides thrice. First and second division give rise to subsidiary cells and the third division give rise to guard cells.
4. Voltziales group is often called as transition conifers, present between late paleozoic and mesozoic era.
5. Coniferales (living and extinct both taxa are present): dates back from Carboniferous period to present, mostly evergreen and few deciduous conifers are *Larix*, *Pseudolarix*, *Metasequoia* and *Taxodium distichum*, either monoecious or dioecious, wood is pycnoxylic, presence of multiseriate bordered pits on tracheids, resin canals are present in pith and cortex, haplocheilic stomata, cones are unisexual and compound, male gametes are non-motile, seeds are endospermic and embryo contains two or more cotyledons.
6. During the process of fossilization some features are generated that leads to the preservation of fossils specimens known as artifacts.
7. Fossils are the evidence from the past in the form of preserved living plants or animals or other material.
8. Macrofossils are those which can be seen through naked eyes whereas microfossils are microscopic in nature.
9. Taphonomy is the study of period between death of an organism and the discovery of fossil. Taphonomy encompass the processes between death and subsequent burial of the organism in the sediment (biostratinomy) and physical and chemical changes occur after burial (diagenesis).
10. Diagenesis (informally fossilization) is the process of preservation of direct or indirect information of an organism from the past is known as fossilization. The process of fossil formation is affected by the nature of material to be preserved and the biotic and abiotic factors in the surroundings.
11. Amber are the fossil containing tree resins stabilized after the evaporation of volatile compound.
12. Mass extinction is the loss of huge number of biological species at a time. In our earth's history there has been a total of nine mass extinction.
13. First mass extinction occurred during Proterozoic eon during which billions microbial life forms become extinct.

1.7 QUESTIONS AND EXERCISES

Short-Answer Questions

1. Write down the names of *Cycas* species found in India.

2. Briefly write down the distribution of Gymnosperms across the world.
3. How many types based on the development of guard cells and subsidiary were found in Gymnosperms?
4. Write briefly about Welwitschiales.
5. Write down the classification of gymnosperm proposed by Prof. Birbal Sahni.
6. Write briefly about mesozoic seed fern.
7. What do you understand by the term fossil?
8. What is taphonomy?
9. What is biostratinomy?
10. What do you understand by the word diagenesis?
11. Write down the methods of preservation of fossils.
12. Write briefly about *Amyelon*.

NOTES

Long-Answer Questions

1. Describe general characters of Gymnosperms.
2. Elaborate on the characteristic features of Progymnosperms.
3. Explain the similarity and dissimilarities between Gymnosperms and Pteridophytes.
4. What do you understand by Pteridosperms?
5. Give an account of Pant's and Stewart's classification of Gymnosperms.
6. Describe methods of preservation of fossils.
7. Write down the types of fossils and their properties.
8. What do you understand by taphonomy? Give a detailed account of the processes under taphonomy.

1.8 FURTHER READING

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NOTES

UNIT 2 CAYTONIALES, PENTOXYLALES AND CORDAITALES

Structure

2.0 INTRODUCTION

The Caytoniales are an extinct order of seed plants known from fossils collected throughout the Mesozoic Era, specifically in the late Triassic to Maastrichtian period, around 250 to 70 million years ago. They are regarded as seed ferns because they are seed-bearing plants with fern-like leaves. Although at one time considered angiosperms because of their berry-like cupules, that hypothesis was later disproven. Nevertheless, some authorities consider them likely ancestors of angiosperms, whereas others consider angiosperms more likely derived from Glossopteridales.

The Pentoxylales are a group of seeds plants that lived during the middle to late Mesozoic. They had long narrow leaves, and wood in a characteristic five wedge pattern (pento-xylon) around the primary xylem. There were probably trees in form. Reproductively, each ovule was surrounded by a cupule, and structures were unisexual. The diversity of characteristics in leaf venation, stomatal patterning, and ovule structure may indicate that they are cousins to the angiosperms.

The Cordaitales is another fossil group which lived side by side with the Cycadofilicales in Palaeozoic times. Both the groups were very common, the Cordaitales being then the prevailing gymnospermous forest plants. The group extends from Devonian through Carboniferous up to the Permian times, and in India they had been found even in the lower Mesozoic, i.e., in Lower Gondwana strata of India.

In this unit, you will study about the salient features and phylogeny of Caytoniales, Pentoxylales and Cordaitales in detail.

2.1 UNIT OBJECTIVES

After going through this unit, you will be able to:

- Discuss the phylogeny of Caytoniales, Pentoxylales and Cordaitales
- Understand general features of Caytoniales, Pentoxylales and Cordaitales

NOTES

2.2 CAYTONIALES

Caytonales are an important extinct group of seed ferns. Group of Mesozoic seed fern (pteridosperm) established by H.H. Thomas in 1925 and the type was based on seed bearing organ *Caytonia*. In 1983, Stewart had divided Caytoniales in three families Caytoniaceae, Corystospermaceae and Peltaspermaceae. Later on all the families were raised to order rank, i.e., Caytoniales, Corystospermales and Peltaspermales. In 1971, Harris had reconstructed *Caytonia* plant as a small tree with woody axes attached to *Sagenopteris* (leaves).

Leaf: *Sagenopteris* (Middle Triassic to Cretaceous)

It is a palmately compound leaf with three to five leaflets and were associated with *Caytonia* based on cuticular similarities and occurrence. It is found in fossil beds of different localities, such as Japan, Antarctica, Europe, Greenland, North and South America.

Pollen Bearing Organ: *Caytonanthus* (Middle Jurassic)

It is found associated with the *Sagenopteris* leaves and was assigned to *Caytonia* based on the similarities between pollens. Pollens were produced in synangia borne laterally on pinnately branched axis. Synangia were radially symmetrical, contains one to four pollen sacs and dehisce towards the centre. Pollen grains are small and winged. Two sacs (wings) are found in the pollens on each side of corpus (central body). Saccate pollen grains are of two types i.e., Protosaccate and Eusaccate. Protosaccate pollens have extensive webbing on the sacs and corpus surface walls, for example *Caytonia*, while eusaccate pollens have limited webbing on the sac, for example *Pinus* (Refer Figure 2.1).

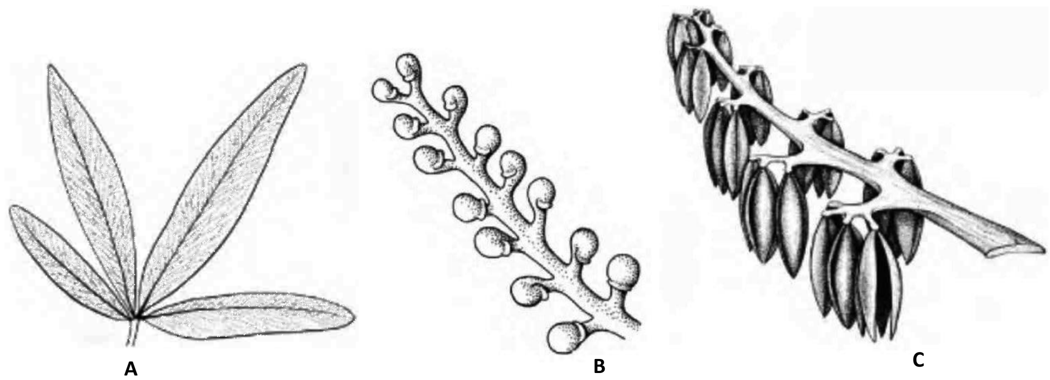

Fig. 2.1 *A. Sagenopteris; B. Caytonia; C. Caytonanthus*

Ovule Bearing Organ: *Caytonia*

Caytonia consists of ca. 5cm long axis with two rows of multiovulate lateral cupules. The cupules were globose, recurved and a lip like projection is present at the point of attachment (base). Depending upon species, number of seeds present in each cupules varies from 8 to 30. Seeds are cs. 2mm long stalked, radially symmetrical, orthotropous and unitegmic.

Ktalenia circularis was another ovule bearing organ belonging to caytoniales. It differs from *Caytonia* in having only two seeds per cupule (Refer Figure 2.2).

NOTES

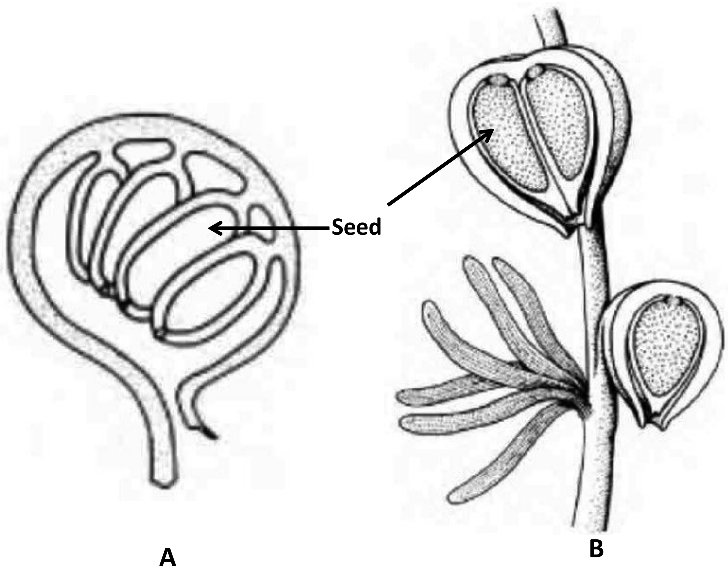

Fig. 2.2 A. Caytonia Cupule (After Dilcher, 1979) B. Ktalenia Circularis Cupule (After T. Taylor and Archangelsky, 1985)

Phylogenetic Significance

In 1925, Thomas has described *Caytonia* as an angiospermous fruits. In his initial description he interpreted pollen grains present in the liplike of cupule and described it as angiospermous fruit containing many seeds. He also misinterpreted the fine strands of cuticle extended between seeds and cupule as remnants of pollen tubes or an extension of micropyles. In 1940, Harris demonstrated that pollen are present in the cupules and the pollination was performed by pollination droplet mechanism as in other gymnosperms. In 1973, Reynanowna demonstrated that each seed has a canal extending from micropylar end to the outer lip of cupule. The cupule and ovule arrangement in the Caytoniales represents a course of evolution in which the seeds becomes enclosed. In 1946, Gaussen has proposed a theory of angiosperm origin from Caytoniales based on several assumptions such as reduction in the multiple ovules of *Caytonia* and interpreted cupule wall homologous to the second integument of angiosperms (angiosperms are bitegmic whereas gymnosperms are unitegmic) and the axis of cupule give rise to carpel.

At present, the Caytoniales represents a monophyletic group of very little information and needs more investigations to decide any phylogenetic relationships.

'Check Your Progress'

1. What are Caytonales?
2. In how many families did Stewart divided Caytoniales and when?
3. How many types of Saccate pollen grains are there?

2.3 PENTOXYLALES

The **Pentoxylales** are a group of seeds plants that lived during the middle to late Mesozoic. They had long narrow leaves, and wood in a characteristic five wedge pattern (pento-xylon) around the primary xylem. There were probably trees in form. Reproductively, each ovule was surrounded by a cupule, and structures were unisexual. The diversity of characteristics in leaf venation, stomatal patterning, and ovule structure may indicate that they are cousins to the angiosperms.

NOTES

In 1948, Professor Birbal Sahni proposed pentoxyleae for the fossil specimens of Jurassic and Cretaceous gymnosperms reported from Rajmahal Hills, Jharkhand, India (Refer Figure 2.3). The exact habit of these fossils is unknown. Few paleobotanists considered them as small trees with long and dwarf shoots and others suggests that they were shrub like in habit and inhabits the river floodplains.

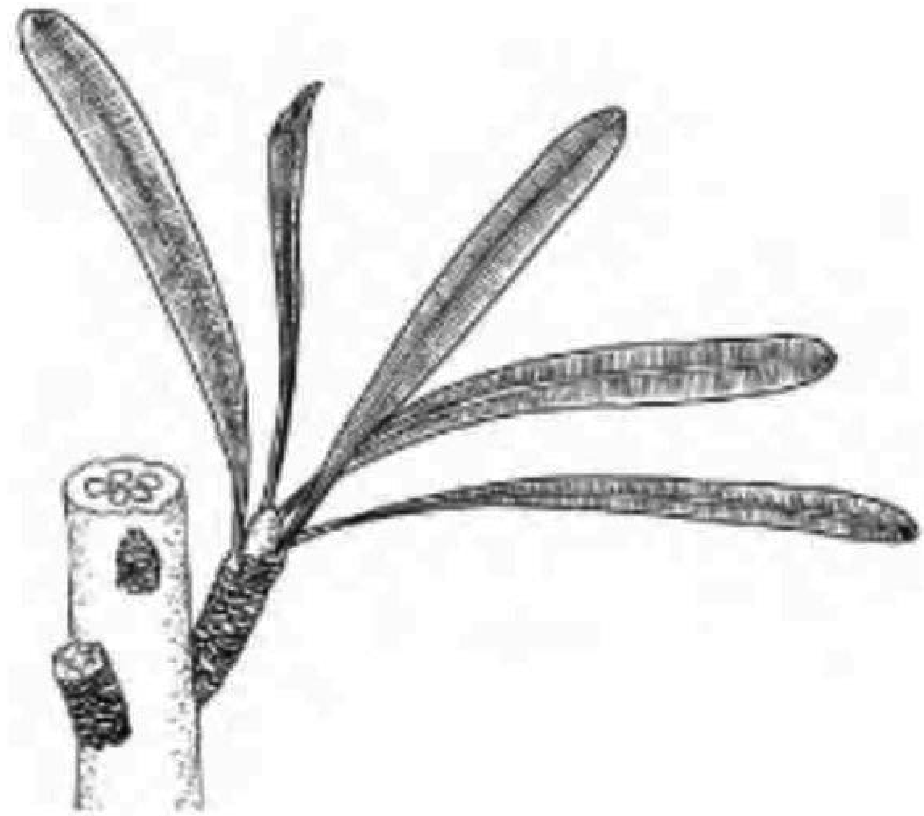

Fig. 2.3 *Reconstructed plant of Pentoxylon after Sahni (1948) Pentoxyleae: A New Group of Jurassic Gymnosperms from the Rajmahal Hills of India*

Stem: *Pentoxylon*

Two types of stems (dimorphic) were present like in the *Ginkgo* and Conifers i.e. long and dwarf shoots. Long shoot ca. 1 cm in diameter, *Pentoxylon sahnii* five or six wedge shaped vascular tissues (mesarch primary xylem surrounded by secondary xylem) are present and eustelic (Refer Figure 2.4). Secondary growth was due to endocentric activity of cambium, i.e., more wood was produced towards pith. Wood is pycnoxylic like that of Conifers and uni-biseriate circular bordered pits were present on the tracheids. Medullary rays are up to seven cells in height. Parenchymatous pith and cortex is present and there were some specimens exhibiting the periderm. Phloem fibers were lacking in the secondary phloem (consists of sieve elements and phloem parenchyma). Growth rings were well defined.

Dwarf shoot or short spur is less than one centimeter in diameter and the surface was covered by rhomboidal leaf cushions, arranged helically, with seven to nine vascular bundles scars. Secondary growth is absent and only primary vascular bundles is embedded in the pith and cortex.

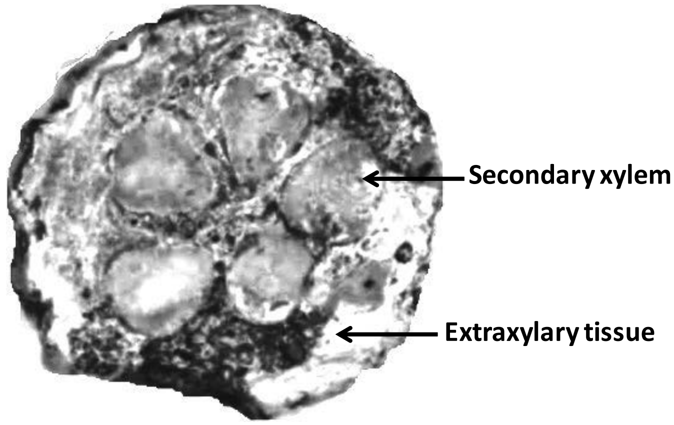

Fig. 2.4 Cross Section of Pentoxylon

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Leaf: *Nipaniophyllum*

Nipaniophyllum raoi were petiolate, strap shaped (1 cm wide and up to 20 cm in length) with round apex. Several parallel veins running through middle portion of the leaf forms a broad mid vein and lateral veins were born at right angle to the mid vein. Occasional branching and fusion of lateral veins near leaf margins was also observed in some specimens. Sunken sydetochelic stomata were present on the abaxial surface. In some specimens stoma exhibits anomocytic pattern, i.e., surrounded by a ring of subsidiary cells. Winged petiole had five to nine bundles were arranged in a tangential row. Each bundle was surrounded by sclerenchymatous sheath.

Pollen Bearing Organ: *Sahnia*

Sahnia nipaniensis (Refer Figure 2.5) borne terminally on the short shoots. Microsporophylls were arranged spirally around dome shaped or cylindrical receptacle. Each microsporophyll bears many pear shaped, sub-sessile or stalked unilocular sporangia. Monocolpate pollen grains were present.

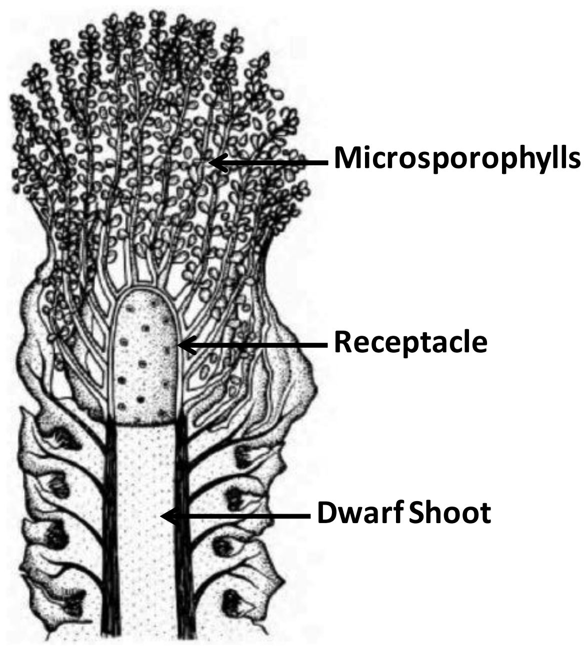

Fig. 2.5 *Sahnia nipaniensis (After Suthar and Sharma, 1988)*

Ovule Bearing Organ: *Carnoconites*

Carnoconites (Refer Figure 2.6) were also termed as infructescences, seed-bearing fruits or seed-bearing cones. Several ovulate megasporophyll were borne terminally on the branches of central axis (peduncle). Each megasporophyll contains ca. 20 helically arranged orthotropous ovules. Ovules are platyspermic and sessile. Nucellus and integuments were fused at base and free at distal end. The untigemic integument is divided into thick sarcotesta and inner sclerotesta.

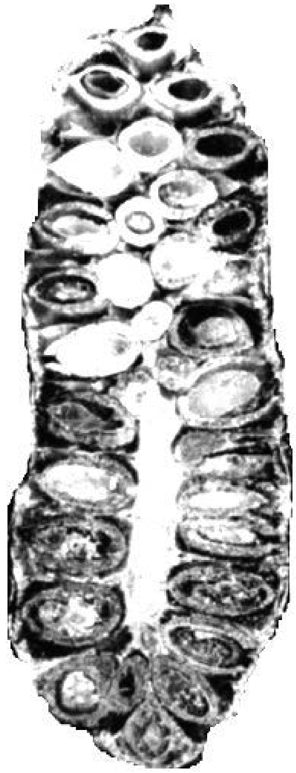

Fig. 2.6 *Longitudinal Section of Carnoconites Bearing many Seeds attached to Axis*

Phylogenetic Significance

The correct phylogeny of Pentoxylales is yet to be deciphered. There are several features common to different groups and Pentoxylales. Pentoxylales and Bennettitales shares platyspermic seeds, monosulcate pollen and thick sclerotesta. Monosulcate pollen grains were also present in *Ginkgo*, cycads and certain pteridosperms. Pycnoxylic wood and stachyosporous (born on stem) reproductive structures were represented by Pentoxylales as well as Conifers. Some researchers thought Pentoxylales as a sister group of Bennettitales others thought that they were closely related to Glossopteridales. *Carnoconites* is a unique structure present in Pentoxylales only.

'Check Your Progress'

4. What are Pentoxylales?
5. What did Professor Birbal Sahni do?
6. What were *Nipaniophyllum raoi?*

2.4 CORDAITALES

NOTES

The Cordaitales is another fossil group which lived side by side with the Cycadofilicales in Palaeozoic times. Both the groups were very common, the Cordaitales being then the prevailing gymnospermous forest plants. The group extends from Devonian through Carboniferous upto the Permian times, and in India they had been found even in the lower Mesozoic, i.e., in lower Gondwana state of India. The plants of this group were trees some even more than ninety feet in height and three feet in diameter. The plant branched at only tips and bore generally narrow and simple leaves in clusters at top.

The order is extinct group from Mississipian to Permian period. The group includes trees, shrubs and small trees. According to Cordaitalean-Mangrove hypothesis cordaitaleans represents the early mangrove plants inhabiting the coastal regions but this hypothesis has been challenged and a present the term 'mangrove' is not used for these fossil specimens (Refer Figure 2.7).

Fig. 2.7 *Diagrammatic representation of Cardaixylon dumusum (After Rothwell and Warner, 1984)*

Distinguishing Features of Cordaitales:

- This group of fossil plants had tall trees with slender trunks and a crown of several well- developed branches.
- Plants were present from Devonian to Permian periods of Palaeozoic era (Fig. 1.1)
- The leaves were simple, spirally arranged and strap-shaped, grass-like or paddel-like.
- The leaves attained a length up to 1 metre or even more, and had parallel venation.
- A scanty primary wood was present.
- In mature stems, the secondary wood was mostly pycnoxylic.
- Compound unisexual cones were present.
- Each compound cone had a main axis with bracts subtending secondary fertile shoots possessing fertile and sterile appendages.
- Mega-strobili had sterile appendages below and ovule-bearing fertile appendages above.

NOTES

- One to four ovules were present on each female fertile appendage.
- Micro-strobili had sterile appendages below and pollen-sac containing fertile appendages above.
- Four to six terminal pollen sacs were present on each male fertile appendage.
- Sperms have not been reported, but presence of pollen chambers suggests that motile sperms might have been formed.

Features of Cordaitales

Morphological Features: The plant was tall and slender. It had a crown of branches near the top, leaves were large simple and pendulate and not found in any living gymnosperms.

Anatomical Features: The internal structure of stem in Cordaites showed a combination of Cycas and conifers characters. Pith like cycads layer but discoid in form, i.e., it was in form of plates at intervals. The vascular cylinder was like those of conifers. It was made up of thick collateral endarch primary bundles which sometimes however, seem to have been mesarch as in Mesoxylon.

There was good deal of normal secondary growth. Secondary xylem was made up of living pitted tracheids with pits on radial walls. In fact it is clear that majority of plants found in Carboniferous period belonging to Cycadofllicales, Cordaitales and a number of fossil pteridophytes. The stems had good deal of secondary growth in them, but in these no annular rings.

The stem anatomy of Cordaitales shows variations from exarch to end-arch collateral primary vascular bundles with good deal of secondary growth in stem. So far anatomical structure is concerned the group is related to Cycadofilicales in having exarch and mesarch bundles and to gymnosperms especially to conifers in having developed endarch bundles.

Reproductive Structures of Cordaitales

The plants were monoecious or dioecious but the strobili were always monosporous and never bisporangiate like Cycadeoideales (Bennettitales) or living Gnetales. Cordaitanthus was the reproductive shoot of Cordaites itself. It was not definitely organized to form a cone but it was more or less a strobilus.

The male and female strobili were borne separately in lateral sides of short simple axis. The strobili were enclosed when young by bracts so outwardly they could not be distinguished unless sections were cut and examined. Both were usually of small size.

Strobilus of Cordaitales

Male Strobilus: The male strobilus had a thick axis bearing spirally arranged bracts with stamens on them, the stamens themselves were either solitary or grouped near the apex and in between the stamens there were sterile bracts present. These bracts might have been sterile microsporophyll's.

Each individual stamen was peculiar in form, in that it had a cluster of three to six terminal sporangia similar types of stamens have also sometimes described belonging to Cycadofilicales, but the important difference was that at the tips were borne synangia and separate or individual sporangia.

If in this male catkin of Cordaites there were no sterile bracts the structure would be very much like the staminate strobilus of Ginkgo but there is a very important difference and that in the Cordaitanthus the sporangia were terminal while in Ginkgo they were pendant and only two in number.

NOTES

In fact the morphology of this male strobilus of Cordaites is not quite clear. Different interpretations are put on male catkin of Cordaites. Some think that whole of strobilus acting as single male flower in which there were large number of stamens, the stalk, being the filamentous bearing, a number of pollen sacs that were simply sterile filaments.

Other workers described this male catkin as inflorescence, each catkin bearing a flower itself, the filament is stalk of flower, the pollen sacs the stamens.

Female Strobilus: The female strobilus when young was enclosed by bracts. It had a thick conical axis bearing a number of spirally arranged bracts. In the axils of some of these bracts there were dwarf shoots present. These dwarf shoots in turn had minute bracts. On the tip of dwarf shoot there was a terminal ovule.

The Ovule of Cordaitales: In the ovule the nucellus was completely separate from the integument. The integument formed a micropyle; at the base of micropyle the nucellus formed a prominent nuclear beak and a large pollen chamber. Round the ovules there were two coats outer thick and fleshy and the inner one delicate in young ovule but hard in older ovules.

Both these coats were separate below but more or less united above. So these coats may be interpreted as two separate integuments which are formed at upper part or a case of single integument which differentiated into three coats one of which not preserved.

The female strobilus is distinctly compound in form as compared to male strobilus. The ovule bearing stalks were distinctly axillary in position just like those of present day conifers.

In Cycadofilicales, Cycadeoideales (Bennettitales) and the living cycads the ovule bearing structures are not axillary in position and the ovules in these groups were borne on leaves while in Cordaitales and the Coniferales the ovules are borne on stem structure. Dr. Sahni according to the position of ovules, recognized two groups.

- **Phyllosperms:** The ovules borne on leaves as seen in pteridosperms and Cycas.
- **Stachysperms:** The ovules as seen in Cordaitales, Ginkgo and the Coniferales.

A large number of detached seeds have been described from Palaeozoic times and when they separated from branches they cannot definitely be assigned to Cycadofilicales and to Cordaitales. Generally according to Dr. Sahni those belonging to Cordaitales were flat and described as platy-sperms and more or less heart shaped in appearance and no embryo in them like those of Cycadofilicales.

Affinities of Cordaitales

Cordaitales and Cycadofilicales lived side by side in Palaeozoic time, both were very abundant in Carboniferous and disappeared just about Permian. Backwards both groups extend to Devonian, which of two is more ancient cannot be definitely stated.

Both seem to be related is clear from their habitat, the general form and structure of plants, the form of strobili especially male one, structure and form of ovule and finally of seed was very primitive in the two in the ovule of the two the presence of free nucellus.

The form of integument with two sets of vascular bundles in it, and the form of pollen chamber and lastly the absence of embryo are really primitive features which naturally present in the primitive groups. All these resemblances mean that either the Cycadofilicales give rise to Cordaitales or the Cordaitales to Cycadofilicales.

All combined features show that Cycadofilicales are more primitive while the Cordaitales show advanced features.

NOTES

The other possibility is that both of them might have arisen from some common ancestral form as they lived side by side. So this second possibility is more accepted but what the ancestral form is not known.

Evidently it must be some heterosporous pteridophyte which lived near about the Devonian might have given rise to Cordaitales and Cycadofilicales, which is clear from the stem anatomy of Cordaitales in which endarch siphonostele was more common.

The strobili of Cordaitales are better organized. The sporophylls here completely lost their leaf like appearance. The female strobilus was more complicated in that ovule bearing branch was always axillary in position. In Cycadofilicales the strobilus was simple and ovules were borne on leaves.

So these Cycadofilicales and Cordaitales can be said to represent two different lines of evolution; the Cycadofilicales was left behind with more primitive features in it and before it disappeared it gave rise to two branches of Cycadophyta line the fossil Cycadeoideales (Bennettitales) and living Cycadales.

The Cordaitales made some advance both in anatomy of stem organization and complexity of its reproductive parts. Being a primitive group naturally it had resemblances with Cycas, which is seen in the presence of large pith, general leaf anatomy, general structure of seed and ovule and presence of sperms.

Chamberlain is of opinion that Cordaitales represents one line of Gymnosperms, the Coniferophyte line characterized by the presence of large sized plant with pro-fused branched stem and simple leaf, small pith, abundant wood and narrow cortex. The reproductive structure organized to form more or less cones.

The Cordaitales seems to have given rise to Ginkgoales and conifers before it disappeared in or about in Permian times. In Ginkgoales there are good deal of resemblances. Both the plants are lofty and branched. The stem anatomy, the structure of ovule, and in presence of sperms two groups seem to be more or less closely related.

There is great similarity in the outward appearance of male strobili of Ginkgo and that of Cordaitales.

Root: *Amyelon*

Roots were profusely branched and shallow. Aerial stilt roots form at the base of stem supports stem. Both protostelic and eustelic fossil specimens of *Amyelon* were observed. Transverse section of stem shows exarch xylem and actinostelic condition. Protoxylem was present at the tip of each of arm. Secondary growth was present and protoxylem was surrounded by the secondary xylem. Uniseriate medullary rays was present. Outside secondary xylem, secondary phloem was present. Outside secondary phloem, aerenchymatous phelloderm and phellem were present. Lenticels were also present in the phellem.

Stem: *Cordaixylon*

There were several stem fossils associated with this group *viz., Cordaixylon-Pennsylvanioxylon*, *Mesoxylon*, *Dadoxylon*, *Shanxioxylon* and *Piracicaboxylon*. *Cordaixylon* stems were eustelic with large pith, uniseriate rays and sympodial architecture (pith is surrounded by separate xylem strands). Pith of *Cordaixylon* contains evenly spaced diaphragms (horizontal septations) or septate pith (Refer Figure 2.8). In *Mesoxylon* non-sympodial vascular architecture, biseriate rays and diaphragms were absent. Xylem parenchyma and resin canals were absent from cordaitalean secondary xylem. Cortex was composed of alternating bands of sclerenchymatous cells. This type of alternating bands of sclerenchyma was absent in *Shanxioxylon*.

NOTES

Fig. 2.8 *Oblique Section of Cordaitalean Stem Showing Horizontal Diaphragm*

Leaf: *Cordaites*

Leaves were, helically arranged, strap shaped, round apex, broad base, midrib absent and parallel venation. Veins occasionally show dichotomy. Haplocheilic stomata were present. Guard cells were surrounded by two lateral cells and two terminal cells at both ends. Stomata may be present on abaxial or adaxial surface depending upon the fossil specimens. Other leaf genera of cordaitalean leaf genera are *Noeggerathiopsis* (Refer Figure 2.9), *Rufloria* and *Euryphyllum*.

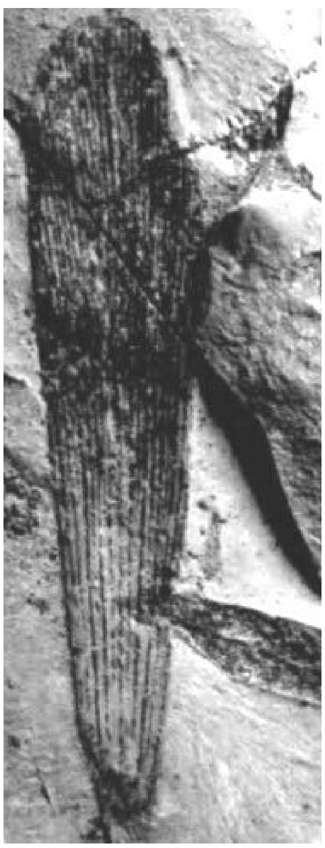

Fig. 2.9 *Noeggerathiopsis sp.*

NOTES

Reproductive Structure: *Cordaianthus* or *Cordaithanthus*

Both the ovule and pollen bearing organs were known as *Cordaianthus* or *Cordaithanthus* due to their morphological similarities. These were monosporangiate (bearing single kind of sporangia) compound cones, with primary axis bearing bracts. From the axils of bracts secondary axis arises giving rise to secondary fertile shoot (cone). Scale like leaves were helically arranged on the secondary fertile axis which bears ovules or pollen sacs. Apart from *Cordaianthus*, *Cathayanthus* is ovule bearing cone of *Shanxioxylon sinense* whereas *Gothania* is the pollen bearing cone of *Mesoxylon multirame* within cordaitales. Pollen grains were monosaccate.

Seeds: *Cardiocarpus*

Seeds were heart-shaped or cordate, platyspermic and were bilateral symmetrical.

Phylogenetic Significance

Many researchers believed that cordaites are closely related to conifers. The pollen cone of Cordaitales are compound whereas as the pollen cone of conifers are simple (ovule cone of conifers are compounds bearing bracts). The aforementioned differences in the pollen bearing cones was discarded after the discovery of some compound pollen bearing cones of fossil conifers. Both the orders exhibits dimorphic stems. Another hypothesis. Based on wood anatomy and vegetative organization was put forward by the researchers which states that cordaites and conifers were evolved from archaeopteridalean progymnosperms. Some researchers believe that conifers and cordaites were evolved from Callistophytales (seed fern group), which is based on the similarities between reproductive structures. Recent phylogeny predicts *Mesoxylon* as a sister group of modern conifers and *Mesoxylon* and *Cordaixylon-Pennsylvanioxylon* is considered in single clade, a sister group to *Shanxioxylon*.

2.4.1 Fossil Cordaitales

The Cordaitales, with the Pteridosperms, formed the vegetation of the late Palaeozoic era. The Lower Gondwana rocks of India have yielded potrified wood which are presumably cordaitean.

The fossil Cordaitales which are found in India are as follows:

- **Neoggerathiopsis:** It is a leaf genus which occurs in the Lower Gondwana in India. It has two most common species *N. hislopi* and *N. stoliczkanus*; leaves are elongate to spathulate in shape with broadly rounded apex. They vary in size, larger ones reaching more than 20 cm. in length.
- **Samaropsis:** It is the seed genus with few species and occurs in the Karbarbari and Raniganj series of Lower Gondwana in India. The seeds are winged, ovate or flat with emarginate apex and found in close association with *Neoggerathiopsis hislopi*.
- **Cordaicarpus:** It is also a seed genus with more than one species, and occurs in the Talchir of Lower Gondwana of India. The base is slightly cordate and the apex pointed. They are small, oval or pear shaped and vary in size.
- **Dadoxylon:** It is the stem genus with more than one species. The important Indian species are *D. indicum, D. bengalense* and *D. zalesskyi*. These occur in the Barakar series of Lower Gondwana. The species are silicified stems with a large pith containing sclerotic cells. The secondary wood has sharply marked growth rings.

'Check Your Progress'

7. What are Cordaitales?
8. What are Neoggerathiopsis?
9. What are Samaropsis?
10. What are Cordaicarpus?

NOTES

2.5 SUMMARY

- Caytonales are an important extinct group of seed ferns. Group of Mesozoic seed fern (pteridosperm) established by H.H. Thomas in 1925 and the type was based on seed bearing organ *Caytonia*.
- In 1983, Stewart had divided Caytoniales in three families Caytoniaceae, Corystospermaceae and Peltaspermaceae.
- Later on all the families were raised to order rank, i.e., Caytoniales, Corystospermales and Peltaspermales. In 1971, Harris had reconstructed *Caytonia* plant as a small tree with woody axes attached to *Sagenopteris* (leaves).
- Synangia were radially symmetrical, contains one to four pollen sacs and dehisce towards the centre.
- Saccate pollen grains are of two types, i.e., Protosaccate and Eusaccate. Protosaccate pollens have extensive webbing on the sacs and corpus surface walls, for example *Caytonia*, while eusaccate pollens have limited webbing on the sac, for example *Pinus*.
- *Caytonia* consists of ca. 5cm long axis with two rows of multiovulate lateral cupules. The cupules were globose, recurved and a lip like projection is present at the point of attachment (base).
- Depending upon species, number of seeds present in each cupules varies from 8 to 30. Seeds are cs. 2mm long stalked, radially symmetrical, orthotropous and unitegmic.
- In 1925, Thomas has described *Caytonia* as an angiospermous fruits. In his initial description he interpreted pollen grains present in the liplike of cupule and described it as angiospermous fruit containing many seeds.
- In 1940, Harris demonstrated that pollen are present in the cupules and the pollination was performed by pollination droplet mechanism as in other gymnosperms.
- In 1973, Reynanowna demonstrated that each seed has a canal extending from micropylar end to the outer lip of cupule.
- The cupule and ovule arrangement in the Caytoniales represents a course of evolution in which the seeds becomes enclosed.
- In 1946, Gaussen has proposed a theory of angiosperm origin from Caytoniales based on several assumptions, such as reduction in the multiple ovules of *Caytonia* and interpreted cupule wall homologous to the second integument of angiosperms (angiosperms are bitegmic whereas gymnosperms are unitegmic) and the axis of cupule give rise to carpel.

NOTES

- The Pentoxylales are a group of seeds plants that lived during the middle to late Mesozoic. They had long narrow leaves, and wood in a characteristic five wedge pattern (pento-xylon) around the primary xylem.
- In 1948, Professor Birbal Sahni proposed pentoxyleae for the fossil specimens of Jurassic and Cretaceous gymnosperms reported from Rajmahal Hills, Jharkhand, India.
- Few paleobotanists considered them as small trees with long and dwarf shoots and others suggests that they were shrublike in habit and inhabits the river floodplains.
- Secondary growth was due to endocentric activity of cambium, i.e., more wood was produced towards pith.
- Wood is pycnoxylic like that of Conifers and uni-biseriate circular bordered pits were present on the tracheids.
- Medullary rays are up to seven cells in height. Parenchymatous pith and cortex is present and there were some specimens exhibiting the periderm.
- Phloem fibers were lacking in the secondary phloem (consists of sieve elements and phloem parenchyma). Growth rings were well defined.
- *Nipaniophyllum raoi* were petiolate, strap shaped (1 cm wide and up to 20 cm in length) with round apex.
- Several parallel veins running through middle portion of the leaf forms a broad mid vein and lateral veins were born at right angle to the mid vein.
- Occasional branching and fusion of lateral veins near leaf margins was also observed in some specimens. Sunken sydetochelic stomata were present on the abaxial surface. In some specimens stoma exhibits anomocytic pattern, i.e., surrounded by a ring of subsidiary cells. Winged petiole had five to nine bundles were arranged in a tangential row.
- The correct phylogeny of Pentoxylales is yet to be deciphered. There are several features common to different groups and Pentoxylales. Pentoxylales and Bennettitales shares platyspermic seeds, monosulcate pollen and thick sclerotesta. Monosulcate pollen grains were also present in *Ginkgo*, cycads and certain pteridosperms.
- The Cordaitales is another fossil group which lived side by side with the Cycadofilicales in Palaeozoic times. Both the groups were very common, the Cordaitales being then the prevailing gymnospermous forest plants.
- The group extends from Devonian through Carboniferous upto the Permian times, and in India they had been found even in the lower Mesozoic, i.e., in lower Gondwana strata of India.
- The plants of this group were trees some even more than ninety feet in height and three feet in diameter. The plant branched at only tips and bore generally narrow and simple leaves in clusters at top.
- The order is extinct group from Mississipian to Permian period. The group includes trees, shrubs and small trees.
- Cordaitales and Cycadofilicales lived side by side in Palaeozoic time, both were very abundant in Carboniferous and disappeared just about Permian. Backwards both groups extend to Devonian, which of two is more ancieant cannot be definitely stated.
- The Cordaitales made some advance both in anatomy of stem organization and complexity of its reproductive parts.

- Being a primitive group naturally it had resemblances with Cycas, which is seen in the presence of large pith, general leaf anatomy, general structure of seed and ovule and presence of sperms.
- Chamberlain is of opinion that Cordaitales represents one line of Gymnosperms, the Coniferophyte line characterized by the presence of large sized plant with pro-fused branched stem and simple leaf, small pith, abundant wood and narrow cortex. The reproductive structure organized to form more or less cones.
- The Cordaitales seems to have given rise to Ginkgoales and conifers before it disappeared in or about in Permian times.
- In Ginkgoales there are good deal of resemblances. Both the plants are lofty and branched. The stem anatomy, the structure of ovule, and in presence of sperms two groups seem to be more or less closely related.
- The Cordaitales, with the Pteridosperms, formed the vegeta-tion of the late Palaeozoic era. The Lower Gondwana rocks of India have yielded potrified wood which are presumably cordaitean.
- Neoggerathiopsis is a leaf genus which occurs in the Lower Gondwana in India. It has two most common species *N. hislopi* and *N. stoliczkanus*; leaves are elongate to spathulate in shape with broadly rounded apex. They vary in size, larger ones reaching more than 20 cm. in length.
- Samaropsis is the seed genus with few species and occurs in the Karbarbari and Raniganj series of Lower Gondwana in India. The seeds are winged, ovate or flat with emarginate apex and found in close association with *Neoggerathiopsis hislopi*.
- Cordaicarpus is also a seed genus with more than one species, and occurs in the Talchir of Lower Gondwana of India. The base is slightly cordate and the apex pointed. They are small, oval or pear shaped and vary in size.
- Dadoxylon is the stem genus with more than one species. The important Indian species are *D. indicum, D. bengalense* and *D. zalesskyi*. These occur in the Barakar series of Lower Gondwana. The species are silicified stems with a large pith containing sclerotic cells. The secondary wood has sharply marked growth rings.

2.6 KEY TERMS

- **Caytonales:** Caytonales are an important extinct group of seed ferns.
- **Pentoxylales:** The Pentoxylales are a group of seeds plants that lived during the middle to late Mesozoic.
- **Cordaitales:** The Cordaitales are fossil group which lived side by side with the Cycadofilicales in Palaeozoic times.

2.7 ANSWERS TO 'CHECK YOUR PROGRESS'

1. Caytonales are an important extinct group of seed ferns. Group of Mesozoic seed fern (pteridosperm) established by H.H. Thomas in 1925 and the type was based on seed bearing organ *Caytonia*.
2. In 1983, Stewart divided Caytoniales in three families Caytoniaceae, Corystos-permaceae and Peltaspermaceae.

3. Saccate pollen grains are of two types i.e., Protosaccate and Eusaccate. Protosaccate pollens have extensive webbing on the sacs and corpus surface walls, for example *Caytonia*, while eusaccate pollens have limited webbing on the sac, for example *Pinus.*
4. The *Pentoxylales* are a group of seeds plants that lived during the middle to late Mesozoic. They had long narrow leaves, and wood in a characteristic five wedge pattern (pento-xylon) around the primary xylem.
5. In 1948, Professor Birbal Sahni proposed pentoxyleae for the fossil specimens of Jurassic and Cretaceous gymnosperms reported from Rajmahal Hills, Jharkhand, India.
6. *Nipaniophyllum raoi* were petiolate, strap shaped (1 cm wide and up to 20 cm in length) with round apex.
7. The Cordaitales is another fossil group which lived side by side with the Cycadofilicales in Palaeozoic times. Both the groups were very common, the Cordaitales being then the prevailing gymnospermous forest plants.
8. Neoggerathiopsis: It is a leaf genus which occurs in the Lower Gondwana in India. It has two most common species *N. hislopi* and *N. stoliczkanus*; leaves are elongate to spathulate in shape with broadly rounded apex. They vary in size, larger ones reaching more than 20 cm. in length.
9. Samaropsis: It is the seed genus with few species and occurs in the Karbarbari and Raniganj series of Lower Gondwana in India. The seeds are winged, ovate or flat with emarginate apex and found in close association with *Neoggerathiopsis hislopi*.
10. Cordaicarpus: It is also a seed genus with more than one species, and occurs in the Talchir of Lower Gondwana of India. The base is slightly cordate and the apex pointed. They are small, oval or pear shaped and vary in size.

2.8 QUESTIONS AND EXERCISES

Short-Answer Questions

1. Describe leaf of Caytoniales in brief.
2. Describe pollen bearing of Caytoniales in brief.
3. Describe ovule bearing of Caytoniales in brief.
4. Discuss the phylogenetic significance of Caytoniales.
5. Who proposed Pentoxylae and from where?
6. Describe Pollen bearing organ of *Pentoxylon*.
7. Discuss the phylogenetic significance of Pentoxylae.
8. Describe stems of Cordaitales.
9. Describe leaf of Cordaitales.
10. Describe the reproductive structures of Cordaitales.
11. Discuss the phylogenetic significance of Cordaitales.

Long-Answer Questions

1. Describe *Caytonia* and mention the plant parts in detail.
2. Write down the salient features of Caytoniales similar to those of Gymnosperms.

3. Differentiate between Caytoniales and Lygniopteridales.
4. Describe the reproductive organs of Caytoniales.
5. Write about the reproductive structures of Pentoxylae.
6. Describe *Pentoxylon* in detail.
7. Write briefly about the Pentoxylae.
8. Differentiate between Pentoxylales and Caytoniales.

NOTES

2.9 FURTHER READING

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UNIT 3 GINKGOALES, EPHEDRALES AND GNETALES

NOTES

Structure

3.0 INTRODUCTION

Ginkgoales or Ginkgophyte is a gymnosperm order containing only one extant species: Ginkgo biloba, the ginkgo tree. It is monotypic, (the only taxon) within the class Ginkgoopsida, which itself is monotypic within the division Ginkgophyta. The order includes five families, of which only Ginkgoaceae remains extant. The first Ginkgo leaves were found from the Triassic period, but there were many species of Ginkgo during the Jurassic and Cretaceous periods as well. These periods, known collectively as the Mesozoic era, were when diversity and distribution for all plants were at their highest, including in Ginkophytes. It was in the early Cenozoic period that Ginkgophytes nearly became extinct, specifically during the early Cretaceous and Tertiary periods. The only remaining Ginkgophyte was *Ginkgo adiantoides* – a polymorphic species. Modern Ginkgotrees are native to China.

Ephedra is a genus of gymnosperm shrubs, the only genus in its family, Ephedraceae and order, Ephedrales. The various species of Ephedra are widespread in many lands, native to Southwestern North America, Southern Europe, Northern Africa, Southwest and central Asia, Northern China and Western South America. In temperate climates, most Ephedra species grow on shores or in sandy soils with direct sun exposure. Common names in English include Joint-Pine, Joint Fir, Mormon-Tea or Brigham Tea. The Chinese name for Ephedra species is Mahuang. Ephedra is also sometimes called Sea Grape, a common name for the flowering plant *Coccoloba uvifera*.

Gnetales comprise three extant genera (*Ephedra*, *Gnetum*, *Welwitschia*) that are morphologically very distinct. The phylogenetic position of the group is uncertain. It was sometimes placed close to the angiosperms, but has recently been associated with the conifers. *Ephedra* and *Gnetum* include trees, shrubs, vines and climbers with proliferate branching and decussate or whorled phyllotaxis. *Welwitschia* is unusual in having a very condensed, unbranched stem and two persistent leaves that grow for the entire life of the plant. The plants are mostly dioecious, rarely monoecious.

In this unit, you will study about the general features, distribution, phylogeny and economic importance of Ginkgoales, Ephedrales and Gnetales in detail.

NOTES

3.1 UNIT OBJECTIVES

After going through this unit, you will be able to:

- Understand the general features and characters of Ginkgoales, Ephedrales and Gnetales
- Explain the distribution, phylogeny and economic importance of Ginkgoales, Ephedrales and Gnetales

3.2 GINKGOALES

Ginkgoales or Ginkgophyte is a gymnosperm order containing only one extant species: Ginkgo biloba, the ginkgo tree. It is monotypic, (the only taxon) within the class Ginkgoopsida, which itself is monotypic within the division Ginkgophyta. The order includes five families, of which only Ginkgoaceae remains extant.

Ginkgoales is represented by one living genera *Ginkgo* and other fossil genera. The history of members dates back to paleozoic era and Ginkgoales also referred as 'living fossil', like Cycads. Presence of swimming sperm in *Ginkgo* (a characteristic feature of ferns) represents the paleozoic seed plants feature. *Baiera* is the extinct member of Ginkgoales.

Distribution: Many genera and species were present in order gingkoales which are reported from Permian. They became dominant in Mesozoic era. They started to disappear by the end of Jurassic and except gingko all other members became extinct during cretaceous. The only surviving member of gingkoales, i.e., *Ginkgo biloba* is limited in its geographical distribution. They are restricted to small part of Southeastern China (Refer Figure 3.1).

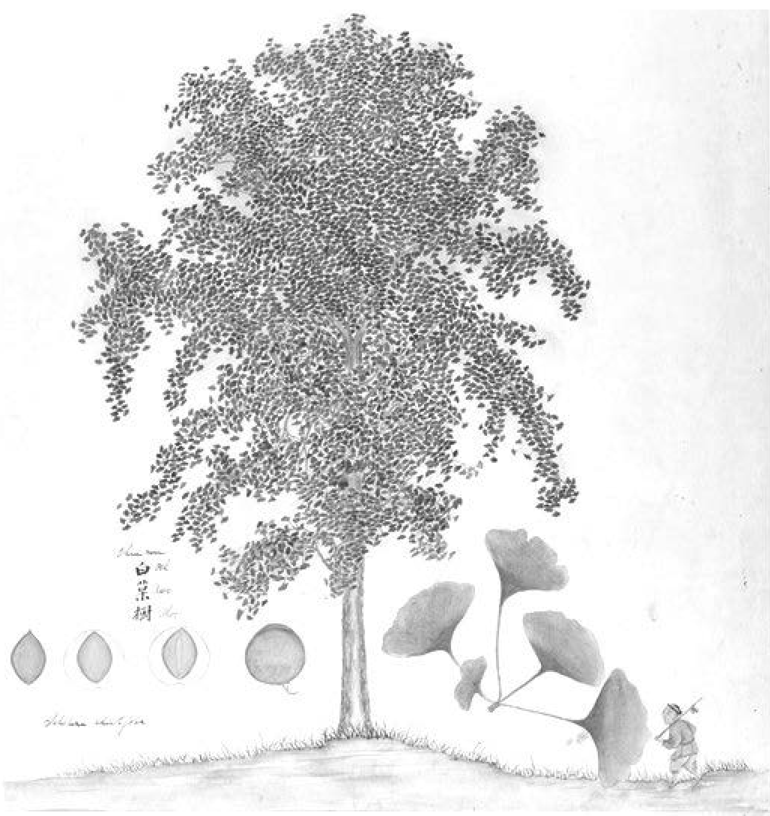

Fig. 3.1 *An Illustration of Ginkgo biloba*

NOTES

Morphology

Ginkgo biloba (n=12) is a tree having height of 30 m and has diameter more than 1.5 m. Its general habit is like that of conifers, i.e., strongly excurrent trunks. As the age increases, the crown becomes irregular and broad and branching pattern varies. Profused branching occurs in its main axes. Two types of shoots are present in *Gingko*; first, long shoots- that rapidly elongate and scattered leaves are present and second, dwarf shoots (short spur)- that grow slowly and occurs a terminal cluster of leaves. Leaf scars of previous years are present on the older portion. Young spur shoot or dwarf shoot is covered by bud scales. There is similarity in the apical meristems of the two types of shoots. The difference depends on the cell division and cell elongation duration in the stem tissues which is originated from the shoot apex. The deciduous foliage leaves have unique shape and venation. Long, smooth, black and slender petiole is present which is traversed by two vascular bundles having collateral condition. Leaf lamina is lobed in various manners and have broadly wedge shaped and the venation is dichotomous which is clear. The leaves are similar to those of *Adiantum* in its form and venation, hence commonly known as 'maidenhair tree'. The same tree consists of differently lobed leaves. Several notches are present in leaves of seedlings and therefore give palm like appearance.

Anatomy

Root: Diarch condition is usually present in young roots whereas old roots have tetrarch or hexarch condition. The endodermis is present which has thick radial walls and broad pericycle is present. Tracheids follow the spiral elements of the protoxylem and are characterized by reticulate pitting; simple pits which are transversely elongated and bordered pits. Secondary growth takes place but annual rings are not strongly marked. The tracheids are composed of thinner walls. Some of the xylem parenchyma cells include crystals and phloem has abundant thick-walled fibres. One to many cell of medullary rays are present and frequently show crystals. Mucilage cavities is present in the pith and primary cortex of the stele. Tanins and starch is very abundant in the roots.

Stem: The shoot apex consists substantive apical initials, a conspicuous subapical zone having central mother cells and proximal side has a zone of rib meristem. A young stem consists of an epidermis, a cortex and pith which is parenchymatous and vascular cylinder is present. Endarch siphonostele is present (Refer Figure 3.2). A long shoot consists of thick zone of wood, narrow pith and cortex is present**.** The dwarf shoots have a narrow ring of wood, broad cortex and pith is present. Primary xylem has a number of separate strands and exhibits sympodial branching. A broad zone is formed by phloem. The double leaf traces are prominent. A radial section of wood has tracheids which has numerous opposite pits. One to three cells deep uniseriate rays is present in the long shoots and are deeper in dwarf shoots. Sometimes, calcium oxalate crystals are present in some of the xylem parenchyma cells. Bars of Sanio are present in the secondary wood but absent in the primary wood. Due to scattered pits Bars of Sanio is not formed in the primary wood (Refer Figure 3.3).

NOTES

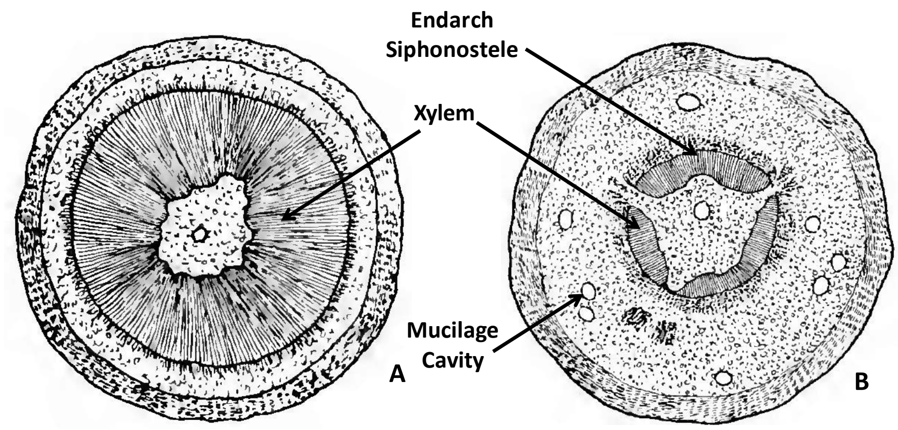

Fig. 3.2 A T.S. of Long Shoot B. T.S. of Spur Shoot

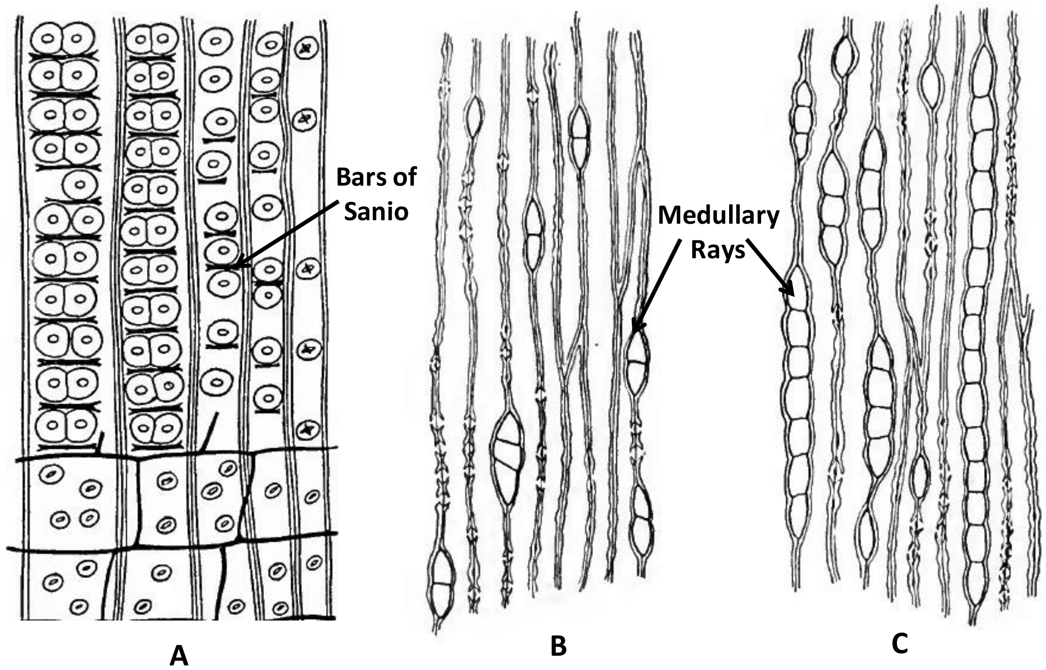

Fig. 3.3 *A. L.S. of Mature Wood Showing Bars of Sanio (after Jeffrey); B. T.L.S. of Long Shoot; C. T.L.S. of Short Shoot*

Leaf: The leaf comprises of double trace. Two endarch vascular bundles is present in petiole. The two traces to any leaf arise autonomously from two distinct primary strands**,** dividing at the base of blade and the veins are formed in dichotomous manner. The venation of the two halves of the leaf is not dependent. The veins of the leaf contain mucilage cavities. The lamina has a thick cuticle, stomata on the lower surface of the leaf, leaves having distinct palisade on the long shoots, mucilage canals and vascular bundles having endarch condition in which traces of centripetal xylem are present having one or two tracheids. Sheath of thick walled cells surrounds the bundles. Stomata occur irregularly on the lower epidermis which is scattered throughout the veins. Haplocheilic stomata are present which is surrounded by four to six subsidiary cells, each one having a blunt papilla (Refer Figure 3.4).

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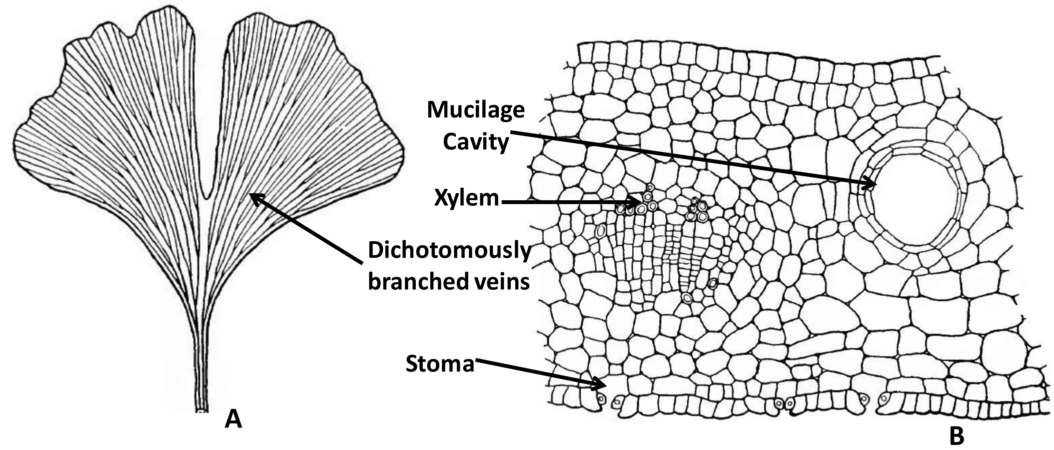

Fig. 3.4 *A. Leaf of Ginkgo biloba; B. T.S. of Leaf*

Reproduction

Ginkgo is dioecious having male cones that are catkin-like and pendant shaped which is borne on short shoots as normal leaves or scaly leaves.

Male strobilus: Forty to fifty microsporophylls are present in each dwarf shoot. Often two microsporangia per sporophyll is present in *Ginkgo* but the number may vary between two to seven. Sporophyll is slender and surmounted by a hump (terminal knob) that bears two pendant microsporangia. Two collateral endarch bundles are present in the stalk. Mucilage cavity is present in the hump. Dehiscence of microsporangia took place by longitudinal slit. The development of microsporangium is of eusporangiate type. Archesporial cell divides into primary wall cell and primary sporogenous cell. Primary sporogenous cell give rise to sporogenous tissue which develops into pollens. Monosulcate pollen is present.

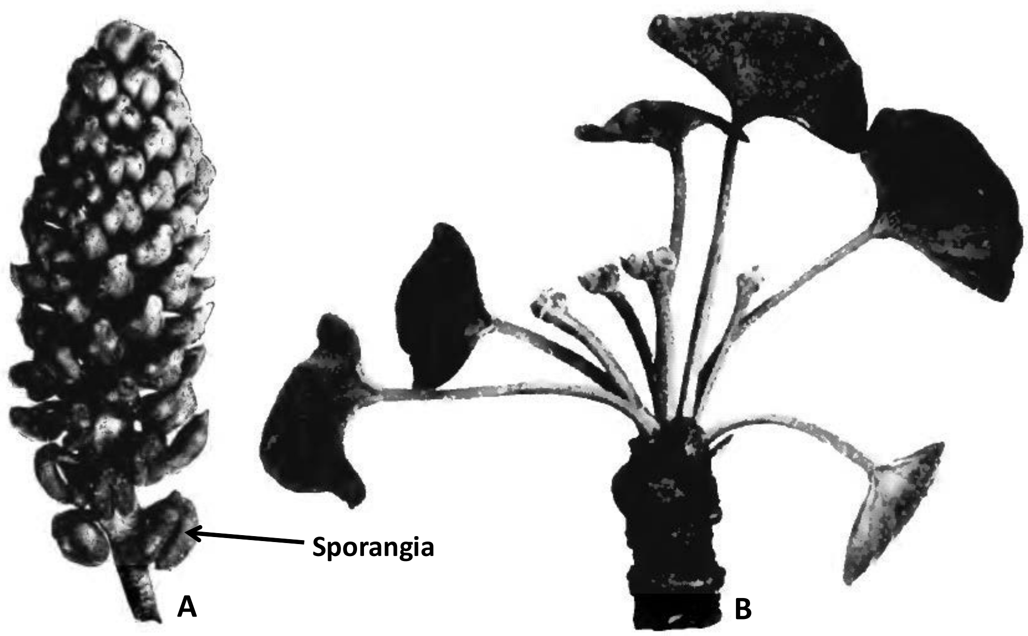

Fig. 3.5 *A. Male Strobili (after Coulter); B. Dwarf Shoot Bearing Ovules (after Coulter)*

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Female Strobilus: Ovules are borne on dwarf shoots in groups. Each shoot has two ovules in the axil of scale leaf (Composite Strobilus). The leaves bearing ovules are round (not bilobed). The ovules are borne on the peduncles bearing two ovules and one of the ovules aborts early. Each ovule has a collar at its base which is a modified leaf blade. The peduncle always contains twice the number of vascular bundles present irrespective of their ovules. Orthotropous ovule with a beaked nucleus is present having highly cutinized epidermis. A pollen chamber is formed by breaking down of the nucleus apex cells. Some of the broken down material exuded at the top of micropyle and forms pollination drop. The further development of ovule is stimulated by the presence of pollen in the pollen chamber (Refer Figure 3.5).

Gametophytes

Male Gametophyte: Microspore is the first cell of male gametophytic germination and started to germinate in the enclosed microsporangium. The microspore divides unequally into two cells (i) Prothalial cell (small); (ii) Inner larger cell. Later divides further producing second prothalial cell (small) and an antheridial cell. The first prothalial cell starts degenerating and antheridial cell divides to produce a generative cell and an inner tube cell. At this four celled stage the pollen is shed. Pollen top lacks exine and only covered by intine. Upon reaching the pollen chamber, pollen tube (haustorial in nature as in *Cycas*) formation took place, generative cell divide into two producing a stalk cell and body cell and pollen chamber start to enlarge until nothing remains between pollen tube and female gametophyte. The body cell divides and produces two sperm cells. The sperms are elongated, spiral and ciliated at the apical region (Refer Figure 3.6).

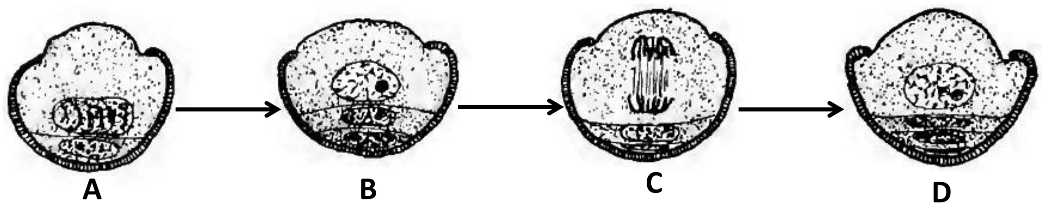

Fig. 3.6 *Various Stages of Development of Male Gametophyte*

Female gametophyte: Megaspore is the first cell of female gametophytic generation. The megaspore mother cell divides meiotically giving rise to four megaspores but only the lower megaspore survives and give rise to female gametophyte. After pollination, the development of pollen tube and the development of female gametophyte took place together. Megaspore development took place through free nuclear division (more than 256 free nuclei are formed) and the cell wall is laid down from periphery towards the center. Later on production of chlorophyll took place. Archegonium initials starts to develop before wall formation reaches to center and usually two (occasionally three) archegonia are formed. The archegonial chamber is crevice-like and bears a tent pole to support nucleus at top. A mature female gametophyte is very large (containing 8000 nuclei) (Refer Figure 3.7).

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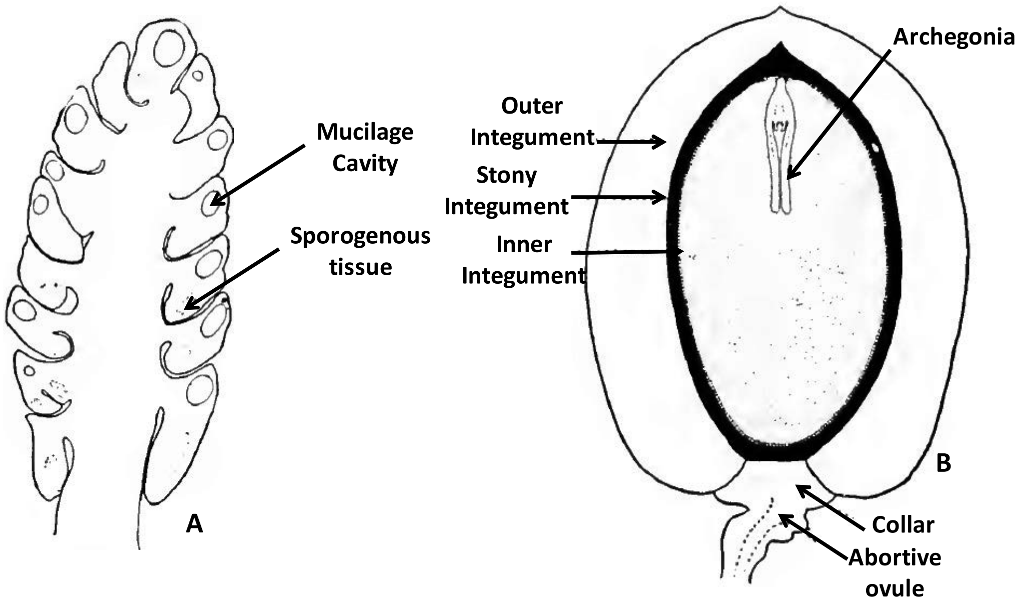

Fig. 3.7 *A. L.S. of Male Strobili B. L.S. of Ovule*

Pollination and Fertilization: Like other gymnosperms the pollen are wind pollinated and the pollen drop, secreted by the top cells of nucleus acts a medium to fix the pollens.

Embryogeny: After fertilization, perisperm (haploid) develops from female gametophyte (nucellus) due to absence of double fertilization and free nuclear division took place in zygote giving rise to 256 free nuclei in the egg region. Formation of cell wall took place and cells of equal size is formed. There is no organized suspensor but the embryo is divided into three regions stem, root and cotyledons.

Phylogeny: The swimming sperm, present in pteridophytes, is a lost character of spermatophytes but retained by Cycads and *Ginkgo*. The extremely fern like (*Asplenium* like leaf) favors the origin of *Ginkgo* from heterosporous ferns and supports the evolution of Ginkgoales from Cycadofilicales like ancestors. Branching habit of *Ginkgo*, development of wood with small pith and cortex with simple leaves indicates the resemblance from Coniferophytes.

Economic Importance: Leaves are used externally to treat sores, freckles and internally to diarrhoea. Seeds are used for the treatment of lungs, asthma, enuresis, urinary frequency, suppressing coughing and leucorrhea. *Ginkgo* is used for longevity and to increase sexual endurance by the Chinese. Recently extracts of *Ginkgo* is used for the treatment of Alzheimer's, Dementia, varicose and post thrombic syndrome. The seeds are eaten roasted or cooked where are raw seeds are toxic. In Japan and China wood is used for the manufacturing of chessboard and toys. The extract contains terpenoids, such as ginkgolides and bilobalides.

'Check Your Progress'

1. What are Ginkgoales?
2. How are Ginkgoales represented?
3. What is the height of *Ginkgo biloba?*

NOTES

3.3 EPHEDRALES

Ephedra (commonly known as joint pine, joint fir, Mormon tea or Brigham tea) is the only genus in family Ephedraceae and order Ephedrales. It is represented by 50 species.

Ephedra is a genus of gymnosperm shrubs, the only genus in its family, Ephedraceae and order, Ephedrales. The various species of *Ephedra* are widespread in many lands, native to southwestern North America, southern Europe, northern Africa, southwest and central Asia, northern China and western South America.

Florin (1931) and Eames (1952) had established Ephedrales as an order. Plants are dioecious, herbs or woody lianas, leaves are scale-like and stems are jointed and green. Vessels are present. Compound male and female cones are present in contrast to conifers where only female cone is compound whereas in cycads both male and female cones are simple.

Distribution: Ephedrales consist of single family and have around 42 species of *Ephedra* which is distributed worldwide. These species are different from those that were present in the Old worlds and the new worlds. The height attained by these plants is 5000m above sea level. Mostly species are inhabitant of desert or arid regions. They also bind sand in saline tracts. In india, eight species are found out of which 7 species are *E. major*, *E. intermedia* (n=14)*, E. saxatilis* (n=14)*, E. gerardiana, E. nebrodensis, E. pachyclada and E. regeliana* are present in northwest Himalayan region and single species *E. foliata* (n=7) is present in plains of Punjab and Rajasthan.

Sporophyte

Morphology: The plants of *Ephedra* are highly branched herbs or shrubs. *E. campylopoda* is cultivated as ornamental plant. *E. triandra* is a small tree, and *E. gerardiana* is a perennial herb. *E. foliata* (Refer Figure 3.8) is a shrub of about 6m height, climbs up the trees or walls, and in the absence of support, it spread on the ground. The stem is long and green and has distinct nodes and internodes. The shoot has indeterminate and determinate branches as well. On each node, the indeterminate shoot has three to four leaves in a whorl. The axil of the leaf bears determinate shoots has opposite leaves and decussate pairs. It has axillary branching and accessory buds also arise below at the base of axillary buds. An intercalary meristem is also present above each node and forms the internodal tissue. Scaly leaves are deciduous and may be opposite or whorled. Vessels are present in secondary wood. The plants are dioecious with compound male and female strobili. The ovule has two envelopes. Dicotyledonous embryo is present.

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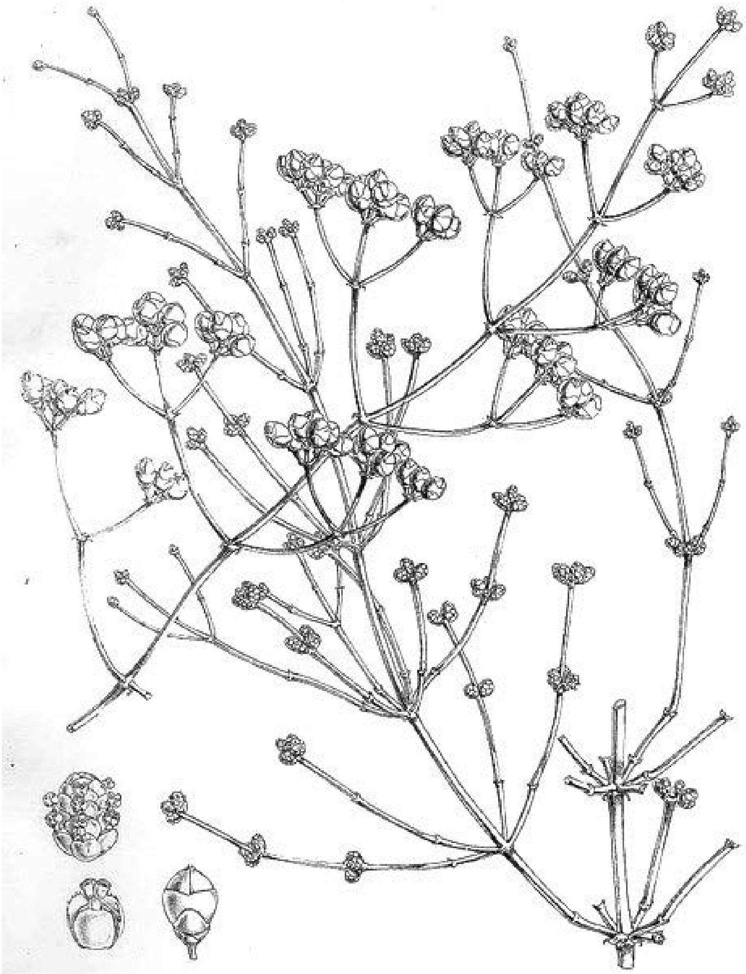

Fig. 3.8 *An Illustration of Ephedra foliate*

Anatomy

Root

The root is divided in epiblema, cortex and vascular region. Epiblema-Single layer of cells form epiblema. Some elongated cells of epiblema forms root hairs. **Cortex:** It is divided into outer and inner cortex. Outer cortex is made up of collenchymatous cells and inner cortex is made up of parechymatous cells. Endodermis is formed by the innermost layer of cortex which is followed by pericycle which is a layer made up of thin walled cells. Vascular cylinder may be diarch or triarch and a broad strip of phloem runs between the xylem.

Stem

Primary growth: The tissue of stem is differentiated into epidermis, cortex and stele. Outermost layer is epidermis made up of thick walled cells which is covered with a cuticle. Just below the epidermis, hypodermis is present helps in providing mechanical strength. Stomata are haplochelic. Cortex is divided into outer and inner region. 2-3 layers of radial, elongated palisade cells are present in outer cortex. Inner cortex also consists of 2-3 layers but of spongy parenchyma which has spherical or oval loosely arranged cells. Innermost layer has

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endodermis which is not properly defined and it is followed by pericycle. Eight vascular bundles are present arranged in ring form: small vascular bundles in two pairs representing leaf traces and four larger axial vascular bundles. Vascular bundles are conjoint, collateral and endarch. Thin cambium is present between xylem and phloem. Xylem has vessels, tracheids and xylem parenchyma. *Ephedra* shows resemblance with angiosperms as it has vessels in its xylem. Phloem is made up of sieve tubes, albuminous cells and phloem parenchyma. Medullary rays are present in vascular bundles. Parenchymatous pith is also present at the center of stem and it is formed of strongly lignified cells in the nodal region (Refer Figures 3.9 and 3.10).

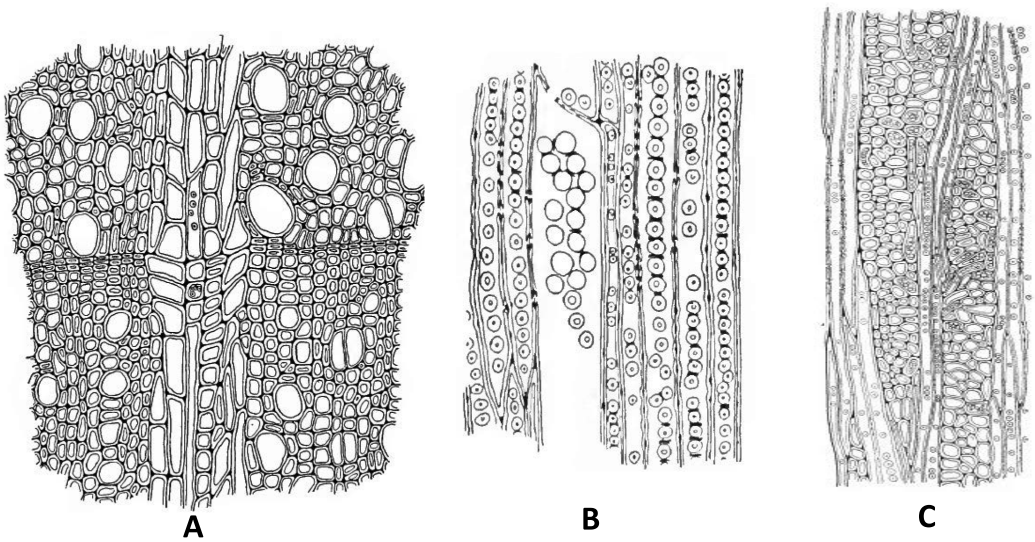

Fig. 3.9 *A. T.S. of Part of Stem of Ephedra trifurca; B. R.L.S. of Stem C. T.L.S. of Stem*

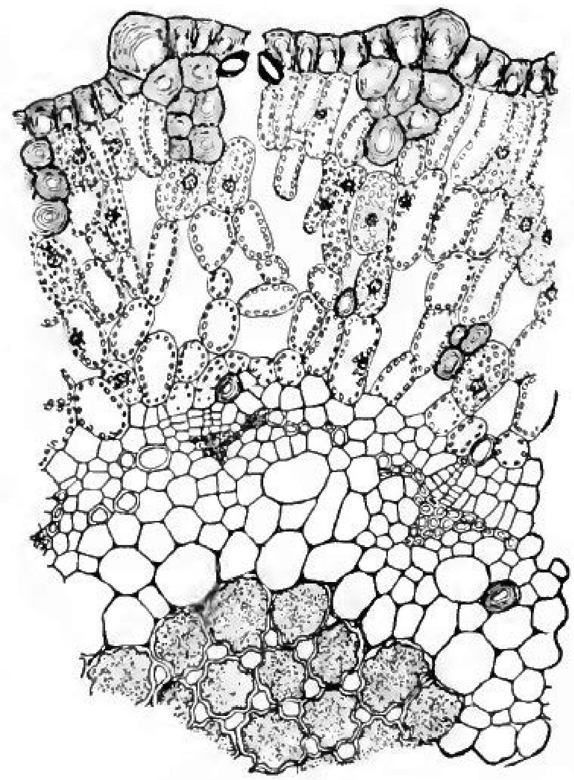

Fig. 3.10 *T.S. of Green Stem of Ephedra trifurca*

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Leaf: Leaf of *Ephedra* is highly reduced and appears scale like. It is differentiated internally into epidermis, mesophyll and vascular region. Epidermis is made up of thick walled cells arranged in a single layer which is covered by a thick cuticle. It also has haplochelic stomata. It has undifferentiated mesophyll cells and also has palisade like elongated cells and has large intercellular spaces in between these are chloroplasts rich cells. The parenchymatous tissue in mid rib region of leaf has two vascular bundles. The vascular bundles are closed and collateral.

Reproduction: Most of the *Ephedra* species are dioecious. However, in some species like *E. foliate* and *E. intermedia* sometimes bisporangiate cone occurs. In *Ephedra*, both male and female strobili are compound.

Male cones are present in the axils of scale leaves and occur as whorl at the node of fertile branch. Globular in shape. It consists of central axis which is short in length with 2-8 pairs of decussate and opposite bracts. The bracts are fertile with the exception of one or two pairs of basal bracts which are sterile. The sporangia are multilocular (Refer Figure 3.11).

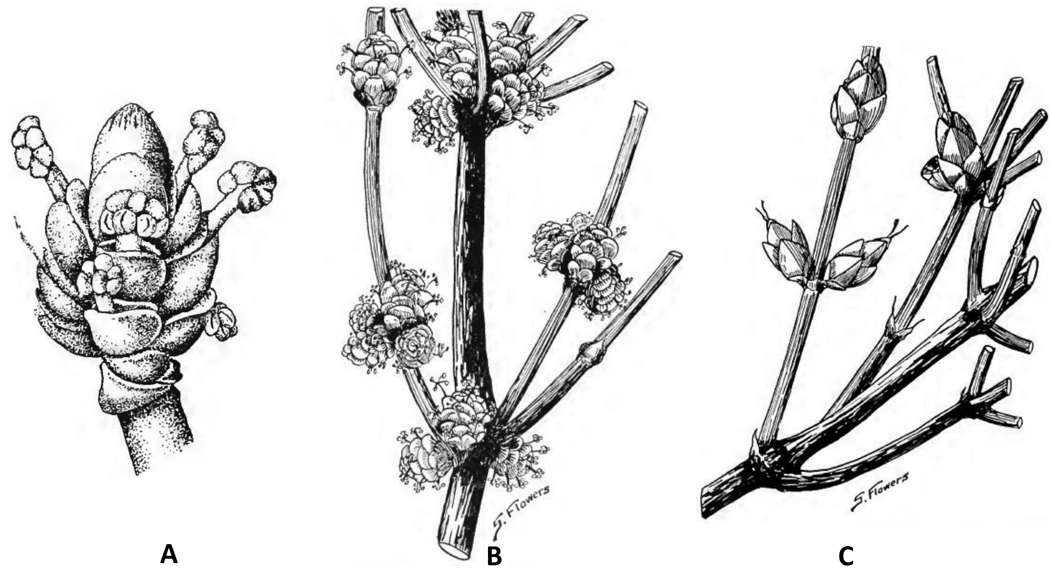

Fig. 3.11 *A. Bisporangiate strobilus of E. campylopoda (after Wettstein); B. Male flowers of E. viridis (unpublished figures of Dr. S. Flowers); C. Female flowers of E. viridis (unpublished figures of Dr. S. Flowers)*

Female cones or strobili (elongated in shape) also arise on scale leaves axil at the fertile branch nodes as the male cone. But they arise only in 2-4 whorls and generally smaller than male strobili. Female cone also has deccusate bracts present on central axis and 2-4 pairs in number. The upper two bracts (perianth) have ovule and other bracts are sterile. Occasionally, due to abortion of any one of the ovule, the strobili become uniovulate. Ovules are bitegmic (two ovules) and deepest pollen chamber amongst gymnosperms is present with two archegonia below pollen chamber.

Gametophyte

Male gametophyte: First division in microspore produces a prothalial cell and a second prothalial cell and antheridial initial after second division. The antheridial cell divides into a tube cell and generative cell. Then generative cell nuclei divides into stalk and body nuclei.

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The two nuclei remain in single cell and no cell wall is laid down and the pollen is shed. The fertilization took place by the formation of pollen tube.

Female gametophyte: In *E. trifurcata* and *E. foliata* (n = 7) megaspore, at chalazal end, divides by free nuclear division and form 256 nuclei whereas as in *E. distachya* number of free nuclei reaches up to 1000. The wall formation starts from periphery towards the centre. The cellular female gametophyte is differentiated into three regions upper reproductive region near micropyle (archegonia develops here), middle storage region and lower haustorial region (Refer Figure 3.12).

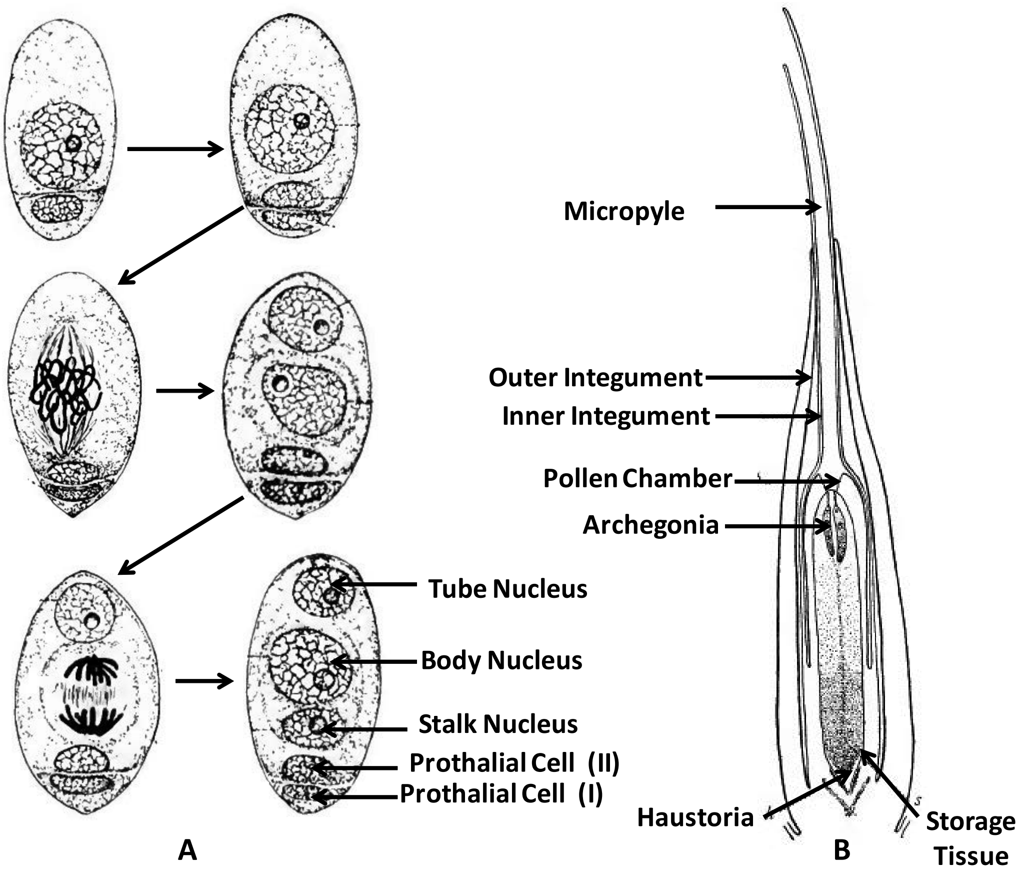

Fig. 3.12 *A. Development of Male Gametophyte (after Land); B. L.S. of Ovule (after Land)*

Pollination and Fertilization

Pollination is through wind but partial insect pollination had also been reported in *E. aphylla.* The pollen grain germinates after entering pollen chamber and four nuclei are released through small pollen tube into the archegonium. Two prothalial cells were degenerated and a tube nuclei, a stalk nuclei, and two male nuclei were released. The two male nuclei were formed by the division of body cell. One male nucleus fuses with the egg cell nucleus and other with the ventral canal cell nucleus. The fusion of one male nucleus with the ventral canal cell nucleus is often referred as double fertilization in *Ephedra*.

Embryogeny

Polyembryony has been reported in the genus *Ephedra*. Polyembryony is the phenomenon where more than one embryo are formed within the single ovule. Polyembryony is of three types first, simple polyembryony: more than one embryo are produced after the fertilization

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of more than one archegonia; second, cleavage polyembryony: when more than embryo are formed by the cleavage of zygote of prozygotic cells; third, rossette polyembryony: embryo develops from the rosette cells during the proembryogeny. In *Ephedra*, the zygote divides and forms eight nucleate stage. At this stage cell wall is laid down around each nucleus. Every cell of this octant is capable to develop into an embryo. Foster and Gifford (1959) termed this type of polyembryony as precocious polyembryony.

Phylogeny

According to Eames (1952), *Ephedra* shows close relation with cordaites and conifers rather than *Welwitschia* and *Gnetum*. According to him, the difference in ovule and microsporangia of *Ephedra* (appendicular) and that of *Welwitschia* and *Gnetum* (cauline) indicates the broad phyletic gap.

Ephedra also differs in embryological development from *Welwitschia* and *Gnetum*. Stalk cell is present in male gametophyte. In female gametophyte, *Ephedra* has well developed archegonia and specific type of proembryogeny.

Economic Importance

Ephedra, also known as ma-huang is a common medicine which has been used in China for more than 5000 years. *E. intermedia, E. nebrodensis, E. equisetina, E. gerardiana, E. sinica* and *E. major* are the major sources used for obtaining drugs. 0.5-2.0% of alkaloids content are present in *Ephedra***,** that varies from species to species. The alkaloid content also depends on the age of plant, which is maximum around the age of 4 years. Alkaloids ephedrine (30-90%) and pseudoephedrine are present which has been isolated in 1887. Nowadays, it has high pharmacological value. Ephedrine is also used in treatment of allergic disorders, bronchospasms, hay fever, asthma and nasal congestion. *E. antisyphilitica* is used for treating syphilis. Ephedrine has same physiological and chemical activity as epinephrine (hormone that acts on sympathetic nervous system). Macrocyclic alkaloids called ephedradines are present in roots which is used as a drug used in lowering blood pressure. In China, rhizomes of *E. gerardiana* is used as fuel. Mormon tea is an aromatic beverage obtained from *Ephedra* species in United States.

'Check Your Progress'

4. What is Ephedra?
5. How many families and species does Ephedrales consists of?
6. What types of plants *Ephedra* consists of?

3.4 GNETALES

The Gnetales comprise three disparate genera, *Gnetum*, *Ephedra* and *Welwitschia*. *Gnetum* comprises about 40 species of climbers and small trees in tropical rainforests of South America, Africa and south-east Asia. They closely resemble angiosperms except in their reproductive structures, and their leaves are almost identical to those of a dicotyledonous angiosperm. One species is cultivated for its edible seeds in Asia. *Ephedra* has 40 species of much-branched shrubs, with a few small trees and climbers, in arid warm temperate parts of Eurasia, North Africa and North and South America. They have photosynthetic stems with whorls of scale leaves. *Ephedra* provides the important drug ephedrin. *Welwitschia* has a single extraordinary species confined to the deserts of South-Western Africa. It is unlike any other plant in that it produces a woody central crown at the top of a mainly underground stem, from which two leaves grow continuously, fraying at the ends and splitting. In mature plants, which can live for more than 1000 years, these can reach 3 m or more long and 1 m wide.

The Gnetales, unlike any other seed plants except angiosperms, have xylem with cells with such large pits that they can be described as vessels, and phloem with cells associated with sieve elements resembling companion cells. On morphological grounds they have been considered to be closely related to the angiosperms, but molecular studies suggest that they are closer to conifers and other gymnosperms and that the similarities in anatomy have arisen independently.

The order gnetales is considered as the most evolved group of gymnosperms. It consists of opposite decussate leaves. It has unicostate reticulate venation. Shoot apex has tunica corpus configuration. It has inflorescence consists of male and female strobili. Female gametophyte has tetrasporic development. Archegonia are completely eliminated. There is no free nuclear division in the development of embryo. It has dicotyledonous embryo. This order consists of single family Gnetaceae and single genus *Gnetum*.

Distribution

Gnetales comprise of only one family Gnetaceae which includes single genus *Gnetum* which consists of about 40 species. It is mostly present in tropical forests of Asia, Africa, Northern parts of South America and some islands between Asia and Australia. About 30 species of this group are endemic. Particular species are exclusively present in particular region as no species present in Asia are found in Africa or America. Eastern Malaysia is considered as the core of present diversification. In India, 5 species of *Gnetum* are present viz. *G. contractum* in Tamil Nadu, Kerala and Nilgiri hills, *G. brunonianum* in Assam, *G. montanum* from Sikkim to Assam, *G. latifolium* in Andaman and Nicobar, *G. ula* in Western Ghats, Odisha and Andhra Pradesh.

Sporophyte

Morphology: *Gnetum* plants are dicotyledonous plant. They may be shrubs as *G. contractum* or small trees like *G. gnemon* (n= 22) (Refer Figure 3.13). Parasitic species are also found, such as *G. trinerve* (illegitimate name). Climbers with twining stem. The main stem has two types of branches: a short shoot which has limited growth with internodes and a long shoot having unlimited growth in which internodes are absent. The climber species *G. ula*, the short shoots has leaves higher which are grown on the branches of the tree used as a support by them. The leaves lie in one plane arranged in decussate pairs and hence the branch appear like a pinnate leaf. The leaf is large and oval having entirely reticulate venation and appears typically dicotyledonous. Articulated stems are present in several *Gnetum* spp. Two parts are present in the joint which lies immediately above and below the node, which is separated by an annular groove. Roots do not grow much deep and are branched tap root.

NOTES

***Fig. 3.13** An Illustration of Gnetum gnemon*

Anatomy

Stem: *Gnetum* stem is very similar to dicot stem in its primary structure. Outermost layer is epidermis, compactly arranged and cells are rectangular. Sunken stomata interrupts the epidermis. Cortex is differentiated into three regions, outer cortex is made up of chlorenchyma, middle ceels are parenchymatous and inner one is sclerenchymatous. Outer region is made up of 5-7 layers and contain chloroplasts. Middle cortex is made up of few layers and has thin walled cells which are compactly arranged. Inner cortex is 2-5 layered structure having thick walled cells which have branched and unbranched canals. Endodermis is represented by the innermost cortex. It is not well distinguished from the other cortical cells. Pericycle is also not very clear. Vascular cylinder is made up of primary vascular bundles which are 20-24 in number which are arranged in a ring. Vascular bundles are endarch, conjoint, collateral and open. Xylem has both tracheids and vessels and phloem consists of sieve tubes and phloem parenchyma (Refer Figure 3.14). In the centre of the stem, parenchymatous pith is also present.

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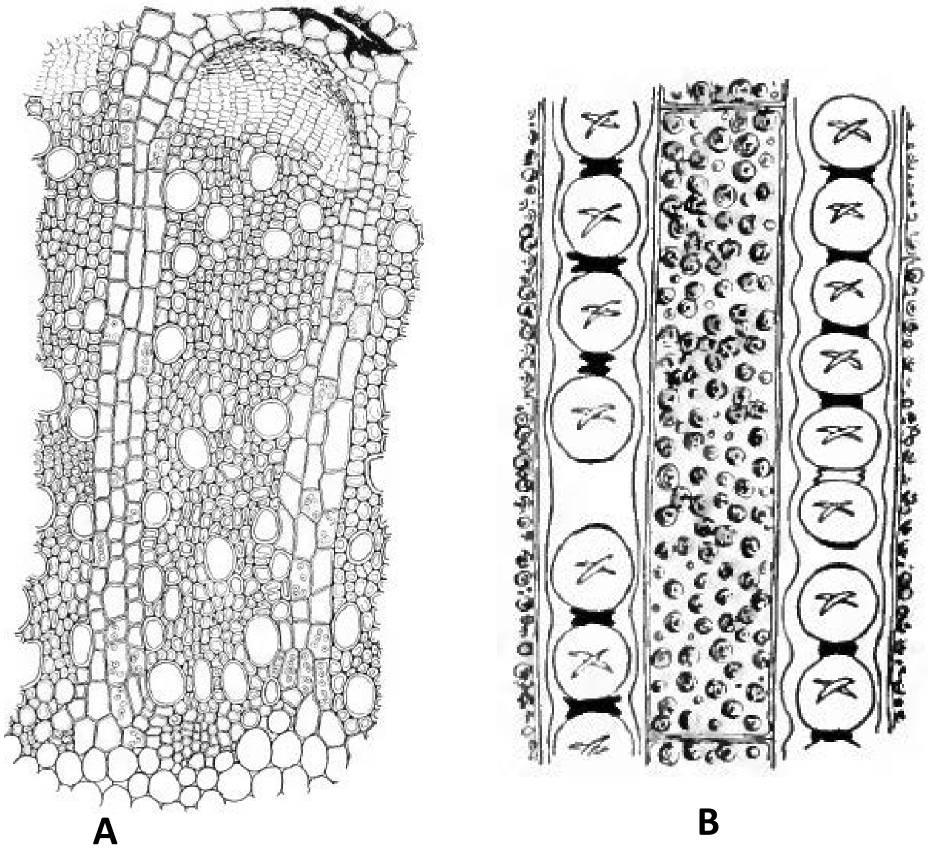

Fig. 3.14 *A. T.S. of Stem of G. gnemon showing Single Vascular Bundle; B. L.S. of Tracheids and Parenchyma showing Bars of Sanio*

Root: The root is differentiated into epiblema, cortex and vascular region. Epiblema is the outermost layer composed of compactly arranged cells. It forms unicellular root hairs. Cortex is made of many layers having parenchymatous cells. Endodermis is formed of single layer and then multilayered pericycle is present. Vascular bundle of root may be diarch or triarch, radial and exarch.

Leaf: The leaves of *Gnetum* are like that of dicots in their appearance, venation as well as in the internal structure. Epidermis forms upper and lower layer. Epidermal cells have sinuous walls. Thick layer of cuticle covers the upper epidermis and stomata are exclusively present on lower epidermis. Mesophyll cells are divided into palisade tissue and spongy parenchyma. Palisade has elongated cells arranged in a single layer and have large amount of chloroplasts. Spongy parenchyma has loosely arranged cells. The midrib of leaf comprises of adaxial xylem and abaxial phloem. It has vascular bundles which are conjoint, collateral and endarch vascular bundles. Xylem has tracheids, vessels and xylem parenchyma whereas phloem is composed of sieve cells and phloem parenchyma. Petiole has transfusion tissue which is mixed with vascular bundles.

Reproduction

Gnetum plant is dioecious but in some species bisexual strobili is also present as in *G. africanum*. Reproductive organs are organized in male and female inflorescence. Both of the inflorescence are generally axillary in position and also terminal. The inflorescence which is a compound strobilus is a long axis having several flowers which occurs in a decussate pairs of bracts. Cupules (collar) are the annular flowers arranged in acropetal succession (new ones at top and older ones at base) on axis. Below each cupule annular rim is present.

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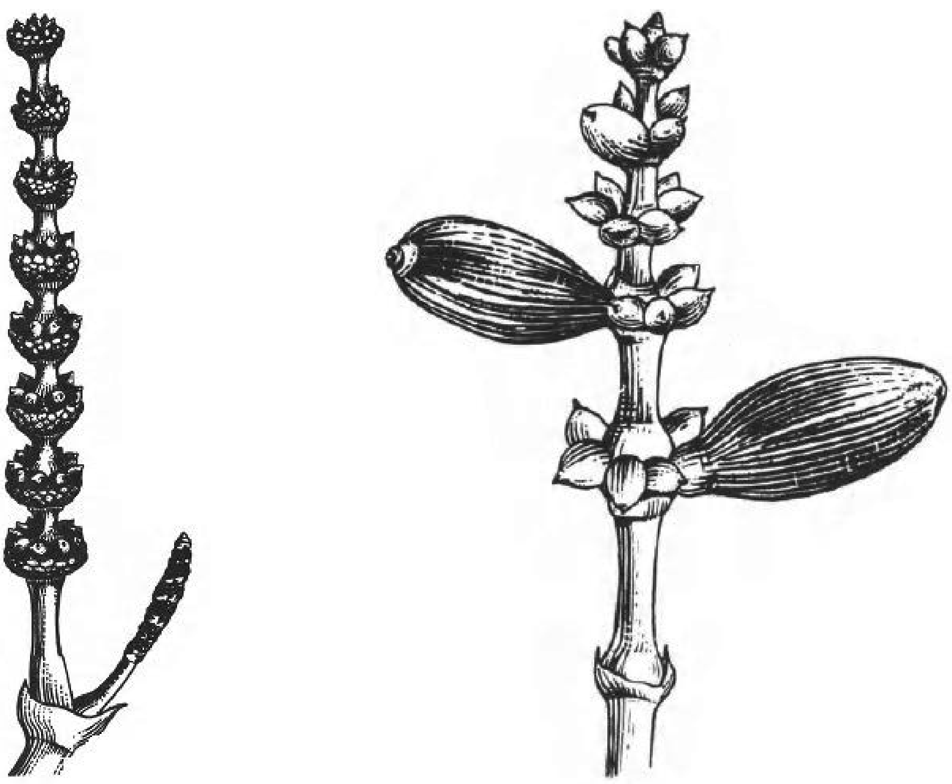
In young inflorescence the cupules are tightly arranged and due to elongation of internodes annular rim and cupules get separated. The flowers (both staminate and ovulate) were surrounded by hairs.

Male spike or strobilus is long slender and have decussate, crescent shaped bracts in pairs. Staminate flowers borne in whorls above annular rim and often there is a ring of sterile ovulate ring of flowers present in *G. gnemon*. In *G. africanum* and *G. buchholzianum* sterile ovulate ring of flowers is absent in male spike. Presence of sterile ovulate flowers does not inhibit the development of nearby staminate flowers but when a developed ovulate flower is present in the male spike the nearby microsporangia (staminate flowers) aborts. Staminate flower is sterile and consists of a perianth (at base) and two unilocular anthers with stalks. The development of pollen grains took place through hypodermal archesporial cells. Archesporial divides to produce a multicellular mass of parietal cells and primary sporogenous cells. The primary cells divides to produce a two layers of cells between epidermis and tapetum. Primary sporogenous cells divides and form spores and tapetum. A unique feature of *Gnetum* is that the tapetum is derived from sporogenous cells and endothecium is absent. Endothecium is present in angiosperms.

Female spike or strobilus bears ovulate flowers in annular arrangement like that of staminate flower. Single ovule is enclosed by three envelops. Some researchers referred them as three integuments others states than as two integuments (bitegmic) which is surrounded by perianth while Lignier and Tison stated that the inner integument is true ovary while outer envelops are perianth, suggesting that the ovary is devoid of integuments. In *Gnetum* the megaspore mother cell divides meiotically and produces four megaspores. Out of four megaspores there is possibility of germination of more than one megaspore in embryosac.



A B

Fig. 3.15 *A. Male spike of G. gnemon B. Female spike of G. gnemon*

Gametophytes

Male gametophyte: Microspore is the first cell of male gametophytic generation. Prothalial cells are absent. The first mitotic division gives rise to tube nucleus and a generative nucleus which further divides to produce a body nucleus and a stalk nucleus. At this three celled (a tube nucleus, a stalk cell and a body cell) stage the pollens were shed. Pollen grain germination took place at the surface of nucellus and at a distance from the nucellus, The tube nucleus migrates first into the pollen tube and stalk nucleus remains behind.

Female gametophyte: The megaspore is the first cell of female gametophytic generation. Free nuclear division took place in megaspore. The cells at micropylar end remains in the free nuclear stage till the time of fertilization. Archegonium and archegonium initial is absent and a free nucleus functions as an egg cell. After fertilization the gametophyte becomes cellular and most of the gametophytic tissues were formed. In gymnosperms, endosperm is formed before fertilization but in angiosperms endosperm is formed after double fertilization. In *Gnetum*, the endosperm is formed after fertilization but no double fertilization took place as in the case of *Ephedra*.

Pollination and Fertilization

Mostly wind pollinated as in other gymnosperms and pollen get fixed in the pollen drop present at the style tip. Fertilization took place at the time of free nuclear division of female gametophyte. Pollen germination took place in the micropylar tube, i.e., away from the nucellus.

Embryogeny

Both free nuclear division and nuclear division have been reported in the *Gnetum* depending upon the species and several zygotes are formed after fertilization. The zygotes divides to form several cells and each cell gives rise to a proembryonal tube or suspensor tube. This branched proembryonal tube cells stage is termed as proembryo. The proembryonal nucleus divides into peculiar cell (pyriform cell with dense cytoplasm and small nucleus) which gives rise to embryo proper and secondary suspensors. The mature embryo have two cotyledons, lactiferous ducts and stomata. Polyembryony is also reported.

Phylogeny

Gnetum resembles very much to the angiosperms. The external appearance of leaf is related to that of angiosperms as both has netted venation. Stomata present in *Gnetum* is mesoparacytic (syndetocheilic stomata with two subsidiary cells, parallel to the guard cells) type which is fundamental type in flowering plant evolution as described by Takhtajan (1969).

Shoot apex of *Gnetum* also resembles that of angiosperms in organization of tunica and corpus. Sieve cells are present in phloem of *Gnetum* in association with development of unrelated parechymatous cells. It was concluded that true companion cells were absent in primitive angiosperm *Austrobaileya scandens*. However, parenchyma cells and sieve elements are formed from different initials are connected by lateral sieve regions. This shows the close proximity of *Gnetum* with angiosperms.

Vessels of xylem consist of circular pits and non-scalariform perforation plates which were similar to that of angiospermous taxa. There were many similarities in perforation plates of *Gnetum* and angiosperms. Torus in pit is absent and vestured pits are some angiospermic features which are present in *Gnetum*. Absence of archegonium and germination of pollen in the style and at the tips of stigma (micropylar tip) are angiospermic features. As *Gnetum* consists of both angiospermic and gymnospermic features, it has been reported that *Gnetum* contains 58% angiospermic character whereas nearly 30% gymnospermic character.this resemblance shows the possibility of *Gnetum* having ancestral relation with angiosperms, it might be assumed that angiosperms have gone through the stage of *Gnetum*. However, there is no direct evidence of having close relation with angiosperms.

Economic importance

Gnetum ula (n=22) has 14.2 % oil content in its seed kernel which is used for illumination, cooking, massage in rheumatism and eating purpose. *G. montanum* has piscicidal property. Bark of *G. latifolium* is used in preparing ropes and nets and seed kernel is used for eating. Almost all parts of *G. gnemon* (n=22), i.e., fruits, seeds, flower and young leaves are used for edible purpose. Wood of *G. gnemom* is used for making rafts and bark is used for making fishing nets and paper pulp.

'Check Your Progress'

7. What does Gnetales comprise of?
8. How many families does Gnetales comprises of?
9. What type of plants does *Gnetum* have?

3.5 SUMMARY

- Ginkgoales is represented by one living genera *Ginkgo* and other fossil genera.
- The history of members dates back to paleozoic era and Ginkgoales also referred as 'living fossil', like Cycads.
- Presence of swimming sperm in *Ginkgo* (a characteristic feature of ferns) represents the paleozoic seed plants feature. *Baiera* is the extinct member of Ginkgoales.
- Many genera and species were present in order gingkoales which are reported from Permian. They became dominant in Mesozoic era. They started to disappear by the end of Jurassic and except gingko all other members became extinct during cretaceous.
- *Ginkgo biloba* (n=12) is a tree having height of 30 m and has diameter more than 1.5 m. Its general habit is like that of conifers, i.e., strongly excurrent trunks.
- Two types of shoots are present in *Gingko*; first, long shoots- that rapidly elongate and scattered leaves are present and second, dwarf shoots (short spur)- that grow slowly and occurs a terminal cluster of leaves.
- *Ginkgo* is dioecious having male cones that are catkin-like and pendant shaped which is borne on short shoots as normal leaves or scaly leaves.
- In male strobilus forty to fifty microsporophylls are present in each dwarf shoot. Often two microsporangia per sporophyll is present in *Ginkgo* but the number may vary between two to seven.
- Sporophyll is slender and surmounted by a hump (terminal knob) that bears two pendant microsporangia. Two collateral endarch bundles are present in the stalk. Mucilage cavity is present in the hump.
- Dehiscence of microsporangia took place by longitudinal slit. The development of microsporangium is of eusporangiate type.

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- Archesporial cell divides into primary wall cell and primary sporogenous cell. Primary sporogenous cell give rise to sporogenous tissue which develops into pollens. Monosulcate pollen is present.
- Pollination and Fertilization: Like other gymnosperms the pollen are wind pollinated and the pollen drop, secreted by the top cells of nucleus acts a medium to fix the pollens.
- After fertilization, perisperm (haploid) develops from female gametophyte (nucellus) due to absence of double fertilization and free nuclear division took place in zygote giving rise to 256 free nuclei in the egg region.
- Phylogeny is the swimming sperm, present in pteridophytes, is a lost character of spermatophytes but retained by Cycads and *Ginkgo*.
- The extremely fern like (*Asplenium* like leaf) favors the origin of *Ginkgo* from heterosporous ferns and supports the evolution of Ginkgoales from Cycadofilicales like ancestors.
- Branching habit of *Ginkgo*, development of wood with small pith and cortex with simple leaves indicates the resemblance from Coniferophytes.
- Leaves are used externally to treat sores, freckles and internally to diarrhoea. Seeds are used for the treatment of lungs, asthma, enuresis, urinary frequency, suppressing coughing and leucorrhea. *Ginkgo* is used for longevity and to increase sexual endurance by the Chinese.
- Recently extracts of *Ginkgo* is used for the treatment of Alzheimer's, Dementia, varicose and post thrombic syndrome. The seeds are eaten roasted or cooked where are raw seeds are toxic.
- In Japan and China wood is used for the manufacturing of chessboard and toys. The extract contains terpenoids, such as ginkgolides and bilobalides.
- Ephedra (commonly known as joint pine, joint fir, Mormon tea or Brigham tea) is the only genus in family Ephedraceae and order Ephedrales. It is represented by 50 species.
- *Ephedra* is a genus of gymnosperm shrubs, the only genus in its family, Ephedraceae and order, Ephedrales.
- Florin (1931) and Eames (1952) had established Ephedrales as an order. Plants are dioecious, herbs or woody lianas, leaves are scale-like and stems are jointed and green.
- Ephedrales consist of single family and have around 42 species of *Ephedra* which is distributed worldwide. These species are different from those that were present in the Old worlds and the new worlds. The height attained by these plants is 5000m above sea level.
- The plants of *Ephedra* are highly branched herbs or shrubs. *E. campylopoda* is cultivated as ornamental plant. *E. triandra* is a small tree, and *E. gerardiana* is a perennial herb. *E. foliata* is a shrub of about 6m height, climbs up the trees or walls, and in the absence of support, it spread on the ground.
- Cortex is divided into outer and inner cortex. Outer cortex is made up of collenchymatous cells and inner cortex is made up of parechymatous cells.
- Endodermis is formed by the innermost layer of cortex which is followed by pericycle which is a layer made up of thin walled cells. Vascular cylinder may be diarch or triarch and a broad strip of phloem runs between the xylem.

- Leaf of *Ephedra* is highly reduced and appears scale like. It is differentiated internally into epidermis, mesophyll and vascular region.
- Epidermis is made up of thick walled cells arranged in a single layer which is covered by a thick cuticle. It also has haplochelic stomata.
- Most of the *Ephedra* species are dioecious. However, in some species like *E. foliate* and *E. intermedia* sometimes bisporangiate cone occurs. In *Ephedra*, both male and female strobili are compound.
- First division in microspore produces a prothalial cell and a second prothalial cell and antheridial initial after second division. The antheridial cell divides into a tube cell and generative cell.
- Pollination is through wind but partial insect pollination had also been reported in *E. aphylla.* The pollen grain germinates after entering pollen chamber and four nuclei are released through small pollen tube into the archegonium.
- Polyembryony has been reported in the genus *Ephedra*. Polyembryony is the phenomenon where more than one embryo are formed within the single ovule.
- Polyembryony is of three types first, simple polyembryony: more than one embryo are produced after the fertilization of more than one archegonia; second, cleavage polyembryony: when more than embryo are formed by the cleavage of zygote of prozygotic cells; third, rossette polyembryony: embryo develops from the rosette cells during the proembryogeny.
- According to Eames (1952), *Ephedra* shows close relation with cordaites and conifers rather than *Welwitschia* and *Gnetum*. According to him, the difference in ovule and microsporangia of *Ephedra* (appendicular) and that of *Welwitschia* and *Gnetum* (cauline) indicates the broad phyletic gap.
- *Ephedra*, also known as ma-huang is a common medicine which has been used in China for more than 5000 years. *E. intermedia, E. nebrodensis, E. equisetina, E. gerardiana, E. sinica and E. major* are the major sources used for obtaining drugs. 0.5-2.0% of alkaloids content are present in *Ephedra*, that varies from species to species.
- Ephedrine is also used in treatment of allergic disorders, bronchospasms, hay fever, asthma and nasal congestion. *E. antisyphilitica* is used for treating syphilis.
- Ephedrine has same physiological and chemical activity as epinephrine (hormone that acts on sympathetic nervous system).
- Macrocyclic alkaloids called ephedradines are present in roots which is used as a drug used in lowering blood pressure. In China, rhizomes of *E. gerardiana* is used as fuel.
- The Gnetales comprise three rather disparate genera, *Gnetum*, *Ephedra* and *Welwitschia*. *Gnetum* comprises about 40 species of climbers and small trees in tropical rainforests of South America, Africa and south-east Asia.
- The Gnetales, unlike any other seed plants except angiosperms, have xylem with cells with such large pits that they can be described as vessels, and phloem with cells associated with sieve elements resembling companion cells.
- The order gnetales is considered as the most evolved group of gymnosperms. It consists of opposite decussate leaves. It has unicostate reticulate venation. Shoot apex has tunica corpus configuration. It has inflorescence consists of male and female strobili.

- Female gametophyte has tetrasporic development. Archegonia are completely eliminated. There is no free nuclear division in the development of embryo. It has dicotyledonous embryo.
- *Gnetum* plants are dicotyledonous plant. They may be shrubs as *G. contractum* or small trees like *G. gnemon* (n= 22). Parasitic species are also found, such as *G. trinerve* (illegitimate name).
- Climbers with twining stem. The main stem has two types of branches: a short shoot which has limited growth with internodes and a long shoot having unlimited growth in which internodes are absent.
- *Gnetum* stem is very similar to dicot stem in its primary structure. Outermost layer is epidermis, compactly arranged and cells are rectangular. Sunken stomata interrupts the epidermis.
- Cortex is differentiated into three regions, outer cortex is made up of chlorenchyma, middle ceels are parenchymatous and inner one is sclerenchymatous.
- The root is differentiated into epiblema, cortex and vascular region. Epiblema is the outermost layer composed of compactly arranged cells. It forms unicellular root hairs.
- Cortex is made of many layers having parenchymatous cells. Endodermis is formed of single layer and then multilayered pericycle is present. Vascular bundle of root may be diarch or triarch, radial and exarch.
- The leaves of *Gnetum* are like that of dicots in their appearance, venation as well as in the internal structure. Epidermis forms upper and lower layer. Epidermal cells have sinuous walls.
- Palisade has elongated cells arranged in a single layer and have large amount of chloroplasts.
- Spongy parenchyma has loosely arranged cells. The midrib of leaf comprises of adaxial xylem and abaxial phloem.
- *Gnetum* plant is dioecious but in some species bisexual strobili is also present as in *G. africanum*. Reproductive organs are organized in male and female inflorescence.
- In *Gnetum* the megaspore mother cell divides meiotically and produces four megaspores. Out of four megaspores there is possibility of germination of more than one megaspore in embryosac.
- *Gnetum* resembles very much to the angiosperms. The external appearance of leaf is related to that of angiosperms as both has netted venation.
- Stomata present in *Gnetum* is mesoparacytic (syndetocheilic stomata with two subsidiary cells, parallel to the guard cells) type which is fundamental type in flowering plant evolution as described by Takhtajan (1969).
- Shoot apex of *Gnetum* also resembles that of angiosperms in organization of tunica and corpus.
- Vessels of xylem consist of circular pits and non-scalariform perforation plates which were similar to that of angiospermous taxa.
- As *Gnetum* consists of both angiospermic and gymnospermic features, it has been reported that *Gnetum* contains 58% angiospermic character whereas nearly 30% gymnospermic character.

3.6 KEY TERMS

NOTES

- **Ginkgoales:** Ginkgoales or Ginkgophyte is a gymnosperm order containing only one extant species: Ginkgo biloba, the ginkgo tree.
- **Ephedra:** Ephedra is a genus of gymnosperm shrubs, the only genus in its family, Ephedraceae and order, Ephedrales.

3.7 ANSWERS TO 'CHECK YOUR PROGRESS'

1. Ginkgoales or Ginkgophyte is a gymnosperm order containing only one extant species: Ginkgo biloba, the ginkgo tree.
2. Ginkgoales is represented by one living genera *Ginkgo* and other fossil genera.
3. *Ginkgo biloba* (n=12) is a tree having height of 30 m and has diameter more than 1.5 m. Its general habit is like that of conifers, i.e., strongly excurrent trunks.
4. Ephedra (commonly known as joint pine, joint fir, Mormon tea or Brigham tea) is the only genus in family Ephedraceae and order Ephedrales. It is represented by 50 species.
5. Ephedrales consist of single family and have around 42 species of *Ephedra* which is distributed worldwide.
6. The plants of *Ephedra* are highly branched herbs or shrubs. *E. campylopoda* is cultivated as ornamental plant. *E. triandra* is a small tree, and *E. gerardiana* is a perennial herb. *E. foliata* is a shrub of about 6m height, climbs up the trees or walls, and in the absence of support, it spread on the ground.
7. The Gnetales comprise three disparate genera, *Gnetum*, *Ephedra* and *Welwitschia*.
8. Gnetales comprise of only one family Gnetaceae which includes single genus *Gnetum* which consists of about 40 species. It is mostly present in tropical forests of Asia, Africa, Northern parts of South America and some islands between Asia and Australia.
9. *Gnetum* plants are dicotyledonous plant. They may be shrubs as *G. contractum* or small trees like *G. gnemon* (n= 22).

3.8 QUESTIONS AND EXERCISES

Short-Answer Questions

1. Write down the salient features of leaves of *Ginkgo*.
2. Discuss briefly about the development of male gametophyte in *Ginkgo*.
3. Write about embryogeny in *Ginkgo*.
4. Discuss the phylogenetic significance of *Ginkgo*.
5. Write down the economic significance of *Ginkgo biloba*.
6. Write down the salient feature of *Ephedra*.
7. Describe double fertilization in the *Ephedra*.
8. What is polyembryony? Explain the polyembryony in *Ephedra*.
9. Write down the phylogenetic significance of *Ephedra*.

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10. How *Ephedra* is beneficial to human kind?
11. Write down the distribution of *Gnetum*.
12. Describe *Gnetum* morphologically.
13. Explain the development of male gametophyte in *Gnetum*.
14. Describe the embryogeny in *Gnetum*.
15. Write down the economic importance of *Gnetum*.

Long-Answer Questions

1. Write about distribution and morphology of *Ginkgo biloba*.
2. Why *Ginkgo* is considered as living fossil?
3. Discuss the anatomy of vegetative structures of *Ginkgo*.
4. Explain the reproductive structures of *Ginkgo biloba*.
5. Explain the development of gametophytes of *Ginkgo biloba*.
6. Write about distribution and morphology of *Ephedra*.
7. Discuss the anatomy of *Ephedra* root and stem.
8. Explain the reproductive structures of *Ephedra*.
9. Explain the development of gametophytes of *Ephedra*.
10. Write briefly about distribution and morphology of *Gnetum*.
11. Discuss the anatomy and reproductive structures of *Gnetum* root.
12. Explain the development of gametophytes of *Gnetum*.
13. Discuss the phylogenetic significance of *Gnetum*.

3.9 FURTHER READING

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SECTION 'B' (ANGIOSPERMS)

NOTES

UNIT 4 ANGIOSPERMS: ORIGIN, EVOLUTION AND TAXONOMICAL TOOLS

Structure

4.0 INTRODUCTION

Flowering plants are called as angiosperms. The flowering plants are the most dominant vascular plants that are found in the fauna all around the world. The pleasing and attractive colours of their flowers certainly add much more colour and brighten the landscape of any place. Due to the presence of flowers and enclosed seeds, they are called the phanerogams. Scientifically speaking, in these plants, the seeds are enclosed, with the ovules present in a hollow ovary.

All angiosperm plants have the characteristic vascular bundle with the xylem and phloem tissues for conduction of water, minerals, and nutrients. The plant body is well differentiated with a well-developed root system, shoot system and leaves. Specialised structures called as the flowers are present. Within these flowers, the male and female gametes develop. After fertilization, when these flowers mature, fruits are formed which have the seeds within them. Angiosperms can be found in varied habitats and can come in a different range of sizes. Wolfie is an angiosperm that is microscopic whereas the Australian mountain ash tree is about 100 meters tall. The diversity that the angiosperms display is very wide. There are many plants that are tall woody trees, shrubs, and even herbaceous plants. These plants also have many adaptations in the roots, stems and leaves depending on the habitat that they grow in.

A herbarium (plural: herbaria) is a collection of preserved plant specimens and associated data used for scientific study. A botanical garden or botanic garden is a garden dedicated to the collection, cultivation, preservation and display of a wide range of plants labelled with their botanical names. It may contain specialist plant collections, such as cacti and other succulent plants, herb gardens, plants from particular parts of the world, and so on; there may be greenhouses, shade houses, again with special collections, such as tropical plants, alpine plants, or other exotic plants. Visitor services at a botanical garden might include tours, educational displays, art exhibitions, book rooms, open-air theatrical and musical performances, and other entertainment

In this unit, you will study about the origin and evolution of angiospermic flower, different taxonomic tools, herbarium and botanical garden and salient features of ICBN in detail.

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4.1 UNIT OBJECTIVES

After going through this unit, you will be able to:

- Understand the origin and evolution of angiospermic flower
- Explain different taxonomic tools
- Discuss about herbarium and botanical garden
- Analyse the salient features of ICBN

4.2 ORIGIN AND EVOLUTION OF ANGIOSPERMIC FLOWER

The origin of angiospermic flower during the late Jurassic to early Cretaceous period (between 132 to 112 mya) (Bhattacharyya, 2005) was a key evolutionary innovation. The origin and early evolution of angiosperms are enigmas that have intrigued botanists past over a century. The origin and evolution of angiospermic flower constituted an 'abominable mystery' to Charles Darwin. Darwin's abominable mystery has little if anything to do with the fossil prehistory of angiosperms, identification of the closest relatives of flowering plants, characteristics features of flowering plants or the phylogeny of flowering plants (Refer Figure 4.1).

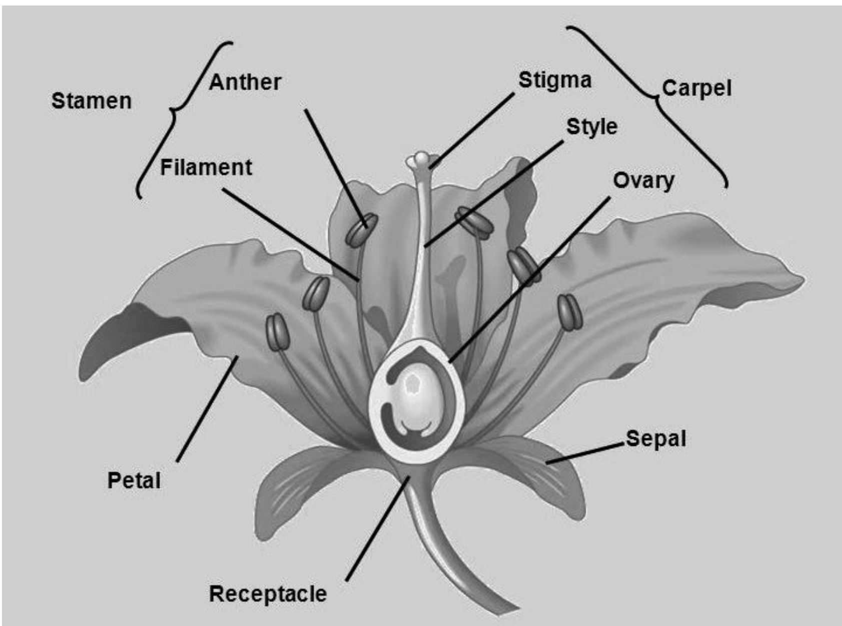

Fig. 4.1 *Structure of an Angiosperm Flower*

Angiosperms form a distinct group of seed plants sharing a unique combination of characters. It includes:

- Diversified habit and vegetative forms.
- Well-developed vascular system; the xylem in addition to tracheids, contains wood vessels and the phloem possesses companion cells.

- Bewildering morphological diversity.
- Development of ovules within ovary which ensures proper protection to the developing ovules and seeds.
- Pollen grains germinating on stigma.
- Double fertilization resulting in triploid endosperm formation.
- Bisexual flower with carpels surrounded by stamens and stamens by petals and sepals. Bisexuality ensures self-pollination if cross-pollination fails, hence seeds formation is ensured in any case.
- Arbuscular mycorrhizae are also unique to angiosperms (except *Amborellaceae, Nymphaeales* and *Austrobaileyales*).

Angiosperms or Flowering Plants

The flowering plants or Angiosperms are the most diverse group of land plants, with ca. 406 families having 14,064 known genera and approximately 3,69,000 known species (The Plant List, 2010). The ancestors of flowering plants diverged from the gymnosperms in the Triassic period, 242 to 202 mya (Million Years Ago) and the first flowering plants are known from 160 mya. Angiosperms diversified extensively during the 'Early Cretaceous' became widespread by 120 mya and replaced conifers as the dominant trees from 100 to 60 mya. The first angiosperms must have evolved from one of the gymnosperms species that dominated the world at that time. For many years, the earliest well-documented angiosperm fossil was considered to be the form-genus *Clavitopollenites* (Couper, 1958) from Barremian and Aptian strata of early Cretaceous of Southern England, (132 to 112 mya) to be the oldest recorded angiosperm fossil with monosulcate pollen having distinct sculptured exine, resembling the pollen of extant genus *Ascarina*. Many claims of angiosperm records from the strata earlier than the Cretaceous were made, but largely rejected.

The number and diversity of angiosperms fossil increased and by the end of Early Cretaceous period major groups of angiosperms, including herbaceous Magnoliidae, Magnoliales, Laurales, Winteroids and Liliopsida were well represented (Singh, 2004). In Late Cretaceous, at last 50 percent of the species in the fossil flora were angiosperms.

In the last few years Sun *et al.*, 1998, 2002, have described fossils of *Archaefructus* from Upper Jurassic (~124 mya) of China, with well-defined spirally arranged conduplicate carpels enclosing ovules, a feature not reported in earlier angiosperms.

Probable Ancestors of Angiosperms

Phylogenetic studies carried out recently shows Gnetopsids to be the closest living relatives of the angiosperms whereas the closest extinct group is Bennettitaleans (Refer Figure 4.2).

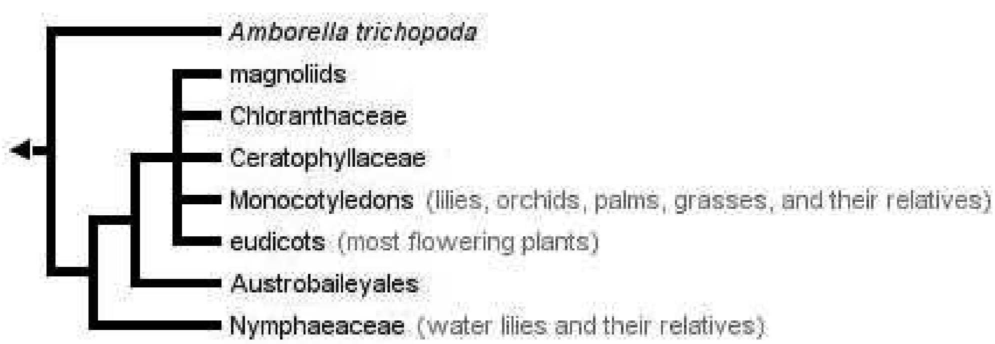

***Fig. 4.2** A phylogenetic Diagram to Show the Sister Groups of Angiosperms, Gnetopsids are the Closest Living Groups and Bennettitales the Closest Extinct Group*

NOTES

Diagram source: Relationships after Qiu *et al.* (1999, 2000), P. Soltis *et al.* (1999), D. E. Soltis *et al.* (2000), Zanis *et al.* (2002) and Hilu *et al.* (2003).

Amborella remains the sister group to all other flowering plants, but the *Hydatellaceae* join the *Nymphaeales* (water-lilies) as the next diverging subsidiary branch of the tree. This new alignment5 raises questions about the origin of classic bisexual flowers in the *Nymphaeales* and other angiosperms. The unisexual flowers of *Hydatellaceae* — with male and female flowers consisting of a single organ only (stamen and carpel, respectively), aggregated in dense unisexual or bisexual inflorescences — contrast with the solitary, bisexual flowers of the *Cabombaceae*, represented here by Cabomba, which were previously regarded as the basic condition in the *Nymphaeales*. More generally, simple and often unisexual flowers occur among several early-diverging angiosperm lineages, for example in the *Trimeniaceae* (*Piptocalyx*, *Trimenia*) and *Chloranthaceae* (*Sarcandra*, *Hedyosmum*), as well as early-diverging eudicots (Buxus). But whether this simplicity reflects the basic phylogenetic condition or ecological adaptation is an open question. Flowers of *Amborella* are also small, and functionally unisexual, but female flowers have staminodes, indicating a basic bisexual organization. In this situation, interpretations of character evolution depend on the position of the root of the phylogenetic tree, and may also be sensitive to the addition of new taxonomic groups. Infl, inflorescence (flower cluster). Drawings by P. von Knorring (Refer Figure 4.3).

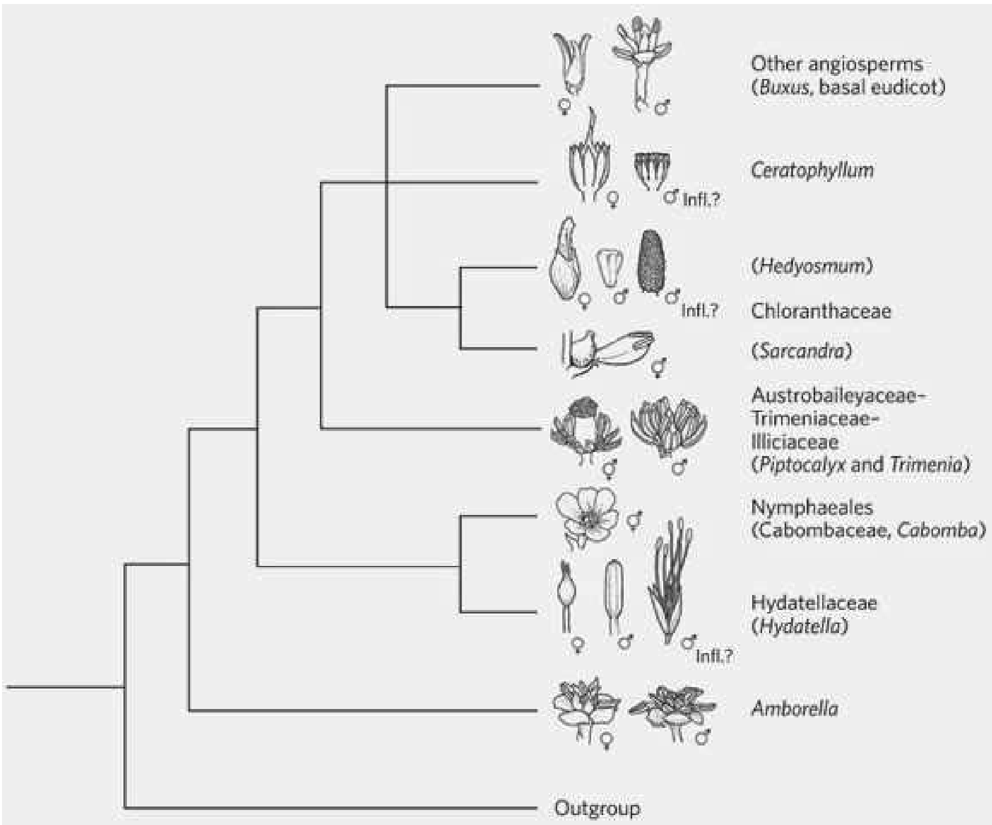

Fig. 4.3 *Sister Groups of Angiosperms*

The theories proposed regarding the probable ancestors of angiosperms could be placed in two groups:

Euanthial Theory or Anthostrobilus Theory: Proposed by Arber and Parkin (1907). According to this theory angiosperms originated from various gymnospermous stocks termed as Hemiangiosperms. The angiosperm flower is interpreted as being derived from an unbranched bisexual strobilus bearing spirally arranged pollen and ovule bearing organs. Carpel here is regarded as a modified megasporophyll. Agreeing to this general principle, various authors have regarded different gymnospermous groups as possible ancestor to angiosperms:

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Bennettitales (Cycadeoidales)

Now known as *Cycadeoidales*. Lemesle (1946) considered the *Bennettitales* as the probable ancestor which appeared in Triassic and disappeared in Cretaceous. Bennettitales is primarily considered ancestral to angiosperms because of its hermaphrodite nature which had an elongated receptacle with perianth like bracts, a whorl of pollen-bearing microsporophylls surrounding the ovuliferous region having numerous ovules and interseminal scales packed together (Refer Figure 4.4).

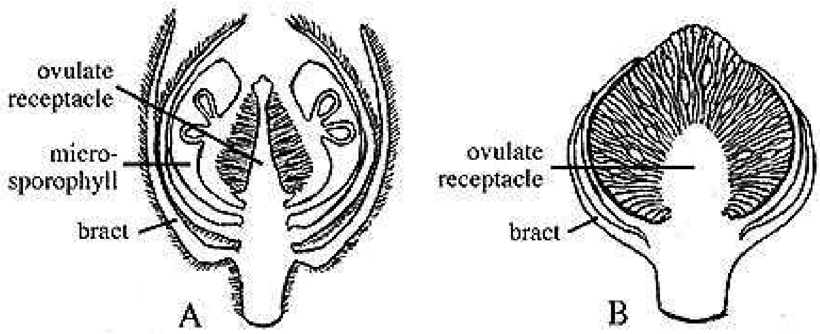

Fig. 4.4 *Bennettitales (Cycadeoidales) Structure*

Caytoniaceae: In the recent years strong inclination towards the probability that angiosperms has arisen from Pteridosperms (seed ferns) often placed in order Lyginopteridales but more commonly under Caytoniales because of the following characters:

- Large usually pinnately compound leaves and some species with reticulate venation.
- Stem simple or branched, when branched, branching monopodial.
- The ovules of Lyginopteridales or Pteridosperms were mostly borne on margins of the megasporophyll and in some members on the abaxial or the adaxial surface. Either position is acceptable to consider the origin of angiosperms from this group.
- Absence of vessels in tracheary element in Pteridosperms is a character similar to what is found in primitive angiosperms fossil.

Cycadales: This has possible links with angiosperms as suggested by Sporne (1971), on the basis of ovule- bearing structure. Although it may be difficult to assume Cycadales as ancestral to angiosperms, the fact that they have been derived from pteridosperms and yet resemble angiosperms further favours the opinion of origin of angiosperms from pteridosperms.

Pseudanthial Theory: First proposed by Wettstein (1907). The theory is commonly associated with Englerian school of thought about the most primitive living angiosperms according to this view, the taxon Amentiferae including families with highly reduced unisexual flowers borne in catkins, are the most primitive angiosperms and also regarded the showy insect pollinated bisexual flowers of Magnolia as 'pseudanthia' derived by aggregation of unisexual units, the carpel thus representing a modified branch, (Stachyosporous origin of carpel) (Singh, 2004). The theory was strongly supported by Young (1981). He emphasized that angiosperms were originally vesselless and these were lost in several lines during early stage of development. The basal group of angiosperms according to this theory included amentiferous-hamamelid orders Casuarinales, Fagales, Myricales and Juglandales.

Features refuting Gnetophytina as an ancestral from of angiosperm are:

- Different origin of vessels (Bailey, 1944) in angiosperm and Gnetopsids.
- Similarity between the inflorescence of Gnetophytina and the Amentiferae is also surprising because Amentiferae is an advanced taxon with highly reduced flowers (according to Besseyan school of thought). The primitive angiospermous flower is bisexual with well developed perianth numerous stamens, and numerous free (apocarpous) carpels.
- Although most of the angiosperm are dicotyledonous it is also possible that they might have developed from polycotyledonous ancestors.
- Most importantly Gnetopsida is a very young group.

But, the theory of accepting Gnetophytina as an ancestral from of angiosperm has been supported by young (1981). He laid emphasis on the fact that angiosperms were originally vesselless and these were lost in several lines during early stages of development. The importance of Gnetales in origin and phylogeny of angiosperms has further been strengthened with the discovery of *Welwitschia* like fossil described by Cornet (1996) as *Archaestrobilus cupulanthus* from the late Triassic period in Texas, USA.

Gnetales and Angiosperms Theory:

Richard von Wettstein (1901) emphasized the close relationship between Gnetales and angiosperms, after modifying the Engler's system as mentioned in Handbuch der Systematis che Botanik. Later on, Markgraf (1930) and Fagerlind (1947) strongly supported their view. Fagerlind descibe the homology among the three genera of Gnetales (Ephedra, Welwitschia and Gnetum) and proposed that Gnetales and Pro-angiosperms evolved from a common ancestor.

Similarities between Gnetales and Angiosperms:

- Presence of two cotyledons in both.
- Vessels are present in the secondary wood;
- Venation is reticulate in both.
- Unisexual inflorescence (similar to catkin of many Amentifers).
- In Welwitschia, the male flowers are bisexual and they are formed by reduction of female organs.
- Stamens of Welwitschia, Ephedra, and Gnetum seems to be similar to angiosperms.
- The female flowers of all the above three genera have 2 or more envelops around the nucellus like the perianth of angiosperms.
- The well-developed micropylar tube of female flowers looks like the style of angiosperm flower.
- Like angiosperms, female gametophyte of Gnetum is tetrasporic and without archegonia.
- First division of zygote in Gnetum is accompanied by cell wall formation as in angiosperms.

Differences between Gnetales and Angiosperms:

- Gnetum have vessels in secondary wood, while it is absent in some primitive dicots like Tetracentron, Trochodendron.

- The origin of vessels of Gnetales is entirely different from angiosperms.
- Characteristic of primitive angiosperms, that is, presence of scalariform pitted tracheids, is absent in both primary and secondary xylem of Gnetum.
- Gnetum also differs from angiosperms in development of vessels.

The similarity between Gnetales and certain angiosperms is now considered as superficial and appears due to tilting towards convergence during evolution. Similarities in the number of cotyledons (two) also appear due to convergence. It can be suggest that angiosperms might have been evolved from polycotyledonous ancestors not from dicotyledonous one.

Fossil Evidences for the Origin of Angiosperms

Early history of flowering plant based on living groups is poorly documented. Current phylogenetic models incorporate sparse data from fossils record from early Devonian (405 myr). Discovery of fossils similar to angiosperms, or their sister groups (Bennettitaleans and Gnetaleans) can help in understanding of homologies among these groups. The two basic hypotheses have developed regarding the form of ancestral angiosperm:

- The Magnolialean Hypothesis
- The Herbaceous Origin Hypothesis

The Magnolialean Hypothesis: The hypothesis suggested that the ancestral angiosperm was a woody asborescent plant with large, many parted flowe, (Cronquist, 1988; Takhtajan, 1991; Thorne, 1997). Doyle and Hickey (1976) and Hickey and Doyle (1977) based on fossil evidences, expanded Stebbins (1974), concept and suggested that the first angiosperms were 'shrubs of semixerophytic origin which entered mesic areas as colonizers of unstable habitats -the weeds of early Cretaceous (135 myr)'. According to this hypothesis, the transition of the angiosperms was viewed from the bisexual strobiloid reproductive organs of the Bennettitaleans and this has been supported by some recent phylogenetic analyses (Donoghue and Doyle, 1989; Loconte and Stevenson, 1991; Crane *et al.*, 1995, Loconte, 1997).

The alternative Herbaceous Origin Hypothesis (which includes the 'Paleoherb' variants) suggests that ancestral angiosperm was small in size and had many small few parted flowers (Burger, 1981; Taylor and Hickey, 1992).This hypothesis is similar to the Pseudanthial theory proposed by Wettstein (1907, 1935). In this view the angiospermic flower was thought to be derived from a compound gymnosperm strobilus where a central axis is surrounded by numerous secondary axes subtended by bracts, similar to that found in Gnetopsids. A major difference between the Herbaceous origin and Pseudanthial hypothesis is that, in herbaceous origin the ancestral plant is considered to be a rhizomatous, perennial herb instead of a tree. With increasing phylogenetic analysis of morphological characters (Taylor and Hickey, 1992) and molecular sequences (Zimmer *et al.*, 1989; Hamby and Zimmer, 1992; Chase *et al.*, 1993; Qui *et al.,* 1993; Doyle *et al*, 1994) support the herbaceous origin hypothesis.

Time of Origin and Diversification of Angiosperms

The time and origin of the angiosperms is a debatable concept. Some botanists suggest the origin flowering plants during pre-cretaceous period, such as Jurassic (180 myr) or Triassic (225 myr) or even as early as Paleozoic (270 myr) era, (Bhattacharyya, 2005). But according to Wolfe *et al.,* (1975), there is 'no unequivocal evidence that indicates pre-Cretaceous origin for the angiosperms'. The earliest angiosperm fossil records have been reported from the rocks of *Valanginian* age (141 myr) of Lower Cretaceous in Israel (Brenner, 1997).

Major groups of angiosperms including the herbaceous *Magnoliidae, Magnoliales*, *Laurales, Winteroids*, *Liliopsida* and *Eudicots* all appear by the end of the Early Cretaceous. The number of species increased so rapidly that early in Late Cretaceous at least 50 per cent of the species in fossil flora are angiosperms (Lidgard and Crane, 1988). By the end of the cretaceous period many extant angiosperm families have appeared (Muller, 1981; Taylor, 1990). The diversification of angiosperms even followed a **geographical pattern**, with the earliest occurrences in equatorial regions and later dispersed towards the pole. Angiosperms wide distribution during Early Cretaceous was quiet dominant, but during Late Cretaceous they are to some extent overshadowed by the fossils of gymnosperms and ferns.

Although there have been evidences from fossil records suggesting the origin of flowering plants during pre-Cretaceous period, there has been an alternative of a much earlier date for the origin of the angiosperms as suggested by several molecular clock models. Although the predicted dates vary widely and varying rates of base-pair substitution among different clades causes problems in dating the emergence of lineages, the minimum congruence of the times predicted by the various analyses suggests that angiosperm originated around Triassic period (Taylor and Hickey, 1996). This is compatible with at least one evolutionary interpretation of the anthophyte fossil records that points to the apparent long independence of the line leading to the angiosperms (Doyle and Donoghue, 1986). Another support for this early date is the occurrence of putatively angiospermous characters in pollen and megafossil remains from the late Triassic and Jurassic (Cornet, 1986, 1989a, 1989b; Cornet and Habib, 1992).

In context to the place of origin of angiosperms the first cretaceous flora with abundant angiosperm reproductive organs was discovered in 1979 in Southern Sweden. Also, with the study of paleoecology of Early Cretaceous sites provides evidence supporting the view that the angiosperms first lived along stream and lake margins (Doyle and Hickey, 1976; Hickey and Doyle 1977; Upchurch and Wolfe, 1987; Hickey and Taylor, 1992). Later they appear in more stable backswamp and channel sites, and last on river terraces (Taylor and Hickey, 2007). Paleoecological studies of Late Cretaceous localities shows that although angiosperms were taxonomically diverse, they were not dominant forms but mostly understory herbs (Wing *et al*., 1993).

Role of Ecology, Genetics and Insects in the Evolution of Angiosperms

The rise to dominance of the angiosperms is frequently considered to be directly or indirectly due to co-evolutionary mutualisms with vertebrate seed dispersers and insect pollinators (‘reproductive co-evolution hypotheses). The decline of the gymnosperms is considered to be due to the inefficiency of wind pollination in maintaining heterozygosity in angiosperm-enriched communities or the limited scope for speciation of wind-pollinated taxa. Contrasting hypotheses for the rise of the angiosperms focus on either environmental change or superior reproductive and vegetative innovations leading to faster growth rates.

Coevolution is a term used to describe the mutual changes in two or more species, usually one following the other that affect their interactions. Flowering plants (angiosperms) and their pollinators are often used as the classic example of this evolutionary phenomenon. The plant and the pollinator place evolutionary pressure on each other for changes in morphology, physiology, or habits that benefit both.

The flowering plants are the most ecologically diverse and species-dense branch on the green plant tree of life. With roughly 250 000 extant species angiosperms have evolved an unparalleled spectrum of growth habits and ecologies in response to a broad range of habitats also, angiosperms dominate the composition, biomass, and biogeochemical functioning of most terrestrial ecosystems, with the exception of boreal and some temperate rainforest zones.

The ecological factor for the Cretaceous explosion of angiosperm diversity, is 'competitive superiority' of angiosperms. The angiosperms are also the youngest of the major green plant lineages, having arisen and radiated long after plants colonized the terrestrial habitat about 500–470 million years ago, during the Ordovician. A diverse assortment of angiosperms appears abruptly in the fossil record of the Early Cretaceous, starting approximately 125 mya, and representatives of all major extant flowering plant lineages can be recognized in Mid-Cretaceous deposits. The precipitous origin and rapid diversification of flowering plants was famously referred to as an 'abominable mystery' by Charles Darwin because their rapid appearance contradicted his gradualist view of evolutionary change.

The most conspicuous key evolutionary innovation of angiosperms is the flower itself, and breakthroughs in floral developmental genetics provided new impetus for studies of floral evolution and development. Among these are novel ideas about how flowers evolved from transformed gymnosperm cones. Complementing developments in flower, analyses of the burgeoning collection of flowering plant genome sequences have suggested a role for whole-genome duplications in the origin and subsequent diversification of flowering plants.

The Early Cretaceous is a time of important developments in angiosperms. The earliest unequivocal remains of angiosperms are generally thought to be pollen grains in the early Hauterivian. The fossil record shows that angiosperms rose to dominance during the Albian–Cenomanian, and become forest dominants during the Campanian–Maastrichtian. The angiosperm radiations provided new food resources and habitats, and had a profound effect on beetles and other insects. The Early Cretaceous is also an important period for the evolution of beetles. The Scarabaeoidea, Tenebrionoidea, Curculionoidea, and Chrysomeloidea are among the commonest pollinators of most extant basal angiosperms. The probable impact of floristic changes on beetles during the Early Cretaceous has been widely accepted. Early Cretaceous fossils have been described and our knowledge of the evolution of beetles has improved greatly. These new fossils, therefore, provide important clues to explore the co-evolutionary process between beetles and angiosperms.

Conclusion

The origin, evolution and phylogeny of the angiosperms continue to be areas of keen interest and serves to be an '**abominable mystery**'. The new and recent phylogenetic analyses no longer support the division of angiosperm into two distinct lineages dicots and monocots. Instead two major monophyletic groups higher dicots (eudicots) and monocots are now recognized. These are known to be embedded in a grade of basal dicots referred to as Magnoliids. Eudicots are distinguished from the magnoliids and monocots by their pollen, which is three aperturate. Most magnoliids and monocots have a single aperturate pollen grains.

In many earlier classification, Magnolia was considered to be a basal taxon with its large, many parted flowers believed to be primitive amongst the angiosperms. However, the fossil record indicates that the ancestral flowers might have been smaller and simpler. This is in congruence with the new phylogenetic analyses that identify a basal grade of magnoliids referred to as ANITA (constituting of Amborellaceae, Nymphaeales, Illiciales, Trimeniaceae, Austrobaileyaceae), which includes several taxa with small simple flowers. The fossil record continues to be a rich source of novel insights and further detailed paleoecological studies of early angiosperm sites will help in solving this abominable mystery of origin and diversification of angiosperms. Early Cretaceous fossils study is crucial to further enhance our understanding of the diversity and relationships of the groups in its earliest phases. Finally, additional phylogenetic analyses of structural and molecular characters is important and should be extended to include putative angiosperm outgroups, particularly within the gnetopsids. This will help in knowing the homologies between angiosperms and their plausible outgroups. The extent of the "abominable mystery" of angiosperm origin is rapidly diminishing and with the ongoing pace of research, it is believed that in next 20 years the issue will be no more mysterious than for any other major plant group.

'Check Your Progress'

1. What are the probable ancestors of angiosperms?
2. What is the sister group to all other flowering plants?
3. Define Euanthial theory.

4.3 TAXONOMIC TOOLS: HERBARIUM AND BOTANICAL GARDENS

Taxonomy is a branch of biology dealing with study of identification nomenclature and classification of all plants, animals and microorganisms of the world.

Plant taxonomy aims at classifying the unknown species based on the previously available taxonomic literature. Taxonomic literature is any botanical work associated with identification, classification and determination and use of correct botanical name of a taxon. A good knowledge of existing literature based on taxonomic aids (World Floras and Manuals, Monographs and Revisions, Bibliographies, Catalogues and Reviews, Periodicals, etc.) is essential to a plant taxonomist.

Taxonomic Process

Taxonomists begin by sorting specimens to separate sets they believe represent species. Once sorted the next step is to check whether or not the species/specimen already have names. This may need the involvement of taxonomic literature (viz. identification guides, reading descriptions written perhaps 200 years ago and comparing it with already named specimens from museums or herbaria). Such comparison may involve external characters, internal structures or anatomical features or even molecular aspects. If there is no matching of the sample with the previously existing description, the specimen may represent a new species not previously given a name. The taxonomist then has to write a description, including ways in which the new species can be distinguished from others, and give a name to it, in a Latin format and in accordance with the rules of ICN (International Code of Nomenclature).

Taxonomic Tools

The tools used in the identification of plants are:

Herbarium, **Botanical Gardens and Museums:** Herbarium is a type of botanical literature helpful in identification and classification of various taxa (Refer Figure 4.5). For the past three centuries, scientists have documented the earth's flora (plants) and fungal diversity through dried reference specimens maintained in collections known as herbaria. It is a collection of dry pressed and preserved specimens of plants affixed to paper, which are arranged systematically for the purpose of reference and identification.

Fig. 4.5 *Herbarium*

The invention of herbarium goes to an Italian – Luca Ghini (1490-1556), a professor of botany who for the first time developed it at Pisa, Italy in 1544. Collection and preservation of specimens was started in early 1532, by one of the students of Luca Ghini. This art of herbarium making was disseminated throughout Europe by Ghini's students who mounted sheets and bound them into book volumes. Herbarium techniques was even a well-known practice at Linnaeus time and he practiced mounting the dried herbarium specimens on thick single sheets of standard size/dimension and stored them horizontally, almost in a manner practiced today (Stearn, 1957). From being a general method and isolated personal collection during the second half of 18th century, herbaria have now grown into large institutions of national and international stature with millions of specimens from different parts of the world. Index Herbariorum (IH), edited by Dr. Patricia Holmgren, lists the world's important herbaria (Holmgren and Barnett, 1990). The first six editions of IH (Index Herbariorum) were published by the International association for plant Taxonomy in the Netherlands (1952-1974). Dr. Patricia, then director of the New York Botanical Garden, served as co-editor of edition 6, and subsequently became the senior editor of Index Herbariorum (IH). The IH entry for a herbarium includes its physical location, URL, contents (for example number and type of specimens), record date, as well as names, contact information and areas of expertise of associated staff. Only those collections that are permanent scientific repositories are included in IH.

As of December 1, 2017 there are 3,001 active herbaria in the world today (Thiers, 2017). Collectively the World's herbaria contain an estimated 387,007,790 specimens that document the earth's vegetation for the past 400 years.

NOTES

IH (Index Herbariorum) is a guide to this crucial resource for biodiversity science identification and conservation. The founding of IH dates back in 1935.

Table 4.1 *The Major Herbaria of the World with Approximate Number of Specimens in the Order of Importance*

	Herbarium	No. of Specimens (approx)
1	Museum National d' Historia naturelle, Paris	10,500,000
2	Royal Botanical Garden, Kew	75,000,000
3	Komarov Botanical Garden, Leningrad	75,000,000
4	Conservatoire et Jardin Botaniques, Geneva	5,000,000
5	New York Botanical Garden, New York	4,300,000
6	Harvard University, Cambridge, USA	4,250,000
7	U. S. National Herbarium, Washington DC	4,110,000
8	British Museum (National History), London	4,000,000
9	Institute de Botanique, Mont Pellier	4,000,000
10	Naturhistoriske Riksmuseet, Stockholm	4,000,000
11	Royal Botanic Garden, Edenburgh	2,350,000
12	Gray Herbarium, Harvard University Cambridge USA	1,485,000
13	Botanical Research Institute of Texas, Texas (1985)	5,00,000
14	University of Minnesote Herbarium, Venezuele (1992)	8,30,000
15	Washington State University-Marion Ownbey Herbarium, Marion (1995)	3,50,000

Roles of Herbarium

Herbarium serves as a safe place for storing pressed specimens especially the type specimen. Herbaria have become major centres of taxonomic research. It is an invaluable conservatory of plant material and data. The herbaria generally aid in all kinds of taxonomic researches. The classification of world flora is primarily based on herbarium material and associated literature. More recently, herbaria have gained importance since it aids in assessment of conservation status of a taxon. The major role played by herbarium includes:

- Acts as a repository of plant specimen: Primary role is to safely store and safeguard dried plant specimens, against loss and destruction by insects and any fungal attack.
- Storehouse of type specimen: Type specimens are the principal proof of existence of a species or an intraspecific taxon. Therefore these are kept in safe custody.
- Compilation of Floras, Manuals and Monographs: Herbarium specimens are the original document upon which identification, distribution of a taxa and description rests. Floras, Manuals and Monographs are largely based on herbarium resources, no matter how old the specimen or resources are.
- Training Facilities: Many herbaria carryout training graduates and undergraduates in herbarium practices and methods.
- Identification and Description: Majority of herbaria have a wide range of collection of specimens and offer facilities for on-site identification and providing relevant information to the researchers. Researchers thus can personally identify their collection by comparison with already identified herbarium specimens kept in herbaria.
- Information on geographical location and distribution of species : Major herbaria have collections from different part of the world thus by going through the herbarium specimens one can easily get the information on geographical location of the taxon or plants of interest.

Function of National herbaria/Major herbaria could be grouped under four headings:

- Their own research programmes.
- Serve as repositories/storehouse of type specimens and other important specimens.
- Providing of specimens for taxonomic and other studies at different institutions.
- Training of graduate students in taxonomic work.

Herbarium Methods

Herbarium methods aims at collection of specimens. But 'what to collect' is of prime importance for a collector. Collection of specimens involves field trips and the collector should seek some advice from the persons working in a local herbarium.

Collection

For collection of plant specimens from the field, the following equipments are required; a plant press, a pruning knife, a small shovel, newspaper, blotting paper coarse, a field note book and a hand lens.

Plant press is the most important equipment for pressing plants. It normally consists of a pair of wooden or metal frame held together with the help of leather straps/belts or strong rope. Standard size of the plant press is 12 inches X 18 inches (30 cm X 45 cm), between which are placed corrugated sheets, blotters and news-paper sheets. The straps/belts are used to higher the belt after keeping the specimen in between corrugated sheets or ventilators are made up of cardboard, and help ventilation and the consequent drying of specimens. The plant press carried in the field is called a field press and then the press is arranged in such a way that every pressing paper or newspaper with specimen alternates with a blotter. Then the leather straps are tightened as much as possible making the parts of specimen flattened onto the pressing sheets. Changing of newspaper or pressing paper is necessary after 24, 48 or 72 hours depending upon season and type of specimen pressed.

Field Note Book: Field notebook or field diary is a small notebook carried to the field with ease. It has numbered sheets with printed proforma for entering field notes or details about the specimen collected. This includes scientific name, family, local name, locality, altitude, date of collection, name of collector and details of the plant/specimen collected. There are multiple detachable strips at the lower end of the field notebook. Sheet bearing serial number that can be used as tags for multiple specimens of a species collected from a site (Refer Figure 4.6).

Department of Botany
Universty of Kashmir
Srinagar - 190006

Date 14-3-1970 **No. 1068**

Name:	Iris ensata
Local Name:	Krishm
Family:	Iridaceae
Locality:	Harwan, Kashmir
Altitude:	1900 m
Habitat:	Open grassland meadow
Collector:	Gurcharan Singh
Determinavit:	Self
Notes:	Perennial herb, forming solated patches, flowers light blue

	No. 1068 ❍	**No. 1068** ❍

Fig. 4.6 *A Sheet From Field Notebook*

Vasculum

Vasculum is a metallic box with a tightly fitted metal lid, usually with a shoulder sling to carry it with ease. Specimens can be temporarily stored in this box for 3-4 hrs before pressing them. It is always good to press the specimens immediately after collection in the field itself but sometimes it becomes necessary to postpone pressing of the plants at a later time. Bulky parts like rootstock, rhizomes, bulb can also be stored in this box. It is generally painted white to deflect heat and for easy detection in the field. Nowadays vasculum is commonly substituted by polythene bags or zipper pouches which are easy to handle being light in weight and thus carried in large number in field.

Mounting

For mounting the specimens special type of papers are used. Mounting papers are usually hard and tough. The mounting sheet is usually 29 cm × 42 cm (11.5" × 16.5"). Specimens are first poisoned and then dried completely before mounting to protect them against insect pests and fungal attack. Now after poisoning, the specimen is mounted in three different ways:

- It may be glued to the paper and some portions like the stem or branches, leaf petioles, flower pedicels are stitched with the help of thread and needle. This is a usual practice employed for mounting of specimen.
- Nowadays use of adhesive linen, paper or cellophane strips are found to be much easier and faster method of mounting the specimens.
- Using liquid adhesive or glue is also seen. The glue is applied to the backside of the specimen to be mounted and pressed on the surface of mounting sheet. The specimen is then slightly pressed so that it gets stick to the mounting sheet. Then the specimen is allowed to dry in pressed condition.

Herbarium Label (Labelling)

Once the mounting has been completed, each herbarium sheet should now have a herbarium label pasted onto it usually at right hand side lower corner. The size of label is 8 cm × 12 cm (2.75" × 4.25") or sometimes even be up to (4" × 6").

A herbarium label is an essential part of a permanent plant specimen. Herbarium label contains all the information recorded in the field notebook at the time of collection of specimen. The necessary information is recorded on the pre-printed proforma on label (Refer Figure 4.7). Labels are pasted on the herbarium sheets. It is always good to type the information on the labels or if handwritten it should be with a permanent ink. The information commonly recorded on a herbarium label is:

- Name of the Institute to which the herbarium is attached.
- Scientific name
- Vernacular name
- Collection number
- Date of collection
- Name of family to which the genus belongs
- Locality of collection
- Notes about the specimen collected

NOTES

Deshbandhu College Herbarium

(University of Delhi)

Name of the Plant ……………………………………………………………………………..

……………………………………………………………………………………………………

Family ……………………………………………………………………………………….…....

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Locality …………………………………………………………………………………………....

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Date of Collection ……………....................

Roll No …………….................................

Determinor …………………………………………….......................................……

……………………………………………………………………………………………………

Notes ………………………………................……………………………………..

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Fig. 4.7 *Specimen of a Label*

A specimen without a label, even it is well pressed and neatly mounted is insignificant and serves no purpose. However, it is sometimes noted that an expert visiting a herbarium may want to correct the identification or record a name change.

Identification is the next step, once the specimen has been mounted. For identification the scientific method is to first study the characters (morphological) of the plant both from the specimen as well as from the description mentioned on the label attached to the mounting sheet and further check then with the flora of that locality or region and compare it with the description and illustration. For a correct identification one must use the identification keys. If the correct identification records a name change then such correction is never done on the original label but it is done on a small annotation label or determination label usually 2 cm X 11 cm in dimensions. The annotation label appended left of the original label. The label in addition to the correction records the name of the person and the date on which the change was recorded.

Voucher herbarium specimens of a research study often have authentic information about the specimens recorded in the form of voucher label (Singh, 2004).

Accession

Mounted, labelled and identified specimens are later stamped with a distinctive mark of the herbarium, usually on the top right hand side corner of mounting sheet. Stamping may be done with rubber stamps or printed label. The stamp carries the name of the institution, a serial number called the accession number and even sometime carries the date of accession (Refer Figure 4.8).

NOTES

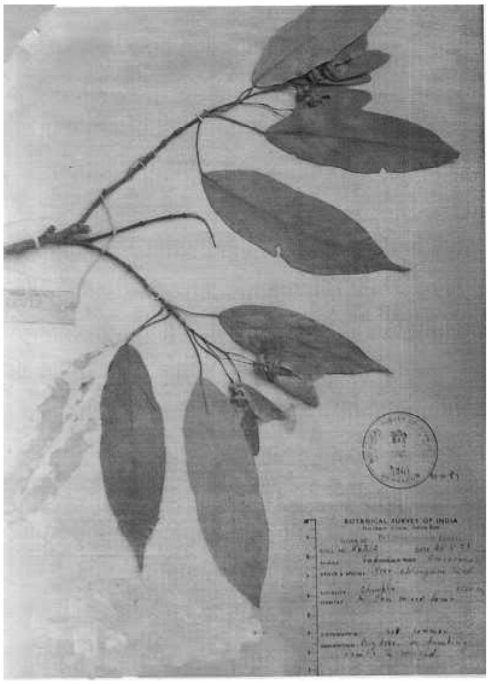

Fig. 4.8 Specimen of Stamped Herbarium Sheet

Filing

The specimens are now ready for filing and are sorted out according to family, genus and species wise. Now all the sheets of one species are placed in covers of lighter color and are called as species cover or folder. All the species of one genus are placed in one or more than one folders of heavy paper of a different color called as genus-cover. Use of such covers help in sorting out species, genus and makes it easy to handle. Name of the species and genus are written on the covers itself. Now these genus covers/folders are placed in pigeonholes of herbarium cases usually a steel almirah which are insect and dust proof (Refer Figure 4.9).

Fig. 4.9 Herbarium Double Specimens Cabinet

Type specimens are usually kept separately in distinct folders or often in separate herbarium cases and sometimes even in separate rooms for safety and quick location of type specimen. A herbarium commonly maintains an index register in which all the specimens/ genus present in the herbarium are listed alphabetically.

Poisoning and Preservation of Filed Specimen

If Herbarium specimens are poisoned before pressing the specimen they are killed immediately and thus abscission layer is not in poisoning solution (Mercuric chloride, Formalin (10%), Lauryl Pentachlorophenate) for about 15-20 seconds depending upon the thickness of the specimen formed and the plant remains intact. Poisoning is generally done by dipping the whole plant /plant species. The specimen is then blot dried so that excess solution is removed and then the specimen is pressed in a drying plant press.

Pest Control

Most of the specimens submitted to the herbarium are sufficiently dry and therefore not attacked by bacteria and fungi. But still some treatment is required to protect the plant specimen against certain pests, such as Silverfish, Dermestid beetles, etc. Pest control measures include:

- **Heating**: Some herbaria uses electric heat treatment in which temperature is raised up to 60°C for 4-8 hr in a heating cabinet. Using specially insulated cases with bottom placed centrally heating element. The system is quiet effective but at the same time it makes the specimen more brittle.
- Deep freezers like nowadays are replacing heating cabinets in most-herbaria. This works at a temperature of -20 to -60°C.
- Microwave ovens were earlier used in many herbaria but Hill (1983) indicated that the use of microwave ovens has some serious shortcomings which includes, sudden vaporization of water leads to stem burst, overheating may result in the killing of embryo inside seed, etc.

Repellents and Fumigation

Chemicals like Naphthalene balls and Para Dichloro Benzene (PDB), with an unpleasant odour are kept in herbarium cases to keep pests away from specimens. Usually the chemicals like PDB and naphthalene are kept in muslin bags and then placed in pigeonholes.

Fumigation is necessary for proper management of the herbarium. Fumigation involves exposing specimens to the vapours of certain volatile substances, such as methyl bromide (CH_3Br), Carbon disulphide (CS_2) or Carbon tetrachloride (CCl_4) is used. Certain fumigant used earlier has been banned by the government because of its toxic nature. One such fumigant is a mixture of ethylene dichloride and carbon tetrachloride in the ratio of 3:1.

Dowfume -75 has been cleared by Environmental Protection Agency to be used as a fumigant in various herbaria. Fumigation should be done at regular time intervals since fumigants do not kill egg or pupae of insect.

Herbarium Ethics

Herbaria consultation for research identification teaching or any other purpose needs to follow certain rules. There should be an instruction manual kept at every herbaria. The manual should be provided to those who wish to consult/use a herbarium. Such a manual/ guideline should introduce the user to systematic and geographic arrangement of the collections. Use of instruction manual with help in understanding any color code (for species or genus cover), location of species (alphabet wise), a list of families with their numbers and the case number in which they are kept, a sketch of the arrangement of cases, location and arrangement of any special collection, such as type specimens and a catalogue of all the genera. All this information helps in proper handling of specimens and save time of both the visitors and the herbarium staff. Therefore, there is an utmost need to take care of the long time preserved specimens as these specimens are invaluable and irreplaceable. So some suggestions are made for proper handling of the specimens:

- Herbarium sheets should be kept flat and not be shuffled up or lifted just like the pages of a book since during the course of preservation the specimens have become dry and brittle and may easily break.
- It is necessary to properly store the specimen so that it can be easily located as mentioned in the catalogue.
- No heavy object like a book, etc., should not be placed on dry mounted specimens.
- Seeds and other parts of a specimen should be properly stored in small zipper pouches or paper bags along with the specimen.
- While viewing the specimen it should be made sure that the specimen should not be touched with hand and should not write anything on the herbarium sheet.
- It is necessary to dissect flowers and fruits from the specimens since the fruit being heavier in weight may separate out from the specimen over years also, it is always good to store flowers and fruits separately along with the specimen.
- It is always good to use a stiff board while transferring the specimen even to a short distance.

Botanical Gardens

Botanical gardens maintain large collections of living plants meant for research, conservation, display and education. Gardens and the cultivation of plants dates back to around 3000 years ago in ancient Egypt and Mesopotamia. The Romans were also keen gardeners and they were also aware of the medicinal properties of plants. But these gardens were not botanical gardens in the true sense. These existed for growing food and important crop plants, herbs and ornamentals for aesthetic, religious and beauty purpose (Refer Figure 4.10). The famous 'hanging gardens' of Babylon in Mesopotamia is a typical example.

Fig. 4.10 *Botanical Garden*

During the 16th and 17th centuries, physic gardens of Italy affiliated to the medical faculties of many universities were established where medicinal herbs were grown. The first of these modern botanical garden was the garden of the University of Pisa created by Luca Ghini in 1543, following this other Italian universities followed the pattern and gardens were created at Padua (1545), Florence (1545) and Bologna (1547). Many other important gardens came up at all over Europe during these early years for example, Leyden (Netherlands) 1587, Montpellier (France) 1593, Heidelberg, Germany (1593) and so many others.

Role of Botanical Garden

Botanical gardens are repository of living plants with some scientific arrangement. The plants growing in the botanical garden are usually well labelled is the scientific name and the family to which they belong for easy identification to the visitors (researchers, trainee, students). Botanical gardens have proven instrumental in motivating well known authors to develop their own system of classification. Botanical gardens have set up controlled enclosures in the form of screen house and glass house to support the growth of specific plants. Botanical garden acts as a safe house for growing rare and endangered plant species. It also serves as centres of horticultural research. Apart from this the other important roles of botanical garden are:

- Botanical gardens aim at providing information on medicinal plants, exotic plants, and ornamental plants.
- Botanical garden acts as an aesthetic appeal and attracts a large number of visitors to observe the existing diversity of plants. For example: *Ficus benghalensis*, the great banyan tree in the Indian Botanical Garden at Calcutta.
- Botanical gardens generally have a wide variety of species growing together and offer ready material for research and other integrated projects. Also botanical gardens serve a good purpose for onsite teaching and can be used for demonstration of various plants according to families, genera or habitats.
- Many botanical gardens in association with various academic institutes helps in teaching subjects like plant taxonomy, systematic, horticultural methods, plant propagation, etc. The **Glasgow Botanical garden**, **Scotland** (Refer Figure 4.11) was a physic garden meant for teaching medicine associated with the university throughout 18th century.
- Botanical gardens are considered as the most convention method of ex-situ conservation (Hamilton, 1994). Botanical gardens play an imp role in conserving the genetic diversity and also inhabit many rare and endangered plant species. The increasing role of botanical gardens in conservation has been emphasized by the botanical garden conservation congress held in November 1985.
- Botanical garden across the world operate an informal seed exchange programme and annual sale of plant materials like seedlings, seeds, bulbs, corms, etc. are often arranged as part of public service by many botanical gardens.
- Several major botanical gardens of world have herbaria and libraries as an integral part of the facilities provided by botanical garden and offer material for research and other purposes.
- Botanical gardens provide general information about the identification of plant species to common people.

Fig. 4.11 *Glasgow Botanical garden, Scotland*

Major Botanical Gardens of the World

Royal Botanical Garden, Kew, London

Commonly known as 'Kew Gardens'. The garden was developed by Kew house owned by Richard Bennet in the 1600's. Kew's garden covers an area of 120 ha. It is one of the world's most important botanic garden with an illustrious history of research and exploration in the world of plants. The conservatories of Kew, the living collection from the tropics, deserts, mountains and oceans belonging to 351 families, 5465 genera and over 28,000 species (Singh, 2004). Kew herbarium is the largest in the world with more than 7 million preserved plant specimens. The library at Kew holds more than 750,000 books and journals for easy consultation and reference.

Kew also maintains databases on plant names, taxonomic literature and economic importance on plants of special interest. Kew is also involved in making 10,000 identifications every year through its Herbarium services and also provides specialist advice on taxonomy.

New York Botanical Garden, New York, USA

It is one of the two largest and one of the most active botanical garden of United States of America. This is known to conduct national and international programs of research, education, horticulture, plant conservation, ecology and other training programmes. The New York Botanical Garden came into existence in 1891, when the Torrey Botanical Club adopted its foundation along with Department of Botany, Columbia University. This garden is the only place in the New York city, where original forested areas remain uncut. Dr. Britton, the most productive taxonomist of his time, landscaped the garden and added living plants and also helped in the advancement of botanical knowledge through carrying out research and educational programs at his garden. He remained the director of this garden until 1929. New York Botanical Garden has one of the largest botanical garden museums in the world, the largest herbarium and the best botanical library in the United States of America and also the largest green house. The garden houses a systematic arrangement of trees and shrubs, making it a place of interest for general public. The garden also plays major role in conservation of endangered and rare species. The garden has two important areas: Enid-A-Haupt conservatory and Thompson Rock Garden. The herbarium collection covers the entire plant kingdom including phanerogams, fungi collection, bryophytes and ferns are well represented in this botanical garden herbarium. The herbarium houses over 5 million specimens from all over the world majority of which belongs to New World.

Munich Botanical Garden, Munich, Germany

A multipurpose garden, where apart from research, teaching and information, it also serves as a place of relaxation and recreation for general public. In this garden the usual systematic arrangement of plants was changed in favour of plant geographical and ecological arrangements. The attraction of this garden includes an 'Ornamental Garden' where with the changing seasons, the colour of the bloom changes. For practical studies, the garden hosts the material including Cacti, Succulents, Aroids, Orchids and Bromeliads, Rhododendrons, Ferns, Palm house, etc. School children of primary and secondary classes use this garden. The scientific work is mainly in the field of systematic botany although some work in the field of morphology, physiology and genetics is also carried out at this garden. Research have been carried on Crassulaceae, some aroids and Primulaceae and also some other groups.

Missouri Botanical Garden, St. Louis, USA.

It is considered as one of the top three botanical gardens in the world. Popularly known as Shaw's garden after Henry Shaw who set up this garden and opened to public in 1859 with help from Asa Gray, Sir William Hooker and Enelmann. Missouri Botanical Garden is a historical landmark, and a centre for botanical research, education and horticultural display. The garden houses North America flora, Floral display houses, xerophytes house, Rose garden, experimental green house and large lily with Victoria and other water lilies. The garden is famous for collections of Chrysanthemums, orchids, and succulents. A large and big library along with herbarium containing over 2 million specimens is asset to the garden. It is an important centre for carrying out taxonomic studies. The garden is known for its Climatron conservatory (geodesic greenhouse dome with climatic control) supporting a tropical rainforest under '0.5' acre of roof area. Missouri botanical garden is also one of the world's leading research centres, with around 25 major flora projects.

The information is shared in a website TROPICOS is the world's largest database, containing more than 920,000 scientific plant names and over 1,800,000 specimen records (Singh, 2004). The Herbarium of Missouri Botanical Garden ranks second in the USA and 6th in the world.

The Herbarium have collections dating back to mid 1700's and includes specimens of major taxonomists including Charles Darwin, Joseph Banks and many other. The major research activities of this botanical garden includes **Flora of North America** project, in 5 volumes already published covering plants of USA, Canada and Greenland.

Pisa Botanical Garden, Italy

The first modern botanical garden was developed by Luca Ghini in Pisa, Italy (1544). The garden was known for the finest specimen of some species including *Magnolia grandiflora* and *Aesculus hippocastanum*. The garden does not exist by the same name today and is known by the name of '**Orto Botanico di Pisa'**. The Botanical Garden of Pisa is part of the legacy left behind by Cosimo Ide' Medici. This served as the first university botanical garden in Europe, built to serve as an 'office' to legendary botanist Luca Ghini. For centuries the garden has been collecting illustrations, artwork, seeds, rare and endangered specimens. The garden has plantations of ancient *Ginkgo biloba* trees planted in 1787.

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Aims and objectives of Botanical Garden

- Botanical garden is considered as living repository of plants with some scientific arrangement. The plants are usually labelled in the botanical gardens for easy recognition and identification. Sixteenth century botanical gardens were renowned for the novel species they grew procured through exchange from distant lands. The evolution of botanical gardens came up with the study of systematic botany. Plants in botanical gardens were arranged on the basis of their diagnostic features placing plants of particular group together. Botanical gardens served as centres for the study of economically important plants. It also houses economically important plants from various part of the world. Also comparative study of the plants grown in the botanical gardens is carried out as a result of advancement in modern taxonomy.
- Also as centres for horticultural research. This includes trials, selection, hybridization and cultivation of new varieties useful to mankind.
- Botanical gardens of present era are considered to be the centres for conservation of rare and threatened plants and thus saving them from extinction.

In brief, aim of botanical gardens is to serve as a living repository of plants, a house for growing rare and endangered plants, should act as centre for research, education, training in botany and horticulture, it should act as centres for introduction of economic and commercially exploitable species, these should be a proper place to grow species of different climatic origin in conservatories, phytotrons, greenhouses or glass house, and also takes into account propagation of rare, endemic and endangered species, serves as data bank for information and documentation of plants growing in different botanical gardens of the country, and last but an important one is to generate awareness about the value of plants and to interest people into growing beautiful and exotic plant species and exchange such with other institutes.

'Check Your Progress'

4. What is taxonomy?
5. What does plant taxonomy aims on?
6. What is taxonomic literature?
7. What is herbarium?

4.4 SALIENT FEATURES OF THE INTERNATIONAL CODE OF NOMENCLATURE (ICN) FOR ALGAE, FUNGI AND PLANTS

Formerly called as International Code of Botanical Nomenclature (ICBN). The name was changed at the International Botanical congress in Melbourne in July 2011 as part of the Melbourne code (Ref: Mc Neill *et al*. (2012) which replaced the Vienna code of 2005. The current version of the code is the Shenzhen code adopted by International Botanical Congress held in Shenzhen, China, in July 2017.It took effect as soon as it was approved by the congress (on 29 July 2017). The ICN can only be changed by International Botanical Congress

(IBC) with the International Association for Plant Taxonomy (IAPT) providing the supporting infrastructure.

The code ICN written and documented through the efforts of IAPT (International Association for Plant Taxonomy) helps in deciding the single correct name acceptable to the whole botanical community. ICN is the set of rules and recommendations dealing with the formal botanical names that are given to plants. Its intent is to have one correct name for each taxonomic group ('taxon' plural 'taxa'). The guiding principal in Botanical Nomenclature is priority. The ICN sets the formal starting date of plant Nomenclature as 1 May 1753, in publication of *Species Plantarum* by Carolus Linnaeus. The ICN applies not only to plants as they are now defined but also to other organisms (Algae, Fungi, Slime moulds, photosynthetic protists and taxonomically related non-photosynthetic groups) traditionally studied by botanists.

For the naming of cultivated plants there is a separate code. The International Code of Nomenclature for Cultivated Plants (ICNCP).

Principles of Botanical Nomenclature

The principles are the set of rules for legitimate naming of taxon which are as follows:

- Botanical nomenclature is independent of zoological nomenclature. The code is also applied equally to the names of taxonomic groups treated as plant whether or not these groups were originally so treated.
- The application of names of taxonomic groups is determined by means of nomenclatural types. According to this principle, the name of the each species is permanently associated with a particular type specimen, the nomenclature type.

  The names of different taxonomic groups are based on type method. In this method certain representative of the group serves as the source of name for that particular group. This representative is called as nomenclature types and the methodology as **typification**. The type need to be the most typical member of the group representing the group. The type for a family and the higher groups is a genus. For example, *Mimosa* serves as a type for Mimosaceae family. A type for a particular genus is a species.

  The following types are recognized:

  - **Holotype**: It is a particular specimen or illustration designated by the author in the original publication to serve a nomenclatural type of a species. It is essential to designate a holotype while publishing a new species and submit the same in a national herbarium.
  - **Isotype:** It is a duplicate of holotype, collected at the same time, from the same place and by the same person when the holotype was originally collected.
  - **Syntype**: Any one of the two or more specimens cited by the author when no holotype was designated by the author.
  - **Paratype**: A paratype is a specimen cited with the original description in addition to the holotype. It is neither a holotype, nor an isotype, nor one of the syntype if two or more specimens are simultaneously designated as types.
  - **Lectotype**: A lectotype is a specimen selected from the originally collected material cited by the author with original description when no holotype was originally designated or when the holotype no longer exists. A lecotype is then selected from either isotype or syntype depending upon the existence of both the types.

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- o **Neotype**: A specimen or an illustration selected when no holotype, isotype, paratype or syntype exists. A neotype is a specimen selected from the material that was not cited by the author with original description.

- The nomenclature of a taxonomic group is based upon priority of publication. According to this principle, each taxon should have only one correct name and that should be the earliest published name that is in accordance with the rules of ICN.
- The principle of priority does not apply to names of taxa above the rank of family.
- Each taxonomic group with a particular circumscription position and rank can have only one correct name that is validly and effectively published name and is in accordance with the rules.

All the names published in printed form in scientific journal and are available in botanical institutions viz. herbarium and libraries, which are accessible to botanists are effectively published names. For a valid publication a botanical name must be effectively published and must be accompanied with a description or a reference to previously published description of that taxon.

- Scientific names of taxonomic groups are treated as '*Latin*' regardless of their derivation.
- The rules of nomenclature are retroactive unless expressed limited. The principle states that anyone proposing a charge in the code needs to consider the effect that the proposed change will have on names published in a wide range of literature and over a considerable period of time. This is why all proposed changes undergo committee scrutiny before being voted on.

All proposals to change The Code are published in Taxon, but they remain proposals only until they are voted on at the next International Botanical Congress.

Other Key Provisions of the Code

- Any changes in The Code should be designed as such to increase the stability in relation to plant nomenclature.
- Every plant belongs to a species, every species to a genus, every genus to a family, every family to an order, every order to a class, every class to a division.

  This is termed as **taxonomic hierarchy**

Rank	Ending	Example
Division (phyhm)	phyta	Magnoliophyta
Class	opsida	Magnoliopsida
Order	ales	Magnoliales
Family	aceae	Magnoliaceae
Tribe	eae	Magnolieae
Genus	A noun	*Magnolia*
Species	Depends	*Magnolia grandiflora*
Variety	Depends	

Family name must be formed by combining a generic name with the suffix (at the end) - aceae but there are eight exceptions to this rule. The eight names are:

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		Alternative name	Type Genus
Gramineae	(Grass family)	Poaceae	*Poa*
Palmae	(Palm family)	Arecaceae	*Areca*
Cruciferae	(Mustard family)	Brassicaceae	*Brassica*
Leguminosae	(Pea family)	Fabaceae	*Faba*
Gultiferae	(St John's Wort family)	Clusiaceae	*Clusia*
Umbellifera	(Carrot family)	Apiaceae	*Apium*
Labiatae	(Mint family)	Lamiaceae	*Lamium*
Compositae	(Daisy family)	Asteraceae	*Aster*

Each of the eight exceptional family names are accepted universally.

The name of a species is always a binomial. Earlier the names of plants appeared as polynomials - long descriptive phases, often difficult to recall. Caspar Bauhin (1623) introduced the concept of Binomial Nomenclature under which the name of a species consists of two parts the first part, the name of the genus to which it belongs and the second being the specific epithet. Thus for a maple species (*Acer oblongum*), Acer is the generic name and oblongum is the specific epithet. Bauhin, however, did not use the concept of binomial nomenclature for most of the species and then Carolus Linnaeus firmly established the system of Binomial nomenclature in his publication *Species Plantarum* (1753). Priority of nomenclature for vascular plants is applicable from May 1st, 1753, which is the publication date of Linnaeus Species Plantarum.

***Table 4.2** Four Different Sets of Name-Endings used in Latin*

Masculine	Feminine	Neuter
1. –us (sativus)	-a (sativa)	-um (sativum)
2. –er (niger)	-ra (nigra)	-rum (nigrum)
3. –er (sylvester)	- ris (sylvestris)	- re (sylvestre)
4. –is (occidentalis)	-is (occidentalis)	-e (occidentale)

(*From: Bharati Bhattacharya, 2005*)

Scientific names (Botanical names) are treated as Later because Latin is specific, i.e., gives precise meaning and is a dead language and thus do not creates any controversy. Also, Latin is written is the Roman alphabet and thus avoids any confusion that would have been created by the usage of any other language of different scripts, such as Chinese, Greek or Sanskrit.

Importance and Need for Scientific Names

Scientific names treated in Latin are preferred over vernacular or common names since common name are not universal and thus pose lots of problems.

- Common names are known for relatively fewer species.
- Common names are applied indiscriminately to genera, species or varieties and therefore difficult to make out whether talking of genus or species.
- Common names usually do not provide any information regarding its family or indicate any relationship with the other genus and name of the author who gave the name.

- Common name or vernacular names are restricted in their usage and are applicable in a single language or sometime in more than one language.
- Sometimes because of the same common name applied to two different unrelated species results in confusion therefore scientific name are well preferred over common name to avoid any confusion.

Author Citation

For a botanical/scientific name of a plant to be complete, accurate and readily verifiable, the name of the plant should be accompanied by author's name (the name of the person who first identified and gave the description of that particular taxon and suggested the name based on the description and published it). In botany, it is important to abbreviate author names according to a recognized list of standard abbreviations.

Commonly abbreviated names of authors are-

Linn.Or L.	for Carolus Linnaeus
Benth.	For G. Bentham
Hook.	For William Hooker
Hook. F.	For Sir J.D. Hooker (F. stand for filius the son)
R. Br.	For Robert Brown
Lamk.	For J.P. Lamarck
DC.	For A.P. de Candolle
A. DC.	For Alphonse de Candolle.

When there is a single author proposing a name for example: *Solanum nigrum* L. (i.e., the first time the binomial of solanum was validly published by Carolus Linnaeus).

When two or more authors are involved in proposing a name of a taxon jointly then their names are linked by 'et.', for example *Rubus ursinus* Cham. *et.* , Schldl. The abbreviations Cham. (Adelbert von Chamisso) and Schldl. (Diederich Franz Leonhard von Schlechtendal) are the two author who jointly published the species *Rubus ursinus* in 1827.

Rules and recommendations for author citation in botany are covered by articles 46-50 of the International Code of Nomenclature (ICN).

- **Use of Parentheses**: In many cases the author citation will consist of two parts, the first author being kept in parentheses, for example: In case *Cynodon dactylon* (Linn.) Pers., where the epithet was originally published in another genus, i.e., *Panicum dactylon* Linn. by the first author Carolus Linnaeus. The rules of botanical nomenclature states that whenever the name of a taxon is changed by the transfer from one genus to another, or by upgrading or downgrading the level of taxon, the original epithet should be retained and the name of the taxon providing the epithet is called as **basionym**. So in the above example of *Cynodon dactylon*, the original epithet is retained based on the basionym *Panicum dactylon* given by Linnaeus and hence the name of the original author whose epithet is being used in the changed name is placed within parentheses and the author who made the changes in the previous name outside the parentheses. Thus, (Linn) Linnaeus is kept inside parentheses and (Pers.) Persoon outside parentheses.

- **Use of ex**: When a name is proposed by one author but it was validly published by second author at a later date, the first author failing to satisfy all the needs of the code, then the names of two author are linked by 'ex'. for example, *Acer oblongum* Wall. ex DC. The name of the common Himalayan maple was proposed by Nathaniel Wolff Wallich but it was validly published by A.P. de Candolle in 1824.
- **Use of in**: When a proposed name, described and diagnosed by one author is published in the work of another author publication, the two authors name are linked by 'in'. For example, *Carex kashmirensis* Clarke in Hook. F.
- **Use of emend**: The name of two authors are linked using emend of the second author made some changes in the diagnosis of a taxon, and the original authorship description is not altered, but a taxonomic statement is added to the original authorship using the abbreviation emend. For example, Phyllanthus L. emend. Mull.

Basic Terminologies related to Nomenclature

Synonyms: Synonyms are different names for the same plant. Often rejected due to wrong application or difference in taxonomic judgement. Synonyms are illegitimate names.

Example: *Malosma laurina* (Nutt.) Abrams

Synonym: [*Rhus laurina* Nutt.]

Two types of synonym: (1) Homotypic (nomenclatural type) based on the same type specimen.

Example, *Cryptantha decipiens* (M. E. Jones) A. Helter

synonymn (*Krynitzkia decipiens* M. E Jones)

Heterotypic (taxonomic type) based on the type different from the type specimen.

Example, *Aesculus* L. (1753)

synonymn [*Pavia* Mill. (1754)] Synonyms are kept in brackets (parentheses).

In homotypic types of synonyms the same plant specimen can be renamed or say correctly named after looking at the type specimen in the herbarium. However, in heterotypic type of synonyms the plant specimens are named based on different type specimen. In the above example *Aesculus* was named by Carolus Linnaeus in 1753 but looking at some different specimen Philips Miller named it as Pavia in 1754.

Homonym: As a taxon should have only one correct name, the code does not allow the same name to be used for two different species (or taxa). These are termed as homonyms. The one which was published at an earlier date amongst two, should be retained and is legitimate is called earlier homonym and the one at a later date is called as later homonym and is rejected. The code rejects later homonyms even if the earlier one is illegitimate.

For example, *Prunus communis* (Linn.) Archangeli (1882) is a later homonym of *Prunus communis* Huds. (1762), which is a species of plum. *Prunus communis* (Linn.) Archangeli (1882) species of almond was later replaced by *Prunus dulcis* (Mill.) Webb.

Tautonym: The botanical nomenclature does not allow the generic name and specific epithet to be similar. These are illegitimate names and are called as Tautonyms and often rejected. However tautonyms are accepted in Zoological Nomenclature.

For example, *Malus malus* is rejected. The words in the tautonym are exactly similar and thus replaced according to the code, *Sassafras sassafras* a tautonym and thus rejected.

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Autonym: It is an automatically created tautonym for infrageneric or infraspecific taxa. It is legitimate. In case of autonym, however the infraspecific epithet does not bear the author's name since it is based on the same type as the species.

For example, *Sesbania sesban* var. sesban.

Acacia nilotica ssp. Nilotica.

(var. refers to variety, ssp. refers to subspecies)

Nomen nudum: It is a name without description and thus rejected. These names of plants are later validated by some author at a later date providing the description. If by then, the name has already been used by some other author for a different species, the nomen nudum even if validated is rejected. For example, *Sassafras triloba* Raf. (1840) was a nom. nud. for *Laurus sassafras* L. (1753) and therefore rejected.

'Important Abbreviations' used in Botanical Nomenclature

comb. nov. (combination nova) means a new nomenclature combination

Emend. (emendation) means correction or amendment.

et is Latin for 'and'

ex is Latin for 'from' meaning validly published by

gen. nov. (genus novum) means a new genus

'In' is latin for 'in' meaning in the publication of

nom. cons. (nomen conservandum) means a conserved name

nom. nud. (nomen nudum) means published without a description or diagnosis making the name invalid.

sp. nov. (species nova) means a new species.

typ. cons. (typus conservanda) means a conserved type specimen.

Criteria for valid publication

- Name must be effectively published (in printed form available to botanists)
- Name must be published in correct form. Properly Latinized, with correct rank endings.
- Should be followed by the name of the author who gave the description and identification of the taxon.
- Rank must be indicated (for example 'sp. nov.', 'subsp. nov.' or 'var. nov.')
- Nomenclatural type must be indicated for genus and below.

Effective Publication

When a publication comes in printed format (form), through exchange with general public or with botanical institutions with libraries accessible to botanists especially plant taxonomists. It is not an effective publication by means of communication only. The publication in newspapers and catalogues (1 January 1953 onwards) is not an effective publication. Publication of hand written material reproduced by some mechanical or graphic process before 1 January 1953 serves as effective publication. The handwritten description of a new taxon is treated as unpublished.

Principle of Priority and its Limitations

Priority is a fundamental principle of botanical nomenclature. Essentially it is the principle recognizing the first valid application of a name to a plant species or taxonomic group. (In short principle of priority is selection of a single first valid correct name). The first properly published scientific name of a genus or species takes precedence over any subsequently published name. If more than one legitimate names are available for a taxon, the correct name, is the earliest legitimate name in the same rank. For taxa at species level and below the correct name is either the earliest legitimate name or a combination based on the earliest legitimate basionym.

There are certain limitations to the principle of priority which are as follows:

- 1, May 1753 (1-5-1753) is the starting date of principle of priority. The principle of priority starts with the publication date of 'Species Plantarum' of Linnaeus. The starting date of different groups is not same and hence publications before these dates for different groups are ignored while deciding the priority.
- While choosing a correct name for a taxon, names or epithets available at that rank can only be considered and not outside the rank. It can be done only when a correct name at that rank is not available.
- In order to avoid name changes of well-known families or genera – especially those containing many species a list of conserved species, generic and family names has been published in code in Appendix II and III that are conserved (*nomina conservanda*). Such *nomina conservanda* are to be used as correct names replacing the earlier legitimate names, which are rejected and constitute *nomina rejicienda*. The family name 'Theaceae' is a conserved name and constitutes *nomina conservanda*.

Triticum aestivum Linn. was the first species name conserved at Berlin congress in 1987 and got published in subsequent code in 1988.

Given below are examples of few of the species name which constitutes *nomina conservanda*. Each name followed by the (=) sign indicating taxonomic synonyms and (==) sign indicating nomenclatural synonym, then followed by name of binomial against which it has been conserved.

- *Lycopersicon esculentum* Mill (1768) (==)
- *Lycopersicon lycopersicum* (L.)Karsten, 1882 (nomenclatural synonym)
- *Triticum aestivum* L. (1753) (=) *Triticum hybernum* L. (1753) (taxonomic synonym).

'Check Your Progress'

8. What is a Taxon?
9. Why the names (botanical names) are changed?
10. What are legitimate and illegitimate names?
11. Why common names are not used in botanical nomenclature?

4.5 SUMMARY

- The origin of angiospermic flower during the late Jurassic to early Cretaceous period (between 132 to 112 mya) (Bhattacharyya, 2005) was a key evolutionary innovation.
- The origin and early evolution of angiosperms are enigmas that have intrigued botanists past over a century.
- The origin and evolution of angiospermic flower constituted an 'abominable mystery' to Charles Darwin. Darwin's abominable mystery has little if anything to do with the

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fossil prehistory of angiosperms, identification of the closest relatives of flowering plants, characteristics features of flowering plants or the phylogeny of flowering plants.

- The flowering plants or Angiosperms are the most diverse group of land plants, with ca. 406 families having 14,064 known genera and approximately 3,69,000 known species (The Plant List, 2010).
- The ancestors of flowering plants diverged from the gymnosperms in the Triassic period, 242 to 202 mya (Million Years Ago) and the first flowering plants are known from 160 mya.
- Angiosperms diversified extensively during the 'Early Cretaceous' became widespread by 120 mya and replaced conifers as the dominant trees from 100 to 60 mya.
- The first angiosperms must have evolved from one of the gymnosperms species that dominated the world at that time.
- The number and diversity of angiosperms fossil increased and by the end of Early Cretaceous period major groups of angiosperms, including herbaceous Magnoliidae, Magnoliales, Laurales, Winteroids and Liliopsida were well represented (Singh, 2004).
- Phylogenetic studies carried out recently shows Gnetopsids to be the closest living relatives of the angiosperms whereas the closest extinct group is Bennettitaleans.
- Amborella remains the sister group to all other flowering plants, but the *Hydatellaceae* join the *Nymphaeales* (water-lilies) as the next diverging subsidiary branch of the tree.
- In the last few years Sun *et al*., 1998, 2002, have described fossils of *Archaefructus* from Upper Jurassic (~124 mya) of China, with well-defined spirally arranged conduplicate carpels enclosing ovules, a feature not reported in earlier angiosperms.
- Euanthial theory or Anthostrobilus theory: Proposed by Arber and Parkin (1907). According to this theory angiosperms originated from various gymnospermous stocks termed as Hemiangiosperms.
- The angiosperm flower is interpreted as being derived from an unbranched bisexual strobilus bearing spirally arranged pollen and ovule bearing organs.
- Cycadales has possible links with angiosperms as suggested by Sporne (1971), on the basis of ovule-bearing structure.
- Pseudanthial Theory was first proposed by Wettstein (1907). The theory is commonly associated with Englerian school of thought about the most primitive living angiosperms according to this view, the taxon Amentiferae including families with highly reduced unisexual flowers borne in catkins, are the most primitive angiosperms and also regarded the showy insect pollinated bisexual flowers of Magnolia as 'pseudanthia' derived by aggregation of unisexual units, the carpel thus representing a modified branch,
- Early history of flowering plant based on living groups is poorly documented. Current phylogenetic models incorporate sparse data from fossils record from early Devonian (405 myr).
- Discovery of fossils similar to angiosperms, or their sister groups (Bennettitaleans and Gnetaleans) can help in understanding of homologies among these groups.
- By the end of the cretaceous period many extant angiosperm families have appeared (Muller, 1981; Taylor, 1990).
- The diversification of angiosperms even followed a geographical pattern, with the earliest occurrences in equatorial regions and later dispersed towards the pole.

- Angiosperms wide distribution during Early Cretaceous was quiet dominant, but during Late Cretaceous they are to some extent overshadowed by the fossils of gymnosperms and ferns.
- The origin, evolution and phylogeny of the angiosperms continue to be areas of keen interest and serves to be an 'abominable mystery'. The new and recent phylogenetic analyses no longer support the division of angiosperm into two distinct lineages dicots and monocots.
- Taxonomy is a branch of biology dealing with study of identification nomenclature and classification of all plants, animals and microorganisms of the world.
- Plant taxonomy aims at classifying the unknown species based on the previously available taxonomic literature. Taxonomic literature is any botanical work associated with identification, classification and determination and use of correct botanical name of a taxon.
- A good knowledge of existing literature based on taxonomic aids (World Floras and Manuals, Monographs and Revisions, Bibliographies, Catalogues and Reviews, Periodicals, etc.) is essential to a plant taxonomist.
- Taxonomists begin by sorting specimens to separate sets they believe represent species. Once sorted the next step is to check whether or not the species/specimen already have names.
- Herbarium is a type of botanical literature helpful in identification and classification of various taxa. For the past three centuries, scientists have documented the earth's flora (plants) and fungal diversity through dried reference specimens maintained in collections known as herbaria
- Herbarium methods aims at collection of specimens. But 'what to collect' is of prime importance for a collector. Collection of specimens involves field trips and the collector should seek some advice from the persons working in a local herbarium.
- Field notebook or field diary is a small notebook carried to the field with ease.
- Vasculum is a metallic box with a tightly fitted metal lid, usually with a shoulder sling to carry it with ease.
- Specimens can be temporarily stored in this box for 3-4 hrs before pressing them.
- Type specimens are usually kept separately in distinct folders or often in separate herbarium cases and sometimes even in separate rooms for safety and quick location of type specimen.
- Botanical gardens maintain large collections of living plants meant for research, conservation, display and education. Gardens and the cultivation of plants dates back to around 3000 years ago in ancient Egypt and Mesopotamia.
- Botanical gardens are repository of living plants with some scientific arrangement. The plants growing in the botanical garden are usually well labelled is the scientific name and the family to which they belong for easy identification to the visitors (researchers, trainee, students).
- Formerly called as international code of Botanical Nomenclature (ICBN). The name was changed at the International Botanical congress in Melbourne in July 2011 as part of the Melbourne code (Ref: Mc Neill *et al*. (2012) which replaced the Vienna code of 2005.

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- The current version of the code is the Shenzhen code adopted by International Botanical Congress held in Shenzhen, China, in July 2017.It took effect as soon as it was approved by the congress (on 29 July 2017).
- The ICN can only be changed by International Botanical Congress (IBC) with the International Association for Plant Taxonomy (IAPT) providing the supporting infrastructure.
- Botanical nomenclature is independent of zoological nomenclature. The code is also applied equally to the names of taxonomic groups treated as plant whether or not these groups were originally so treated.
- The application of names of taxonomic groups is determined by means of nomenclatural types.
- Holotype is a particular specimen or illustration designated by the author in the original publication to serve a nomenclatural type of a species. It is essential to designate a holotype while publishing a new species and submit the same in a national herbarium.
- Isotype is a duplicate of holotype, collected at the same time, from the same place and by the same person when the holotype was originally collected.
- Syntype is any one of the two or more specimens cited by the author when no holotype was designated by the author.
- A paratype is a specimen cited with the original description in addition to the holotype
- A lectotype is a specimen selected from the originally collected material cited by the author with original description when no holotype was originally designated or when the holotype no longer exists. A lecotype is then selected from either isotype or syntype depending upon the existence of both the types.
- A specimen or an illustration selected when no holotype, isotype, paratype or syntype exists. A neotype is a specimen selected from the material that was not cited by the author with original description.
- The nomenclature of a taxonomic group is based upon priority of publication. According to this principle, each taxon should have only one correct name and that should be the earliest published name that is in accordance with the rules of ICN.
- The principle of priority does not apply to names of taxa above the rank of family.
- Any changes in The Code should be designed as such to increase the stability in relation to plant nomenclature.
- Every plant belongs to a species, every species to a genus, every genus to a family, every family to an order, every order to a class, every class to a division.
- When a proposed name, described and diagnosed by one author is published in the work of another author publication, the two authors name are linked by ‘in’. For example, Carex kashmirensis Clarke in Hook. F.

4.6 KEY TERMS

- **Clade:** A group of organisms believed to comprise all the evolutionary descendants of a common ancestor. (Clades are termed monophyletic groups).
- **Anthophyte:** The anthophytes were thought to be a clade comprising plants bearing flower like structures. The group contained the angiosperms- the extant flowering plants, as well as Gnetales and extinct Bennettitales.

- **Putative angiosperm:** Supposed or generally considered to be an angiosperm.
- **Homologies:** Various taxa of different ranks are constructed on the basis of overall resemblances, which may be due to homology or analogy. (Same organ in different taxa with a variety of form and functions)
- **Synapomorphies:** Monophyletic groups recognized by shared derived characters.
- **Phytotrons:** It is an enclosed research greenhouse used to study interactions between plant and environment.
- **Endemic:** Found only in particular habitat or place and nowhere else.
- **ICN:** International code of nomenclature for algae fungi and plants.
- **Taxon:** Taxon refers to taxonomic group belonging to any rank.
- **Authorship:** The name of the person who first validly published the name.
- **Rank:** Hierarchial classification in which a higher rank is inclusive of all lower ranks.

4.7 ANSWERS TO 'CHECK YOUR PROGRESS'

1. Phylogenetic studies carried out recently shows Gnetopsids to be the closest living relatives of the angiosperms whereas the closest extinct group is Bennettitaleans.
2. Amborella remains the sister group to all other flowering plants, but the *Hydatellaceae* join the *Nymphaeales* (water-lilies) as the next diverging subsidiary branch of the tree.
3. Euanthial theory or Anthostrobilus theory: Proposed by Arber and Parkin (1907). According to this theory angiosperms originated from various gymnospermous stocks termed as Hemiangiosperms. The angiosperm flower is interpreted as being derived from an unbranched bisexual strobilus bearing spirally arranged pollen and ovule bearing organs. Carpel here is regarded as a modified megasporophyll.
4. Taxonomy is a branch of biology dealing with study of identification nomenclature and classification of all plants, animals and microorganisms of the world.
5. Plant taxonomy aims at classifying the unknown species based on the previously available taxonomic literature.
6. Taxonomic literature is any botanical work associated with identification, classification and determination and use of correct botanical name of a taxon.
7. Herbarium is a type of botanical literature helpful in identification and classification of various taxa.
8. Taxon (Plural- Taxa) refers to a taxonomic group belonging to any rank. Every plant is treated as belonging to a number of taxa.
9. The botanical names are changed due to the following reasons:
    - The names which are contrary to the rules of ICN (International code of nomenclature) for algae, fungi and plants or which are illegitmate names.
    - Additional research has lead to change in the definition or rank of particular taxon.
10. Legitimate names are in accordance with the rules of ICN and is a validly published name accepted universally, whereas illegitimate names are those which violates one or more rules of ICN.

11. Common names are not used in botanical nomenclature due to the following reasons:
    - Only scientific names are universal, used worldwide, for example Ipomoea-(Woodbine, Morning glory)
    - Common names are not consistent
    - Creates confusion as a taxon may have more than one common name.
    - One common name may refer to more than one taxon
    - Common names tells nothing about rank, as scientific names do

4.8 QUESTIONS AND EXERCISES

Short-Answer Questions

1. Explain the theories proposed regarding the probable ancestors of angiosperms.
2. What is ANITA grade?
3. Write a short note on Index Herbariorum (IH).
4. What is an annotation label or determination label?
5. Write a short note on herbarium ethics.
6. What is the role of botanical gardens in near future?
7. What is a Taxon?
8. Write a short note on priority of publication.
9. Why common names are not used in botanical nomenclature?
10. What are the limitations to principle of priority?
11. What is *Nomina rejicienda*?
12. Differentiate between an Isotype and Lectotype.

Long-Answer Questions

1. State and explain the two hypothesis developed regarding the form of ancestral angiosperm.
2. Describe the magnolilean hypothesis.
3. What are the roles of a herbarium? Name some of the major herbaria of the world.
4. Why a field notebook is required in the field? Discuss.
5. What is a botanical garden and how it is different from herbarium? Write a note on major botanical gardens of the world.
6. What are the major roles played by a botanical garden? Describe each one of it.
7. Differentiate between homotypic and heterotypic types of synonyms.
8. Briefly explain the following:
    (i) *Carex kashmirensis* Clarke in Hook. F.
    (ii) *Phyllanthus* L. emend. Mull.
9. Define typification and the different types included or recognized by the code.
10. What is the use of parentheses in botanical nomenclature? State with an example.

4.9 FURTHER READING

NOTES

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NOTES

UNIT 5 CLASSIFICATION AND TAXONOMIC FEATURES OF ANGIOSPERMIC PLANTS

Structure

5.0 INTRODUCTION

Flowering plants are called as angiosperms. The flowering plants are the most dominant vascular plants that are found in the fauna all around the world. The pleasing and attractive colours of their flowers certainly add much more colour and brighten the landscape of any place. Due to the presence of flowers and enclosed seeds, they are called the phanerogams. Scientifically speaking, in these plants, the seeds are enclosed, with the ovules present in a hollow ovary.

Based on the types of cotyledon present, angiosperms are divided into two classes. They are monocotyledons and dicotyledons. The dicotyledonous angiosperms have two cotyledons in their seeds and the monocotyledonous angiosperms have one cotyledon. One of the earliest classification systems is what we now refer to as an artificial classification system. This means that plants are grouped based on similar characteristics, not on their genetic makeup.

Under an artificial classification system, an angiosperm could be placed in a group based on the colour of its flowers, the shape of its foliage, or the size of its fruit. In this type of system, a lily and an orchid might be placed in the same group based on flower color, even though we know that lilies and orchids are not closely genetically related (aside from both being part of the angiosperm group). Natural classification systems attempt to group angiosperms based on more scientific factors, such as their chemistry, preferred growth locations, anatomical features, and other similarly scientific features. Natural classification is much more like the taxonomy you might be familiar with from biology class. Taxonomy considers the same factors that natural classification systems do, and breaks them into clearly defined classifications and groupings based on those characteristics. Instead of grouping the plants based on a singular factor, like habitat, as a natural classification system might, taxonomy takes it a step further by factoring in multiple features and placing the organisms into a clearly defined hierarchy. Phylogenetic systems classification systems came up after Darwin's theory of evolution was proposed and widely accepted.

In this unit, you will study about classification system and taxonomic features of angiospermic orders in detail.

5.1 UNIT OBJECTIVES

After going through this unit, you will be able to:

- Explain classification system
- Discuss taxonomic features of angiospermic orders

5.2 SYSTEM OF CLASSIFICATION

Plant classification is the placement of plants or its allied groups in separate compartments at different levels based on phenetic similarities, phylogenetic relationships or merely based on artificial criteria. Plants can be classified in many different ways based on certain important characters like presence or absence of seed, whether the plant beans flowers or not, etc.

Radford (1986) stated that 'classification is the arrangement of groups of plants with particular circumscriptions by rank and position according to artificial criteria, phenetic similarities or phylogenetic relationships'.

Types of Systems of Classification

Taxonomic literature described three major system of classification, .i.e., as follows:

- Artificial Systems
- Natural Systems
- Phylogenetic Systems

Artificial Classification System: The earliest systems of classification which remained dominant from 300 B.C. up to about 1830 were artificial systems, which were based on one or a few easily observable characters of plants, such as habit (trees, shrubs, herbs, etc.) or floral characters (particularly the number of stamens and carpels).These systems use the habit and importance to man as the taxonomic characters, .i.e., based on superficial characters.

Theophrastus (370-285 B.C.) who is known as the father of Botany and apparently the first to provide a difference between dicots and monocots, Secundus (23-79 A.D) Dioscorides (62-128 A.D.), Magnus (1200-1280 A.D.) and many more. It starts with Theophrastus (370-285B.C.). Theophrastus was a philosopher and naturalist of Greece. He proposed his classification in *Historia Plantarum* divided plants into (1) trees (2) Herbs and (3) Shrubs.

These systems of classification were based on one or few morphological characters.

In some systems habit and habitat have been considered for this purpose:

- Theophrastus (370 – 285 BC), a Greek philosopher, in his book Historia Plantarum classified about 480 plants into four groups on the basis of their habit-herbs, undershrub's, shrubs and trees.
- Otto Brunfels (1464-1534) for the first time classified plants into Perfecti and Imperfect based on the presence or absence of flowers.

- Andrea Caesalpino (1519-1603), an Italian botanist and Physician, in his book De Plant is classified about 1500 plants on the basis of habit (herbs and trees) and then subdivided them on the basis of fruits and seeds which they produced.
- Joseph Pitton de Tournefort (1656-1708), a French Botanist and Physician, in his book Elements de botanique divided flowering plants into herbs and trees. He further sub-divided them on the basis of several morphological features, such as petal bearing or non-petal bearing flowers, simple or compound flowers (now referred to as polypetalous and gamopetalous), flowers regular or irregular.
- John Ray (1627-1705), an English naturalist, in his book Methods Plantarum Nova (1682) for the first time divided herbs, shrubs and trees into dicotyledons and monocotyledons on the basis of two or one cotyledons. Broadly he divided the plants as under:
- Carolus Linnaeus (also called Carl Linnaeus) (1707-1778), a Swedish naturalist in his book Species Plantarum (1753) classified 7300 species of plants into 24 classes, mainly on the basis of number, union and length of stamens. For example, he described the classes as Monandria (1 Stamen), Diandria (with 2 stamens), Triandria (with 3 stamens) and so on Polyandria (with 20 or more stamens). This system is commonly known as sexual system of classification.

Natural System of Classification (from 1760-1880)

In this system the plants were classified on the basis of their natural affinities (i.e. the basic similarities in the morphology). This system of classification used as many taxonomic characters as possible to group taxa. So in this system, the plants were grouped and placed into different taxa like classes, orders, families and genera. The first scientist to reject all the artificial systems and support the natural system of classification was Michel Adanson (1727-1806). Other botanist supporting this system of classification were A.L. de Jussieu (1748-1836) and his three family members (Antoine, Bernard and Joseph). A.P. de Candolle (1778-1841) and his son Alphonse (1806-1893) and Bentham (1800-1884) and Hooker (1817-1911). It starts with Bernard de Jussieu (1699-1777) who was a contemporary of Linnaeus. He modified the system of Linnaeus by dividing the flowering plants into Monocots and Dicots based on position of ovary, free or fused petals.

In these systems the organisms are classified on the basis of their natural affinities (i.e., the basic similarities in the morphology) rather than on a single character for determining the affinities.

A.L. de Jussieu (1748-1836) published a natural system of classification of plants in his book Genera Plantarum secundus ordines Naturales Disposita. He grouped all plants into 15 classes which were further divided into 100 orders (now called families).

He divided the plants into three main groups, i.e., Acotyledones (plants without cotyledons, for example algae, fungi, mosses, etc.) Monocotyledones (plants with one cotyledon) and Dicotyledones (plants with two Cotyledons). He mainly emphasized on the number of cotyledons and their presence or absence, number of petals and their presence or absence, and position of stamens.

Bentham and Hooker's Classification

The most important and the last of the natural systems of classification of seed plants was proposed by two British taxonomists George Bentham (1800-1884), a self trained botanist, and Joseph Dalton Hooker (1817-1911), the first director of the Royal Botanical Garden, Kew (England).

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A.P. de Candolie (1778-1841) a French botanist published Theorie elementaire de la Boanique in which he classified about 58,000 species into 161 families. He divided plants into two major groups, i.e., cellulares (non-vascular plants) and vasculares (vascular plants).

Comparison Artificial Classification

- The artificial classification is based on fewer or even a single arbitrary character.
- Artificial classification is based on priory weighting of taxonomic characters.
- The characters do not show any relationship.
- Artificial classification is a downward classification based on dichotomous branching (for example, the animal kingdom is divided on the presence or absence of red blood cells).
- This classification does not find any missing link or common ancestors.
- This system does not help in establishing evolutionary and phylogenetic relationship.

This system of classification was used by Aristotle (384-322 B.C.), Linnaeus (1707-1778), and his followers.

Comparison Natural Classification

- The natural classification is based on more than fewer characters, and mainly totality of characters are considered.
- It is based on posteriori weighting of the taxonomic characters.
- Natural Classification is based on diagnostic or hidden characters which show relationships.
- Natural Classification is an upward classification based on the grouping of related species that resemble each other and forming a hierarchy of higher taxa by grouping similar taxa of the lower rank.
- This classification helps to find out the missing link and their common ancestors.
- Natural Classification can establish the relationship among the taxa, so it helps to find out the phylogeny among different taxa.

This system of classification was introduced by middle of 19th century and most prominent authors are Ray Lankester (1847-1919), Mayr (1940, '65, '69), Simpson (1961), and Mayr and Ashlock (1991), and others.

Phylogenetic System of Classification

These classification systems came up after Darwin's theory of evolution was proposed and widely accepted. These systems used as many taxonomic characters as possible in addition to phylogenetic (evolutionary) interpretations. Some of the scientist who proposed phylogenetic system of classification were Engler and Prantl (1849-1893), Hutchinson (1884-1972), Bessey (1845-1915), Takhtajan (1910-2009), Cronquist (1919-1992) and more. In this system the first to practice is August Wilhelm Eichler's (1839-1887). He only modified Bentham and Hooker's system by placing gymnosperm before angiosperms (Dicot and Monocot).

Classification based on evolutionary features is known as phylogenetic system.

Important Phylogenetic Systems are:

Engler and Prantl (1884-1930)

They published detailed classification in 23 volumes of 'Die Naturlichen Pflanzenfamilien'. They arranged flowering plants according to increasing complexity of their floral morphology. They considered monocot' primitive than dicots.

John Hutchinson (1884-1972)

He was author of 'Families of flowering plants' (in 2 volumes) and director of Royal Botanic Garden at Kew, England. Classification proposed by him was based on 24 principles. This system is mostly followed. They placed monocots after dictos.

Major System of Classifications

A Bentham and Hooker's System of Classification

The two English botanists, George Bentham and Sir J.D. Hooker presented the classification of seed plants in the natural system of classification.

The classification was published in three volumes of *Genera plantarum* (1862-83). The system of classification is based on groups of plant characters which are correlated with each other. The *Genera plantarum* of Bentham and Hooker provided the classification of seed plants describing 202 families and 7569 genera. This work includes names, description and the classification of all the seed plants then known. The classification system given by Bentham and Hooker was a refined version of the system earlier proposed by Lindley and A.P. de Candolle, which inturn were based on that of de Jussieu. Bentham and Hooker system of classification is very popular and many important herbaria of the world have arranged the specimens according to this system of classification. But system of classification on the other hand had many short comings too, which were realized by the other taxonomists but still accepted because the identification of plants with this system is easy to carry out in the field compared to other system of classification's.

The most important and the last of the natural systems of classification of seed plants was proposed by two British taxonomists George Bentham (1800-1884), a self-trained botanist, and Joseph Dalton Hooker (1817-1911), the first director of the Royal Botanical Garden, Kew (England).

They recorded precise description of most of the plants known at that time. Their monumental work which took about quarter of a century for completion was described in three volumes of Genera Plantarum, published in Latin during July 1862 and April 1883. Bentham and Hooker's system of classification is still used and followed in several herbaria of the world. It is supposed to be the best system for the students to identify plants in the laboratory (Refer Figure 5.1).

Salient Features of Bentham and Hooker's System

- It is a classification of only the 'seed plants' or phanerogams.
- They described 97,205 species of seed plants belonging to 7,569 genera of 202 families starting from *Ranunculaceae* up to *Gramineae*.
- They classified all the seed plants into 3 groups or classes i.e. Dicotyledons (165 families), gymnosperms (3 families) and monocotyledons (34 families).
- They included disputed orders among *Ordines Anomali* which they could not place satisfactorily.
- Monocotyledons were described after the dicotyledones.
- The dicotyledons were divided into 3 Divisions (*Polypetalae*, *Gamopetalae* and *Monochlamydeae*) and 14 series. Each series again divided into cohorts (modern orders) and cohorts into orders (modern families).
- The authors did not mention anything about the origin of the angiosperms.

- Creation of the Disciflorae, a taxon not described by the earlier taxonomists.
- Among the Monochlamydeae, major taxa, like the series, were divided on the basis of terrestrial and aquatic habits.
- Polypetalae carries 82 families, 2610 genera and 31,874 species. Gamopetalae carries 45 families 2619 genera and 34,556 species. Monochlamydae includes 36 families, 801 genera and 11,784 species. Similarly Monocotyledons consist 34 families, 1495 genera and 18,576 species.

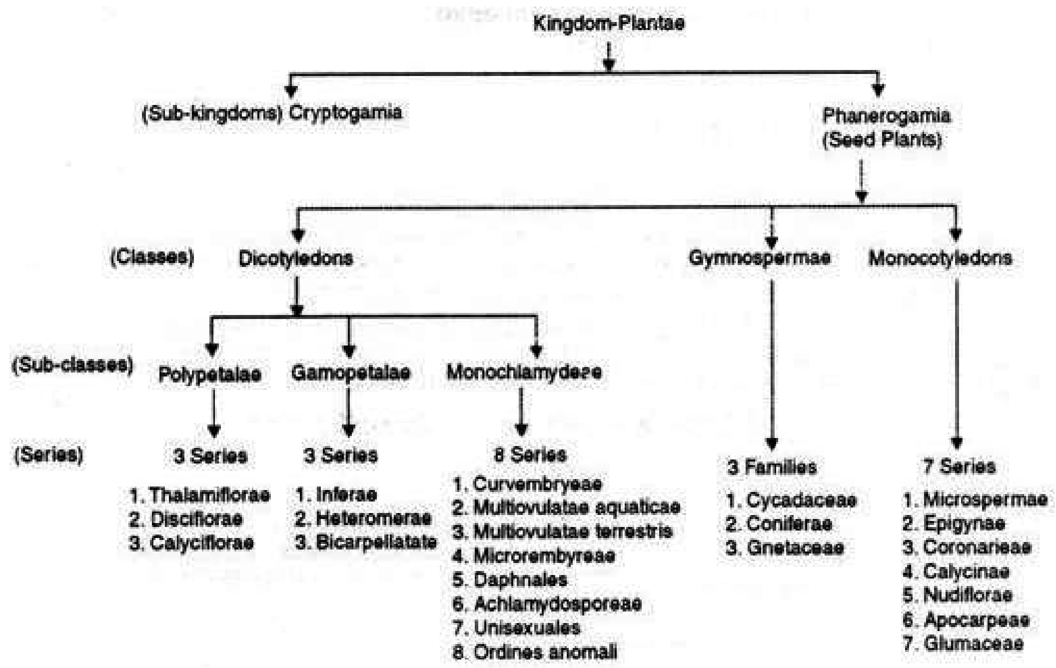

Fig. 5.1 *Classification of Bentham and Hooker's System*

Merits of Bentham and Hooker's System

- Each plant has been described either from the actual specimen or preserved herbarium sheets so that the descriptions are detailed as well as quite accurate.
- The system is highly practical and is useful to students of systematic botany for easy identification of species.
- The flora describes geographical distribution of species and genera.
- The generic descriptions are complete, accurate and based on direct observations.
- Larger genera have been divided into sub genera, each with specific number of species.
- Dicots begin with the order Ranales which are now universally considered as to be the most primitive angiosperms.
- Placing of monocots after the dicot is again a natural one and according to evolutionary trends.
- The placing of series disciflorae in between thalami florae and calyciflorae is quite natural.
- The placing of gamopetalae after polypetalae is justified since union of petalsis considered to be an advanced feature over the free condition.

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Demerits of Bentham and Hooker's System

- Keeping gymnosperms in between dicots and monocots is anomalous.
- Subclass monochlamydeae is quite artificial.
- Placing of monochlamydeae after gamopetalae does not seem to be natural.
- Some of the closely related species are placed distantly while distant species are placed close to each other.
- Certain families of monochlamydeae are closely related to families in polypetalae, for example Chenopodiaceae and Caryophyllaceae.
- Advanced families, such as Orchiadaceae have been considered primitive in this system by placing them in the beginning. Placing of Orchidaceae in the beginning of monocotyledons is unnatural as it is one of the most advanced families of monocots. Similarly, Compositae (Asteraceae) has been placed near the beginning of gamopetalae which is quite unnatural.
- Liliaceae and Amaryllidaceae were kept apart merely on the basis of characters of ovary though they are very closely related.
- There were no phylogenetic considerations

Table 5.1 *Phanerogams or Seed Plants*

Class 1. Dicotyledons	(Seed with 2 cotyledons, flowers pentamerous or tetramerous, leaves net-veined) 14 series, 25 orders and 165 families
Subclass 1. Polypetalae	(sepals and petals distinct, petals free)
Series 1. Thalamiflorae	(flowers hypogynous, stamens many, disc absent) 6 orders: Ranales, Parietales, Polygalineae, Caryophyllineae, Guttiferales and Malvales
Series 2. Disciflorae	(Flowers hypogynous, disc present below the ovary) 4 orders: Geraniales, Olacales, Celastrales and Sapindales
Series 3. Calyciflorae	(flowers perigynous or epigynous) 5 orders: Rosales, Myrtales, Passiflorales, Ficoidales and Umbellales
Subclass 2. Gamopetalae	(sepals and petals distinct, petals united)
Series 1. Inferae	(ovary inferior) 3 orders: Rubiales, Asterales and Campanales
Series 2. Heteromerae	(ovary superior, stamens in one or two whorls, carpels more than 2) 3 orders: Ericales, Primulales and Ebenales
Series 3. Bicarpellatae	(ovary superior, stamens in one whorl, carpels 2) 4 orders: Gentianales, Polemoniales, Personales and Lamiales
Subclass 3. Monochlamydeae	(flowers apetalous; perianth lacking or if present not differentiated into sepals and petals)
Series 1. Curvembryeae	(embryo coiled, ovule usually 1)
Series 2. Multiovulatae aquaticae	(aquatic plants, ovules many)
Series 3. Multiovulatae terrestres	(terrestrial plants, ovules many)
Series 4. Microembryeae	(embryo minute)
Series 5. Daphnales	(carpel 1, ovule 1)
Series 6. Achlamydosporae	(ovary inferior, unilocular, ovules 1-3)
Series 7. Unisexuales	(flowers unisexual)
Series 8. Ordines anomali	(relationship uncertain)
Class 2. Gymnospermae	(ovules naked) (3 families)

Class 3. Monocotyledons	(flowers trimerous, venation parallel) 7 series, 34 families
Series 1. Microspermae	(ovary inferior, seeds minute)
Series 2. Epigynae	(ovary inferior, seeds large)
Series 3. Coronarieae	(ovary superior, carpels united, perianth coloured)
Series 4. Calycinae	(ovary superior, carpels united, perianth green)
Series 5. Nudiflorae	(ovary superior, perianth absent)
Series 6. Apocarpae	(ovary superior, carpels more than 1, free)
Series 7. Glumaceae	(ovary superior, perianth reduced, flowers enclosed in glumes)

Merits of the System

The system of classification given by Bentham and Hooker is more than 100yrs old and is still an important system of classification owing to the following merits of this system.

- It is a natural system of classification with immense practical utility. It is very popular system of classification in many countries and has been used for arrangement of plant species in Kew Herbarium and many other known herbaria of world including India.
- The system of classification has great practical value for identification of plants and easy to follow routine identification in fields. The British and Commonwealth herbaria therefore still adopt this system in arrangement of families.
- The system is based on a careful examination of actual specimen study of seed plants thus making the system detailed, authentic and highly practical and is not merely a compilation of known facts.
- The accuracy of Latin descriptions is unparalleled.
- The system is based on form relationship and correlated characters.
- The Gymnosperms are not placed along dicots but rather form an independent group in this system.
- Dicotyledons are placed before the Monocotyledons, which is accepted by all present day taxonomists.
- The larger genera are divided into subgenera with definite number of species which helps in easy identification of plants.
- Keys for identification of genera and families are precise and useful.
- The seed plants were arranged based on overall natural affinities based on morphological features. Monocotyledons are treated as the most advanced.
- Ranales are placed in the beginning of Dicotyledons which is considered as the most primitive amongst the angiosperms.
- Heteromerae is placed before Bicarpellatae in this natural system of classification.

Demerits of the System

The classification though widely accepted, had certain shortcomings. The system was also pre-Darwinian in approach.

- The system of classification does not include any information about the origin of angiosperms and phylogeny even though it was published after Darwin's theory of evolution.

NOTES

- The position of gymnosperms between dicots and monocots is inappropriate according to the accepted evolutionary sequence. However, gymnosperms constitute an independent group from angiosperms.
- The grouping of Monochlamydeae is artificial as it is based on single character and has separated some closely related families, for example:
  - o Chenopodiaceae, Illecebraceae (placed in Monochlamydeae) are related to Caryophyllaceae (placed in Polypetalae), and placed in same order by modern day taxonomists.
  - o Similarly Podostemaceae belonging to Multiovulate aquaticae (Monochlamydeae) a separate series is regarded closely related to Saxifragaceae or Crassulaceae of Rosales, (placed in Polypetalae).
  - o Chloranthaceae was placed under Micro-embryeae and Laurineae under Daphnales (Monochlamydeae), is considered related to Magnoliaceae of Ranales (belonging to Polypetalae).
- Advanced family like Orchidaceae with inferior ovary and zygomorphic flowers has been considered primitive since it has been placed in the beginning of Monocotyledons.
- Liliaceae and Amaryllidaceae are generally regarded as closely related families and often included in same order, in the class Monocotyledons. Some authors including Cronquist merged Amaryllidaceae with Liliaceae. But in the natural system of classification they are placed under different series, Amaryllidaceae under Epigynae and Liliaceae under Coronarieae.
- Another drawback of the system was many large families, for example Urticaceae, Euphorbiaceae, Liliaceae and Saxifragaceae formed unnatural assemblages, represented polyphyletic groups. These have been split by subsequent authors into smaller, natural and monophyletic families.
- The system divides angiosperms into monocotyledons and dicotyledons whereas the modern phyhogenetic systems has placed paleoherb families and magnoliids before monocotyledons and eudicots.
- In this system, Unisexuales is a loose assemblage of diverse families, sharing one major character ie. Unisexual flowers. This has been separated by modern day taxonomists under two distinct subclasses.

Hutchinson System of Classification

John Hutchinson (1884-1972) a British botanist proposed the most widely used classification which is also known as the Hutchinson's classification. Hutchinson was associated with the Royal Botanic Garden's Kew, England and also served as keeper of Kew Herbarium for many years.

The Hutchinson's classification broadly divided angiosperms into:

- Dicotyledons
- Monocotyledons

He proposed his classification of angiosperms in the Book 'The families of flowering plants'. The first volume of the book on Dicotyledons (1926) and second volume of the book on Monocotyledons in 1934. The classification system was revised periodically.

Hutchinson's system is a phylogenetic system that classified plants. It is systematic and grouped plants based on evolution along with morphological features.

The system of classification was based on the principles followed by 'Bessey'. The system of classification was revised in British flowering plants (1948) and later in the second edition of 'The Families of Flowering Plants' (1959). The principles of Hutchinson system (Refer Figures 5.2 and 5.3) are more like Besseyan system of classification than the Englerian system. In addition to the system of classification for angiosperms, Hutchinson also published other valuable works, such as Flora of West Tropical Africa (1927-29), Common wild flowers (1945), A Botanist in South Africa (1946), Evolution and classification of Rhododendrons (1946), British Flowering Plants (1948), British Wild Flowers (1955) and Key to the families of flowering plants of the world (1968). Hutchinson also made efforts revising '*Genera plantarum*' of Bentham and Hooker under the title 'Genera of Flowering Plants', but could complete only 2 volumes of '*Genera plantarum*' published in 1964 and 1967. The work was left incomplete due to his demise.

The classification system given by Hutchinson was based on 24 principles relating to general habit, general structure of flowering plants and those relating to flower and fruits:

- The evolution is both upward and downward, upward evolution tending towards preservation and downward tends towards reduction and degeneration of characters.
- Evolution does not necessarily involve all the organs of a plant at the same time or simultaneously.
- Evolution has generally been consistent and when a progression or retrogression has set in, it is persistent till the end of the phylum.
- Trees and shrubs are more primitive than herbs, in certain groups.
- Perennials are more primitive than biennials and annuals.
- Trees and shrubs are older than climbers.
- Aquatic phanerogams are derived from terrestrial and same applies for saprophytes, parasites and epiphytes.
- Plants with collateral vascular bundles arranged in a ring (Dicotyledons) are more primitive in origin in comparison with those in which vascular bundles are scattered (Monocotyledons).
- Spiral phyllotaxy (arrangement of leaves on the stem) is considered primitive than that of opposite and whorled types.
- Simple leaves are considered primitive than compound leaves.
- Bisexual flowers are considered primitive than unisexual flowers and the dioecious condition is considered advance as compared to monoecious condition.
- Solitary flower is more primitive than the inflroscence form.
- Spirally imbricate floral parts are more primitive than whorled and valvate arrangement.
- Polymerous flowers precedes oligomerous flowers.
- Petaloid flowers are more primitive than apetalous flowers, the latter being the result of reduction.
- Gamopetally is more advanced than polypetalae.
- Actinomorphic flowers are considered primitive then zygomorphic flowers.
- Free carpels (apocarpous condition) are more primitive than fused carpels (syncarpy condition).
- Flowers with numerous stamens are more primitive than those with fewer stamens.
- Free stamens precedes fused stamens (connate stamens).

- Endospermic seeds with small embryo are more primitive than non-endospermic seeds with large embryo.
- Hypogynous condition is considered more primitive and from it perigynous and epigynous conditions were derived.
- Parietal placentation is more primitive than axial and free central placentation.
- Aggregate fruits are more evolved than single fruit and capsules precedes berry or drupe.

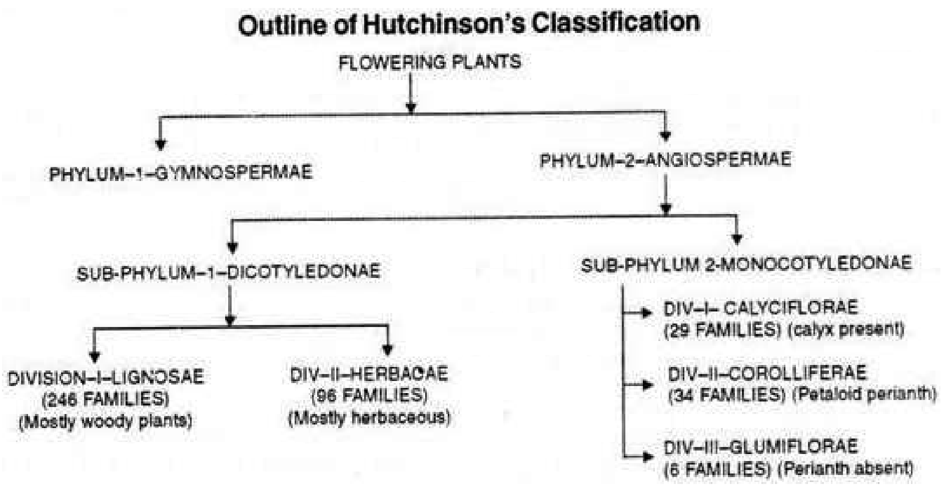

Fig. 5.2 Hutchinson System Classification

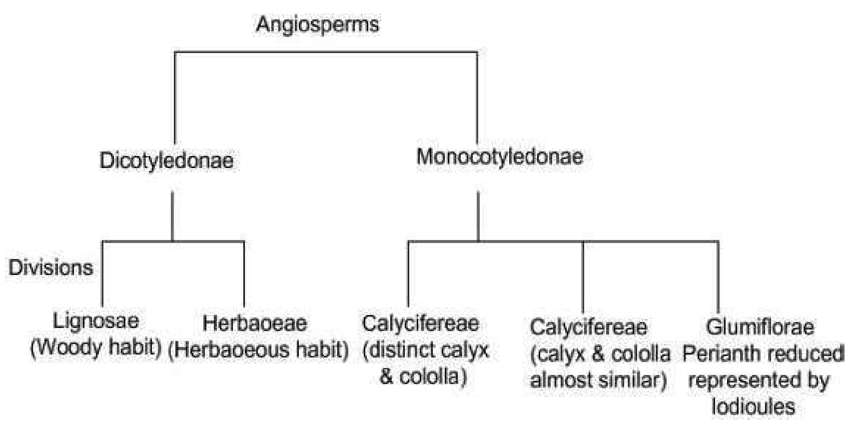

Fig. 5.3 Outline of the Hutchinson System of Classification of Flowering Plants in 3rd Edition of the Families of Flowering Plants (1973)

Merits of Hutchinson's Classification

Hutchinson system of classification being based on a number of sound phylogenetic principles, showed many improvements over earlier system of classification which are as follows:

- This system is more phylogenetic based on natural characteristics of plants as compared to that of Engler and Prantl system of classification.
- The system was based on evolutionary tendencies and interrelationship among angiospermic plants and thus widely accepted than other systems of classification.
- In this system, Magnoliales is treated as the starting point in evolutionary series of Dicotyledons which is in agreement with existing views.

NOTES

- Origin of monocots from dicots and placement of dicots first and then monocotyledons is widely accepted and correct in all respects.
- Phylograms made for dicotyledons and monocotyledons are more superior and illustrative as compared to Besseyan cactus.
- The classification given for monocots is more sound and widely appreciated.
- The positioning of Alismatales towards the beginning of Monocotyledons is generally accepted.
- Many large families have been split into smaller natural families. Euphorbiaceae has been split into Euphorbiaceae, Ricinaceae and Buxaceae in Hutchinson system of classification.
- 'The Genera of Flowering plants' provides detailed classification upto generic level, together with identification keys and description for some families.
- Standard of the description provided is quite high and the keys are very useful for identification of the families.

Demerits of the Classification given by Hutchinson

The classification system given by Hutchinson was ignored because of the following drawbacks.

- The system gave much importance to the habit and thus not useful for practical identification arrangement in floras and herbaria. The system of classification does not proceed above the family level in the majority of taxa and thus ignored.
- In this system, Dicotyledons division into Lignosae and Herbaceae is most artificial, since it has resulted in separation of closely related families like Araliaceae and Apiaceae in Lignosae and Herbaceae respectively. In contemporary system of classification, Lamiaceae and Verbenaceae are often placed in same order, which in Hutchinson system have been placed separately.
- Hutchinson system was lacking in providing full explanation for the majority of evolutionary concepts.
- According to Hutchinson angiosperms are derived from proangiosperms, but the information about the hypothetical ancestral group was lacking.
- In splitting up the larger unnatural families into small natural ones, in doing so, Hutchinson even split up some families which were already natural monophyletic groups. Ranunculaceae has been split into Ranunculaceae and Helleboraceae on the basis of achene and follicle fruit. Studies on floral anatomy have shown that Ranunculaceae of Bentham and Hooker system of classification represents a monophyletic group and need not be split into two.
- Placement of some closely related families into distinct taxa was another drawback. The family Calycanthaceae is related to Laurales, but has been placed in Hutchinson system in Rosales.
- Hutchinson considered Magnoliaceae as the most primitive family of living Dicotyledons, but most of his contemporaries considered Winteraceae, or paleoherbs as most primitive.
- Placement of monocots after dicots in this system of classification.
- In Hutchinson classification family Liliaceae, which is a large unnatural assemblage, has been split into several smaller monophyletic families like Liliaceae, Alliaceae, Asparagaceae, Asphodelaceae in the recent classification system of Judd *et al.* (2002) and APG II (2003).

System of Classification Proposed by Armen Takhtajan

Armen Takhtajan (1910-1997), a Russian Plant Taxonomist of the soviet Academy of Sciences, Leningrad USSR (now named as St. Petersburg) gave his system of classification in 1954 and the same was translated into English in 1958 in Origin of Angiospermous Plants.

The system of classification was elaborated in *Die Evolution der Angiospermen* (1959) and *Systema et Phylogenia Magnoliophytorum* (1966), in Russian.

Takhtajan has provided a classification system of angiosperms upto the family level. He belongs to the Besseyan school and was strongly influenced by the Hutchinson system of classification and 'Hallier' had made a great impression on him, along with other German workers.

Hallier gave synthetic evolutionary classification of flowering plants. Takhtajan believed in **monophyletic origin of angiosperms**, the group having evolved from seed ferns Lyginopteridophyta. Takhtajan, believed that angiosperms are of neotenous origin (retention of juvenile characters in adult plants). Thus Magnoliales was considered most primitive among the living angiosperms. He also opined that angiosperms arose under environmental stress.

Takhtajan, for many years considered Winteraceae along with Degeneriaceae as the most primitive family of angiosperms placed under Magnoliales.

Later, Takhtajan chose Degeneriaceae as the most primitive family of angiosperms under order Magnoliales and shifted Winteraceae to a separate order Winterales after Magnoliales. Instead of the conventional terms, he used Magnoliophyta for the angiosperms, Magnoliopsida for the dicots and Liliopsida for the monocots. Takhtajan derived Magnoliophyta monophyletically from Bennettitalean ancestors.

Major conclusions of the Takhtajan system of classification

- Woody plants are of primitive origin than herbaceous plants. Taller trees and deciduous woody plants are considered to have evolved from evergreen plants.
- Simple leaves having entire margin are considered primitive.
- Moderate size flower in few flowered cyme is of primitive origin as in Degeneria. The large flowers of Magnolia and Nymphaeceae seems to be of secondary origin.
- Petals are of dual origin, from the bracts in Magnoliales (Bracteopetals) and from the stamens in Caryophyllales (andropetals).
- Early angiosperms have flowers with an indefinite or variable number of floral parts considered to be of primitive origin.
- Primitive stamens were broad and were not differentiated into filament and connective.
- Monocolpate pollen grains are considered primitive and from which tricolpate pollen grains arose.
- Apocarpous (free carpels) gynoecium is considered primitive over syncarpous (fused carpels) gynoecium which is a later development.
- Takhtajan (and Cronquist) earlier regarded monocotyledons as being of aquatic origin from Nymphaeales via Alismatales.
- Also Takhtajan and Cronquist named angiosperms as division Magnoliophyta and dicots and monocots are given rank of a class and named Magnoliopsida and Liliopsida respectively.

NOTES

Takhtajan indicated the presumed relationship of various subclasses and super orders, like other phylogenetic systems of classification with the help of bubble diagram. Bubble diagram or more appropriately a phylogram where the size of each bubble representing the relative size of each group, the branching pattern, the phylogenetic relationship and the length of bubble its evolutionary advancement (Refer Figures 5.4 - 5.6)

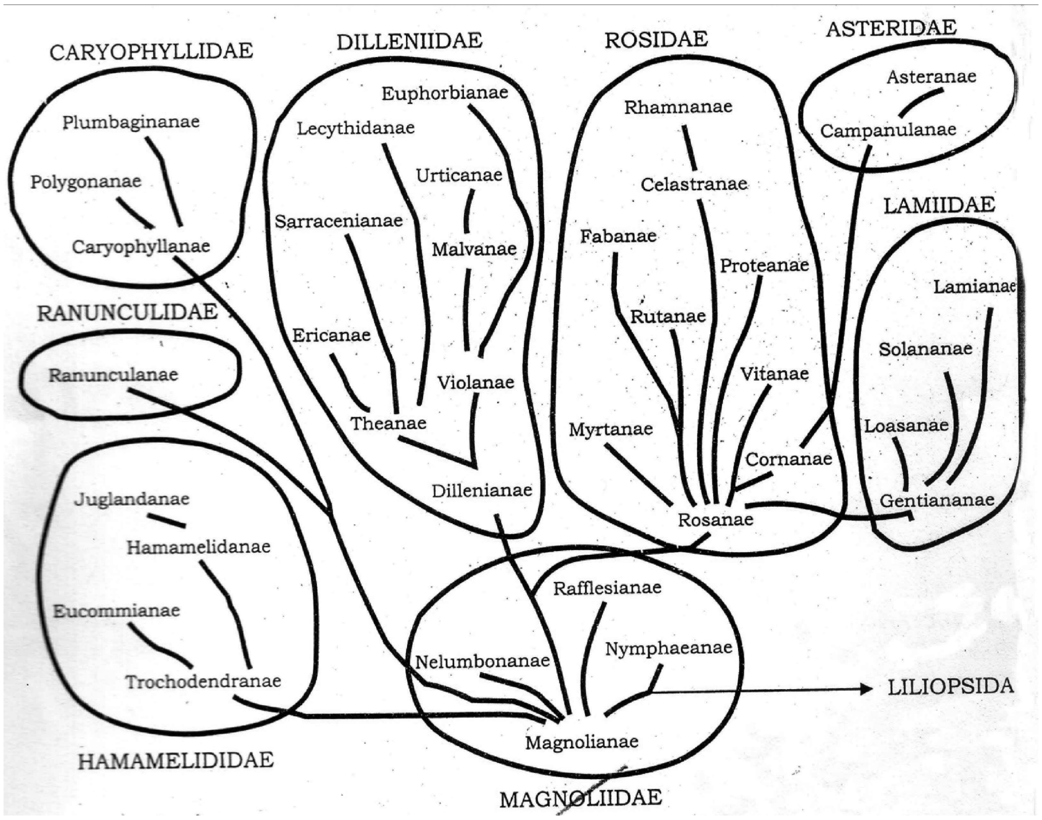

Fig. 5.4 *Bubble Diagram of Takhtajan Showing the Probable Relationship between Subclasses and Superorders Of Dicotyledons (Based On Takhtajan, 1987).*

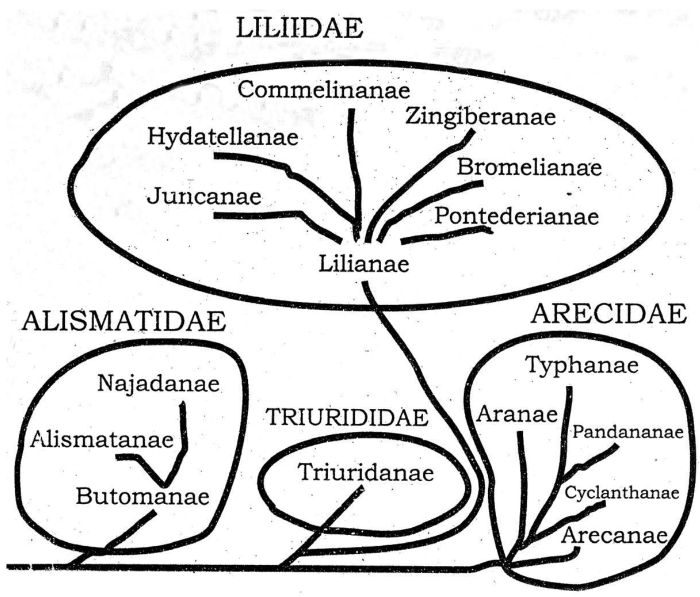

Fig. 5.5 *Bubble Diagram of Takhtajan Showing the Probable Relationship between Different Subclasses and Superorders of Monocotyledons*

Division.Magnoliophyta 2 classes, 17 subclasses, 71 superorders, 232 orders, 589 families (2 classes, 12 subclasses, 53 superorders, 166 orders, 533 families in 1987 classification); estimated genera 13,000, species 2,50,000.
Class 1.Magnoliopsida (Dicotyledons) 11 subclasses, 55 superorders, 175 orders, 458 families (8 subclasses, 37 superorders, 128 orders, 429 families in 1987 classification); estimated genera 10,000, species 1,90,000 **Subclass** 1. Magnoliidae 2. Nymphaeidae* 3. Nelumbonidae* 4. Ranunculidae 5. Caryophyllidae 6. Hamamelididae 7. Dilleniidae 8. Rosidae 9. Cornidae* 10. Asteridae 11. Lamiidae
Class 2. Liliopsida (Monocotyledons) 6 subclasses, 16 superorders, 57 orders and 131 families (4 subclasses, 16 superorders, 38 orders, 104 families in 1987 classification); estimated genera 3,000, species 60,000 **Subclass** 1. Liliidae 2. Commelinidae* 3. Arecidae 4. Alismatidae 5. Triurididae 6. Aridae*

Fig. 5.6 *Outline of the System of Classification of Angiosperms Proposed by Takhtajan in 1997*

Merits of Takhtajan's System of Classification

Takhtajan's latest classification (1997) showed several improvements in relation to information on phylogeny and phenetics. Major achievements of the system include:

- This system is largely accepted mainly due to its clearly defined evolutionary principles and also because it is in agreement with the major contemporary systems of Cronquist, Dahlgren and Thorne. The system of classification included both phylogenetic and phenetic information for the delimitation of orders and families.
- The dicots (Magnoliopsida) have been discussed before Monocots (Liliopsida).
- The derivation of Monocotyledons from the terrestrial hypothetical extinct group of Magnolidae (proangiosperms) is much favoured and accepted as among monocots, the Alismatales, considered to be most primitive living monocots, have been placed at the starting point which is satisfactory.
- Artificial groups like polypetalae, Gamopetalae, Lignosae, Herbaceae, etc. has been abolished in this system, resulting in more natural grouping of taxa. Lamiaceae and Verbenaceae are thus brought together in this system under the order Lamiales which was placed under separate groups by Hutchinson.

- Nomenclature in this system is in accordance with the international code of Botanical Nomenclature, up to division level.
- Takhtajan depicted the relationship of major subclasses and superorders with the help of bubble diagram which seems to be very useful as it gives some idea about the relative size of the groups, degree of advancement (apomorphy) and cladistics divergence. Larger bubbles represent larger groups, vertical length represent the degree of advancement and the point of separation of a branch its cladistics divergence.
- Asteridae in this system was split up into two subclasses: Lamiidae and Asteridae. This has resulted in more rational distribution of sympetalous families.
- Nymphaeales, placed within dicots earlier, has been placed in a distinct subclass Nymphaeidae under Magnoliopsida.
- Asclepiadaceae merged with Apocyanaceae has been supported by the other contemporaries (Judd *et al.* 1994).

Demerits of Takhtajan's System of Classification

The latest revision of Takhtajan's system of classification in 1997, attempted to remove major deficiencies seen in the earlier versions of classification. Certain drawbacks of the system recorded are:

- The system though highly sound and phylogenetic is not helpful for identification in herbaria as it provides classification only upto the level of family.
- Another major drawback to Takhtajan's system is his derivation of Monocotyledons from the stocks ancestral to Nymphaeales.
- Another limitation of this system is it gives more weightage to the cladistic information compared to phenetic information.
- Most authors regard vesselless Winteraceae or paleoherbs Amborellaceae the most primitive among living angiosperms. However, Takhtajan regarded Degeneriaceae to be most primitive.
- The splitting of families and thus increase in the number of families has resulted in a very narrow circumscription of taxa.
- Takhtajan in his later version of classification (1997) failed to provide a bubble diagram which was considered to be a positive feature of his earlier version of classification given in 1987.
- Takhtajan was of an opinion and suggested that smaller families are more natural which was later disproved by 'Stevens' in 2003. Steven suggested that monophyletic groups including fever taxa do not necessarily have more apomorphies
- Position of several taxa has been shifted by later contemporaries based on numerical analysis, multigene analyses and other analyses.

System of Classification by Arthur Cronquist

Arthur Cronquist (1919-1992), a leading American taxonomist, associated with the New York Botanical Garden produced and published his classificatory system of Embryobionta along with Takhtajan and Zimmerman (1966).

Cronquist published his classification in his book, Evolution and classification of flowering plants (1968) which was later revised in 1981 in the book 'An Integrated System of Classification of Flowering Plants'. However the final revised classification was published in second edition of 'The evolution and Classification of Flowering Plants' (1988). Later Cronquist replaced the usual terminology Dicotyledoneae and Monocotyledoneae with Magnoliatae and Liliatae respectively. This system of classification is an elaboration of Bessey's system of classification and a refinement of Takhtajan's system (1964). The classification is though similar to that of Takhtajan's system, differs in details, Also unlike Takhtajan who gave more importance to cladistics, Cronquist gave more importance to morphology (Ehrendorfer, 1983)

Merits of the Classification System

Cronquist classification system is based largely on the principles of phylogeny and finds acceptance with his major contemporaries. The system showed certain merits over the previous systems of classification.

- In arrangement of various groups/taxa, this system of classification incorporates all the evidences from all sources and is in general agreement with major contemporary classification system of Takhtajan, Dahlgren and Thorne.
- Detailed information on phytochemistry, anatomy, ultrastructure and chromosome studies besides morphology was given in revised classification system in 1981 and 1988.
- The text of the classification written in English by Cronquist was readily adopted in books and floristic projects (English being easily understood) originating in USA.
- The system of classification like that of Takhtajan is based on largely accepted phylogenetic principles.
- Winteraceae placed at the beginning of Dicotyledons is favoured by most of the authors including Ehrendorfer (1968), Gottsberger (1974) and Thorne (upto 1992).
- Position and placement of taxa finds general agreement with other authors. Placement of Magnoliidae as the most primitive group of angiosperms, dicots before monocots, Magnoliales at the beginning of Magnoliidae and Butomaceae at the beginning of Liliopsida is favoured by other authors.
- Compositae (Asteraceae) in dicotyledons and Orchidaceae in monocotyledons are considered as advanced families and are rightly placed towards the end of each group respectively.
- Nomenclature of taxa is in accordance with the rules of ICN (International Code of Nomenclature for algae 'fungi' and plants).
- The relationship of various taxa/groups depicted with the help of diagrams, provide valuable information related to advancement, cladistic relationship and size of various groups.

Demerits of the System of Classification

The system of classification became much popular, especially in the USA, where many books are following this classification. However, the following drawbacks may be pointed out:

- Cronquist system of classification at some level has shown too much reliance on single characters like centrifugal stamens, free-central placentation, etc.
- The system being highly phylogenetic is not very useful for identification and classification in herbaria and museums.
- Dahlgren (1983, 1989) and Thorne (1981, 2003) considered angiosperm to deserve a class rank and not that of a division, as has done by Cronquist.

NOTES

- Cronquist did not recognize superorder (rank above order) and thus different from contemporary system of classifications.
- Recent classification systems by various authors do not believe in the aquatic ancestry of monocotyledons. Cronquist believed that monocotyledons arose from vesselless ancestors resembling present day Nymphaeales.
- Recent classifications places monocotyledons between primitive angiosperms and the eudicots unlike Cronquist and earlier authors who placed monocotyledons after dictoyledons.
- Positioning of certain taxa by Cronquist was not correct and was corrected in the recent classification system based on multigene analyses and also on basis of unique combination of anatomical characters. Metcalfe and Chalk (1983) on the basis of anatomical features suggested that Dioncophyllaceae family should occupy an isolated taxonomic position. Also, (Soltis *et al.*, 1999; Zanis *et al.*, 2002, 2003) have provided 99-100% bootstrap support in the relationship of Winteraceae and Canellaceae which otherwise by Cronquist has been placed in the beginning and towards the end respectively in Magnoliales.
- The position of certain families in Liliales has also been strongly criticized.

'Check Your Progress'

1. How many types of systems of classification are there?
2. What is artificial classification system?
3. What is natural systems of classification?
4. What is phylogenetic systems of classification?

5.3 DISTINCTIVE TAXONOMIC FEATURES OF THE ANGIOSPERMIC ORDERS

Taxonomic groups or Taxa are arranged in order of their successive inclusiveness, the least inclusive at the bottom (usually a species), and the most inclusive at the top (usually a division).

A species is a group of individuals which resemble each other very closely and share common taxonomic features and can interbreed. Those species which share many common characters are placed together in a larger group called genus, these in turn are arranged in a larger group called family and then in order and so on.

5.3.1 Order Magnoliales

The Magnoliids recognized by APG III (2009) contains four orders- Laurales, Magnoliales, Canellales and Piperales. Magnoliales, the magnolia order of flowering plants consisting of six families, 154 genera, and about 3,000 species. Many unspecialized features of the angiosperms can be found in Magnoliales (Refer Figure 5.7).

The six families included in the order are:

- Annonaceae
- Degeneriaceae
- Eupomatiaceae

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- Himantandraceae
- Magnoliaceae
- Myristicaceae

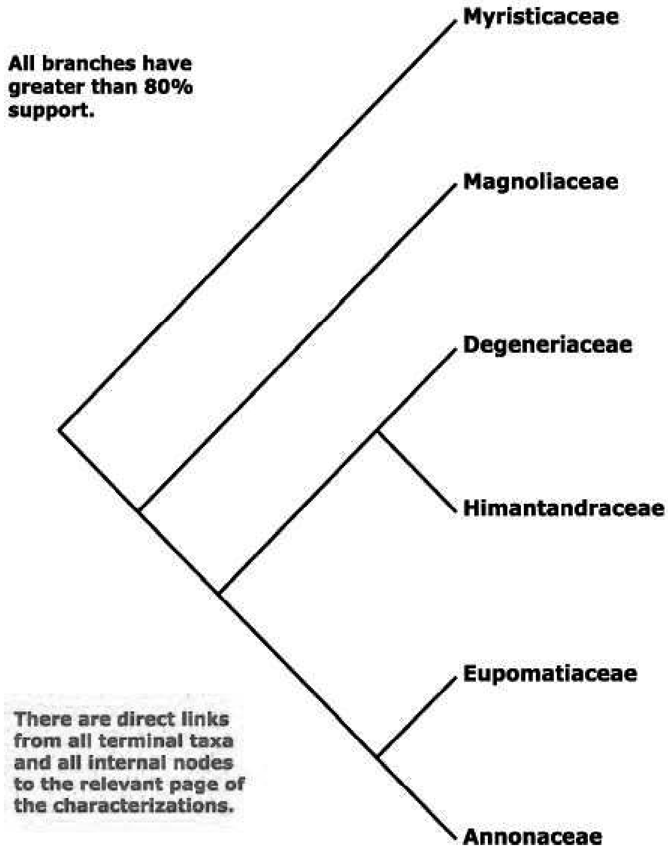

Fig. 5.7 *Magnoliales Classification*

Earlier the Cronquist system (1981) placed the order in the subclass Magnoliidae of class Magnoliopsida (Dicotyledons) and used this circumscription:

Order Magnoliales

Family–

- Annonaceae
- Austrobaileyaceae
- Canellaceae
- Degeneriaceae
- Eupomatiaceae
- Himantandraceae
- Lactoridaceae
- Magnoliaceae
- Myristicaceae
- Winteraceae

Magnoliales comprises of primitive families, mostly distributed in the tropics and subtropics of the Southern hemisphere.

Plants evergreen or deciduous, usually large to medium sized trees or shrubs. Leaves simple, mostly alternate in the order Magnoliales. Flowers usually solitary, large and showy. Numerous whorls of sepals and petals and indefinite number of stamens arranged spirally. Gynoecium monocarpellary or multi-carpelled and apocarpous.

Wood anatomy shows presence of primitive vessels with scalariform end-walls.

Pollen grains are usually shed at 2-celled stage. Ovules anatropous, bitegmic, crassinucellate. Most of the members of the order Magnoliales are rich in alkaloids.

The family Myristicaceae included in Magnoliales, containing *Myristica fragrans*, from which are derived nutmeg and mace (from the seeds and aril respectively) is notable among others families.

Magnoliaceae – Magnolia family (after Pierre Magnol (1638-1715) includes 7 genera/ 200 species (Simpson, 2010). The family Magnoliaceae consists of species of trees or shrubs. The leaves are simple, spiral, pinnate-netted, and stipulate with caducous stipules enclosing the buds. Inflorescence is a terminal solitary flower. Flowers are large bisexual (rarely unisexual), actinomorphic, hypogynous, the receptacle grows into an elongated axis (called a torus or androgynophore) which bears androecium and gynoecium. The perianth is multi-whorled or spiral, apotepalous. Stamens numerous, spiral, apostemonous, longitudinal dehiscence, tetrasporangiate, dithecous. Gynoecium apocarpous, with [2-] numerous superior, spirally arranged carpels, each unilocular with one terminal style and one stigma, marginal placentation, ovules anatropous and bitegmic. Fruit is an aggregate of follicles, samaras or berry-like units; seeds endospermous, rich in oil and proteins with a sarcotesta (fleshy seed coat resembling an aril) often present (Simpson, 2010).

The distribution of Magnoliaceae is in tropical to warm temperate regions especially in Northern Hemisphere.

Magnoliaceae includes ornamental cultivars and is also important for its timber eg. *Liriodendron*, *Magolia*, *Michelia*.

5.3.2 Order Caryophyllales

Caryophyllales contain 34 families (sensu APG III, 2009; Stevens, 2001), most corresponding to the traditional 'Centrospermae'. The placement of the Caryophyllales within the eudicots has varied but appears to be more closely related to Asterids than to Rosids (Simpson, 2010) Prior to molecular studies, the Caryophyllales included a number of families previously unsuspected of close relationship to the 'Centrospermae' (Refer Figure 5.8).

Many members of the 'Core Caryophyllales' possess pollen that is trinucleate upon being released from the anther, which is relatively rare feature seen in angiosperms (pollen being binucleate at release). Another feature characteristic of core caryophyllales, they have either free-central or basal placentation.

NOTES

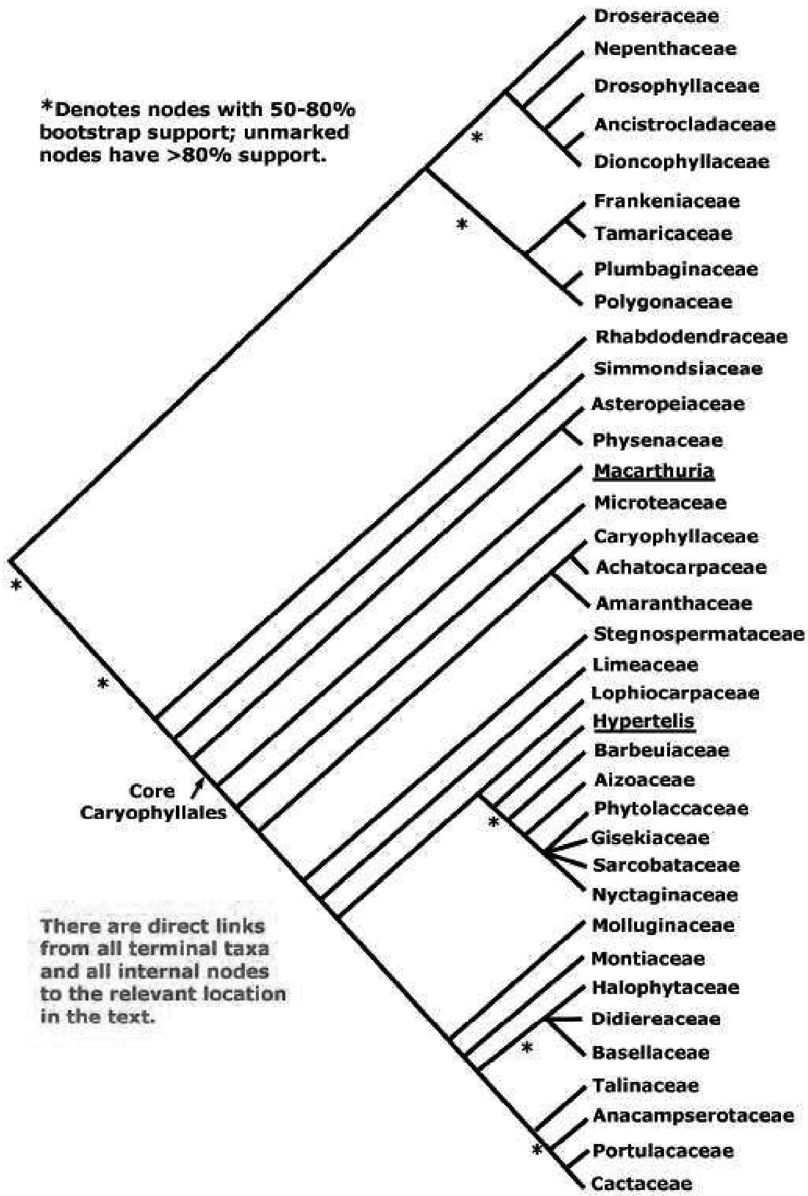

Fig. 5.8 *Caryophyllales Classification*

The order Caryophyllales formely known as the Centrospermae (or Caryophyllidae, after Cronquist 1981), comprises of 4 sub orders (Bhattacharyya, 2005)

Suborder	-	Phytolaccineae
Suborder	-	Portulaccineae
Suborder	-	Caryophyllineae
Suborder	-	Chenopodiineae

The traditional Centrospermae or Caryophyllidae are largely equivalent to 'Core Caryophyllales' a complex of approximately 21 families although Polygonaceae, Plumbaginaceae, Frankeniaceae and Tamaricaceae were often included within these groups in earlier treatments.

Taxonomic characters of the family – The plants are herbs, shrubs, trees or vines. The leaves are alternate (Chenopodiaceae) or opposite-decussate (Caryophyllaceae), usually estipulate, frequently shows anomalous secondary growth in both stem and root. P-type plastids have been reported. Perianth typically biseriate, pollen grain 3-celled; ovules campylo- or amphitropous, bitegmic, crassinucellate with nucellar cap. Embryo generally coiled or curved. Most families (excluding Caryophyllaceae, Molluginaceae) contain betalain pigments. These two families Caryophyllaceae and Molluginaceae are known to contain anthocyanin pigments. The presence of betalain pigments and basal placentation do not leave any doubt about the inclusion of these taxa in Centrospermae.

Caryophyllaceae (Carnation family (clove-leaved) 85-86 genera/ca. 2400 species (Simpson,2010). Distributed primarily in North temperate regions, a few genera in the South temperate regions and higher altitudes areas of the tropics. The Mediterranean region is the centre of distribution.

The Caryophyllaceae consist of annual or perennial herbs, rarely shrubs, lianas, or trees. The stems often have swollen nodes. The leaves are opposite (rarely spiral), simple, usually exstipulate. The inflorescence is of dichasial cymes or solitary flowers. Flowers bisexual or unisexual, actinomorphic, hypogynous, rarely perigynous. The perianth is biseriate, dichlamydeous, hypanthium absent [rarely present]. Pentamerous flowers with distinct clawed petals, stamens 5-10, epipetalous or episepalous, longitudinal in dehiscence. Gynoecium is syncarpous, with a superior ovary with distally free-central or basal placentation, ovules campylotropous to hemitropous, bitegmic, 1-many per ovary. Fruits an achene or capsule, seeds are perispermous often with sculptured seed coat. Anthocyanin pigments present only, betalains absent.

Economic importance of the family includes several ornamental cultivars, such as *Dianthus*, Carnation, etc.

5.3.3 Order Orchidales

A relatively recent name as early systems used descriptive botanical names for the order containing orchids. The Bentham and Hooker and the 'Engler and Prantl' system of classifications had placed the orchids in order Microspermae while the 'Wettstein' system treats them as order Gynandrae. Circumscription of the order varies with the taxonomic system being used. Although mostly the order consists of a single family Orchidaceae containing orchids, but sometimes divided into more than one families in the order as seen in 'Dahlgren' system of classification.

Circumscription in Takhtajan System (1997):

Order	Orchidales
Family	Orchidaceae

Circumscription in the Cronquist System:

Order	Orchidales
Family	Geosiridaceae
Family	Burmanniaceae
Family	Corsiaceae
Family	Orchidaceae

Circumscription in the Dahlgren System:

Order	Orchidales
Family	Neuwiediaceae
Family	Apostasiaceae
Family	Cypripediaceae
Family	Orchidaceae

Circumscription in Thorne System (1992):

Order	Orchidales
Family	Orchidaceae

APG system: According to the APG system the order is not recognized in the APG II system, which assign the orchids to order Asparagales.

Orchidales includes tropical epiphytes and small herbs and do not have a fossil record. However, like palms and some members of the Iridales, they have plicate (corrugated) leaves, and these leaf forms are among the earliest known fossil monocots.

Orchidales comprising of Orchidaceae family consisted of large terrestrial plants, but like bromeliads, Orchids took to trees, where they have diversified to become the largest family of flowering plants. Many species also form mycorrhizal associations with fungi. The 'Orchidales' have traditionally been considered the pinnacle of monocot evolution and so are listed in many floras.

Comparison of the whole-genome sequence of Apostasia shenzhenica with transcriptome and genome data from five orchid subfamilies has permitted the reconstruction of an ancestral gene (Refer Figures 5.9 and 5.10).

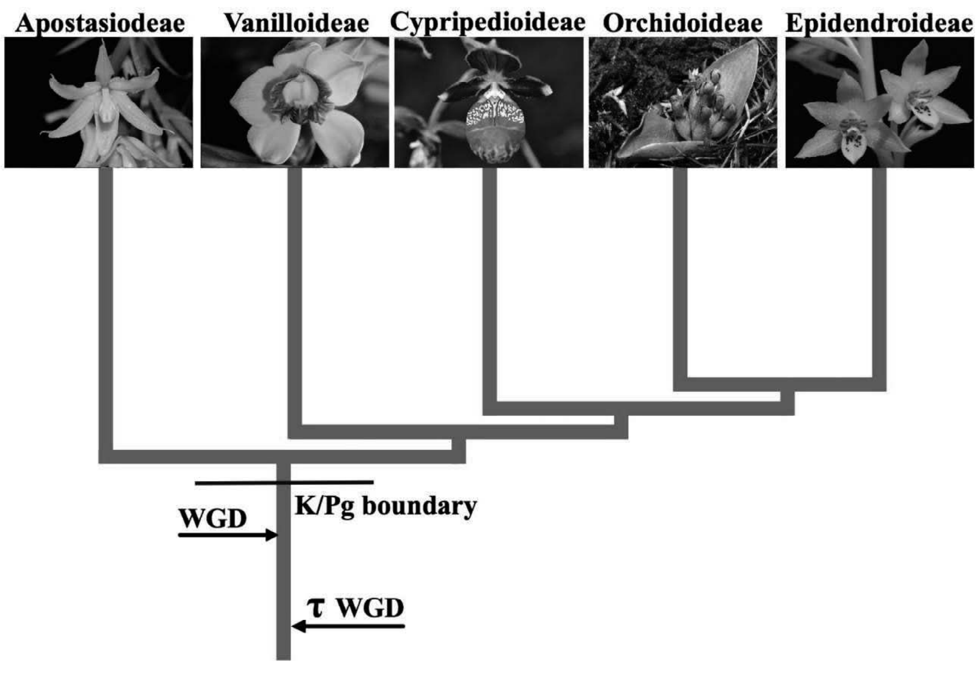

Fig. 5.9 *Orchid Origin and Evolution*

NOTES

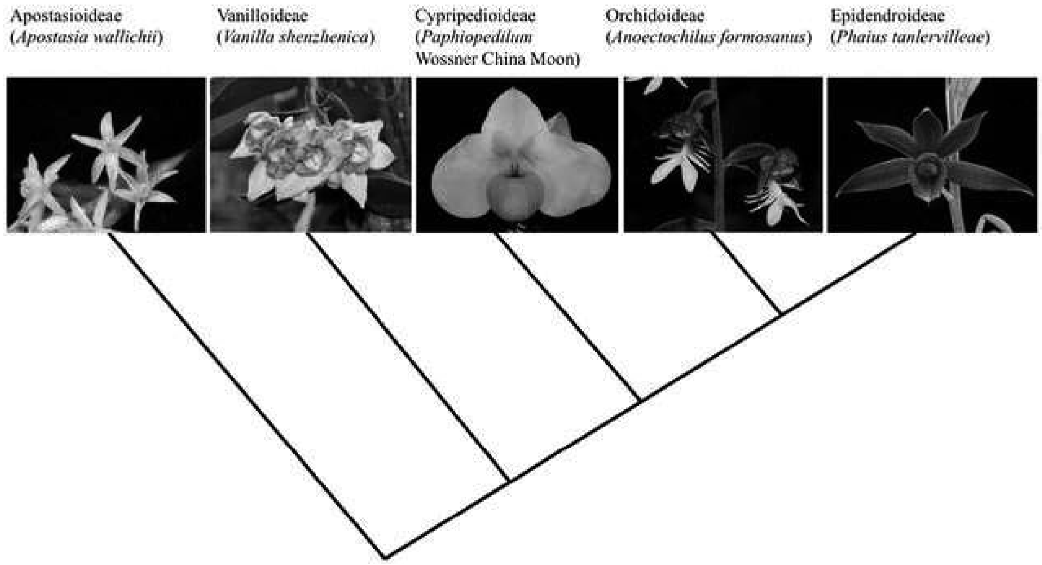

Fig. 5.10 *Post Genomic Era of Orchid Research*

Orchidaceae

700-800 genera/ca. 20,000 species. The Orchidaceae consists of terrestrial or epiphytic perennial herbs. Rarely orchids are annual. Roots often tuberous in terrestrial species or aerial in epiphytic species, typically with a multilayered velamen. Leaves spiral, distichous or whorled usually sheathing, simple and parallel veined. Inflorescence raceme, panicle, spike or a solitary flower. The flowers are bisexual, rarely unisexual zygomorphic usually resupinate resulting in 180°shift of floral parts and epigynous (Simpson, 2010). Perianth biseriate, homochlamydeous (although outer and inner whorls are often differentiated), 3+3 apotepalous or basally syntepalous, extremely variable in shape and color, sometimes spurred or with large sac like tepal.

The stamen in most species of Orchidaceae is solitary, often seen with two vestigial staminodes. The androecium is fused with style and stigma to form the gynostemium (also called as column or gynostegium). Pollen is found in form of pollinia. The pollen consists of tetrads units in most family members, but may be in form of massulae or monads in various groups. Gynoecium is syncarpous, with an inferior ovary, 3 carpels and 1-3 locules.

The style is solitary and terminal and is the major component of gynostemium, a single enlarged lobe termed 'rostellum' and interpreted as part of the stigma.

Placentation parietal or axile, ovules anatropous usually bitegmic with many ovules per carpel. Nectaries present, variable in position and type. Fruit is a loculicidal capsule or rarely a berry. Seeds often membranous-winged, helping in wind dispersal, exalbuminous, endosperm abortive early in development.

Pollination is effected by various insects (often one species having a specific association with one orchid species) birds, bats etc. (Simpson, 2010).

Orchids Examples: – *Epidendrum*, *Ludisia*, *Vanda*, *Cypripedium*, *Dendrobium*.

Orchidaceae are distinctive in consisting of mycorrhizal, mostly perennial, terrestrial or epiphytic herbs having trimerous, often resupinate flowers.

The orchidaceae were recently classified into five subfamilies:

- Apostasioideae (2-3 stamen, axile placentation, lack pollinia)
- Vanilloideae (1 stamen, parietal placentation)

- Cypripedioideae (2 stamens, parietal placentation, lack pollinia)
- Orchidoideae (1 stamen, parietal placentation, pollinia present)
- Epidendroideae (1 stamen, parietal placentation, pollinia present)

5.3.4 Ranales

Ranales are an obsolete taxon of the Dicotyledons, (no longer in existence in current classification systems) with rank of order typified by Ranunculus (Ranunculaceae).

In the Bentham and Hooker classification system (1862-1883), the Ranales were the first cohort of the Thalamiflorae with eight families:

- Ranunculaceae
- Dilleniaceae
- Calycanthaceae
- Magnoliaceae
- Annonaceae
- Menispermaceae
- Berberideae
- Nymphaeceae

Bessey (1915) made it a much larger entity within the Strobiloideae with twenty four families. Later, Hutchinson (1959), circumscribed Ranales more narrowly with only four families (i.e., Ranunculaceae, Cabombaceae, Ceratophyllaceae, Nymphaeaceae) with Archychlamydeae.

Melchior (1964) preferred using Ranunculales to include the Ranunculaceae within Archychlamydeae, the term which is still in use including seven families.

Ranunculales has been used by most subsequent systems with the exception of Thorne (1992). The current APG system uses Ranunculales in the Eudicot clade with seven families.

5.3.5 Some Families of Angiosperms Monocotyledons

Hydrocharitaceae

Hydrocharitaceae, the frog's-bit family of monocotyledonous flowering plants, with some 18 cosmopolitan genera of submerged and emergent freshwater and saltwater aquatic herbs. The largest genera are *Najas* (37–40 species), *Ottelia* (some 21 species), *Lagarosiphon* (9 or 10 species), *Blyxa* (9 or 10 species), *Halophila* (some 10 species), *Vallisneria* (6–10 species), and *Elodea* (5 or 6 species). The three genera *Thalassia* (2 species), *Enhalus* (1 species), and *Halophilaare* marine plants, and the rest grow in fresh or brackish water. The family is a member of the order Alismatales.

Members of Hydrocharitaceae are generally dioecious (individuals are either male or female) and produce radially symmetrical flowers. The female flowers have an inferior ovary (i.e., positioned below the attachment point of the sepals and petals), and the inflorescences are usually subtended by two bracts (modified leaves). The leaves are produced in whorls or clusters at numerous points along the stems, which may be erect or floating. Many species have rhizomes(modified rootlike stems) or stolons and can reproduce asexually.

The family is notable for the unique pollination mechanism of some genera (for example, El*odea, Enhalus, Hydrilla,* and *Vallisneria*). The male flowers become detached and float about until they encounter and transfer pollen to a female flower, which has reached the surface of the water by means of an elongated stalk. After pollination, the developing fruit is drawn under the water to finish ripening.

Other genera are pollinated by wind, insects, or water. Many produce special stems with turions (leaflike buds) that drop off and spend the winter in the bottom mud as a form of asexual reproduction (i.e., *Hydrocharis, Stratiotes,* and *Elodea*).

Several members of the family are cultivated or are otherwise economically important. Elodea, for example, is used in aquariums as an ornamental plant and in schools as an experimental plant. The common frog's-bit (*Hydrocharis morsus-ranae*), from which the family receives its common name, is an ornamental rootless water plant with round or heart-shaped floating leaves and small attractive three-petaled white flowers. The water soldier (*Stratiotes aloides*) bears rosettes of tough sharp-edged leaves that float in summer but sink and decay in the autumn. Vallisneria spiralis and V. americana are two eelgrasses commonly used as aquarium plants. Turtle grass (*Thalassia* species) is often washed ashore in such quantities following storms at sea that it is collected and used as a fertilizer. Hydrilla verticillata, the sole member of its genus, is a troublesome aquatic weed in many places.

Dioscoreaceae, the yam family of the flowering plant order Dioscoreales, consisting of 4 genera and 870 species of herbaceous or woody vines and shrubs, distributed throughout tropical and warm temperate regions. Members of the family have thick, sometimes woody roots or tuber-like underground stems and net-veined, often heart-shaped leaves that sometimes are lobed. The small green or white flowers of most species are borne in clusters in the leaf axils. The fruit is a winged capsule or a berry. Several species of yams (vines of the genus *Dioscorea*) are grown for their edible tuberous roots, such as Chinese yam, or cinnamon vine (D. *batatas*); air potato (D. *bulbifera*); and yampee, or cush-cush (D. *trifida*).

A few species are cultivated as ornamentals. Black bryony (*Tamus communis*) is a European perennial vine with yellow flowers, poisonous red berries, and poisonous blackish root tubers. *Dioscorea* is a principal raw material used in the manufacture of birth-control pills.

***Dioscoreaceae* - Yam Family**

Plants in the Yam Family (*Dioscoreaceae*) are herbaceous vines with twining stems, usually tuberous roots, simple or palmately compound leaves, unisexual flowers, and fruit in the form of longitudinally opening, 3-lobed or 3-angled seed capsules.

NOTES

Listed below (Refer Figure 5.11) is Hawaiian plants in this family.

Fig. 5.11 *Dioscorea Dioscorea bulbifera – Air Yam*

Plant Name

Scientific Name: *Dioscorea bulbifera*

Synonym: *Dioscorea latifolia*

Common Names: Air Yam, Air Potato, Bitter Yam, Aerial Yam, Potato Yam, Hoi, Pi'oi

Plant Characteristics

- **Duration:** Perennial
- **Growth Habit:** Vine, Herb/Forb
- **Hawaii Native Status:** Introduced. This naturalized Polynesian canoe plant and weed is native to Africa, Asia, and Australia.
- **Flower Color:** Pale green (female), White aging to purple (male)
- **Flowering Season:** Late summer, Early fall
- **Height:** Climbing up to 100 feet (30 m) tall
- **Description:** The plants are dioecious with male and female flowers on separate plants, however these plants rarely bloom. When present, the tiny flowers are in slender, pendent spikes or panicles at the leaf axils. The female flowers are followed by seed capsules that are only winged on the basal side. The leaves are large, green, hairless, untoothed, alternate, palmately veined from the leaf base, long-petioled, and broadly heart-shaped. The slender, twining, hairless, green to purple-flecked stems climb to the left (clockwise), are round to slightly angled in cross section, and have no spines. Rounded, up to 5 inch (13 cm) in diameter, potato-like bulbils

(aerial tubers) are formed on the stems at the leaf axils. The plants sometimes also have small underground tubers. Even when the plants are not producing seeds, they can be propagated by both the bulbils and tubers. Here in Hawaii, Air Yam grows in disturbed mesic (moderately wet) forests at lower elevations.

The similar Uhi or Water Yam (*Dioscorea alata*) has opposite leaves and stems that climb to the right (counterclockwise), while Pi'a or Five leaf Yam (*D. pentaphylla*) has compound leaves with 3 to 5 leaflets.

Special Characteristics

- **Canoe Plant** – Ancient Polynesians carried this plant to Hawaii in their canoes. They called it Hoi or Pi'oi and its poisonous if not properly prepared bulbils were eaten only in times of famine.
- **Edible** – The bulbils are poisonous, but they can become edible if well-rinsed in running water, boiled, and properly prepared by someone experienced with them. There are also more edible cultivated varieties. The other two yam species found here in Hawaii are not poisonous and are much better choices for eating.
- **Fragrant** – The male flowers are fragrant.
- **Poisonous** – The very bitter underground tubers and the improperly prepared bulbils are poisonous.

Classification

- **Kingdom:** Plantae – Plants
- **Subkingdom:** Tracheobionta – Vascular plants
- **Super Division:** Spermatophyta – Seed plants
- **Division:** Magnoliophyta – Flowering plants
- **Class:** Liliopsida – Monocotyledons
- **Subclass:** Liliidae
- **Order:** Liliales
- **Family:** Dioscoreaceae – Yam family
- **Genus:** *Dioscorea* L. – yam
- **Species:** *Dioscorea bulbifera* L. – air yam

More About This Plant

Dioscoreaceae is a family of mainly climbers whose best known members are the yams. The family Dioscoreaceae comes under the series Calycina of class Monocotyledons according to Bentham and Hookers (1862 -1883) system of classification. Members of the family have leaves with reticulate veins and occasional evidence of a second cotyledon in their embryo, (Lawton and Lawton, 1969) which are exceptional features for typical Monocotyledon family.

The family is distributed mainly in the tropical and temperate regions of the world. The family consists of six genera namely Trichopus, Stenomeris, Avetra, Dioscorea, Rajania and Tamus. Of these, Tamus is commonly found in temperate regions. All the remaining genera are mainly represented in the tropical regions of the world.

Trichopus is represented by a single species, Stenomeris by two species, Avetra by one species, Dioscorea by more than six hundred species, Rajania by twenty five species and Tamus by five species. All the genera except Trichopus, which is a dwarf shrub, are climbers.

Taxonomically the genus Dioscorea is divided into sections within which the species fall. The genus is divided into seven sections based on the nature of leaves, stamens, sepals, fruits and seeds, etc, in The Flora of British India (Hooker, 1892). It is directly divided 16 into species in The Flora of Presidency of Madras (Gamble, 1928). The direction of twining of the stem on support formed the basis of grouping of species. Engler and Prantl (1925) divided the genus into eight sections as follows; *Stenophora, Stenocorea, Combilium, Shannicorea, Opsophyton, Botryosicyos, Lasiophyton* and *Enantiophyllum.*.

The family Dioscoreaceae is represented mainly by the genera Dioscorea and Trichopus in Kerala state. The later genus has a single species Trichopus zeylanicus – an under shrub which gained much popularity recently for its acclaimed rejuvenating properties. The genus Dioscorea is represented by a number of species – both cultivated and wild. However, the identification and classification of the genus Dioscorea is rendered difficult because of the difficulty in species identification due to a high level of polymorphism with respect to morphological characters (Miege, 1952., 1954., Baquar, 1980., Zoundjihekpon et al, 1990).

Some species of Dioscorea produce bulbils from the leaf axils. The production of bulbils commence after a period of vegetative growth. Once started, the productions of bulbils continue till the end of vegetative growth. Bulbils vary much in their size, color, shape, 18 and weight. Under ideal humid conditions, these structures develop roots while attached to the parent plant. When mature, these get detached and develop into new plants. In many species of Dioscorea, bulbils form the main method of propagation.

5.3.6 Dicotyledon

***Sapotaceae*: Characterstics, Distribution and Economic Importance**

Characteristics of *Sapotaceae*

Trees and shrubs with laticiferous vessels; Leaves, flowers and fruits often clothed with hairs; flower hermaphrodite, hypogynous, actinomorphic; sepals 2-8 in two isomerous whorls or 5 in one whorl, pelals 4-8 gamopetalous in one whorl, rarely double the sepals in two whorls; stamens epipetalous in 2-3 whorls, the outer antisepalous whorl reduced to staminodes or absent; carpels many, syncarpous; ovary superior, completely separated, many chambered, axile placentation.

A.Vegetative Characteristics

Habit: Trees or shrubs with laticiferous milky sap.

Root: Tap, branched.

Stem: Erect, woody, branched.

Leaf: Simple, alternate or opposite usually entire, coriaccous, sometimes stipulate, hairy leathery.

B. Floral Characteristics

Inflorescence: Solitary or in cymose clustes in the leaf axils or on old stems.

Flower: Actinomorphic, hermaphrodite, hypogynous, hairy bracteolate.

Calyx: Sepals 4-8, in two isomerous whorls or 5 in one whorl, free or slightly united at the base, imbricate persistent.

Corolla: Petals 4-8, more or less united, in one whorl or more rarely double the number of sepals in two whorls, united in semi-funnel shaped rotate or lenceolate corolla, corolla lobes imbricate or contorted in bud, rarely petals with dorsal appendages which resemble corolla lobes.

Androecium: Stamens 4-5, sometimes more, in 2 or 3 whorls of 4-5 each but usually only the inner whorl fertile, epipetalous, the outer whorl of steames reduced to staminodes; another bithecous, introrse dehiscing longitudinally.

Gynoecium: Carpels number is double that of stamens, syncarpous, superior ovary; with as many chambers as carpels, axile placentation, style simple; stigma inconspicuous and sticky ovule anatropous, integument one.

Fruit: Berry inner pulp lacticiferous.

Seed: Seeds few or one testa hard, shiny, endosperm oily.

Pollination: Entomophilous.

Floral formula:

$$\oplus, ⚥, K_{4-8 \text{ or } 5}, \overset{\frown}{C_{4-8}}\ A_{\alpha}\ G_{(\underline{\alpha})}.$$

Distribution of Sapotaceae

Sapotaceae includes 40 genera and 60 species of primarily tropical trees common in old world.

Economic Importance of Sapotaceae

- **Food:** Several species of Achras sapota (H. Chiku), Manilkara kauki (H. Khirini), Manilkara hexandra, Mimusops elengi (V. Maulsari), Bassia longifolia yield juicy edible fruits. (Note: the nomenclature of these species is unsettled and authorities on the family are not in accord to identify or names to be used).
- **Oil:** The seeds of Madhuca butyracca produce the vegetable butter called 'phulwa' used as cold cream, lip salve leminant and as substitute for ghee and for soap-making. The latex of Manilkara achras yeilds 'chickle' used for making chewing gum. An aromatic oil is obtained from the flowers of Mimusops elengi and is used in manufacture of perfumes.
- **Gutta percha:** It is obtained from latex of Mimusops, Palaquium gutta and Payena species.
- **Medicinal:** The bark of Bassia longifolia and Mimusops elengi is used in decoction as astringent and emollient and also as a cure for itches.

- **Timber:** The wood of Sideroxylon, Chrysophyllum and Bassia afford hard and useful timber.

Rubiaceae: Characterstics, Distribution and Types

Characters of *Rubiaceae*

Trees or herbs; leaves alternate or opposite; stipules interpetiolar or intrapetiolar, inflorescence cymose; flowers tetra or pentamerous, hermaphrodite, actinomorphic, epigynous, corolla, gamopetalous; stamens 4-5; epipetalous, introrse, dithecous; ovary inferior, bilocular with one or many ovules in each loculus; fruit capsule or berry.

A. Vegetative Characteristics

Habit: Mostly shrubs (Gardenia, Ixora, Mussaenda, Hamelia); trees (Morinda, Adina) and a few herbs (Galium, Rubia).

Root: Much branched tap root system.

Stem: Erect, herbaceous or woody or twinning (Manettia), climbing by hooks (Uncaria), branched, cylindrical or angular, hairy or smooth.

Leaves: Cauline, ramal, opposite or verticillate, simple, entire or toothed, stipulate, stipules bristle like (Pentas) and leafy (Galium, Rubia), stipules mostly interpetiolar or sometimes intrapetiolar; unicostate reticulate venation.

B. Floral Characteristics

Inflorescence: Solitary (Gardenia) usually cymose or globose head (Adina), or panicled cyme; may be axillary (Coffea arabica) or terminal cyme (Mussaenda glabra).

Flower: Actinomorphic, rarely zygomorphic (somewhat bilabiate as in Henriquezia), mostly hermaphrodite, rarely unisexual, epigynous, pedicellate or sessile (Greenia, Randia), bracteate or ebracteate, complete, tetra or pentamerous, cyclic, variously coloured.

Calyx: Sepals 4 or 5, gamosepalous, superior, sometimes one sepal modified into coloured bract like structure (Mussaenda), valvate.

Corolla: Petals 4 or 5, gamopetalous, lobed, generally funnel shaped (Asperula), tubular (Ixora), valvate to twisted or imbricate, superior.

Androecium: Stamens 4 or 5, rarely many (Gardenia), epipetalous, alternipetalous, inserted near the mouth of corolla tube, stamens dithecous, introrse, dehiscing longitudinally, superior.

Gynoecium: Bicarpellary, rarely polycarpellary, syncarpous, inferior rarely half inferior (Synaptanthera) or superior (Paganea), sometimes unilocular (Gardenia) with one to many anatropous ovules in each loculus, axile placentation (parietal placentation in Gardenia), style one sometimes bifid or multifid, stigma simple or bilobed.

Fruit: Capsular (Anotis), berry (Mussaenda, Hamelia, Ixora).

Seed: Endospermic, sometimes winged.

Pollination: Entomophilous; ant pollination is well known.

Distribution of *Rubiaceae*

It is commonly known as Madder or Coffee family. It includes 6000 species and 500 genera. In India it is represented by 551 species. The members of this family are distributed in tropics, sub-tropics and temperate regions.

Economic Importance of *Rubiaceae*

NOTES

Medicinal plants: Bark of Cinchona officinalis yields an alkaloid called Quinine which is the best remedy for malarial fever. The roots of Rubia cordifolia are also used as medicine.

Beverage plants: The seeds of Coffea arabica, C. liberica and C. robusta are roasted and ground to give coffee powder.

Ornamental plants: Rubia, Hamelia, Gardenia, Ixora, Mussaenda are cultivated in gardens for their beautiful flowers.

Primitive Characteristics

- Plants mostly trees and shrubs.
- Leaves simple and stipulate.
- Flowers mostly hermaphrodite and actinomorphic.
- Stamens polyandrous.
- Ovules anatropous and many in some genera.
- Seeds endospermic.

Advanced Characteristics

- A few plants are herbs (Rubia, Galium).
- Leaves opposite or whorled.
- Flowers epigynous and rarely unisexual, zygomorphic.
- Calyx and corolla fused.
- Stamens epipetalous.
- Carpel number reduced to two.
- Fruit simple.

Common Plant of the Family

- Coffea arabica (Coffee): An evergreen shrub, cultivated for seeds.
- Cinchona officinalis (Quinine): Tree cultivated for medicinal importance.
- Hamelia: A large evergreen shrub with reduced flowers.
- Rubia: A common climbing herb.
- Gardenia: A resinous shrub or tree.
- Ixora: Evergreen shrub with showy flowers. Many species are cultivated in gardens as ornamentals.
- Mussaenda: A shrub, very conspicuous during flowering.

Ramal and cauline, simple, opposite decussate, sub-sessile, interpetiolar stipules are present, lanceolate, entire, acute, unicostate reticulate.

3. Mussaenda (Refer Figure 5.12)

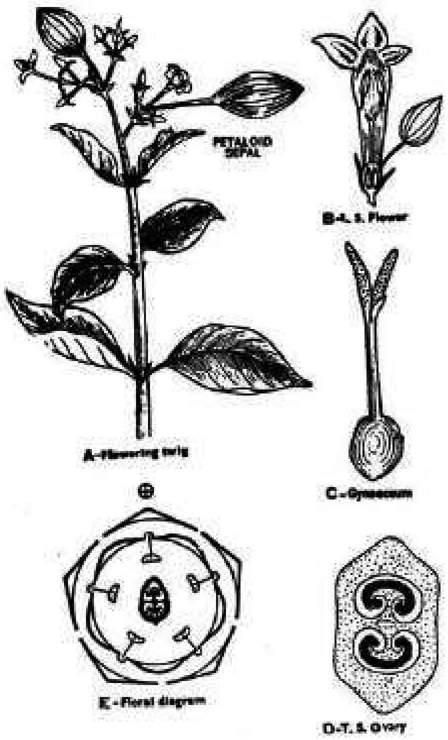

Fig. 5.12 *Mussaenda*

Habit: An ornamental, perennial, evergreen, shrub.

Root: Branched, tap root.

Stem: Herbaceous but woody in the lower portions, erect, cylindrical, branched, differentiating into nodes and internodes; internodes are swollen, hairy and green.

Leaf: Ramal and cauline, simple, opposite decussate, sub-sessile, interpetiolar stipules are present, lanceolate, entire, acute, unicostate reticulate.

Inflorescence: Dichasial cyme.

Flower: Bracteate, pedicellate, complete, hermaphrodite, actinomorphic but mature and older flowers are zygomorphic, pentamerous, epigynous, whitish yellow.

Calyx: Sepals 5, polysepalous or sometimes gamosepalous; 4 sepals are smaller and 5th one is modified into a yellow leafy bract in zygomorphic flowers; all sepals are of same shape, size and colour in actinomorphic flowers; persistent, valvate, green.

Corolla: Petals 5, gamopetalous, corolla tube is elongated and funnel shaped, valvate or rarely imbricate, yellow; coronary structures are present in the form of silky hairs.

Androecium: Stamens 5, alternipetalous, polyandrous, epipetalous, dithecous, basifixed or dorsifixed introrse.

Gynoecium: Bicarpellary, syncarpous, inferior, bilocular, many ovules, axile placentation; style long with two stigmatic lobes.

Fruit: A berry.

Seed: Many, small, endospermic.

Floral formula – (a) Young Flower – Br, $\oplus$ ⚥, K_5, $C_{(5)}$ A_2, $G_{(\overline{2})}$.

(b) Older flower – Br, $\oplus$, ⚥ K_5, $C_{(5)}$ A_5, $G_{(2)}$.

Common Plants of the Family

- Dichopsis pentaphylla: Indian butter tree.
- Madhuca butyracea: Mohwa tree.
- Palaquiu gutta: Common tree in Malaya and South India.
- Mimusops elengi: Bulbet-wood tree or the Indian medlar tree. Molsari.
- Bassia: Large handsome tree.

'Check Your Progress'

5. What are taxonomic group?
6. Define the term species.
7. What is genus and family?

5.4 SUMMARY

- Plant classification is the placement of plants or its allied groups in separate compartments at different levels based on phenetic similarities, phylogenetic relationships or merely based on artificial criteria.
- Plants can be classified in many different ways based on certain important characters like presence or absence of seed, whether the plant beans flowers or not, etc.
- Radford (1986) stated that 'classification is the arrangement of groups of plants with particular circumscriptions by rank and position according to artificial criteria, phenetic similarities or phylogenetic relationships'.
- Artificial classification system is the earliest systems of classification which remained dominant from 300 B.C. up to about 1830 were artificial systems, which were based on one or a few easily observable characters of plants, such as habit (trees, shrubs, herbs, etc.) or floral characters (particularly the number of stamens and carpels).
- Theophrastus (370 – 285 BC), a Greek philosopher, in his book Historia Plantarum classified about 480 plants into four groups on the basis of their habit-herbs, undershrub's, shrubs and trees.
- Otto Brunfels (1464-1534) for the first time classified plants into Perfecti and Imperfect based on the presence or absence of flowers.
- Andrea Caesalpino (1519-1603), an Italian botanist and Physician, in his book De Plant is classified about 1500 plants on the basis of habit (herbs and trees) and then subdivided them on the basis of fruits and seeds which they produced.
- In Natural system of classification (from 1760-1880) the plants were classified on the basis of their natural affinities (i.e., the basic similarities in the morphology). This system of classification used as many taxonomic characters as possible to group taxa.

- In Natural system of classification (from 1760-1880) the plants were grouped and placed into different taxa like classes, orders, families and genera.
- The first scientist to reject all the artificial systems and support the natural system of classification was Michel Adanson (1727-1806). Other botanist supporting this system of classification were A.L. de Jussieu (1748-1836) and his three family members (Antoine, Bernard and Joseph).
- A.P. de Candolle (1778-1841) and his son Alphonse (1806-1893) and Bentham (1800-1884) and Hooker (1817-1911). It starts with Bernard de Jussieu (1699-1777) who was a contemporary of Linnaeus. He modified the system of Linnaeus by dividing the flowering plants into Monocots and Dicots based on position of ovary, free or fused petals.
- Bentham and Hooker's classification is the most important and the last of the natural systems of classification of seed plants was proposed by two British taxonomists George Bentham (1800-1884), a self trained botanist, and Joseph Dalton Hooker (1817-1911), the first director of the Royal Botanical Garden, Kew (England).
- Phylogenetic system of classification came up after Darwin's theory of evolution was proposed and widely accepted. These systems used as many taxonomic characters as possible in addition to phylogenetic (evolutionary) interpretations.
- Some of the scientist who proposed phylogenetic system of classification were Engler and Prantl (1849-1893), Hutchinson (1884-1972), Bessey (1845-1915), Takhtajan (1910-2009), Cronquist (1919-1992) and more. In this system the first to practice is August Wilhelm Eichler's (1839-1887). He only modified Bentham and Hooker's system by placing gymnosperm before angiosperms (Dicot and Monocot).
- Engler and Prantl (1884-1930) published detailed classification in 23 volumes of 'Die Naturlichen Pflanzenfamilien'. They arranged flowering plants according to increasing complexity of their floral morphology. They considered monocot' primitive than dicots.
- John Hutchinson (1884-1972) was author of 'Families of flowering plants' (in 2 volumes) and director of Royal Botanic Garden at Kew, England. Classification proposed by him was based on 24 principles. This system is mostly followed. They placed monocots after dictos.
- John Hutchinson (1884-1972) a British botanist proposed the most widely used classification which is also known as the Hutchinson's classification. Hutchinson was associated with the Royal Botanic Garden's Kew, England and also served as keeper of Kew Herbarium for many years.
- Hutchinson's system is a phylogenetic system that classified plants. It is systematic and grouped plants based on evolution along with morphological features.
- The system of classification was based on the principles followed by 'Bessey'. The system of classification was revised in British flowering plants (1948) and later in the second edition of 'The Families of Flowering Plants' (1959).
- The principles of Hutchinson system are more like Besseyan system of classification than the Englerian system. In addition to the system of classification for angiosperms, Hutchinson also published other valuable works, such as Flora of West Tropical Africa (1927-29), Common wild flowers (1945).
- A Botanist in South Africa (1946), Evolution and classification of Rhododendrons (1946), British Flowering Plants (1948), British Wild Flowers (1955) and Key to the families of flowering plants of the world (1968).

NOTES

- Hutchinson also made efforts revising '*Genera plantarum*' of Bentham and Hooker under the title 'Genera of Flowering Plants', but could complete only 2 volumes of '*Genera plantarum*' published in 1964 and 1967. The work was left incomplete due to his demise.
- Spirally imbricate floral parts are more primitive than whorled and valvate arrangement.
- Polymerous flowers precedes oligomerous flowers.
- Petaloid flowers are more primitive than apetalous flowers, the latter being the result of reduction.
- Gamopetally is more advanced than polypetalae.
- Actinomorphic flowers are considered primitive then zygomorphic flowers.
- Free carpels (apocarpous condition) are more primitive than fused carpels (syncarpy condition).
- Flowers with numerous stamens are more primitive than those with fewer stamens.
- Endospermic seeds with small embryo are more primitive than non-endospermic seeds with large embryo.
- Hypogynous condition is considered more primitive and from it perigynous and epigynous conditions were derived.
- Parietal placentation is more primitive than axial and free central placentation.
- Aggregate fruits are more evolved than single fruit and capsules precedes berry or drupe.
- Asteridae in this system was split up into two subclasses: Lamiidae and Asteridae. This has resulted in more rational distribution of sympetalous families.
- Nymphaeales, placed within dicots earlier, has been placed in a distinct subclass Nymphaeidae under Magnoliopsida.
- Asclepiadaceae merged with Apocyanaceae has been supported by the other contemporaries (Judd *et al.* 1994).
- Taxonomic groups or Taxa are arranged in order of their successive inclusiveness, the least inclusive at the bottom (usually a species), and the most inclusive at the top (usually a division).
- A species is a group of individuals which resemble each other very closely and share common taxonomic features and can interbreed. Those species which share many common characters are placed together in a larger group called genus, these in turn are arranged in a larger group called family and then in order and so on.
- Magnoliales comprises of primitive families, mostly distributed in the tropics and subtropics of the Southern hemisphere.
- Plants evergreen or deciduous, usually large to medium sized trees or shrubs. Leaves simple, mostly alternate in the order Magnoliales. Flowers usually solitary, large and showy.
- Numerous whorls of sepals and petals and indefinite number of stamens arranged spirally. Gynoecium monocarpellary or multi-carpelled and apocarpous.
- Wood anatomy shows presence of primitive vessels with scalariform end-walls.
- Pollen grains are usually shed at 2-celled stage. Ovules anatropous, bitegmic, crassinucellate. Most of the members of the order Magnoliales are rich in alkaloids.

- The family Myristicaceae included in Magnoliales, containing *Myristica fragrans*, from which are derived nutmeg and mace (from the seeds and aril respectively) is notable among others families.
- A relatively recent name as early systems used descriptive botanical names for the order containing orchids.
- The Bentham and Hooker and the 'Engler and Prantl' system of classifications had placed the orchids in order Microspermae while the 'Wettstein' system treats them as order Gynandrae. Circumscription of the order varies with the taxonomic system being used.
- *Orchidales* includes tropical epiphytes and small herbs and do not have a fossil record. However, like palms and some members of the Iridales, they have plicate (corrugated) leaves, and these leaf forms are among the earliest known fossil monocots.
- *Orchidales* comprising of Orchidaceae family consisted of large terrestrial plants, but like *Bromeliads*, Orchids took to trees, where they have diversified to become the largest family of flowering plants.
- Ranales are an obsolete taxon of the Dicotyledons, (no longer in existence in current classification systems) with rank of order typified by *Ranunculus (Ranunculaceae)*.

5.5 KEY TERMS

- **Phenetic:** Classification based on overall similarity, usually in morphology or other observable traits, not taking into account phylogeny or evolutionary relationship.
- **Circumscription:** In taxonomy, circumscription is the definition of a taxon, that is, group of organisms.
- **Phylogenetics:** Phylogenetic methods include cladistics. Developing a classification based on analysis of phylogenetic data.
- **Cladistics:** It is an approach to biological classification in which organisms are categorized in groups (clades) based on the most recent common ancestor.

5.6 ANSWERS TO 'CHECK YOUR PROGRESS'

1. Taxonomic literature described three major system of classification, .i.e., as follows:
   - Artificial Systems
   - Natural Systems
   - Phylogenetic Systems
2. Artificial Classification System: The earliest systems of classification which remained dominant from 300 B.C. up to about 1830 were artificial systems, which were based on one or a few easily observable characters of plants, such as habit (trees, shrubs, herbs, etc.) or floral characters (particularly the number of stamens and carpels).These systems use the habit and importance to man as the taxonomic characters, .i.e., based on superficial characters.
3. Natural system of classification (from 1760-1880): In this system the plants were classified on the basis of their natural affinities (i.e. the basic similarities in the morphology). This system of classification used as many taxonomic characters as

possible to group taxa. So in this system, the plants were grouped and placed into different taxa like classes, orders, families and genera. The first scientist to reject all the artificial systems and support the natural system of classification was Michel Adanson (1727-1806).

4. Phylogenetic System of Classification: These classification systems came up after Darwin's theory of evolution was proposed and widely accepted. These systems used as many taxonomic characters as possible in addition to phylogenetic (evolutionary) interpretations. Some of the scientist who proposed phylogenetic system of classification were Engler and Prantl (1849-1893), Hutchinson (1884-1972), Bessey (1845-1915), Takhtajan (1910-2009), Cronquist (1919-1992) and more. In this system the first to practice is August Wilhelm Eichler's (1839-1887). He only modified Bentham and Hooker's system by placing gymnosperm before angiosperms (Dicot and Monocot).
5. Taxonomic groups or Taxa are arranged in order of their successive inclusiveness, the least inclusive at the bottom (usually a species), and the most inclusive at the top (usually a division).
6. A species is a group of individuals which resemble each other very closely and share common taxonomic features and can interbreed.
7. Those species which share many common characters are placed together in a larger group called genus, these in turn are arranged in a larger group called family and then in order and so on.

5.7 QUESTIONS AND EXERCISES

Short-Answer Questions

1. What is a classification system?
2. What is artificial system of classification?
3. What is natural system of classification?
4. What is phylogenetic system of classification?
5. Write about some of the phylogenetic systems.
6. Give merits of Bentham and Hooker's system.
7. Write short note on Oorder Magnoliales.
8. Write short note on Caryophyllales.

Long-Answer Questions

1. State the major principles of classification of angiosperm given by Hutchinson?
2. Define the three different system of classification.
3. What are the merits of Hutchinson system of classification over other system of classification?
4. Describe in detail the system of classification proposed by Bentham and Hooker.
5. Compare the classification system proposed by Hutchinson with that of Takhtajan.
6. What are the merits demerits of Takhtajan's system of classification?
7. Why is Bentham and Hooker's system of classification still being used in plant identification?

8. State the major principles of Cronquist's system of classification along with its merits and demerits.
9. Discuss in detail about the distinctive taxonomic features of angiospermic orders.

5.8 FURTHER READING

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