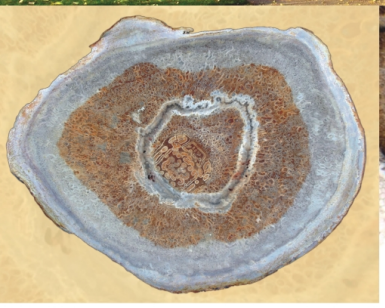
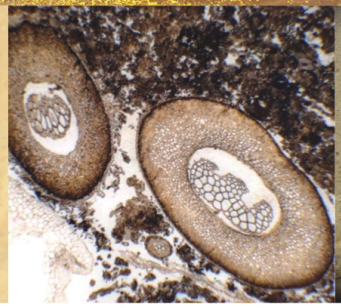
An Introduction to Gymnosperms and Paleobotany



Authors
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A Text Book

of

An Introduction to Gymnosperms and Paleobotany

[For University and College Students in India & Abroad]

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PREFACE

The book entitled “An Introduction to Gymnosperms and Paleobotany” has been planned and designed for the undergraduate students and covers the syllabi in the subject prescribed by most of the Universities in India. A part of the book is compilation from several standard texts and monographs to provide the description of the genera *Cycas, Pinus* and *Ephedra* in a simple language and the other is summarized account of each part of these genera and their life cycle, which is planned in a way quite useful for comparative study, understanding the diversity and answering the objective and other type of questions, conveniently. Hope this innovation will be more purposeful and interesting to both students and teachers. We are indebted to the numerous authors and publishers of various standard works, which have been consulted while preparing the manuscript.

One of the authors, Dr. Gopal Chandra, expresses his deep appreciation to his wife Prof. Smt. Lakshmi for her constant inspiration and helpful criticism during the preparation of the book.

We are greatly indebted to Maharana Pratap Post Graduate College, Jungle Dhusan, Gorakhpur (U.P.) for having undertaken the publication of this book in a neat and presentable form.

Vijayadashmi, 11.10.2016
Gorakhpur

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PART

I

Chapter-1

The Gymnosperms

1. Introduction

The term Gymnosperm (*gymnos* = naked, *sperma* = seed) means naked seed. It was first used by Theophrastus in 300 BC. The plants included in this group of vascular plants are characterized by presence of naked seeds. The seed of gymnospermous plants is the result of the fertilization of egg (usually within the archegoniun) and enlargement of the enclosing ovule or integumented megasporangium (nucellus). The ovules are produced in exposed position (i.e. naked) on the sporophylls or equivalent organs. The fertilized eggs (zygote, 2 n) develop into an embryo embedded in the nutritive tissue of female gametophyte, the endosperm is enclosed in the integument of the ovule. The integument hardens to form a protective covering called seed coat.

A gymnospermous seed, thus, consists of three parts, all of different generations:

1. Seed coat and nucellus belonging to parent sporophyte or old generation (diploid),
2. The female gametophyte or endosperm, representing the present generation (haploid),
3. The embryo representing the new sporophyte or future generation (diploid).

1.1. General Characters

Habit and Habitat :

Gymnosperms are mostly tree or shrub like in habit. They are usually xerophytes.

External Structure :

The plant body is usually differentiated into root, stem and leaves.

Root :

A tap root system is present.

Stem :

It may be unbranched (e.g. in *Cycas*) or branched (e.g. in *Pinus*). Shoots are of two types; the long and dwarf (spur) in *Pinus*.

Leaves :

The leaves may be of two types (dimorphic), the green photosynthetic foliage leaves and the scale leaves, in *Ephedra*, only scale leaves are present.

Foliage leaves are large and pinnate in *Cycas* but needle like in *Pinus*.

A large leaf branching like a fern frond may be called megaphyll and a small leaf microphyll.

Internal Structure

Root :

Vascular bundles radial, xylem exarch.

Stem :

Vascular bundles collateral, conjoint, endarch and arranged in a ring. There is a well marked secondary growth on account of the activity of cambium. In *Cycas*, the first formed cambium ring is short lived functioning only for a short time.

Xylem consists of only tracheids and xylem parenchyma. Xylem vessels are present only in the *Ephedra*, phloem consists only of sieve tubes and phloem parenchyma.

Secondary wood or xylem is manoxylic (e.g. in *Cycas*) or pycnoxylic (e.g. in *Pinus*). Manoxylic wood is soft and relatively sparse (not compact) with very wide parenchyma rays, where as pycnoxylic wood is compact or dense with very narrow rays. The pith and cortex are very small in *Pinus* and the wood forms the main bulk of the stem and branches. Usually the manoxylic wood is found in megaphyllous genera which have radially symmetrical seeds while the pycnoxylic wood occurs in

microphyllous genera which have bilaterally symmetrical seeds.

Leaves :

It shows xerophytic characters with thick cuticle and sunken stomata.

Reproductive Organs

Cones :

The reproductive organs are arranged in the form of cones, the male or micro sporangiate cone and female or megasporangiate cone. The cone is also called strobilus by same botanists. A cone usually consists of an axis with spirally arranged micro or mega sporophylls bearing micro or mega sporangia accordingly. In case of female *Cycas* plant, a structure as called female cone is not formed and the megasporophylls remain spirally arranged like the leaves.

Microsporangia (pollen sacs) may be numerous on a microsporophyll e.g. in *Cycas* or only two in number e.g. in *Pinus*. They are born usually on the lower or the abaxial surface. Numerous microspores are formed in each microsporoangium.

Megasporangia is integumented (ovules). It is generally orthotropous. The body of ovule is called nucellus and is made up of parenchymatous cells. The upper free end of nucellus is surrounded by a collar-like structure called integument. The integument has an opening called micropyle. There is only a single integument in the ovule of all living gymnosperms (except in members of gnetales, where there are two integuments). The integument is differentiated into three layers: an outer fleshy (sarcotesta), a middle stony (sclerotesta) and an inner fleshy (inner sarcotesta).

A linear tetrad of four haploid megaspores is formed deep in nucellus by meiosis as the result of a single megaspore mother cell. Only one megaspore, the lowest is functional.

Spores :

Spores are of two types, the so-called microspore (pollen) produced in microsporangia and the megaspores produced in megasporangia or ovule and, these, in turn, are products of meiotic division of spore mother cells. There may not be any distinction in the size of the two (as found in pteridophytes) and, in some cycads, the microspore may actually be larger than the megaspore, spore gives rise to gametophytes which are endosporic, not green and physiologically dependent upon the sporophyte.

Male Gametophyte

The endosporic male gametophyte becomes partially developed by the time of the dehiscence of microsporangium. Numerous microspores (pollen) are produced in each microsporangium. The male gametophyte may have one (as in *Cycas*) or two prothallial cells (as in *Pinus*).

Female Gametophyte

The functional megaspore is away from the micropyle being seated deep within the nucellus of the megasporangium or ovule and it is never released. The megaspore enlarges and develops to form an endosporic female gametophyte, which remains enclosed in the megaspore wall.

1.2. Pteridophyta versus Gymnosperm

The gymnospermous plants differ from the lower vascular plants, the pteridophytes, with respect to certain characters.

Habitat and Habit :

Pteridophytes : These plants are mostly hygrophytic.

Gymnosperms : These are mostly xerophytic and exhibit the characters accordingly, particularly in the leaves.

Root :

Pteridophytes : Only adventitious roots present.

Gymnosperms : A tap root system is present.

Secondary Growth :

Pteridophytes : A cambium is lacking and secondary growth does not occur.

Gymnosperms : Secondary growth occurs.

Reproductive Cycle: Sporophylls, Sporangia and Spores

Pteridophytes :

In majority of the plants only one type of sporangia occurs while in others the sporangia are of two types, the microsporangia and the megasporangia. Plants, with

one type of sporangia produce only one type of spore. The other plants produce spores of two types, the small microspore and the larger megaspore. The spores in turn are product of the reduction (meiotic) division of spore mother cell or cells within the sporangium. Spores are shed at maturity and form independent gametophyte with sex organs. Fertilization necessitates presence of external water for swimming of antherozoids to the neck of the archegonia called zooidogamy. Fertilized egg (zygote) forms embryo developing into young sporophyte plant. The period of attachment and physiological dependence of the young sporophyte upon the gametophyte generation varies considerably.

Gymnosperms :

In all gymnosperms, the sporangia are of two types; the microsporangia (produced on respective sporophylls). Thus, the spores are also of two types; the so-called microspores and the megaspores and, these, in turn, are products of meiotic divisions of spore mother cells. There may not be any distinction in the size of the two as found in pteridophytes and, in some cycads, the microspore may actually be larger than the megaspore. The gametophytes of the gymnosperms are non-green and physiologically dependent upon the sporophyte.

The endosporic male gametophyte becomes partially developed by the time of the dehiscence of microsporangium. Numerous microspores are produced in each microsporangium. But, there is only one functional megaspore deeply seated within the tissue of the megasporangium (ovule) and it is never released. The megaspore enlarges and develops to form an endosporic female gametophyte (endosperm), which is nourished and protected by the surrounding tissues, the nucellus of the ovule. The retention of the megaspore its growth and development “into a female gametophyte within its own integumented megasporangium (ovule) leads to the formation of the seed”.

1.3. Gymnospermous Ovule

The Ovule :

The body of ovule is called nucellus and is made up of parenchymatous cells. The upper free end of the nucellus is surrounded by a collar-like structure called integument. The integument has an opening called micropyle. There is only a single integument in the ovule of all living gymnosperms except in *Gnetum, Welwitschia*

and *Ephedra* where there are two integuments. The integument is differentiated into three layers: an outer fleshy (sarcotesta), a middle stony (sclerotesta) and an inner fleshy (inner sarcotesta). In the mature seeds the inner fleshy layer appears only as a papery layer linining the inside of the stony layer.

The Female Gametophyte (Female prothallus or endosperm) :

In the development of female gametophyte, first, there occurs free nuclear division within the megaspore, which is followed by wall formation. Wall formation begins at the periphery and proceeds towards the centre resulting in a complete cellular gametophyte with reserve food material. This structure remains enclosed in the megaspore wall.

Two to many archegonia are formed from superficial cells of the gametophyte near the micropylar end. The living gymnosperm are thus archegoniate plants, with the exception of *Gnetum* and *Welwitschia*. The archegoniun encloses an egg (female gamete) and a ventral canal nucleus. Neck canal cells are absent.

Pollination, Formation of Pollen Tube and Fertilization :

Pollens or partly developed endosporic male gametophytes are carried usually by wind to the micropylar end of the ovule. The micropyle usually closes after the pollens are drawn down into the ovule. They now lie in pollen chamber in *Ginkgo*, *Cycas* and *Ephedra*. The pollen chamber is formed by the breaking down of apical region of the nucellus. There is no pollen chamber in conifers and the pollens remain in direct contact of the beak of the nucellus.

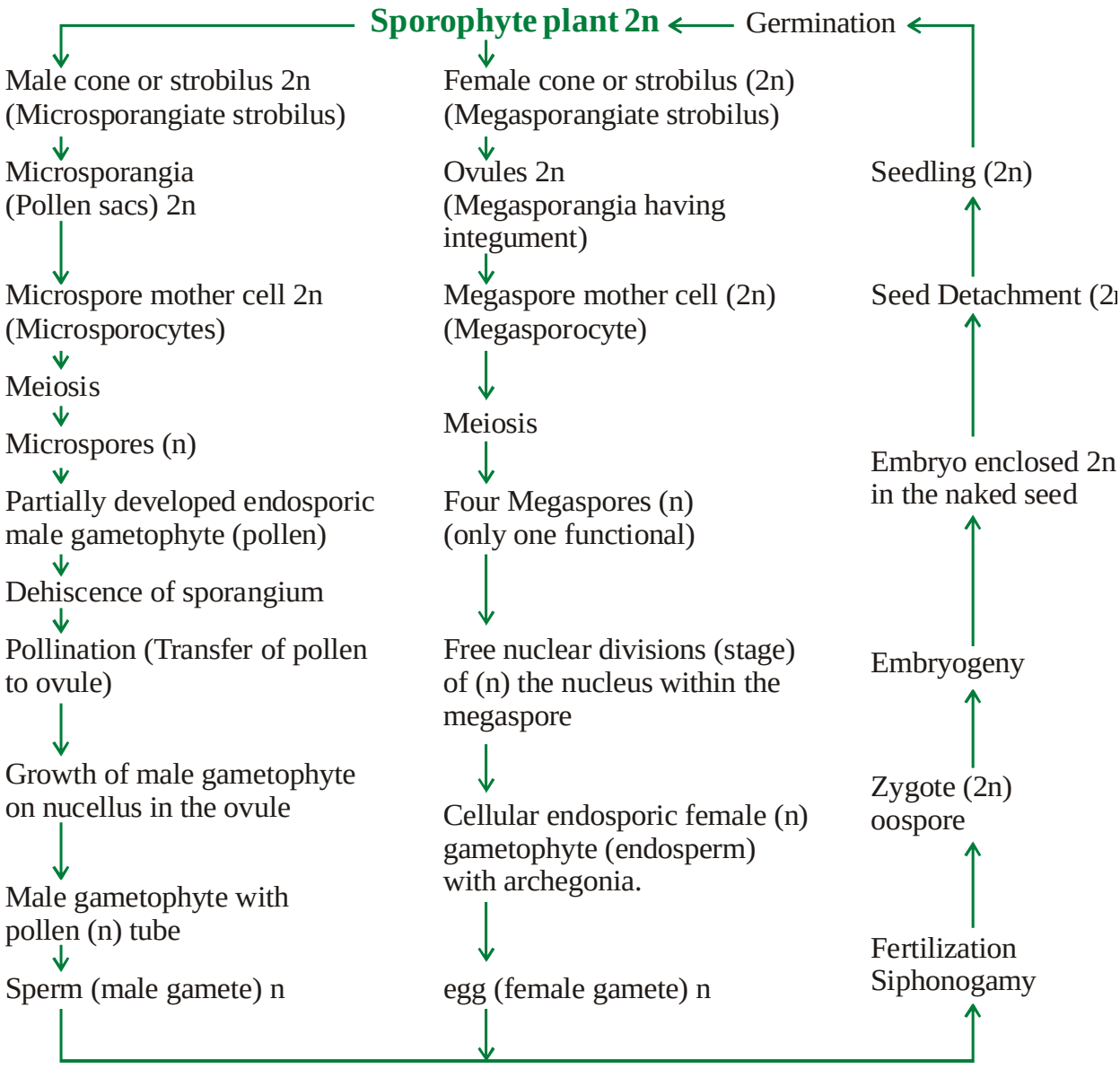
Pollens germinate to form tubular outgrowth, the pollen tube, which contains the gametophyte cells at the lower end. The end of the tube bursts releasing the two sperms or male gametes. The male gametes are released in a cavity above the female prothallus known as archegonial chamber or conveyed directly to the archegoniun in conifers. The archegonial chamber is formed by dissolution of the megaspore wall above the archegonia. On account of male gametes being carried in pollen tubes these plants have been called ‘Siphonogamous’ and the mode of fertilization Siphonogamy.

1.4. Gymnospermous Seed

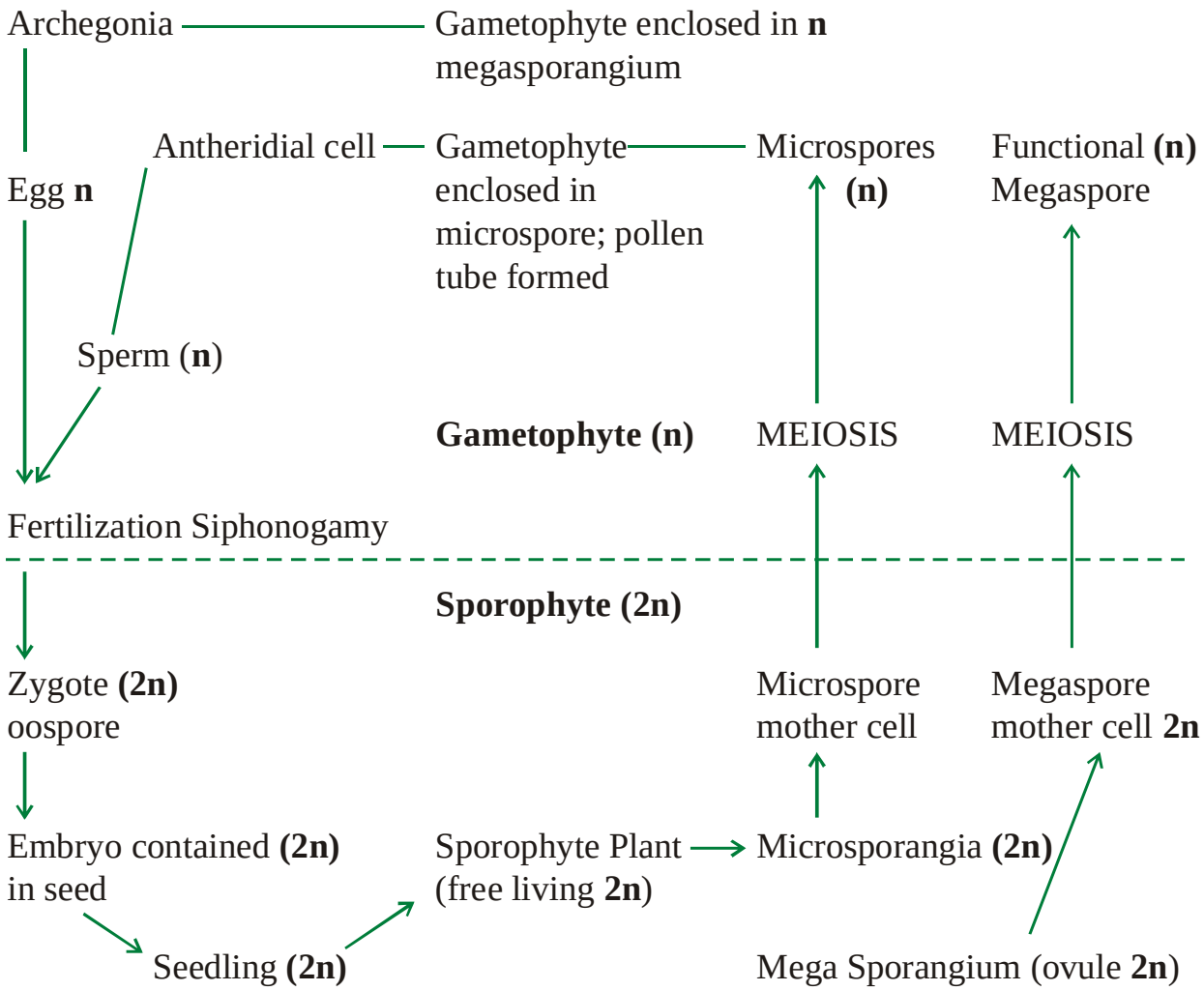
The fertilized zygote develops to form embryo. The type of embryo development in gymnosperms is known as meroblastic in which only a part of the zygote develops

into the embryo. The embryo becomes differentiated into an upper haustorial, middle suspensorial and the basal embryonal cells. During the development of embryo, there occurs the maturation of other parts of seed also. Nucellus disorganises or persists only as cap at the micropylar end. Inner fleshy layer (inner sarcotesta) is only as a paper layer lining inside the stony layer. The latter becomes extremely hard enclosing and protecting the female prothallus and the embryo. The embryo is usually straight and differentiated into a suspensor, shoot apex, cotyledons, hypocotyls and radicle.

The reproductive cycle in gymnospermous plants.



Life cycle of gymnospermous plants in brief



1.5. Classification and Systematic Position

Arnold's classification (1948) :

He dropped the original name gymnospermae

Division: Pteropsida

Class 1 – Pteridophyta (only ferns)

Class 2 – Cycadophyta

Class 3 – Coniferophyta

Class 4 – Chlamydospermophyta

Class 5 – Angiospermophyta

Pilger and Melchior (1954)

He classified the gymnosperms as follows :

Gymnosperms

A. Cycadopsida

1. Pteridospermales (Fossil)
2. Bennettitales (Fossil)
3. Pentoxylales (Fossil)
4. Cycadales

B. Coniferopsida

1. Cordaitales (Fossil)
2. Coniferales
3. Taxales
4. Ginkgoales

C. Gnetopsida

1. Gnetales

Sporne (1970) based his book "The Morphology of Gymnosperms" on this scheme.

D.D. Pant (1957).

This is a modification of Arnold's classification.

Gymnospermous Plants

Division I. Cycadophyta

Class 1. Pteridospermopsida
- Order 1. Lyginopteridales
- Order 2. Medullosales
- Order 3. Glossopteridales
- Order 4. Peltaspermales
- Order 5. Corystospermales
- Order 6. Caytoniales

Class 2. Cycadopsida

Division II. Chlamydospermophyta

Class 1. Gnetopsida
- Order 1. Gnetales
- Order 2. Welwitschiales

Division III. Coniferophyta

Class 1. Coniferopsida
- Order 1. Cordaitales
- Order 2. Coniferales
- Order 3. Ginkgoales

Order 7. Cycadales
Class 3. Pentoxylopsida
Order 8. Pentoxylales
Class 4. Cycadeoideoopsida
(Bennettitopsida)
Order 9. Cycadeoideales
(Bennettitales)
Class 2. Ephedropsida
Order 4. Ephedrales
Class 3. Czekanowskiopsida
Order 5. Czekanowskiales
Class 4. Taxopsida
Order 6. Taxales

It needs a mention here that in older systems of classification *Ephedra* was placed, along with two other genera *Welwitschia* and *Gnetum*, under family gnetaceae of the order gnetales. Later each genus was assigned to a separate family. Eames (1952) recognized three orders- ephedrales, welwitschiales and gnetales separately instead of one gnetales. Pant (1957) transferred the order ephedrales to the division coniferophyta, keeping in view the suggestion of Florin (1931, 1934) and Eames (1952). The order ephedrales was placed under class ephedropsida of division coniferophyta. A number of standard books, e.g. that of Sporne (1965, 1974); Foster and Giffords (1959, 1967) still include the three genera in the single order gnetales, but it is only for the sake of convenience and it is now very well realized that such a system of classification is probably artificial.

1.6. Affinities of Gymnosperms

In all the three groups of vascular plants namely, pteridophytes, gymnosperms and angiosperms, the sporophyte is independent and represented by the plant itself, which is differentiated into root, stem and leaf. The gametophyte is independent in lower pteridophytes, but there is gradual reduction and loss of independence of gametophyte from higher pteridophytes to gymnosperms and angiosperms. The gymnosperms are closely related to pteridophytes on one hand and to angiosperms on the other as they show many resemblances with both. However, the gymnospermous plants have their own specific characteristic (such as naked seed) and show differences with both, the pteridophytes (having no seed) and angiosperms (having seed covered in fruit).

Resemblances with Pteridophytes :

1. Many extinct gymnosperms, particularly, pteridospermales, possessed fern-like foliage and general appearance of the living gymnosperms.This group of

gymnosperms has also been called seed ferns. Cycads resemble the ferns in pinnately compound nature of their leaves and circinate vernation.

2. Xylem is devoid of vessels in both the pteridophytes and gymnosperms, except *Ephedra*, *Welwitschia* and *Gnetum* where the vessels are present. Also, phloem lacks sieve tubes in both the taxa.
3. All the gymnosperms are heterosporous producing two types of spores namely microspores and megaspores. A number of pteridophytes e.g. *Selaginella*, *Marselia* etc are also heterosporous.
4. Female prothallus or endosperm develops from the female gametophyte prior to fertilization.
5. Development of sporangia on sporophyll and formation of a compact strobilus or cone is a common feature both in the pteridophytes and gymnosperms (except in female plants of *Cycas*, where no cone is formed).
6. Sporangia occur in groups called sori in ferns as well as gymnosperms like *Cycas*.
7. Mobile and multiflagellate male gametes or antherozoids are present in the pteridophytes and cycadales.
8. Like heterosporous pteridophyte, e.g. *Selaginella* and *Marselia*, the megaspore is retained in the megasporangium till fertilization and embryo formation.

Dissimilarities with Pteridophyte :

1. Ovule (integumented megasporangia) as it occurs in gymnosperms is not found in pteridophytes. Gymnosperms are seed plants whereas pteridophytes are not so.
2. Gymnosperms, except *Ephedra*, are usually tree like in habit growing in xerophytic habitat but pteridophytes are mostly herbs or shrubs growing in moist shady places.
3. Gymnosperms bear a tap root whereas pteridophytes have adventitions roots.
4. A cambium is invariably present and therefore secondary growth occurs in all the gymnosperms but it is usually absent in pteridophytes.
5. Majority of pteridophytie plants are homosporous producing only one type of spore in contrast to two types of spores produced by gymnosperms.
6. The difference in the size of microspores and megaspores as found in heterosporous pteridophytes is lacking in gymnosperms. In heterosporous

pteridophytes the microspore is small and the megaspore is large whereas in gymnosperms there may not be any distinction in the size of the two and, as in some cycads, the microspore may actually be larger.

7. The gametophyte of gymnosperms is endosporic (remain enclosed in the spore-wall) non green, physiologically dependent upon the sporophyte and unisexual whereas in homosporous pteridophytes spores are shed at maturity and give rise to free living, green auto trophic bisexual prothalli or gametophyte.
8. Pollen tube is present in gymnosperms but absent in pteridophytes.
9. Neck canal cells are not found in the archegoniun of gymnosperms but they are present in pteridophytes.
10. Microspores (pollen grain) are dispersed by wind in gymnosperms but in ptreridophytes fertilization necessitates the presence of external water for swimming of antherozoid or male gamete to the neck of archegoniun (zooidogamy).

Resemblances with angiosperms :

1. Vascular bundles of stem are collateral, conjoint, open endarch and are arranged in a ring.
2. Secondary growth occurs due to the presence of cambium.
3. Vessels are present in xylem and companion cells occur in phloem in gnetales as in angiosperms.
4. Formation of flower like structure in highly evolved gymnosperms, the gnetales, is comparable to flowers of angiosperms. Strobili of gnetales are also similar to angiospermous inflorescence.
5. Pollination is by wind in gymnosperms as well as in many angiosperms.
6. Pollen tube is formed for carrying the male gamete to the egg.
7. Megaspore is retained inside the megasporangium (ovule) and develops into female gametophyte while still attached to the plant.
8. Formation of suspensor during embryo development.
9. Occurrence of polyembryony in some angiosperms like that of gymnosperms.
10. Development of ovules into seeds.

Dissimilarities with angiosperms :

1. The ovules are naked in gymnosperms whereas in angiosperms they are enclosed

within an ovary.

2. Vessels present in the xylem of angiosperms are absent in gymnosperms, except gnetales.
3. In the gymnosperms sieve cells and phloem parenchyma are found in the phloem whereas in angiosperms sieve tube and companion cells are present.
4. Ovary, style and stigma i.e. the carpel, as found in the angiosperms is absent in gymnosperms and pollen grains enter the ovule directly through the micropylar canal.
5. A cone like structure bearing sporophylls with sporangia as it occurs in gymnosperms is absent in angiosperms.
6. Prothallial cells present in the microspore (pollen grain) of gymnosperms are not found in angiosperms.
7. The female sex organ, called archegoniun, is absent in angiosperms but it occurs in the female gametophyte of all the gymnosperms, except in *Gnetum* and *Welwitschia*.
8. Pollination is only by wind in gymnosperms whereas in angiosperms it is by several agencies.
9. In gymnosperms (except gnetales), endosperm formation is a pre-fertilization phenomenon but in angiosperms, its formation is a post-fertilization phenomenon involving double fertilization or triple fusion. Thus, in gymnosperms, endosperm is a haploid but in angiosperms it is triploid usually.
10. The free nuclear division of zygote, occurring in gymnosperms is not found in angiosperms.

We have seen that the gymnosperms although resemble both with pteridophytes and angiosperms in some characters but also differ from them in many other characters. Then they have their own specific characters. It has been regarded that they are an independent and intermediate group of plants between the pteridophytes and angiosperms. Thus, some morphologists have gone to the extent of stating "Gymnosperms are a connecting link between pteridophytes and angiosperms." But to quote of Sporne (1965, 1974) "To what extent they represent true evolutionary links between these two groups is not.....obvious." Faw (1962) prefers the name "Gymnospermous plants" for his book in place of Gymnosperms as it is obvious from the title of his book.

Chapter-2

Cycas Linn.

2.1. Systematic Position

Division	–	Cycadophyta
Class	–	Cycadopsida
Order	–	Cycadales
Family	–	Cycadaceae
Genus	–	*Cycas* Linn

2.2 Distribution in the world

Cycas includes 16 species (Willis, 1951). The species are distributed in Australia, India, China, southern part of Japan, Madagascar and some of the Pacific Islands.

2.3. Distribution in our country

In our country, *Cycas* grows in wild only in the North East region – the plains of Orissa, East Bengal, Assam and the adjacent hills and the south-Madras, Mysore, Cuddupah, Malabar and the Andaman and Nicobar Islands. The plants grow on slopes of hills which are well drained and sun light is available.

The following four species occur naturally in India.

C. circinalis : Western part of Peninsular India, Western Ghats, Malabar and Orissa. This is also cultivated in gardens.

C. pectinata : Sikkim, Assam (Khasi Hills and Manipur), East Bengal (Chittagong).

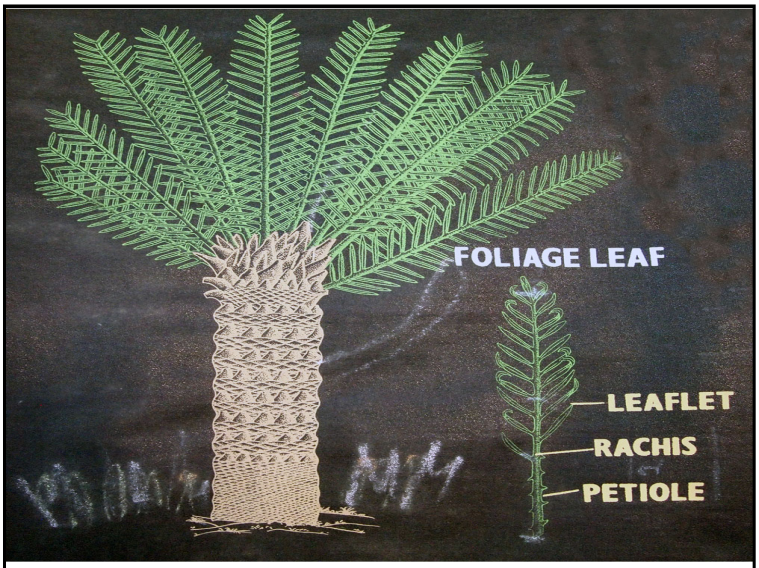
C. rumphii : Coasts of the Andamans and Nicorbars. This is also cultivated in gardens.

***C. beddomei*:** Eastern Andhra, Madras, Cuddapah and other hills.

Besides, ***C. revoluta*** and ***C. siamensis*** are cultivated in gardens in the country.

2.4. External Features of Sporophyte

The plant possesses a stout, columnar, unbranched slow growing trunk (stem) and crowns of leaves at its apex and is palm-like in appearance. The young stem is tuberous.



***Cycas* Plant (Diagram)**

Cycas plant bears two types of leaves: (1) the green assimilatory or foliage leaves, and (2) the scale-leaves arranged round the axis. The green foliage leaves are unipinnately compound. They are showy and large and, in ***C. circinalis*,** may reach a length of about 250 cm. The rachis is long and stout and bears two rows of closely set leaflets (pinnae), but only short spines are present near the base of the petiole. Leaflets are sessile, tough and leathery. They are with narrow bases and are inserted into two grooves. The grooves are towards the adaxial side of the rachis. Scale leaves are brown and small. The clusters of foliage and scale leaves are regularly alternate. Like ferns, the young leaves show distinct circinate vernation.

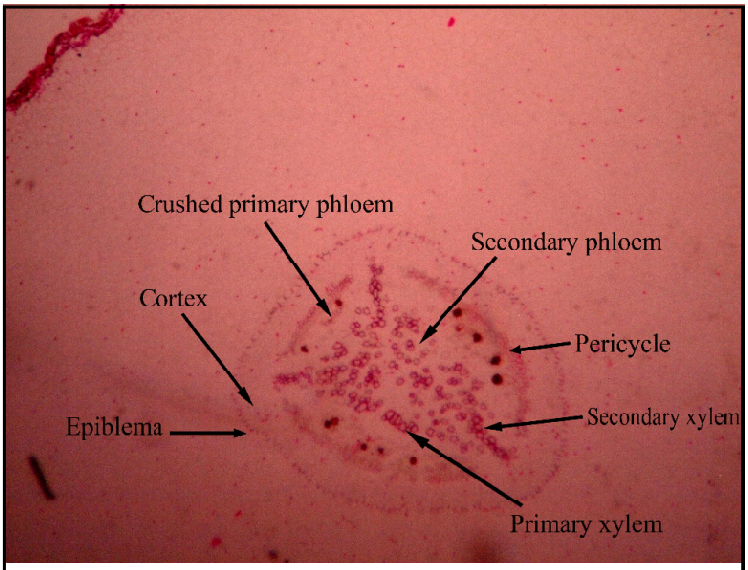
The stem is covered with a hard and thick armour of rhomboidal leaf bases. The bases of the foliage leaves and megasporophylls are small and the two types form regularly alternating bands. In the old trees, stem has only a corky surface at the base and not covered with the leaf bases. Thus, the stem appears thinner at the base in old trees.

After attaining a certain height, the trunk may show irregular branchings. The branching is adventitious. In nature, the branches develop from lateral buds or bulbils. Artificially, the branching can be induced by injury. The lateral adventitious buds or bulbils also serve for the propagation of the plants vegetatively. If planted in the soil, bulbils soon produce root and give rise to a new plant.

There is a tap root system, which according to Worsdell (1906) is short lived. It is replaced by adventitous roots. These roots are positively geotropic. In addition, there is also development of the so-called coralloid roots, which are apogeotropic extending above the surface of the soil. These roots are dense greenish or brown, dichotomously profusely branched and form coralloid masses. A zone of blue-green alga, ***Anabaena***, occurs in the middle of cortex in these roots and provides them the peculiar coralloid appearance.

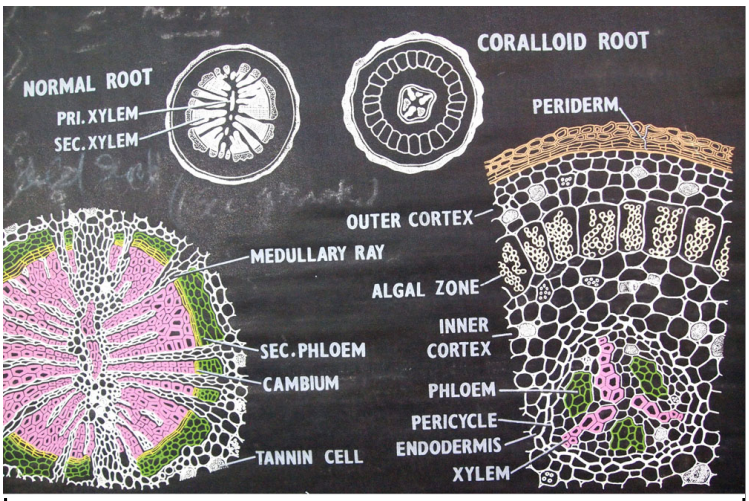
2.5. Internal Structure

Normal root



***Cycas* Ordinary Root T.S.**

The normal or positively geotropic root consists of an outer thin layer of epiblema, which is followed by many layered thick parenchymatous cortex with interspersed mucilage canals. Tannin cells are interspersed in the cortex and are dark brown in colour. Endodermis is single layered and with Casparian strips. Inside the endodermis is many layered pericycle. The bundles of phloem and xylem are radially arranged. Xylem is exarch (facing outward) and usually diarch. In some cases, the number of protoxylem strands ranges from 3 to 8. Metaxylem elements may completely occupy the centre or the individual strands may be separated from each other by a few parenchymatous cells. Phloem is composed of parenchymatous tissue but in older parts bast fibres are also formed.



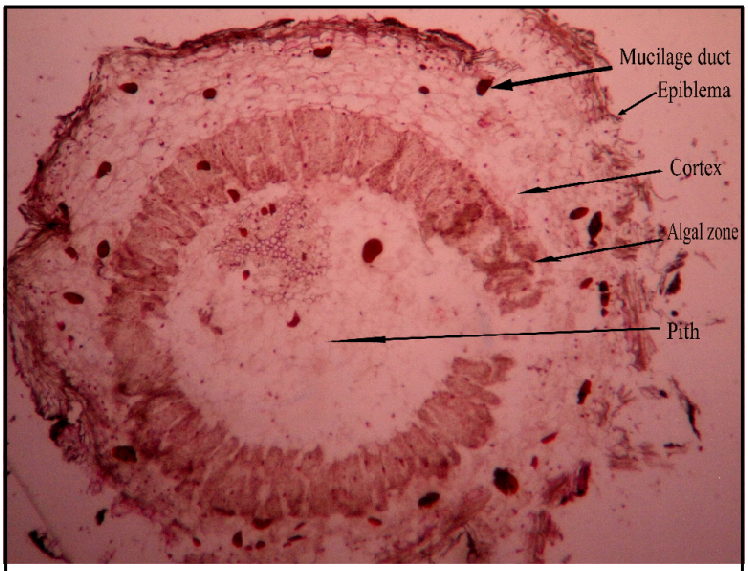
***Cycas* Root T.S. (Diagram)**

Secondary growth: cambial

arcs develop along the inner edges of phloem strands and cut off the secondary phloem on their outer side and secondary xylem on inner side. A complete ring of cambium is then formed and it gives rise to a continuous cylinder of secondary vascular tissue. Primary xylem is pushed inside and primary phloem becomes crushed. There are formed abundant multiseriate rays. The secondary xylem is manoxylic.

The cells of the pericycle lying just inside the endodermis divide to form a phellogen, which produces cork cells on the outer side. Earlier to this, the cells of the cortex below the epiblema form a short lived periderm. But usually with the formation of cork cells all the outlying cells get peeled off.

Coralloid root



***Cycas* Coralloid Root T.S.**

The coralloid root, although similar in structure to normal roots, possesses a much wider cortex with characteristic algal zone. This zone is greenish in colour and occurs in the middle of the cortex. The cells of this zone are thin walled, radially elongated and loosely connected. It is occupied by the blue green algae, identified as ***Anabaena cycadeae*** and/ ***Nostoc punctiformae***. Occasionally, other algae, such as *Oscillatoria* and diatoms, are also present. The bacteria usually occurring in association with the algae are *Azotobacter* and *Pseudomonas radicicola*.

Secondary vascular tissues are absent or may be poorly developed.

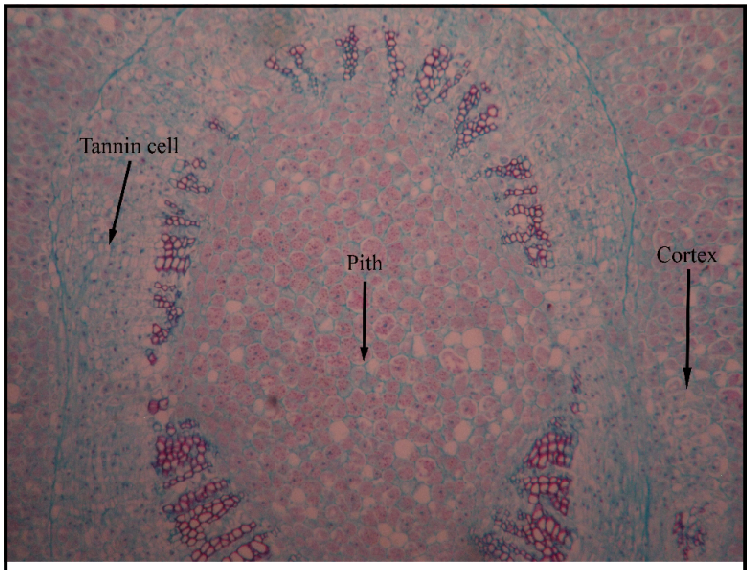
Stem

Primary Structure

T.S. of the young stem shows an irregular outline because of the presence of a number of leaf bases. It is predominantly parenchymatous.

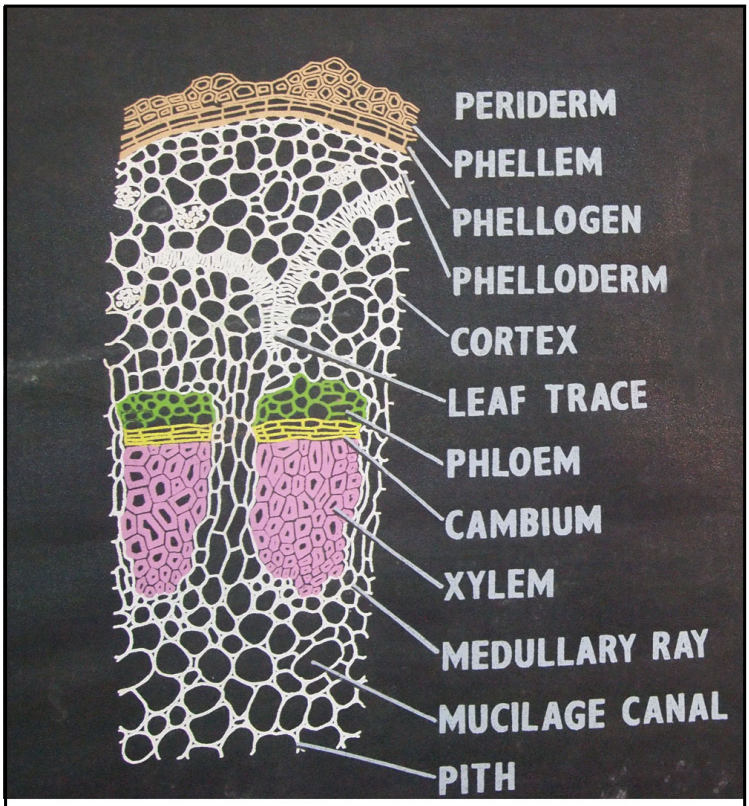
The cortex is wide (about 1/3 to 2/3 of the entire width of the stem) and made

up of parenchyma cells full of starch. It also shows a number of mucilage canals and numerous leaf traces.



Cycas Stem T.S.

Inside the cortex is a ring of numerous conjoint vascular bundles (eustele). Vascular bundles are collateral (phloem on the outer side of the xylem) and open (cambium present). Xylem is endarch (facing inward). The layer of intrafascicular cambium lies between primary phloem and the metaxylem. In the stem of *Cycas*, there is scanty development of xylem (manoxylic). Vessels are lacking in the xylem.



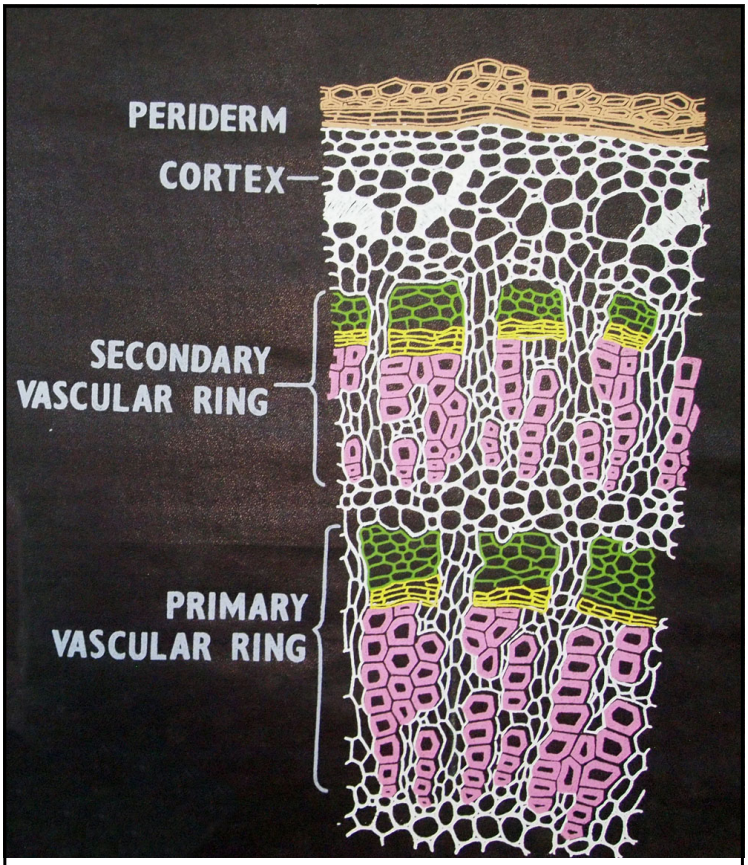
Cycas Stem T.S. Primary (Diagram)

In the centre, there is a wide parenchymatous pith (of the diameter of one-third of the entire stem). The cortex is connected with the pith by broad medullary rays. Mucilage canals are also present in the pith and the medullary rays.

The leaf traces in the stem arise from the vascular bundles of the primary ring. Each leaf is supplied by two direct and two girdle traces, a characteristic feature of the Cycadales, and many radial traces. The girdling traces girdle around the stele and follow a radial course through the cortex. There is formed, a complex network of anastomosing branches from the traces. The leaf trace bundles are endarch in the cortical region.

Secondary Structure

The normal secondary growth takes place through the activity of the primary intrafascicular cambium or the cambium between the primary phloem and the metaxylem. It cuts off secondary phloem on the outer side and the secondary xylem inwards. It also cuts off narrow secondary rays, which traverse the secondary xylem. Probably, the interfascicular cambia are not formed. The primary cambium is active only for a short time. Thus, the formation of growth rings is lacking.



***Cycas* Stem T.S. Secondary (Diagram)**

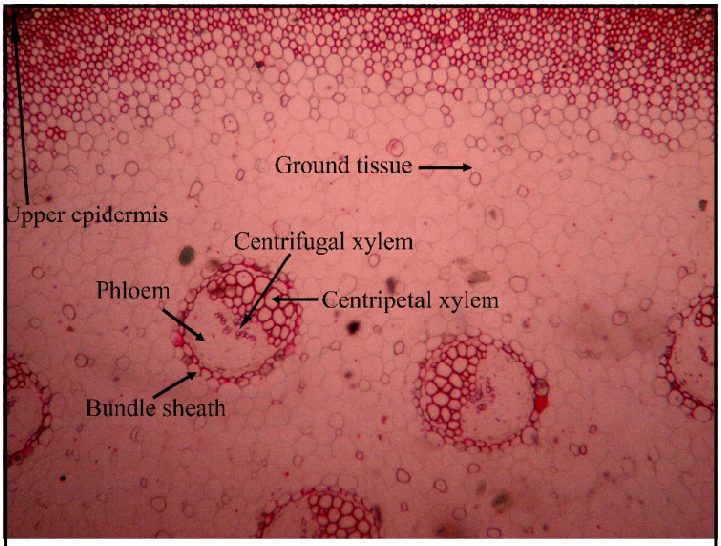
Further growth in thickness of the stem is anomalous and is on account of formation of a second cambium ring outside the first. This produces another vascular cylinder of collateral bundles and later ceases to be active. The process of formation of cambium ring is repeated and several successive rings of vascular bundles are formed showing polyxylic condition. The vascular rings are concentric and progressively narrower towards the periphery. Medullary rays occur between the bundles and are broad.

Not only the secondary rings of bundles, but also the accessory cortical bundles and a periderm are also formed in the cortex. Periderm layers are successively formed first in the leaf bases and all the cells outside the latest cork layer are peeled off. Thus, the stem appears thinner in this region.

Leaf

Rachis :

Rachis, the region bearing the leaflets or pinnae, is cylindrical and the transverse section (T.S.) shows a shield-shaped outline.

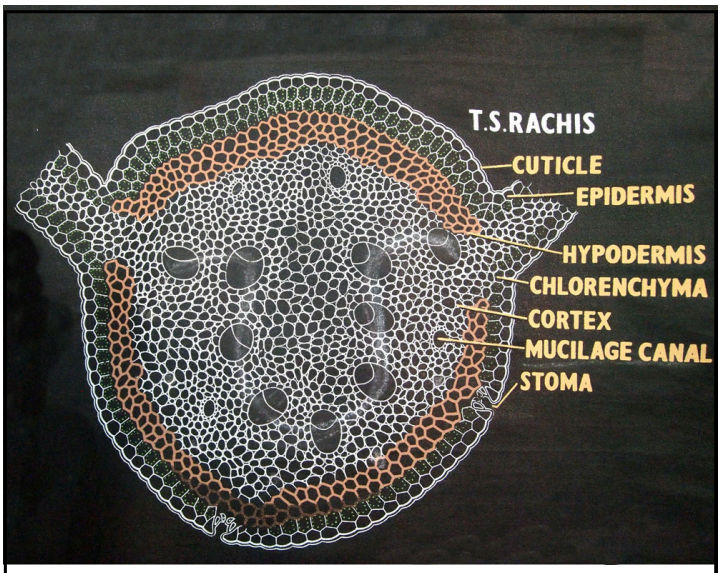


***Cycas* Rachis T.S.**

The epidermis is thick walled and covered over by a thick cuticle. The stomata are irregularly distributed. Underlying the epidermis is a broad hypodermis consisting of thick walled, elongated fibrous cells or sclerenchyma and thin walled, short chlorophyll containing cells or chlorenchyma. The two may be intermixed.

The ground tissue is parenchymatous. A number of mucilage canals are present in the ground tissue. The mucilage canals are lined by an inner wall of epithelial cells surrounded by an outer wall of sclerenchymatous cells.

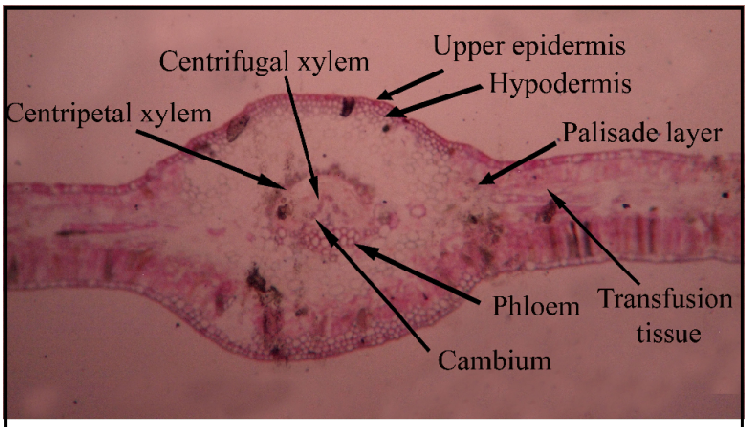
The vascular bundles are arranged like the inverted Greek letter omega (ϖ). Each bundle is enclosed by fibrous bundle sheath. The vascular bundles are diploxylic. The two types of xylem elements are known as centripetal and centrifugal. Centripetal xylem is more or less triangular with the protoxylem outside. Centrifugal xylem occurs usually in two or three separate groups. It is separated from the protoxylem and its adjacent centripetal xylem by parenchymatous cells. The centrifugal xylem is produced by the cambium lying on the outer side of the protoxylem towards the phloem. Because the protoxylem lies between the centrifugal metaxylem and centrifugal xylem, the bundle is said to be mesarch. But, as the centrifugal xylem is separate and of secondary nature the bundles are pseudomesarch.



***Cycas* Rachis T.S. (Diagram)**

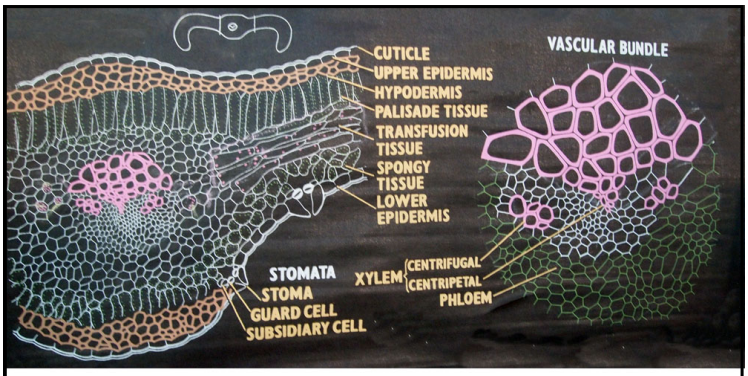
Leaflet :

The epidermis consists of thick walled cells and is covered on its outer surface by a thick cuticle. The dorsiventral leaflet is hypostomatic, i.e. the stomata occur on the lower side and are lacking in the region of midrib. Stomata are sunken and their size is 75-34 . They are of the haplocheilic type.



***Cycas* Leaflet T.S.**

Epidermis is followed by one or more layered hypodermis with highly cuticularized and lignified cells.



***Cycas* Leaflet T.S. (Diagram)**

Inside the hypodermis is mesophyll and a single central bundle in the region of midrib. The bundle is pseudomesarch and diploxylic i.e. its structure is just like that of a bundle in the rachis. The centripetal xylem is positioned towards the upper side and the centrifugal xylem towards the lower. Phloem lies below the centrifugal xylem. On the two sides of the centrifugal xylem of midrib bundle are present two groups of transfusion tissue, which are in connection with it. The tracheid-like cells of this transfusion tissue are short and wide with walls that have reticulate thickenings or bordered pits. According to Ledere (1955) the transfusion tissue also includes the connected parenchyma as the transfusion tracheids form a connected system with these cells.

The mesophyll is differentiated into upper palisade and lower spongy layers and the cells of both the layers contain numerous chloroplasts. In *C. circinalis* and *C. rumphii*, the palisade layer is lacking in the midrib region, whereas it forms a continuous layer in *C. revoluta* etc.

Between the palisade and spongy mesophyll cells lie a few layers of secondary or accessory transfusion tissue, also named as radial parenchyma or hydrostereom.

The tracheid like cells of this transfusion tissue are lignified, colourless and empty and occur at right angles to the longtitudinal axis of the leaflet. The cells are joined end to end and their layers are arranged parallely extending from midrib to the margin of the leaflet. The cells of the secondary transfusion tissue are connected with the xylem through the elements of transfusion tissue proper. Lignier (1892) regarded that the secondary transfusion tissue serves the function of lateral conduction.

2.6. Reproductive Structure

All species of *Cycas* are dioecious; the male and female reproductive structures are borne on separate plants. The branching in the male plant is sympodial after strobilus formation and that in the female plant is monopodial.

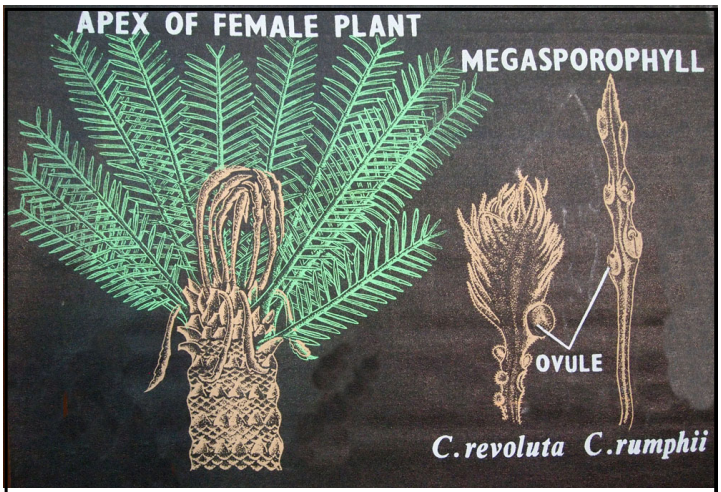
The male strobilus or cone is normally terminal and solitary and possesses a short stalk. Apex of the stem is used up in the production of male strobilus. A lateral bud originating from the base of the stalk takes the position of the apex of the stem and the cone is pushed aside. A fresh crown of leaves and scales, appearing terminal in position, are formed from this new stem apex (actually, the branch of the original stem). This branch of the main stem may ultimately produce another male cone and this process is repeated every year and a new cone is formed. This type of branching is known as sympodial branching and the stem as sympodium.

In *Cycas*, there is no such structure which can be termed female strobilus or cone. A number of megasporophylls are produced in acropetal succession around the apex of the stem above the crown of the vegetative leaves. The apex of the stem is not consumed in the formation of the megasporophylls and it continues to grow monopodially.

The Female Reproductive Structure

Megasporophyll

Megasporophylls are covered with brown colour hairy ramentum. They vary in size in different species and may reach a foot or more in length. The megasporophyll is composed of

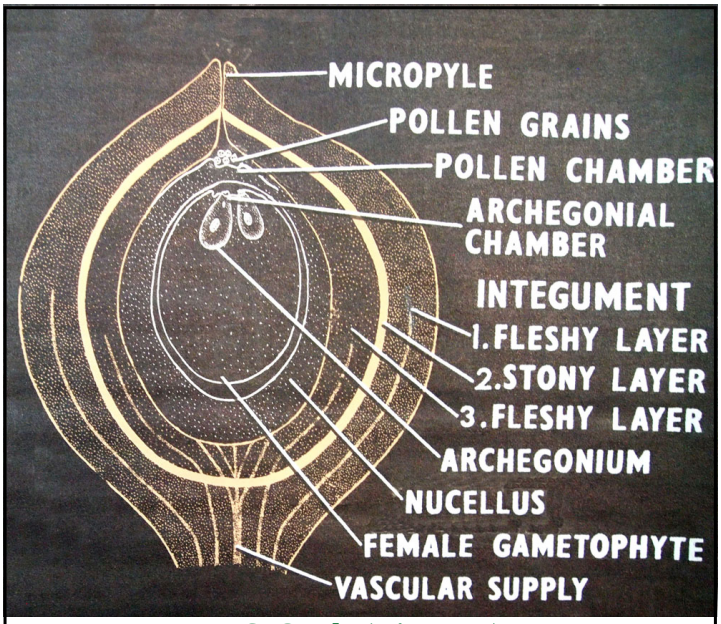


Female Reproductive Structure (Diagram)

three parts: (1) the lower narrow petiolar part (2) the middle part bearing 2 to 12 ovules on its two sides (1 to 6 on each side) (3) the terminal dorsiventrally flattened sterile part. The terminal part is broadly conical or triangular in form with pinnately divided margin (as in *C. revoluta* and *C. pectinata* etc) or variously serrate margin and acutely tapering apex (as in *C. circinalis, C. rumphii* and others).

Ovule (Integumented Megasporangium)

The ovule is orthotropous (erect in orientation) and is having a short stalk. It is enveloped by an integument except for an apical narrow passage called micropyle. The micropyle lies opposite to the side of attachment of the ovule to the megasporophyll. The integument is demarcated into three layers: (1) outer fleshy thick layer, the sarcotesta (2) middle stony layer, the sclerotesta and (3) inner fleshy layer, the inner sarcotesta.



L.S. Ovule (Diagram)

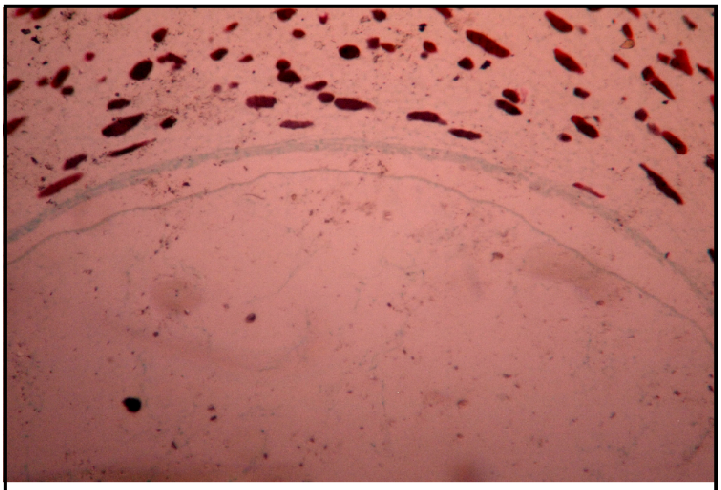
Both the inner and outer fleshy layers have a vascular system. Besides, there is a centre bundle embracing the lower end of the nucellus.

The integument remains in close contact with the nucellus and appears fused with it except only in the upper portion. There occurs a pollen chamber in this apical region of the nucellus. It is this pollen chamber where the microspores come to lie after pollination. Rest of the ovule is occupied by the female gametophyte with 2 to 8 archegonia. A depression in the upper region of the female gametophyte above the archegonia, form the so-called archegonial chamber.

Development of ovule :

Ovule starts developing as four to six marginal protuberances on the megasporophyll. The mass of cells in the protuberances constitute the nucellus (body of megasporangia) and are soon covered by a ring like growth of massive integument. In a developed ovule, the lower part of the nucellus and the integument appear fused.

The upper free part of the integument completely surrounds the nucellus except for an apical narrow passage known as micropyle, which opens into the micropylar tube or canal. The apical region of the nucellus may form a beak-like portion, the nucellar beak, which projects into the micropylar canal.



***Cycas* V.S. Ovule (General Structure)**

Megasporogenesis :

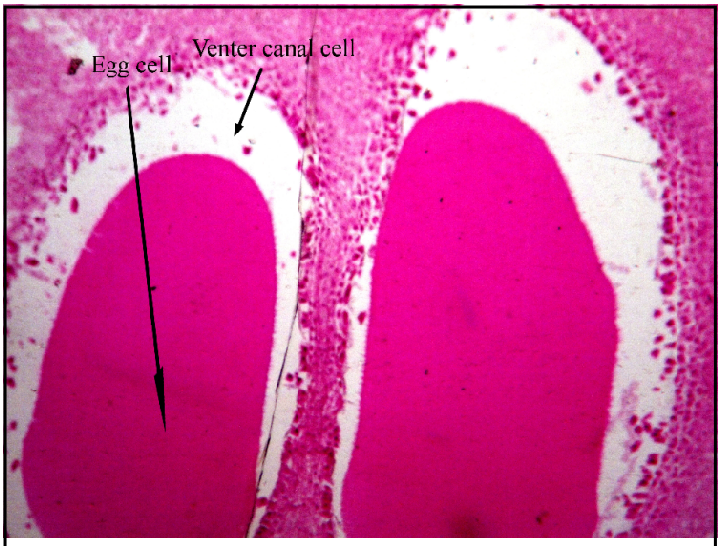
A cell in the lower region of the nucellus elongates to become differentiated as the megasporocyte (megaspore mother cell). Meiotic division takes place but a tetrad has never been observed. A row of only two or three cells is formed due to failure in dividing further of one of the two cells formed by first division of megasporocyte. Only the lowest cell (that toward chalazal end) of the row is functional megaspore. The haploid uninucleate megaspore is the first cell of the gametophytic generation.

Female gametophyte :

The functional megaspore enlarges without undergoing any rest. The megaspore nucleus divides several times and there are formed a large number of free nuclei, which come to lie in the peripheral cytoplasm, around a central vacuole. The ovule enlarges rapidly and the integument starts its differentiation into three layers. The cells of nuclear beak breakdown forming a cavity called pollen chamber. The formation of pollen chamber occurs during the free nuclear stage (De Silva and Tambiah, 1952) (pollen chamber occurs only in *Ginkgo*, cycads and *Ephedra* and not in *Pinus*). After the free nuclear division is over, walls are laid down starting from periphery and proceeding towards the centre (centripetally). The entire structure of the female gametophyte, also called endosperm of female prothallus, becomes cellular. The megaspore wall is persistent and becomes thick. The middle stony layer starts getting hard as late as three months after pollination.

Development of archegonia:

As soon as the cellular female gametophyte is formed, a few cells at the micropylar side get enlarged and become differentiated as archegonial initials.



Cycas Archegonia V.S.

A periclinal division cuts off an upper small primary neck cell and a larger central cell. The primary neck cell divides vertically (anticlinally) once to form two neck cells. The endosperm cells surrounding the central cell form a nutritive archegonial jacket. The nucleus of the central cell divides into a ventral canal nucleus and an egg nucleus and no wall is laid down between the two. Ventral canal nucleus degenerates soon. The egg cell (former central cell) enlarges considerably. The nucleus of *Cycas* egg reaches up to 0.5 mm in size and is the largest among living plants. Generally, the archegonia take 2 to 3 months to reach full maturity. Shortly before the completion of the archegonial development, the upper region of the female gametophyte gets depressed. Thus, a space is formed between the upper surface of the archegonia and the overlying nucellus. This is the so called archegonial chamber.

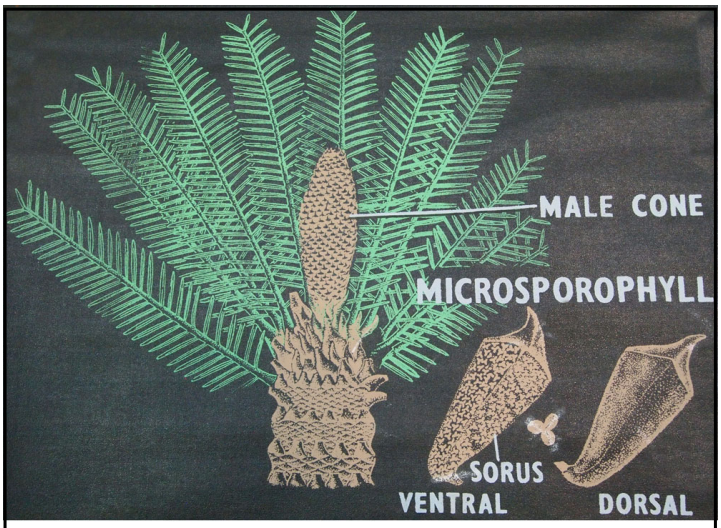
The number of archegonia varies between 2 to 8 in an ovule in different species (2 to 8, usually 3, in *C. revoluta*, 3 to 8 in *C. circinalis* and 3 to 6 in *C. rumphii*).

In *C. revoluta* (in Japan), both the pollination and the formation of archegonia occur in June/July.

The Male Reproductive Structure

Microsporangia or Male cone :

The largest male cones in the plant kingdom are formed by cycads. The length of some of the elongated ripe cones of *C. circinalis* has been found to be nearly 80 cm or more. It is a compact oval or conical structure.

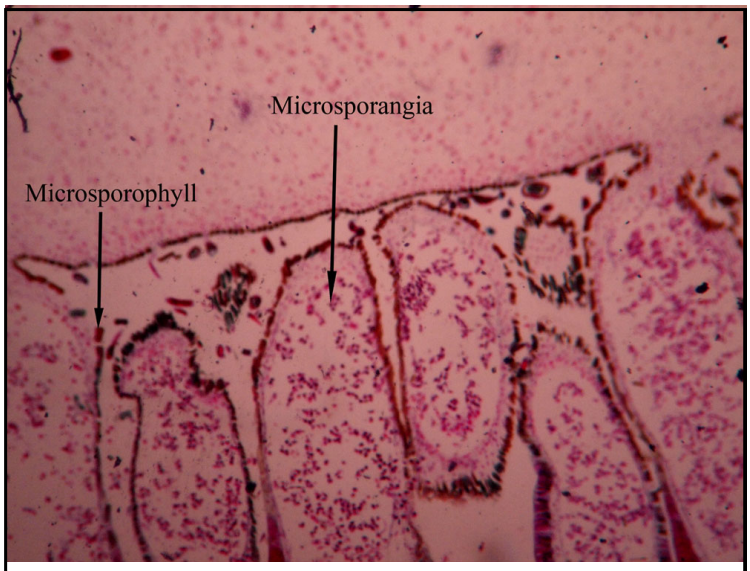


Cycas Male Cone (Diagram)

In a male cone, a number of perpendicularly attached microsporophylls are arranged spirally around the cone axis. To facilitate the dispersal of mature pollen grains, the axis of the cone suddenly elongates and the microsporophylls become separate from each other. Further, the microsporohylls also become somewhat loosely hinged due to drying.

Microsporophyll :

At maturity, it is a flattened, hard, somewhat woody structure and consists of two regions: (1) a wedge shaped fertile region with a narrow basal part and it bears a number of micro sporangia on lower surface except in the quite narrow part (2) an upper sterile part with pointed upcurved apex. The microsporophylls are densely covered with hairs. The microsporophylls of the middle region of the cone are larger and bear maximum number of sporangia. However, the upper most sporophylls mature first. The microsporophylls, in *C. circinalis,* are 3.0 to 3.5 cm in length and 1.2 to 2.3 cm in breadth.



***Cycas* Male Sporophyll V.S.**

Microsporangium :

Microsporangia occur on the lower abaxial surface of sporophylls, arranged in groups (sori) of 3 to 6, usually 5. The number of sporangia may reach upto over 1,000 in the sporopylls of certain species (700 in *C. circinalis*). The groups of sporangia are surrounded by hairs, called soral hairs.

Sporangia dehisce by a longitudinal slit along the line of dehiscence. Sporangia are formed from a group of superficial cells or initials and development of sporangium is of eusporangiate kind.

A mature sporangium is an oval sac with a short stout stalk. Wall of the sporangium is 5 to 6 layer of cells thick, the innermost layer forming the tapetum. Cells of the last generation within the wall of the sporangium become rounded off

and are known as spore mother cells. The tapetum and few other cells break down to provide nutrition. Spore mother cells represent the last cells of the diploid phase.

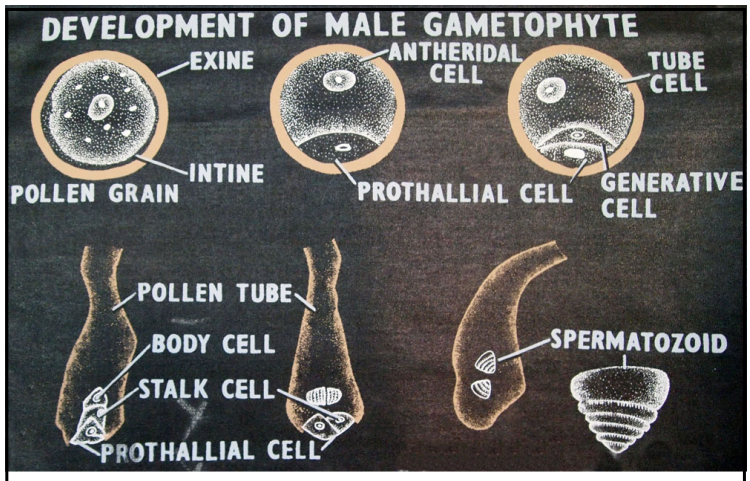
Microsporogenesis :

The origin of the gametophytic generation is from haploid uninucleate spores, the microspores, which in turn are products of two divisions (meiosis) of the spore mother cells.

Microspore or Pollen Grains :

The wall of the microspore is made up of two layers; an outer thick exine and an inner thin intine. The exine is the thickest on proximal side and thins out laterally to become the thinnest on the distal surface. The microsporangium is fully packed with microspores or pollen grains because of their enormous number being produced in it.

Male Gametophyte :



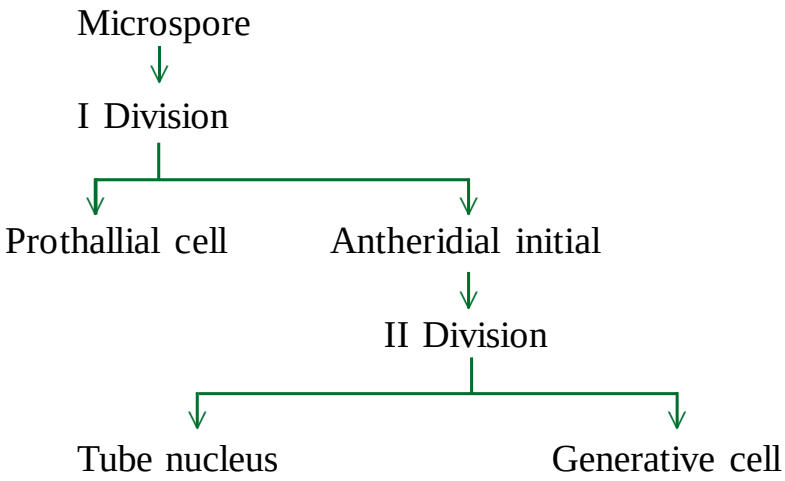
Male Gametophyte (Diagram)

Microspores start development while still enclosed in the microsporangium. The first division cuts off a small prothallial cell on the proximal side. The nucleus of the other larger cell, sometimes called the antheridial initial, then divides to form a generative cell on the side of the prothallial cell and a large nucleus, the tube nucleus in the tube cell. It is at this three celled stage that the pollen grains are shed from the sporangium and carried to the ovule by wind on account of being light in weight. These three celled pollen grains are boat shaped with a depression or furrow on the distal side.

Further development of pollen grains takes place only after they have reached the pollen chamber inside the ovule.

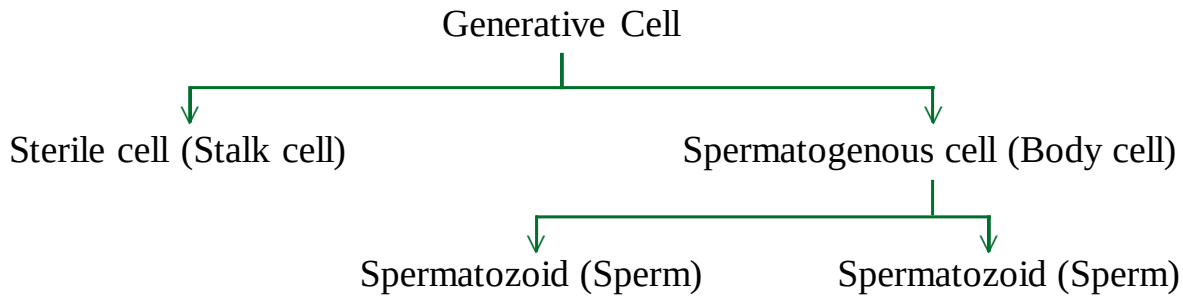
Stages in the formation of the male gametophyte

Development inside the microsporangium



Development inside the ovule

.....TRANSFER OF POLLEN TO OVULE (POLLINATION).....



Post pollination development of pollens or male gametophyte.

Soon after reaching the pollen chamber, the pollen grains begin further development. The intine grows out rupturing the exine and forming a pollen tube containing the tube nucleus. The pollen tube grows sideways, branching horizontally, into the tissue of the nucellus and derives the nutrition. Thus the pollen tube is a haustorial organ in this genus. The pollen grain end, containing the prothallial and generative cells, swells and grows downward into the pollen chamber. The generative cell divides into a sterile cell or stalk cell (toward the prothallial cell) and a body or spermatogenous cell. Nucellar tissue, below the pollen chamber, gives way to basal end (microspore/pollen end) of the pollen tube, which comes to hang downwardly in a free manner into the archegonial chamber. The upper end of the prothallial cell

bulges and penetrates into the stalk cell. The body cell elongates longitudinally and there appears two blepharoplasts one at the anterior and the other at posterior side. The body cell divides by a vertical wall into two sperm mother cells and blepharoplasts break up into many granules. The sperm mother cell nucleus becomes top-shaped and it rotates. The granules of blepharoplast get spirally arranged over its narrower end from which develop the cilia. The sperm mother cell wall ruptures releasing the sperms or spermatozoids (antherozoids) into the fluid contained in the pollen grain end.

The mature antherozoid is top-shaped with five to six spiral bands of cilia at the anterior end and is visible to the naked eye (180 to 210mm in size in *C.revoluta*).

Pollination

Pollen grains or microspores are light and pollination is effected by wind (anemophily). A drop of mucilage, the pollination drop, is secreted out of the micropyle. Pollen grains, while carried by the wind, get attached to it. The mucilage drop is withdrawn and seal up the micropyle. Ovules are pollinated when the young megasporophylls are out in the female *Cycas* plants. In *C.revoluta* both the pollination and the beginning of the formation of archegonia occurs in June/July. Now the ovules start enlarging and acquire their full size.

Time of important events in the life cycle of *C.rumphii* in Ceylon is shown in table 1.

Fertilization

The pollen grain end of the pollen tube bursts releasing the fluid contained in the tube and the sperms. The fluid is of high osmotic pressure and is capable of plasmolysing the neck cells and making them flaccid. This facilitates the entry of sperms into the archegonium. The sperms is then violently drawn into the egg (Chamberlain, 1935). De Silva and Tambiah (1952) are of the opinion that the movement of sperms toward the egg nucleus is amoeboid and chemotactic.

The sperm usually enters the egg naked casting off its spiral ciliary band and sheath in the top part of the egg. Although more than one sperms may sometime enter the egg cell but only the first penetrating sperm unites with the egg nucleus.

In *Cycas*, the occurrence of ciliated motile sperms is accompanied by pollen tube formation (siphonogamy). The pollen tubes are haustorial and derive nutrition

and also act as a channel for carrying the male gametes to archegonia.

Post Fertilization Development of Ovule

Embryogeny (Development of new sporophyte)

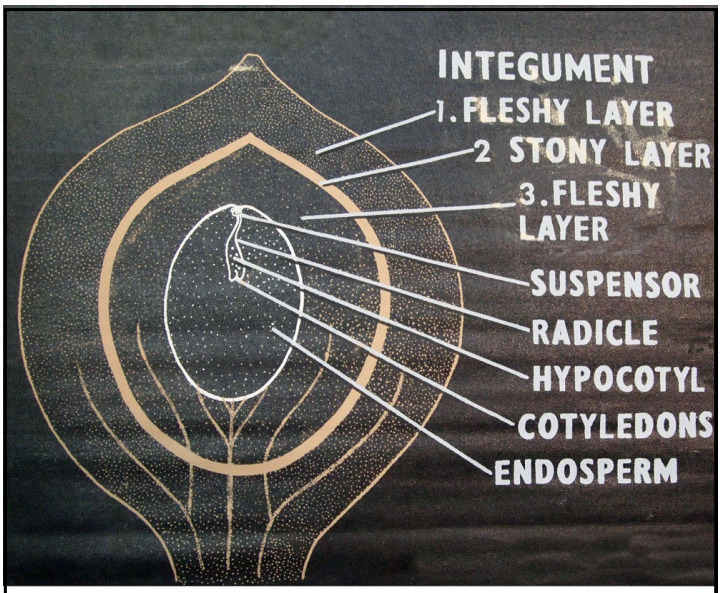
There is no rest period and the zygote (oospore) soon undergoes repeated free nuclear divisions forming 256 or more nuclei. This egg sac or proembryo takes the shape of an oval sac with a large central vacuole and a peripheral layer of multinucleate cytoplasm. The cytoplasm is thick at the base and this region forms the embryo. Walls are laid down and the proembryo becomes cellular. The cells of the basal end constitute the embryonic region. The cells above this region divide and become elongated to form a suspensor. The elongation of suspensor is very rapid and it pushes the embryonic region deep in the centre of the female gametophyte or endosperm. The suspensor is remarkably long reaching a length of even 10 cm, if uncoiled.

As the eggs of all the archegonia within the ovule get fertilized, there are usually several suspensors. These suspensors get twisted together forming a tangled knot. Ultimately, only one embryo reaches maturity in a seed. The young embryo develops a cylindrical stem tip at the sides of which are usually two cotyledons. The root develops quite late and there is a hard coleorhiza protecting the root tip. It takes one years time for the zygote to develop into an embryo. The seeds may shed at different stages of this development. The maturation of the embryo is completed after they have fallen down on the ground.

Seed

Seed is the result of the fertilization and enlargement of the ovule. A gymnospermous seed is a combination of two sporophytic (an old and a new) and one gametophytic generation.

Seeds are slightly flattened laterally, bilobate, fleshy and red or orange coloured. Seeds of *Cycas* are the largest in the plant kingdom



L.S. Seed (Diagram)

and in *C. circinalis* are 6cm long.

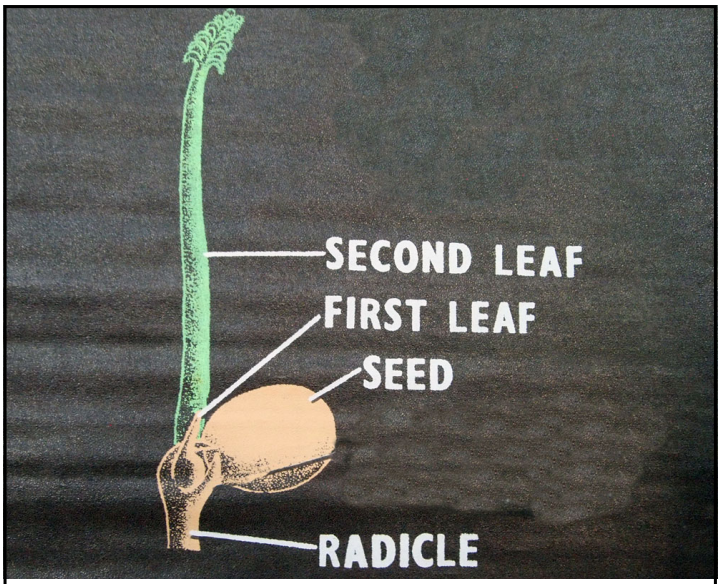
The integument (testa or seed coat) is thick (1cm in *C. circicinalis*) and clearly differentiated into three zones or layers. The inner fleshy layer of the integument becomes thin but the outermost layer remains thick and fleshy. In between the two fleshy layers is the zone of woody shell, the sclerotesta.

Nucellus is thin and an almost papery layer. Enclosed by the nucellus is present the massive female gametophyte (endosperm).

Embryo is straight and long. Two cotyledons enclose the stem tip and leaves at the basal end. The other end of the embryo, which is in contact with the suspensor, develops into the radicle. Hypocotyls is quite small.

2.7 Seed Germination

There is no period of rest after the maturation of seed. However, De Silva and Tambiah (1952) observed in *C.rumphii* that the seed germination does not occur for a long even after the full development of embryo. The germination of the *Cycas* seed is epigeal.



Germination of Seed (Diagram)

The micropylar end of the seed coat gets ruptured by the emerging radicle. The root curves downward and grows rapidly into the soil. The greater part of the two cotyledons remains inside the seed coat. Cotyledons are haustorial in function and absorb nutrients from the gametophyte and pass on to the developing seedling. The first leaf emerges out after several weeks and occurs between the bases of the cotyledons. The first crown of leaves is produced after several years of growth. The seedling stem in *Cycas* remains insignificant for many years.

Table-1 : Time of different events in the life cycle of *C. rumphil* (De Silva and Tambiah, 1952).

Year	Month	Events
First year	March	Male cones and tips of megasporophylls become visible; megasporophylls are with well formed female gametophytes in the ovule
	April-May (middle)	Megasporophylls and male cones mature further.
	May	Pollination and, after about a week, pollen tube formation.
	July	Generative cell divides into a stalk cell and a body cell.
	December	Blepharoplast rotation.
Second year	March (early)	Breaking up of the floor of pollen chamber above the archegonial chamber.
	June	Formation of sperms and fertilization (after thirteen weeks of pollination).
	November	Embryo development (after 5 months of fertilization).
Third year	January (last week)	Beginning of differentiation of cotyledons in the embryo and dropping of seeds (6 months after fertilization).
	March	Cotyledons become well differentiated (Ten months after fertilization).

Seeds germinate only after a long time, when they are physiologically mature.

2.8. Economic Importance

1. A number of species of *Cycas* are grown for ornamentation in gardens throughout the world. *C. revoluta* is the most commonly cultivated species. The leaves are variously used for decoration (being xerophytic, remain green for considerably longer duration). Now a days leaves are used for decorating the flower pots too.
2. Starch extracted from the seeds (chiefly the endosperm) and stem (mainly the pith and cortex) has been used for the formation of useful items of food. The starch obtained from the stem is used for the preparation of "Sago". Various other parts of the plant have also been found edible. However, it remained the food of only poor man and at the time of scarcity.
3. In the indigenous systems of medicine, the different parts of a number of species have been used variously for treating ailments of many types.
4. The different parts of *Cycas* plants have been used in many other ways from time to time by the man, e.g. (i) starch used occasionally in laundrying, (ii) gum obtained from *C. circinalis* and *C. rumphii* used as adhesive, (iii) crushed seeds used as fish poison in Cambodia, and (iv) leaves used for weaving mats or baskets.

Chapter-3

Pinus Linn.

3.1. Systematic Position

Division	–	Coniferophyta
Class	–	Coniferopsida
Order	–	Coniferales
Family	–	Pinaceae
Genus	–	*Pinus* Linn

3.2. Distribution in the world

Pinus includes about 90 species. It is distributed in north temperate and arctic regions forming an evergreen forest belt. It grows wild between an altitude of 1500 to 3600 meters in the hills. A number of species are also cultivated in different types of soil and climate.

3.3. Distribution in India

In India, the genus grows in the North-West and North-East Himalayas and is represented by the following six species :

P. wallichiana (Syn. *P.excelsa*) (blue pine, Kail) : Kashmir, Himachal Pradesh and Punjab.

P. roxburghii (Syn. *P. longifolia*) (Chir) : Kashmir, Punjab, Himachal Pradesh and Uttrakhand.

P. gerardiana (Chilgoza) : Kashmir and Kinnaur district of Himachal Pradesh.

P. merkusii (Merkus or Tenasserim pine) : East India – Assam, Meghalaya, Arunachal and Bengal.

P. insularis (Syn. *P. khasya*) (Khasi pine): Meghalaya Khasya hills.

P. armandi (Armand's pine): North East frontiers of Assam-Arunachal.

Besides, five species, namely, *P. sylvestris*., *P. larico P. monophylla, P. montana* and *P. pinaster* also occur in India, but all are exotic and cultivated.

3.4 External Features of Sporophyte

The fully grown plant is a branched tree which is large in size and pyramidal or conical is appearance. In *P. roxburghii*, the tree may reach a height of 54 meters.

The stem is cylindrical. The branches are of two types (dimorphic): (1) long branches also called the branches of unlimited growth and (2) the short branches or dwarf or spur shoots also known as branches of limited growth.

Leaves are also of two types: (1) needle-like green photosynthetic or foliage leaves and (2) the scale-like leaves. Spur shoots arise singly in the axils of scale leaves on the main axis or branch of unlimited growth. The spur shoot possesses a number of thin imbricated scale leaves below on the short stem and a cluster of a definite number of needle leaves at its apex. The needle leaves are confined to spur shoots only and, according to species, their number varies from 1 to 5. Spur shoots are monofoliar in *P. monophylla*, bifoliar in *P. sylvestris* and *P. merkusii*, trifoliar in *P. roxburghii* and *P. gerardiana* and pentafoliar in *P. wallichiana*. Scale leaves occur on the long shoots also. It is in the axil of scale leaves that both the long and the short shoots develop.

A typical tap root with strongly developed lateral branches is present. The roots are covered with ectotrophic mycorrhiza. Root hairs are scanty or absent.

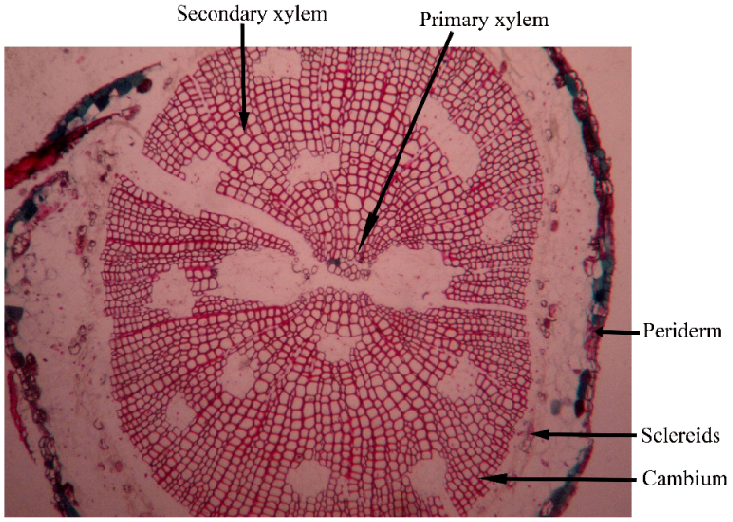
3.5. Internal Structure

Root :

Primary Structure

Transverse section (T.S.) of the root is circular in outline. In the young roots, outermost layer, the epidermis, consists of a few root hairs, which disappear with the appearance of ectotrophic mycorrhiza. Inside epidermis is multilayered cortex of parenchymatous cells. Endodermis is single layered and is followed by the

pericycle, which is multi-layered. Xylem is exarch, diarch to tetrarch and forked in the manner of Y. A resin canal is present opposite of each protoxylem group. Phloem bundles alternate with the xylem and the two are equal in number (radial vascular bundle). There is a small pith in the centre.



***Pinus* Root T.S.**

Secondary Structure

It takes place by means of meristematic activity of cambium formed between xylem and phloem. Cambium cells divide forming secondary phloem externally and secondary xylem internally. Also a cork cambium or phellogen develops from the outer layer of pericycle. It forms phellem or cork cells on the outer side and phelloderm on the inner. The composite structure made up of phellem, phellogen and phelloderm is known as periderm.

Stem :

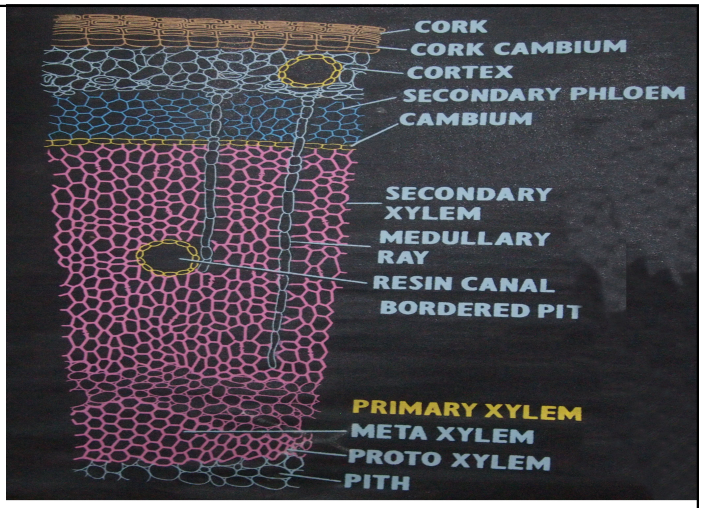
Primary Structure

The outermost layer is epidermis with thickened outer walls. Epidermis is covered over by a thick cuticle.

The epidermis is followed by a multilayered cortex, which is differentiated into an outer sclerenchymatous zone and an inner parenchymatous zone. Numerous resin canals and a few leaf traces are present in the inner zone of the cortex and stele (vascular cylinder) and inside the endodermis is present a multilayered pericycle of parechymatous cells.

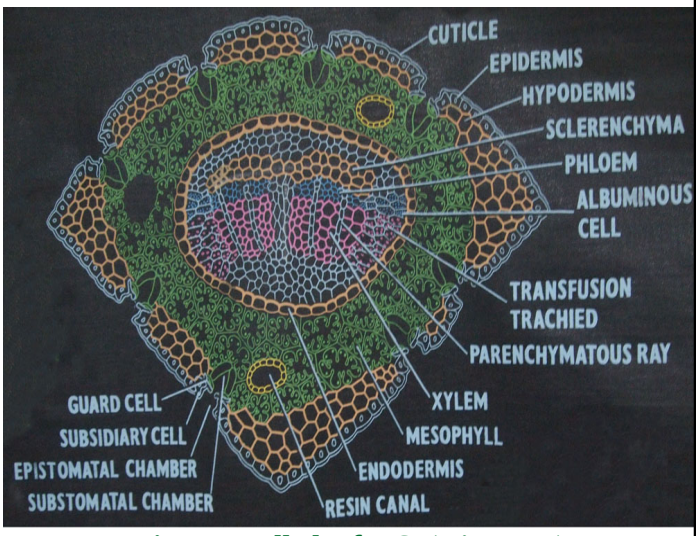
Vascular bundles are five to eight in number and are collateral, conjoint (xylem and phloem in the same bundle or on the same radii) and open. They are arranged in a ring forming a polyfascicular endarch eustelic vascular cylinder. The vascular bundles are separated by narrow medullary rays.

In the centre lies a small parenchymatous pith.

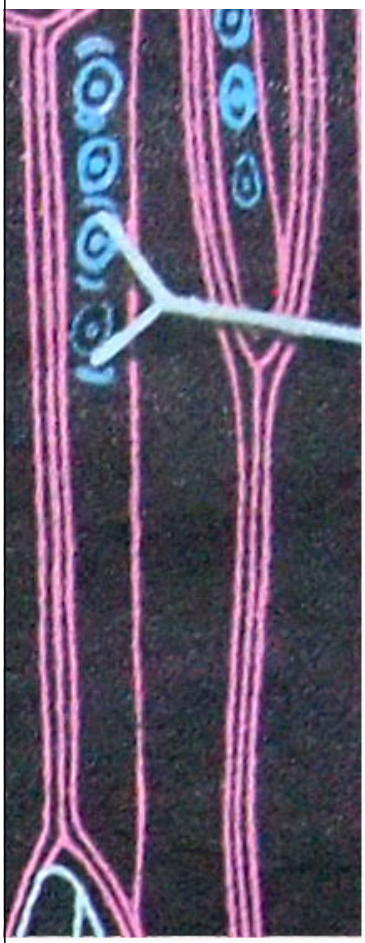


***Pinus* Root T.S.**

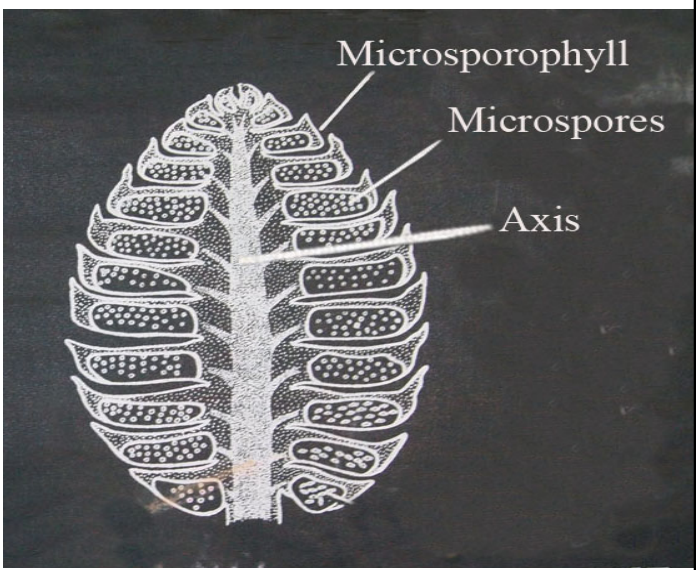
***Pinus* Plant Habit**



***Pinus* Needle leaf T.S. (Diagram)**



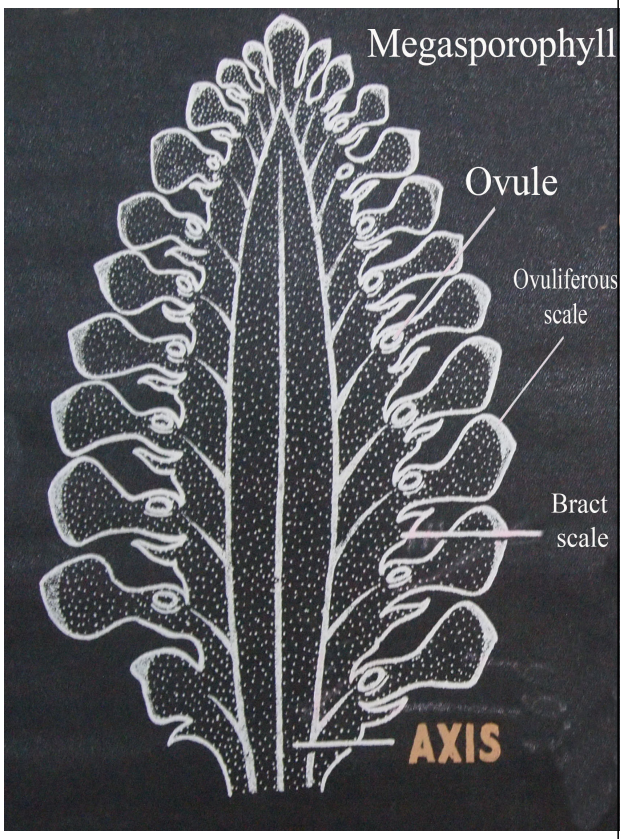
Bodered Pit



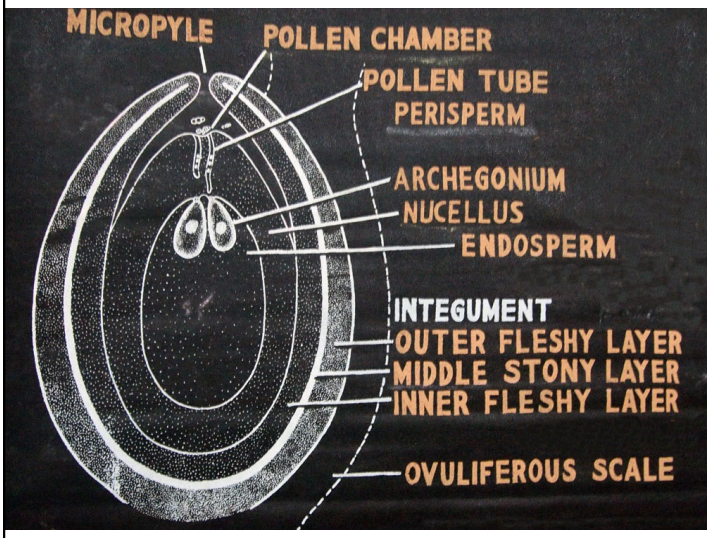
***Pinus* stem R.L.S. (Diagram)**

***Pinus* Male cone L.S. (Diagram)**

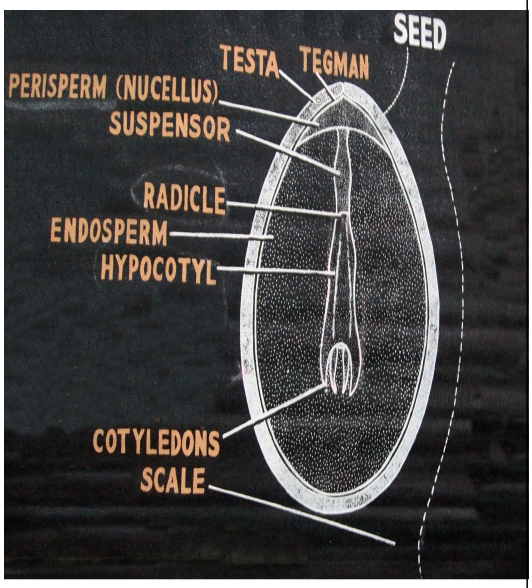
Pinus Female cone (Diagram)



Pinus Female cone L.S. (Diagram)

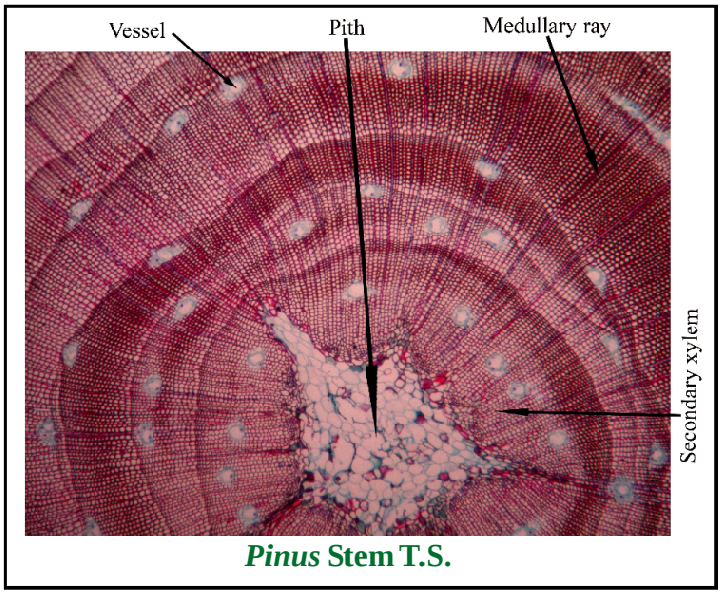


Pinus Ovule L.S. (Diagram)



Pinus Mature Seed L.S.

Secondary Structure :



***Pinus* Stem T.S.**

A complete ring of cambium is formed by the development of interfascicular cambium. The cambium ring cuts off secondary phloem externally and secondary xylem internally. Secondary vasculary rays are formed by the cambium in both the secondary xylem and the secondary phloem.

Primary phloem gets crushed and primary xylem is pushed inside. The xylem lacks vessels but consists of tracheids and is traversed by xylem or wood rays. Cells in the rays are arranged in radial sheets. Resin canals are present in both the primary and the secondary xylem and in the vascular rays.

Continued activity of the vascular cambium gives rise to the annual rings or growth rings, which are clearly demarcated. Rings represent the growth of the secondary xylem occurring annually. Each ring is differentiated into a zone of spring wood and another of autumn wood. The transverse section of wood (or stem) shows that the tracheids of spring wood are thin walled, wide and polygonal, whereas that of autumn wood are small, narrow and squarish.

Phellogen develops in the outer parenchymatous region of the cortex cutting off phellem or cork on its outer side and phelloderm on the inside. The cork and the associated structures form the bark (periderm), which protects the wood.

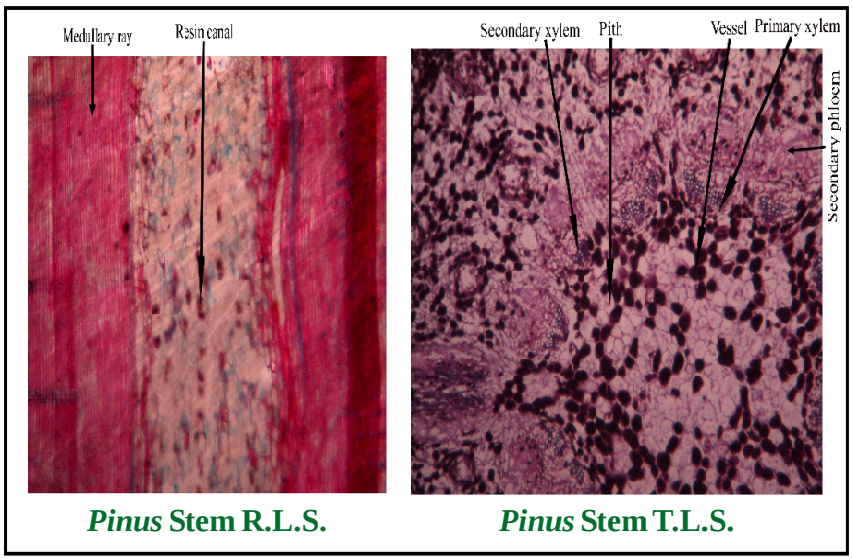
The xylem: It consists of tracheids, which are four sided; two of the sides are nearly radial and two tangential. The bordered pits are restricted to radial walls.

The phloem: It consists of elongated sieve cells, phloem parenchyma and rays. Companion cells are lacking.

The vascular rays: In the secondary wood, the rays are made up partly of parenchymatous cells and partly of tracheidal cells elongated radially. In the secondary phloem, the ray is made up of two types of parenchyma: (1) starch containing normal ray parenchyma and (2) albuminous cells occurring either above and below or on only one side of the ray parenchyma.

Vascular rays, when young, are uniseriate (one cell wide) and two cells high. Later they may become several cells high. Also they become multiseriate on coming in contact with resin canal.

A radial longitudinal section (R.L.S.) of the stem runs parallel to the vascular rays and also the radial walls of the tracheids are not cut through. The bordered pits, thus, are visible in surface view and the vascular rays are seen running horizontally. Special thickening called crassulae or bars of sanio surround the bordered pits. Vascular rays show the cell types already described.

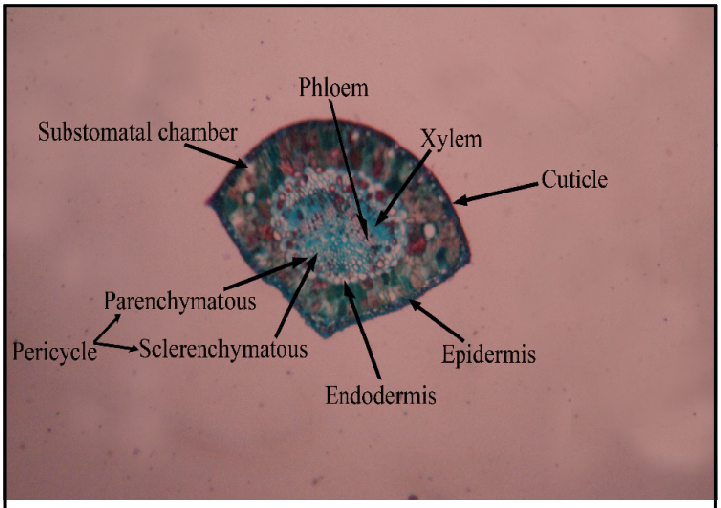


***Pinus* Stem R.L.S.** ***Pinus* Stem T.L.S.**

A tangential longitudinal section (T.L.S.) of the stem cuts across the vascular rays and passes through the bordered pits in the walls of the tracheids. Therefore, the bordered pits are seen in sectional view and with a prominent torus. The medullary rays look as spindle-shaped structures in T.L.S.

Leaf

The outline of the transverse section (T.S.) of leaf, depending upon the number of needles in a spur shoot, may be circular, semicircular or triangular. Thus, in *P.roxburghii*, with three needles in a spur shoot, the outline is triangular. The number of vascular bundles is two, except in *P.monophylla*, where it is one.



***Pinus* Needle T.S.**

Epidermis is single layered

with thick walled cells and is covered by a thick cuticle. *Pinus* needle is a amphistomatic as the stomata occur on all surfaces of the needle. Stomata are sunken and are of haplocheilic type. The cavity external to stomata is known as vestibule.

The epidermis is followed by few layered hypodermis, which is more developed in the corners and absent inside the stomata. The cells of the hypodermis are thick-walled or sclerenchymatous.

The mesophyll consists of only thin walled parenchymatous cells with numerous infoldings in their wall. The infoldings increase the surface area for photosynthesis and, thus, apparently compensate for the reduction of surface of the leaves or needles. The mesophyll cells contain numerous chloroplasts. In *Pinus*, the mesophyll is not differentiated into palisade and spongy layers. There are also many resin canals in this region. The resin canals have an inner layer of thick walled epithelial cell and an outer layer of sclerenchymatous cells.

In the middle, there is one cell thick prominent endodermis surrounding a many layered pericycle with two vascular bundles embedded in it. A few sclerenchyma cells forming a 'T' shaped girder separate the two bundles. Foster and Gifford (1959) state that the transfusion tissue in *Pinus* needle, include the many layers of compactly arranged cells surrounding the vascular bundles and it is separated from the mesophyll cells by the endodermis. Transfusion tissue consists of two types of cells (1) transfusion tracheids and (2) the albuminous cells. It is assumed that their role is the transport of materials between the vascular bundles and the mesophyll.

The vascular bundles are conjoint, collateral and xylem is endarch. A small quantity of cambium may occur at the base. Extending across the xylem and phloem are present sheets of parenchyma.

3.6. Reproductive Structure

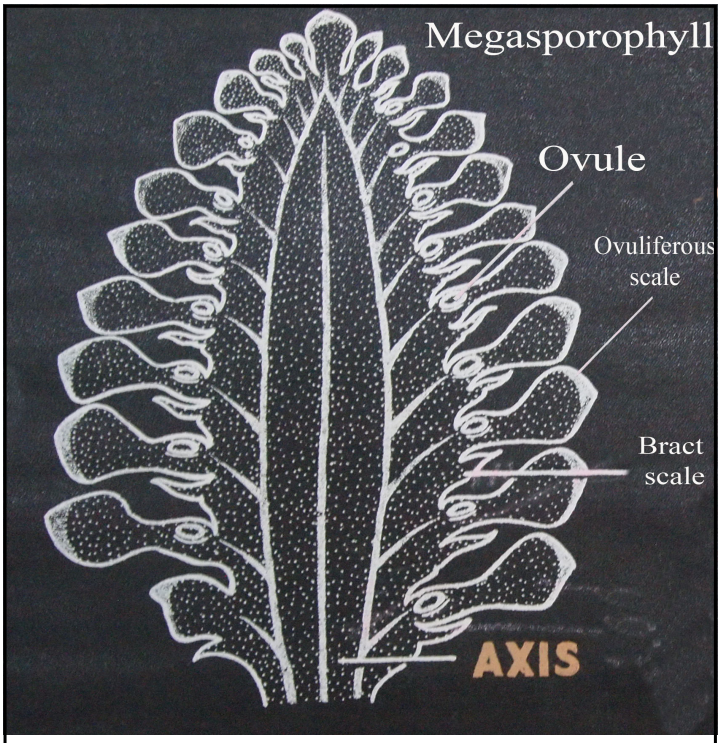
Pinus is predominantly monoecious and both the microsporangiate or pollen bearing cones and megasporangiate or seed bearing cones occur on the same plant. The megasporangiate cone is larger of the two.

The Female Reproductive Structure

Megasporangiate or Female Cone :

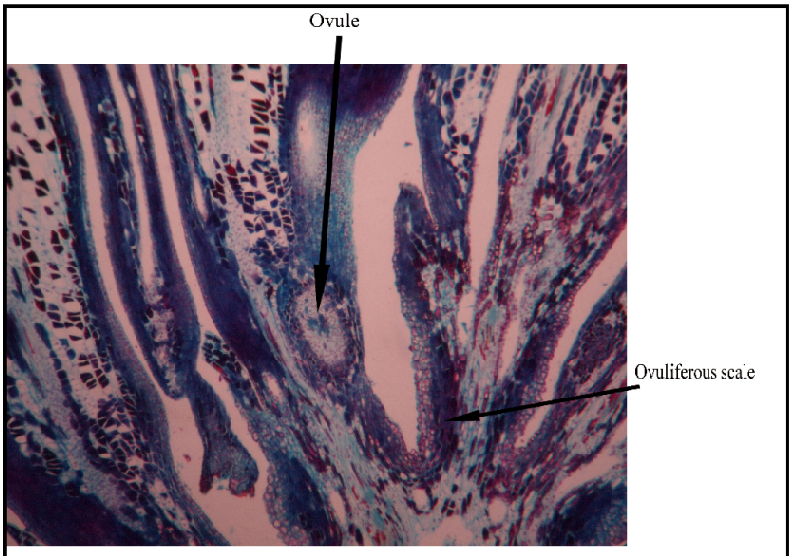
The megasporangiate or female cones are born in clusters of 1 to 4 on branches

of unlimited growth and take more than two years to complete their development. The female cone consists of a central axis bearing spirally arranged small appendages called bract scales. In the axis of each bract scale, there is a thick ovule bearing woody scale known as ovuliferous scale or cone scale. There are two ovules attached to the upper (adaxial) surface of ovuliferous scale near its base. The bract scale develops very slowly and in the mature cone it is a minute structure as compared to ovuliferous scale.



***Pinus* Female cone L.S. (Diagram)**

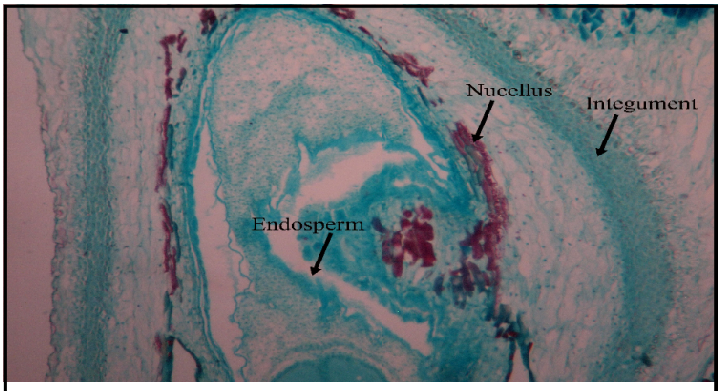
Morphological nature of ovuliferous scale :



***Pinus* Female cone L.S.**

The ovuliferous scale, as it bears ovules, is sporophyll-like. However, its axillary position with respect to bract scale makes difficult the interpretation of the structure. A number of theories (Sachs, 1882; Eichler, 1889; Kubart, 1905; Bessey, 1902; and Florin, 1951) had been proposed regarding the morphological nature of the ovulifereous scale and bract scale. The most accepted view is that of Florin (1951) and accordingly the ovuliferous scale is a highly modified lateral fertile shoot and, hence, not a sporophyll. The female cone has been regarded as a “compound” strobilus comparable to inflorescence of the angiosperms. Florin put forward his views on the evolution of this ovule bearing structure and re-interpreted the seed-scale-complex in different living conifers.

According to him it consists, in Pinaceae, of a rudimentary axis, two basal megasporophylls, and two or three sterile distal scales; the last are fused and form the ovuliferous scale.



***Pinus* Ovule V.S.**

Ovule or Integumented Megasporangium :

The ovule is composed of a nucellus and single integument, which is free at the apex. In many conifers, the outer fleshy layer is rudimentary. The micropyle is directed inward the cone axis.

Megasporogenesis :

There is only one megasporocyte (megaspore mother cell) in each ovule and it is situated deep within the nucellus. The reductional (meiotic) division of the megasporocyte gives rise to a linear tetrad of four haploid cells. The lowest cell is the functional megaspore and the rest degenerate. The megasporogenesis just begins in the ovules at about the time of pollination.

Female gametophyte :

The functional megaspore enlarges in size and a series of free nuclear division takes place forming about 2,000 nuclei. But, there is a period of dormancy after the formation of 32 nuclei. It is only a year after pollination that the female gametophyte becomes cellular by centripetal wall formation. Archegonia appear about a fortnight before fertilization and are usually three in number.

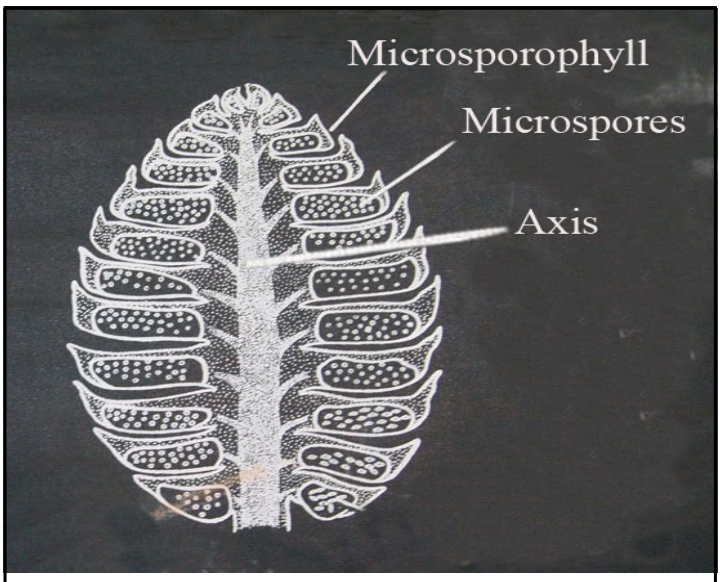
Development of archegonia:

Two or three surface cells at the micropylar end of the gametophyte get differentiated as archegonial initials. Each initial divides periclinally into a primary neck cell and a large central cell. The primary neck cell forms a short neck composed of two tiers of four cells each. The nucleus of the central cell divides to form a ventral canal cell and a large egg cell. The two are separated by a definite wall. Neck canal cells are lacking. A pollen chamber is not formed in *Pinus* unlike *Cycas* and *Ephedra*.

The Male Reproductive Structure

Microsporangiate cone :

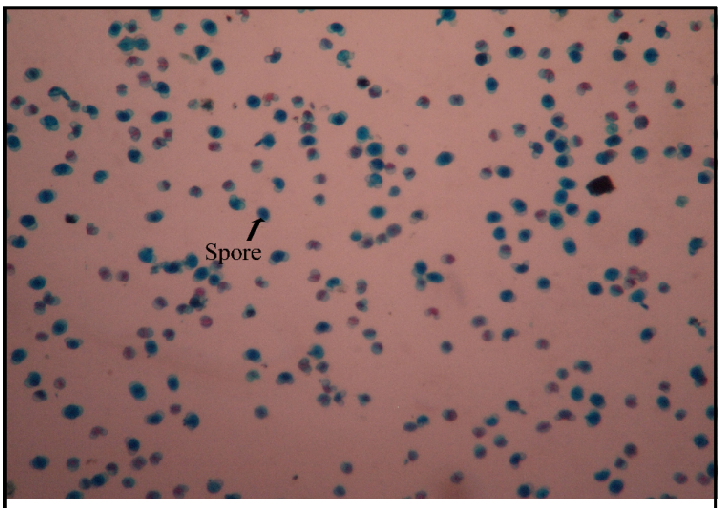
The microsporangiate or male cones are small and crowded near the apex of branches of unlimited growth. Each cone arises in the axil of a scale leaf. The development of male cone completes in about a year.



***Pinus* Male cone L.S. (Diagram)**

The male cone bears spirally arranged microsporophylls around a short central axis. Each microsporophyll has short stalk and a flattened leaf-like triangular appendage and bears two microsporangia on its lower surface. Microsporangium dehisces by a longitudinal slit.

Microsporegenesis :



***Pinus* Pollen Grain W.M.**

The development of the microsporangium is of the eusporangiate type, i.e., the sporangium develops from a series of cells. The hypodermal archesporial cells divide and the diploid cells of the last generation are known as microspore mother cells. Four microspores are formed by the reductional (meiotic) division of each microspore mother cell. A very large number of microspores is formed in each sporangium.

Microspore structure :

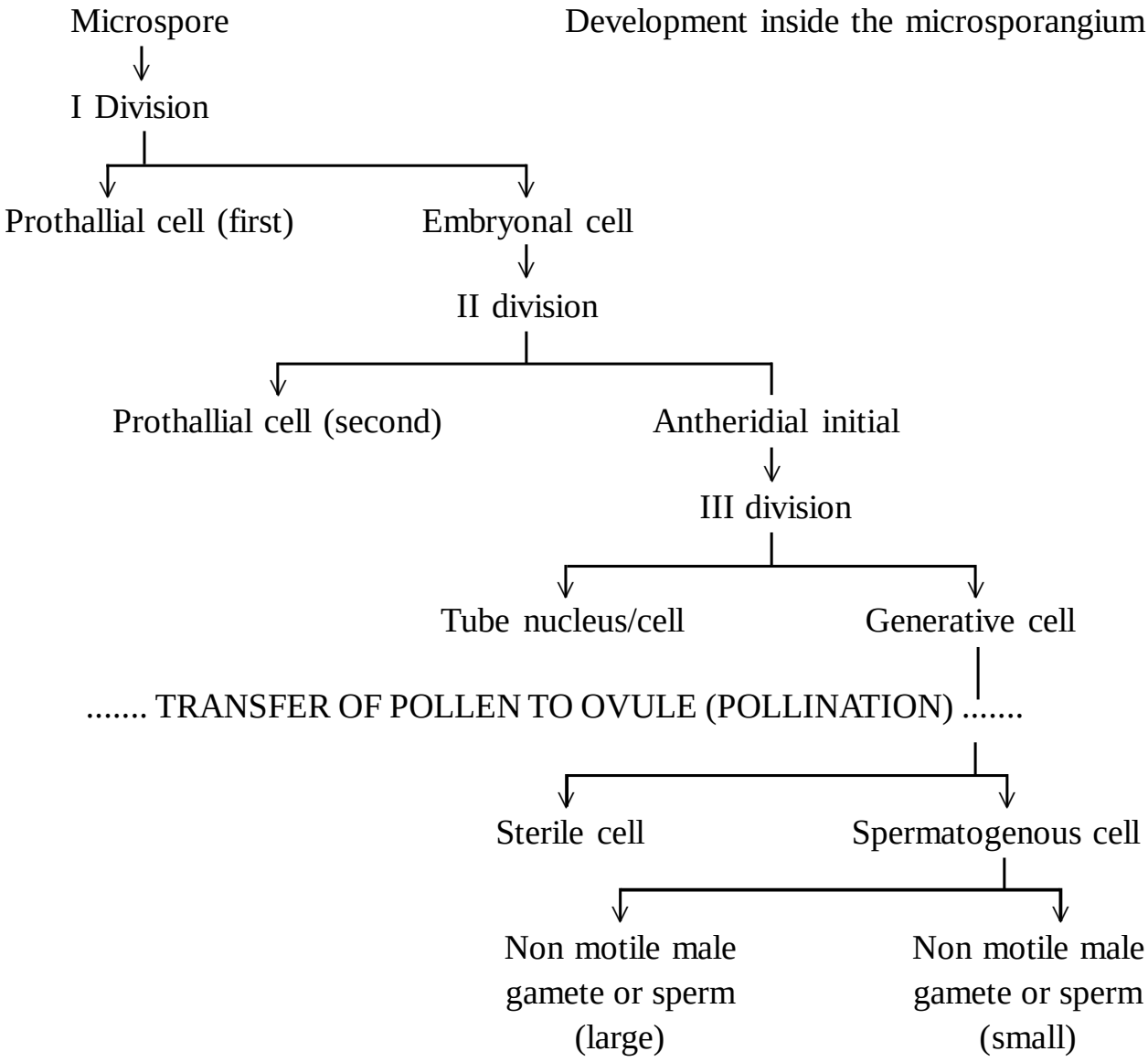
The microspores, characteristically, have two lateral wings or bladders or sacs filled with air. Wings are formed by the separation of the two wall layers, the exine

and the intine. In both the wings, the exine shows a reticulate sculpture. Wings, probably help the microspore to float over the nucellus.

Male gametophyte :

Development of endosporic male gametophyte occurs before the microsporangium dehisces. At the time microspore (pollen grain) is shed its nucleus has already undergone three divisions forming two prothallial cells, a tube nucleus, and a generative cell.

Stages in the formation of the male gametophyte.



Post pollination development of pollens or male gametophyte :

The pollination is followed by a slow period of development of the male

gametophyte. During this period, there is emergence of the pollen tube and the division of the generative cell into a sterile cell (stalk cell) and a spermatogenous cell (body cell). It is about a year after pollination, that the pollen tube actually reaches the archegonium. The stalk and body cells move down toward the lower end of the pollen tube. About a week before fertilization, the body cell divides to form two non-flagellate male gametes or sperm nuclei; which are of unequal size.

Pollination

The ovules are wind pollinated. At the time of pollination, the axis of the female cone elongates so as to separate the ovuliferous scales for the entry of the microspores or pollen grains. A pollination drop is exuded from the micropyle to which the pollen grains get adhered (Chamberlain, 1935). The pollen grains come to lie in a cavity formed by the slight depression of the nucellus (Ferguson, 1904). After this, the ovuliferous scales get closed (drawn together so as to become compact) and they remain so till the time of release of seeds.

Fertilization

There is an interval of about twelve months between pollination and fertilization. The pollen tube grows downward piercing the nucellus and upon reaching the archegonium pushes itself between the cells of the neck and bursts out. Fertilization occurs between the larger male gamete and the egg nucleus giving rise to a diploid zygote or the first cell of the sporophytic generation.

Embryogeny

The zygote (oospore) undergoes three divisions and forms eight cells arranged in two tiers of four cells each. The tiers are formed toward the base. Cells of each of the two tiers divide once again forming four tiers of four cells each.

The upper most tier is without an upper wall and, thus, consists of open cells. Starting from the top, these tiers have been named as below:

	Doyle (1957, 1963)			**Old terms**
1.	Secondary upper tier	(UT)	1.	Open tier
2.	Suspensor tier	(ST)	2.	Rosette tier
3.	First embryonal segment	(ES)	3.	Suspensor tier
4.	Embryonal cells	(EC)	4.	Apical or embryonal tier.

Secondary upper tier (UT) and suspensor tier (ST) do not play any part and degenerate. The mode of elongation and development of the first embryonal segment (ES) is shown in figure. The embryo proper develops from embryonal cells (EC). Several (usually four) embryos may be formed due to splitting of the developing proembryo. This phenomenon is known as cleavage polyembryony. However, only one of the many developing embryos reaches the stage of maturation. The developing embryo derives its nutrition from the conical corrosion region below the archegonia in the female gametophyte. The embryo is straight with its radicle pointing towards the micropyle and plumule on the opposite side. The plumule is hidden in the cotyledons, which are numerous.

Pinus seed

Each megasporophyll bears two seeds. In *Pinus*, the seeds are winged. Wings, strictly speaking, are not part of the seed because they are formed from the upper surface of the ovuliferous scales. Wing is a membranous structure. A mature seed possesses the following structure:

Seed Coat :

It is outer most covering and develops from the middle stony layer of the integument. The inner fleshy layer exists in the form of a thin papery membrane.

Perisperm (nucellus) :

It is the reddish brown, membranous remnant of nucellar tissue. It can be seen as nucellar beak at the micropyler end of the female gametophyte.

Kernel (female gametophyte) :

It is the white nutritive female gametophytic tissue surrounding the embryo. It also contains oil.

Embryo :

The new sporophyte or embryo consists of radicle (root), plumule (stem tip) and 8 to 14 cotyledons and is surrounded by the gametophyte.

Seed dispersal :

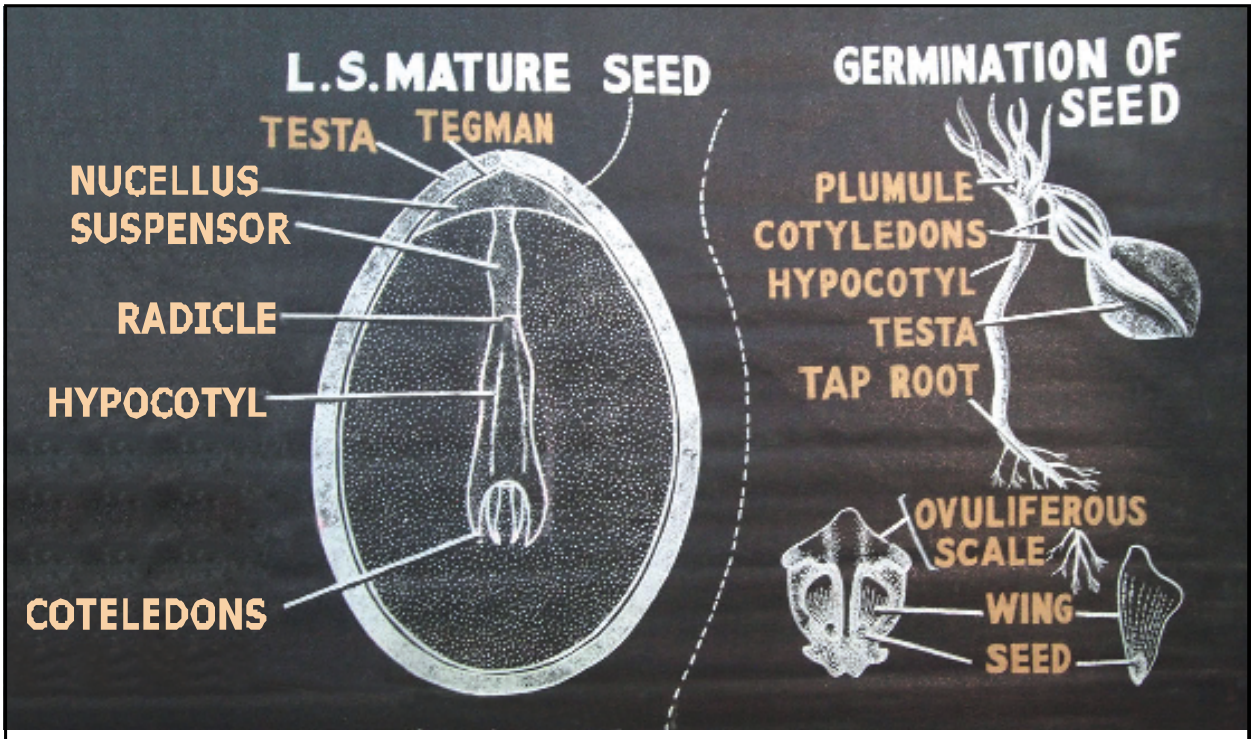
The female cone, when mature, is brown in colour. The ovuliferous scales are woody. A further growth of the cones causes the ovuliferous scales to spring apart. The seeds can now be released and dispersed by the wind.

Successive steps in the reproductive cycle

Male	Year & Month	Female
First year		
Slow growth of male Cone (strobilus)	January	Initiation of female cone (strobilus)
Formation of tapetum in the microsporangium, degeneration of its wall layers and development of fibrous thickenings; formation of uninucleate microspores and start of the development of male gametophyte.	February	Emergence of female strobilus accompanied by differentiation of hypodermal archesporial cell in the ovuliferous scale.
Development of male gametophyte into two prothallial cells (first and second), a tube cell and a generative cell; dehiscence of sporangium and transfer of pollen to ovule (pollination)	March	Pollination followed by closure of micropyle; megaspore nucleus divides into 18 to 32 nucleate female gametophyte.
Germination of pollen grains.	April	
Rest period	May-Aug.	Rest period
Initiation of another cone of male strobili and growth.	Sept. - Dec.	
Second Year		
	Jan. - Feb.	Slow increase in the size of female cone accompanied by further free nuclear division and enlargement of the female gametophyte.
Division of generative cell into a body cell and a stalk cell and their migration into pollen tube; division of body cell into two male gametes.	March	Formation of cellular gametophyte by wall formation; initiation of the archegonial initials and its enlargement.
Growth of one male gamete nucleus; fertilization.	April	Formation of mature archegonia; fertilization, division and development of zygote (oospore) forming suspensor and embryonal tiers (proembryo)
	May	Growth of proembryo continues.
	June	Further growth and differentation of embryo.
	July - Dec.	Embryo maturation
Third Year		
	Jan. - Mar.	Embryo-maturation
	Apr.	Opening of female cone by gaping apart of ovuliferous scale; shedding of seeds (winged).

3.7. Germination of seed

There is no rest period and the seeds may germinate immediately if the conditions are favourable. Under unfavourable condition, the germination may be postponed for several years. The plumule grows out of the soil carrying the cotyledons along with it and forms the shoot of unlimited growth. The primary tap root is developed from the radicle.



Germination of Seed

3.8. Economic Importance

1. Edible seeds called chilgoza is yielded by *P. gerardiana*.
2. *P. roxburghii* and *P. wallichiana* are of great economic importance as sources of soft-wood timber. Timber is used variously and also for manufacturer of packing boxes and match sticks. Besides, the wood is used as fuel.
3. The trees are grown in the gardens for ornamentation.
4. Terpentine oil is obtained from *P. insularis* and *P. roxburghii*.
5. Various species of the genus provide cellulose.

Chapter-4

Ephedra Tourn ex. L.

4.1. Systematic Position

Class	–	Ephedropsida
Order	–	Ephedrales
Family	–	Ephedraceae
Genus	–	*Ephedra* Tourn ex. L.

4.2. Distribution in the world

The genus *Ephedra* includes some forty species (Sporne) distributed in both the Western and Eastern Hemispheres. The species grow mostly in desert or arid regions.

4.3. Distribution in our country

In India, the species occur in North West Himalayas except *E.foliata*, which grows in the plains of Punjab (southern part) and Rajasthan. The following species of *Ephedra* are found in the country.

1. ***E.foliata*** : Plains of Punjab and Rajasthan.
2. ***E.intermedia*** var. *Tibetica* : Himachal Pradesh, Punjab, Jaunsar and Kashmir.
3. ***E.gerardiana***. Alpine and temperate Himalayas, Kashmir and Sikkim.
4. ***E.saxatilis*** var. *Sikkimensis* : Sikkim.
5. ***E.nebrodensis*** var. *Procera* : Kashmir.
6. ***E.regeliana*** (syn. *E. major*) : Ladakh.

4.4. External Features of Sporophyte

Most of the species are profusely branched shrubs. A few species are lianas or climbers, e.g. *E.foliata* and *E.triandra*. South American species may grow into a short tree.

The plant consists of a profusely branched stem and small scale-like inconspicuous leaves. The young stems and branches are green and photosynthetic. The leaves are usually opposite and decussate but in few species they develop in whorls of three (rarely four) at each node. The leaves are united to form a basal sheath. Branches arise in the axils of the leaves. There is a superficial resemblance between the short shoot of *Ephedra* and branch of *Equisetum* (Rigdes, passout on stem).

4.5. Internal Structure of Sporophyte

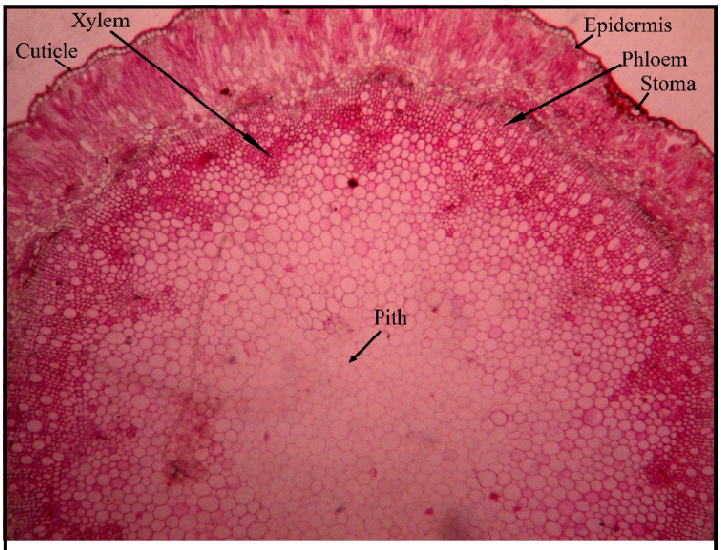
Root

The root is usually diarch.

Stem:

Primary Structure :

The stem is ridged. The outline, in T.S., consists of ridges and furrows. It can be differentiated into epidermis, hypodermis, cortex and stele.



***Ephedra* Stem T.S.**

Epidermis is made up of single layered thick walled cells with a thick cuticle over it. Epidermis is interrupted by stomata, which are present in the furrows and are deeply sunken in pits. The development of stomata is haplocheilic.

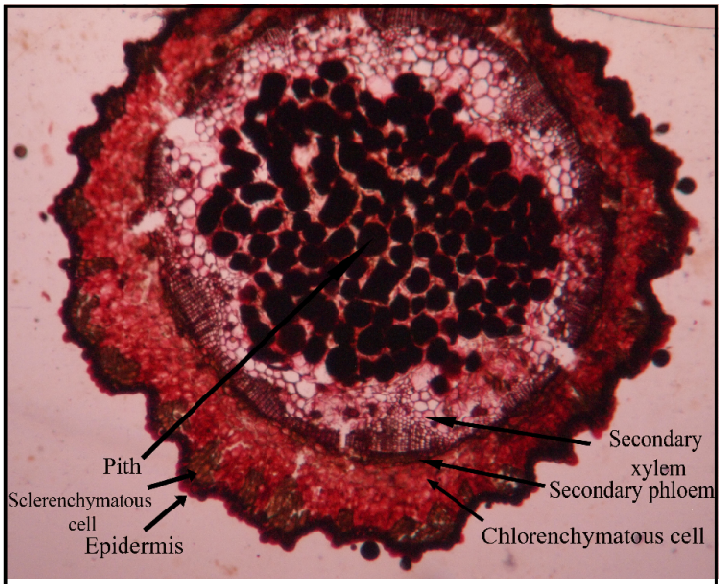
Under the ridges are present groups of fibrous cells known as hypodermal strands.

Cortex consists of thin walled cells containing chloroplasts. It may be differentiated into an outer palisade layer and an inner spongy tissue with large intercellular spaces. There is single cell thick endodermis in the young stem.

Pericycle is not well defined.

Vascular bundles are conjoint, collateral and arranged in a ring. Cambium is present between phloem and xylem. Xylem is endarch.

The central pith is mainly parenchymatous. In the nodal region, the cells are lignified forming transverse plates or diaphragms.



***Ephedra* Stem T.S. 2**

Secondary Structure :

A ring of cambium is developed resulting in the formation of secondary xylem internally and phloem externally. Primary phloem gets crushed and primary xylem is pushed towards the inner side. Xylem consists of both the tracheids and the vessels.

Transitional conditions indicating the evolution of vessels from tracheids can be seen in *Ephedra*. Vessels are formed abundantly in spring wood and are larger in size. In autumn wood they are scarce. Spring wood consists of larger and thin walled cells. The autumn wood cells are smaller and thick walled. The two woods together form an annual ring. Thus, a number of annual rings may be present in an old stem T.S. Xylem rays, when young, are thin and uniseriate. In old stems, the rays become multiseriate and broad. Also a phellogen or cork cambium arises outside the secondary phloem in three or four years old plants.

Leaf :

Leaves do not show marked differentiation of tissues. According to Maheshwari and Vasil (1961) both the haplocheilic and syndetocheilic types of stomata are formed in the leaves of *Ephedra*.

Stomata :

The gymnospermous stomata are classified into two types: (1) the haplocheilic, examples-conifers (living and extinct), the Cycadofilicales, Cordaitales, Cycad, Ginkgoales and the genus *Ephedra* and (2) the syndetochelic examples - Bennettitales (extinct), *Welwitschia* and *Gnetum*.

4.6. Reproductive Structure

Most species of *Ephedra* are typically dioecious, i.e., the microsporangiate and megasporangiate cones develop on different plants. However, Pearson (1928) observed many instances of monoecious type. The strobili arise in whorls of 2, 3 or 4 in the axils of the leaves at the nodes. Both the types of strobili or inflorescences are compound, the axis of the cone bears pairs of bracts, which subtend either ovulate or microsporangiate shoots.

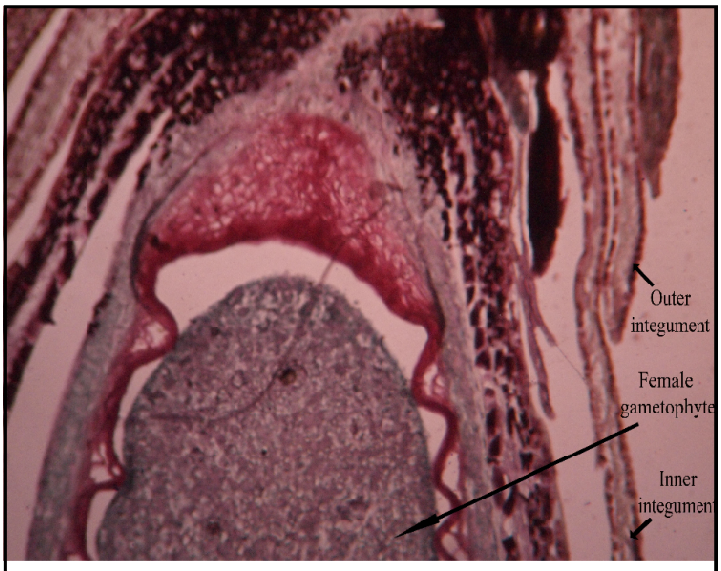
Female Reproductive Structure

The megasporangiate or female cone :

It consists of an axis bearing 2 to 4 or more pairs of opposite and decussately arranged bracts. In a few species, the bracts are swollen and juicy. Most of the lower bracts are sterile.

Ovule (Female flower) :

The female cones of many species of *Ephedra* contain usually only two ovules one in the axil of each of the apical bracts.



***Ephedra* Female Cone V.S.**

The ovule consists of a nucellus enclosed by two 'integuments' or envelops. The ovule of *Ephedra* is unique among gymnosperms in the sense that there are two integuments. The inner one is the true integument and possesses two layers of cells. The outer is regarded as perianth. The lower half of inner integument appears fused to the nucellus and the upper half is free and prolongs into a long free micropyle during pollination. Eames (1952) observed that the inner integument is equivalent to a pair of fused appendages. He further concluded that the so called female flower of *Ephedra* consists of a reduced basal megasporophyll terminating into an ovule. It is enveloped by a pair of fused bracteoles (outer integument).

Megasporogenesis :

The single megasporocyte (megaspore mother cell) is situated deep in the nucellus. A linear tetrad of haploid megaspores may be formed by meiotic division of the megasporocyte. However, sometimes the upper dyad or diploid cell of the two cells formed by the first meiotic division fails to divide as in *Pinus*. Thus a row of only three cells may be formed. The lowest cell is functional and it enlarges and produces the female gametophyte.

Female gametophyte :

The functional megaspore undergoes free nuclear divisions forming 256 free nuclei in *E.trifurca* (Land, 1904) and about 500 free nuclei in *E.foliata* (Maheshwari, 1935). Walls are laid down and the cellular gametophyte comes to be differentiated into an upper and a lower region. The upper region consists of delicate tissue and the lower of compact cells with stored food material.

Archegonium :

There are formed two or three archegonia (or occasionally only one). The archegonium consists of a long neck and a central cell with ventral canal nucleus and an egg nucleus. The archegonium arises from a superficial cell (archegonial initial) in the upper region of the female gametophyte. The superficial cell divides periclinally forming an outer primary neck cell and an inner central cell. The primary neck cell divides to form a long neck, which is 30 to 40 cells high. Central cell enlarges and divides to form a ventral canal nucleus and an egg nucleus. The ventral canal nucleus remains in the upper region, but sometimes it degenerates soon after formation. According to Land (1904), “of all gymnosperms *Ephedra* has the longest-necked archegonium”. The cells of the neck merge with the adjacent cells of the gametophyte. The cells of the gametophyte, adjacent to central cell, form an archegonial wall or jacket. This is one or two cells thick. A conspicuous pollen chamber is formed by the disorganization and obliteration of the nucellar tissue above the female gametophyte. Thus, the apical portion of the gametophyte becomes exposed.

Male Reproductive Structure

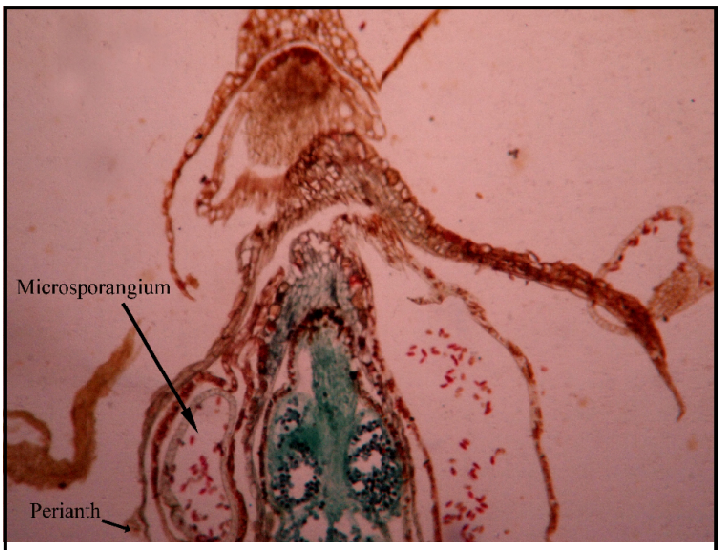
Microsporangiate cone :

It consists of a central axis on which are produced 2 to 8 pairs of opposite and

decussately arranged bracts. The lowest pairs of bracts are sterile while remaining ones are fertile. Each fertile bract develops a microsporangiate shoot (flower) in its axil.

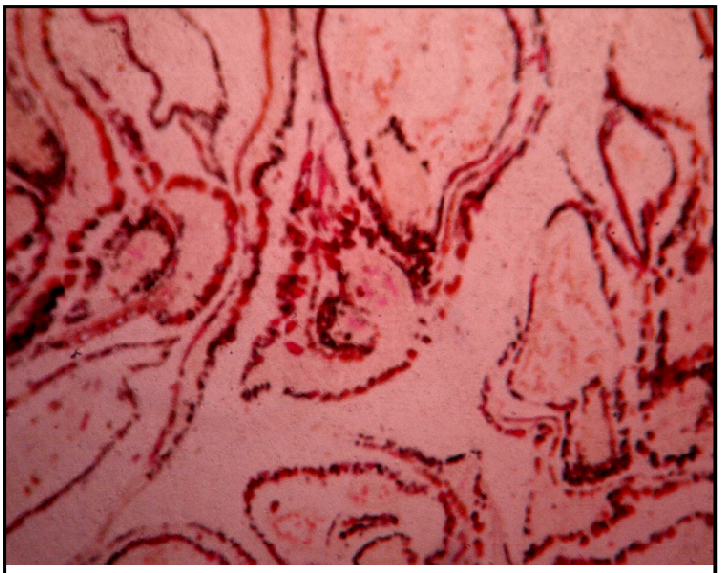
Microsporangiate shoot (flower) :

This shoot consists of a pair of fused bracteoles (two sterile appendages or perianth) and a short axis or column (microsporangiophore or stamen or antherophore) bearing a group of 1 to 8 microsporangia. The number of sporangia varies with the species. In some species the axis is forked. In *E.intermedia* and *E.distachia*, there are two axes or microsporangiophores. According to Eames (1952) these two species show the primary or primitive condition and the other species, having one axis, exhibit fusion of varying degrees. Eames considers that the single axis is the result of fusion of two microsporophylls and that in the other species, regarded as primitive, the two microsporophylls are free. When free, each axis bears four sporangia apically.



***Ephedra* Male Cone V.S.**

Microsporangium (anther) :


***Ephedra* L.S. Flower**

The microsporangium possesses either two or three loculi, each opening by a terminal slit to release the microspores.

The hypodermal cells (sporangial initials) divide periclinally producing primary wall cells externally and the sporogenous cells internally. Primary wall cells again undergo a periclinal division to form a wall made up of single layer of cells and tapetum. The cells of the wall get

flattened and stretched. The cells of the tapetum become multinucleate during the formation of microsporocyte (microspore mother cells).

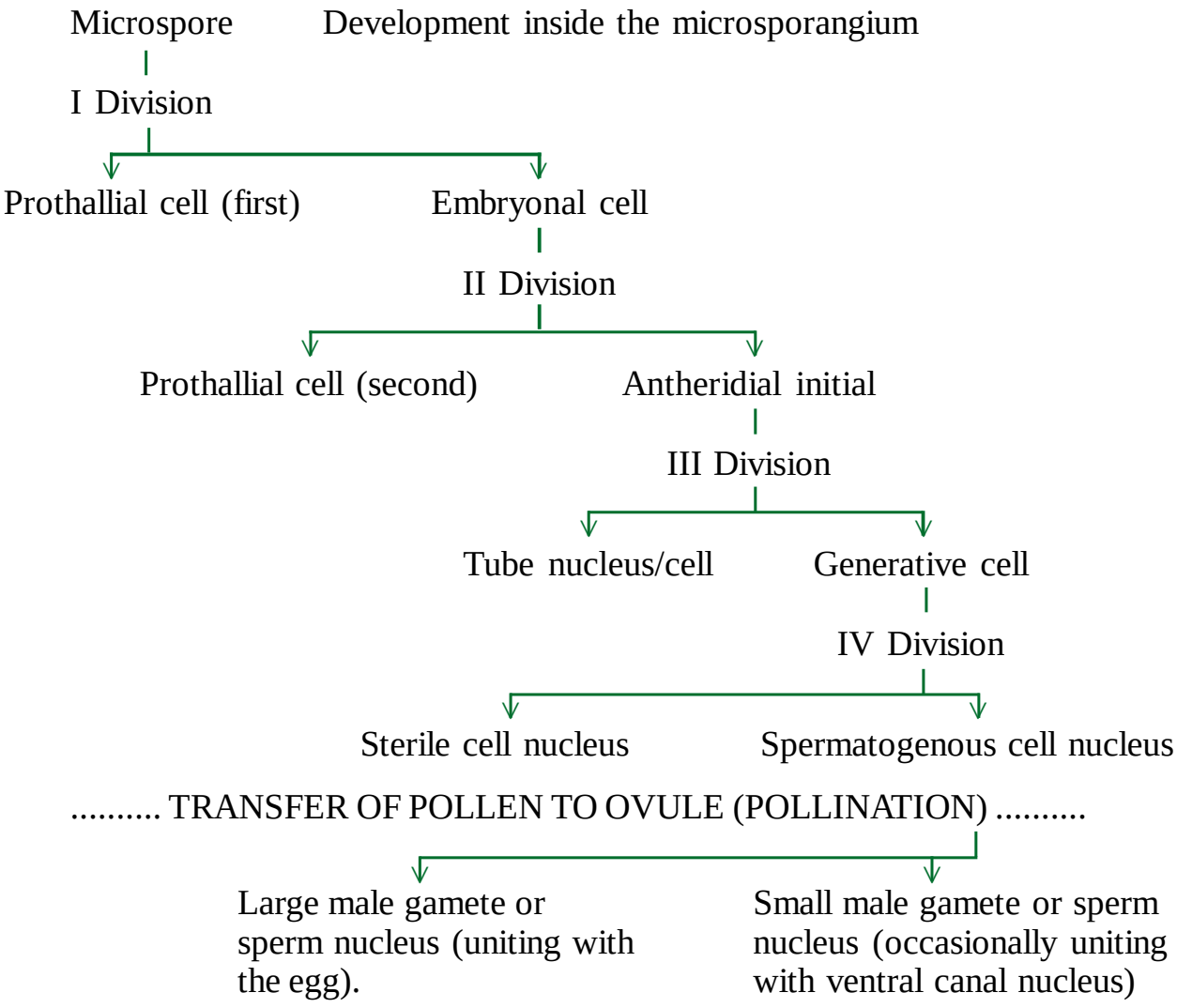
Microsporogenesis and microspores :

The haploid microspores, formed by the reduction division of the microspore mother cell, have a thick exine at maturity. Microspores lack wings.

Male gametophyte :

The microspore nucleus undergoes four successive divisions forming a young male gametophyte with two prothallial cells (the second one is without any demarcation wall), a sterile cell nucleus, a spermatogenous cell nucleus and a tube nucleus. It is at this five-nucleate stage that the microspore is released from the microsporangium.

Stages in the formation of the male gametophyte.



Post pollination development of microspore

Microspores germinate within a few hours of entering the pollen-chamber in the ovule. The emergence of pollen tube is preceeded by shedding of the exine and the division of the spermatogenous cell into two unequal sperm nuclei. The two prothallial cells degenerate.

Pollination

Microspores or pollens are carried by wind to the tip of the micropyle formed by externally projected inner integument. They fall down in the pollen chamber and come in direct contact with the female gametophyte.

Fertilization

In *E.trifurca*, the interval between pollination and fertilization is of ten hours. The pollen tube penetrates the neck of the archegonium. With the rupture of the pollen tube tip, the two male nuclei along with tube nucleus and sterile (stalk) cell nucleus are released into the cytoplasm of the archegonium. One of the male nuclei fuses with the egg nucleus. Khan (1949) observed that the other male nucleus may fuse with the ventral canal nucleus and this may lead to 'double fertilization'. However, no embryo results from this fusion.

4.7. Embryogeny

The nucleus of the fertilized egg undergoes three free nuclear divisions. The eight diploid nuclei, thus formed, become individually surrounded by cytoplasm and later by wall. Each of these eight proembryonal cells are capable of developing into an embryo. Thus *Ephedra* shows a precocious type of cleavage polyembryony. Usually the lower three to five proembryonal cells develop successfully into embryos and only one achieves a fully developed stage in a seed.

Each proembryonal cell divides to form a suspensor cell and an embryo initial. The suspensor cell elongates pushing down the embryo initial into the female gametophyte. The embryo initial, by a number of divisions, develops into embryo proper with two cotyledons and the shoot apex at the lower side.

Seed

The adjacent bracts of the strobilus become thick and fleshy and form an additional integument of the seed.

The seed consists of two integuments. The outer integument encloses the seed externally and consists of thick walled cells. The inner integument is made up of two layers of cells and persists at the upper (micropylar) end of the seed.

Nucellus appears as a disorganized sheath of cells.The embryo is quite conspicuous with its two large cotyledons. It is embedded within the female gametophyte.

Seed germination

There is no rest period for the seed and in *E.trifurca*, it may start germination while still enclosed within its strobilus. Cotyledons grow steadily, becoming many centimetres long and perform the function of photosynthesis in absence of green leaves.

4.8. Economic Importance

Many Asiatic species, namely, *E. gerardiana*, *E. sinica*, *E. nebrodensis* and *E. intermedia* serve as source of an important drug ephedrine used for the cure of asthma and hay fever. It has been used in China for over 5,000 years.

Chapter-5

Summary

5.1. Distribution

***Cycas* :** Species distributed in Australia, India, China, Japan.

Naturally occurring Indian species *C. circinalis, C. pectinata, C. rumphii* and *C. beddomei* grow in North East region and the south; *C. revoluta* and *C. siamensis* cultivated in gardens.

***Pinus* :** Species distributed in north temperate and arctic regions.

Naturally occurring Indian species *P. wallechiana, P. roxburghii, P. gerardiana, P. merkusii, P. insularis* and *P. armandi* grow in North-West and North- East Himalayas.

***Ephedra* :** Species distributed in Western and Eastern Hemisphere;

Naturally occurring Indian species *E. foliata, E. intermedia, E. gerardiana, E. saxatilis, E. nebrodensis* and *E. regeliana* grow in North West Himalayas, Punjab and Rajasthan.

5.2. Habit/ Morphology

***Cycas* :** Plants with unbranched, columnar stem and crown of leaves at the apex; leaves of two types, the green assimilatory or foliage leaves and unbranched (single midrib) scale leaves; foliage leaves large and unipinnately compound; pinnae closely set, univeined, and in two rows on the rachis; scale leaves brown and small; stem covered with hard and thick armour of leaf bases; adventitious branching is not uncommon and by lateral buds or bulbils or induced by injury; vegetative propagation by bulbils; adventitious roots of two types, the positively geotropic or normal roots and apogeotropic, coralloid roots with a zone of blue-green algae in the middle of the cortex.

***Pinus* :** Plants developing into trees with long and short spur shoots; leaves of two types, the green or foliage leaves and scale leaves; green leaves are photosynthetic and confined to lateral spur shoots; the photosynthetic leaves are needle-like and, depending on the species, one to five in number; tap root with scanty hairs and ectotrophic mycorrhiza.

***Ephedra* :** Plant shrubby with profusely branched stem and small scale-like leaves; stem and branches green; leaves inconspicuous; *E. foliata* climber.

5.3. Anatomy

5.3.1. Root

Cycas

(i) **Normal Root :** Epiblema followed by thick cortex of parenchyma interspersed with tannin cells; endodermis single layered; pericycle many layered, phloem and xylem radially arranged; xylem exarch and diarch; metaxylem extending to and occupying the centre or separated by a few parenchymatous cells.

Secondary growth occurs by cambium cutting secondary phloem externally and secondary xylem internally; secondary xylem manoxylic; phellogen giving rise to cork cells externally; outlying cells getting peeled off.

(ii) **Coralloid Root :** Structurally similar to normal root but possessing a wider cortex with characteristic algal zone occupied by algae *Anabaena* and *Nostoc* and bacteria *Azotobacter*; cells of algal zone thin walled, radially elongated and loosely connected; secondary vascular tissues (poorly developed or) absent.

Pinus

Epidermis with few root hairs in the young condition; cortex multilayered and parenchymatous; endodermis single layered and followed by multilayered pericycle; phloem and xylem bundles alternating; xylem diarch to tetrarch and forked like 'Y'; resin canals lying opposite protoxylem point; secondary growth by meristematic activity of cambium and phellogen, the former cutting phloem externally and xylem internally and the latter forming phellem or cork on the outerside and phelloderm on the inner.

Ephedra

Root usually diarch.

5.3.2. Stem

Cycas

Outline irregular due to presence of leaf bases; predominantly parenchymatous and manoxylic; cortex wide and parenchymatous with a number of mucilage canals and numerous leaf traces; numerous vascular bundles arranged in a ring; bundles collateral and open; manoxylic; pith in centre, parenchymatous and wide; leaf traces girdling and radial.

Secondary growth by primary intrafascicular cambia and other cambial rings formed outside in regular succession and cutting of secondary phloem externally and secondary xylem internally (polyxylic); vascular rings concentric; medullary rays broad; xylem development scanty (manoxylic); cork layers formed successively and getting peeled off.

Pinus

Epidermis with thickened outer walls and thick cuticle; cortex multilayered differentiated into outer sclerenchymatous and inner parenchymatous regions, the latter with leaf traces and resin canal; endodermis one layered; pericycle multilayered and parenchymatous; vascular bundles collateral, conjoint, open and separated by narrow medullary rays; pith in centre and small.

Secondary growth by persistent meristematic activity of cambium ring cutting off secondary phloem externally and secondary xylem internally (monoxylic); annual rings or growth rings formed and differentiated into spring and autumn wood; pycnoxylic wood, development of abundant phellogen arising in the outer parenchymatous region of the cortex and cutting cork externally and phelloderm internally.

R.L.S. of the stem shows bordered pits in surface view and medullary rays extend horizontally; T.L.S. shows bordered pits in sectional view with a prominent torus; medullary rays also cut across in T.L.S.

Ephedra

Stem ridged (and furrowed); epidermis single layered, made up of thick walled cells and with thick cuticle; stomata haplocheilic, deeply sunken and situated in furrows; hypodermal strands under the ridges; cortex of thin walled cells containing numerous chloroplasts and differentiated into palisade and spongy tissue; vascular bundles collateral, open, endarch and arranged in a ring; pith central.

Secondary growth by the activity of cambium ring and phellogen as in *Pinus*; growth rings with autumn and spring wood; xylem consisting of both tracheids and vessels; medullary rays uniseriate in young stem and becoming multiseriate in old.

5.3.3. Leaf

Cycas

(i) Rachis : Epidermis thick walled and with a thick cuticle; stomata irregularly distributed; epidermis followed by chlorenchyma and sclerenchyma (hypodermis) successively; ground tissue parenchymatous with mucilage canals; vascular bundles arranged like the inverted omega (a Greek letter); each bundle enclosed by a sclerenchymatous bundle sheath; vascular bundles diploxylic with a triangular centripetal xylem and 2 or 3 small groups of centrifugal xylem separated by parenchyma; protoxylem pseudomesarch; phloem lying external to centrifugal xylem.

(ii) Leaflet (pinna) : Epidermis thick walled and with cuticle; stomata of haplocheilic type with hypostomatic chamber, occurring on the lower side; epidermis followed by one or more layered lignified hypodermis; mesophyll differentiated into palisade and spongy layers and the cells containing numerous chloroplasts; vascular bundle single, diploxylic, pseudomesarch and resembling in structure to that of a rachis bundle; xylem lying on the upper side and phloem on the lower; transfusion tissue in two groups on the two sides of the centripetal xylem; secondary transfusion tissue in parallely arranged layers of cells attached end to end and extending from midrib to margin.

Pinus

Outline triangular (*P. roxburghii*) or semicircular or circular; vascular bundles one (*P. monophylla*) or two; epidermis single layered made up of thick walled cells and with a thick cuticle; stomata haplocheilic and sunken; amphistomatic; hypodermis few layered, sclerenchymatous and absent inside the stomata; mesophyll cells thin walled with infoldings on their walls (arise palisade) and containing numerous chloroplasts; resin canals present; midrib of the leaf occupied by one or two vascular bundles surrounded by many layered pericycle (transfusion tissue as stated by Foster and Gifford, 1959) and one cell thick prominent endodermis; vascular bundles collateral; xylem endarch; sheets of parenchyma running across the xylem and phloem; transfusion tissue consisting of two types of cells, the transfusion tracheids

and the albuminous cells.

Ephedra

Tissues not differentiated markedly.

5.3.4. Stomata

Stomata sunken and haplocheilic in all the three genera, *Cycas*, *Pinus* and *Ephedra*.

5.4. Reproductive Cycle

Cycas

Plants dioecious :

Female plants monopodial; megasporophylls produced, like green leaves, in a loose crown surrounding the shoot apex without forming a cone; shoot apex not used up and maintains its identity; leaves and sporophylls produced by same apex alternately throughout life.

Megasporophylls with basal narrow stalk, middle fertile region bearing 2 to 8 ovules, and terminal sterile part.

Ovules orthotropous consisting of nucellus surrounded by integument which except for a short free region at the top, appears fused with nucellus; upper free part possesses a narrow passage called micropyle; apical region of nucellus projects into micropylar canal forming a nucellar beak; cells of nucellar beak disorganise forming a pollen chamber, where the microspores lie after pollination.

A single diploid megasporocyte (megaspore mother cell) gets differentiated in nucellus and divides meiotically (by reductional division) producing a row of three (never four) cells, lowest being functional haploid megaspore.

Megaspore enlarges with its nucleus dividing several times and forming a large number of free nuclei; wall formation occurs centripetally forming a completely cellular female gametophyte or endosperm; two to eight archegonia develop in upper region of gametophyte and an archegonial chamber forms between this and overlying nucellar tissue; archegonia consists of two neck cells and a central cell containing a ventral canal nucleus and an egg nucleus.

Male plants sympodial :

Male strobili or cones compact, solitary and produced terminally; central axis of cone bears numerous spirally arranged microsporophylls; each microsporophyll with over a thousand microsporangia on lower (abaxial) side; sporangium with a thick wall and numerous sporogenous cells, latter being surrounded by a tapetum (disorganise later); sporogenous cells give rise to microsporocytes (microspore mother cells); each diploid microsporocyte, by reductional division, produces a tetrad of haploid microspores (first cells of gametophytic generation).

Development of endosporic male gametophyte starts inside microsporangium; microspores or pollens shed from sporangium at three celled stage and consist of a prothallial cell, a generative cell and tube nucleus/cell.

Pollination by wind (anemophilous); microspores get trapped in a drop of fluid secreted by micropyle and sucked down into pollen chamber; pollen tube penetrates sides of pollen chamber and haustorial in function; pollen grain anchored by pollen tube, hangs downward; generative cell divides into sterile (stalk) cell and spermatogenous (body) cell, latter dividing and forming two spermatozoids; spermatozoid is pear shaped with spiral bands of flagella and the largest in size in the whole plant kingdom.

Turgid pollen end ruptures into archegonial chamber releasing its fluid along with spermatozoids; fluid facilitates entry of spermatozoids into archegonium; after entering the egg cell, spiral ciliary band of sperm gets detached; sperm nucleus sinks down into egg cytoplasm and unites with the egg nucleus; ciliary band persistent and visible in egg cytoplasm even long after fertilization.

Zygote, by undergoing free nuclear divisions, gives rise to 256 or more nuclei before cross walls formations; upper end of proembryo or egg sac becomes elongated forming suspensor, and thus pushing embryo proper down into centre of female gametophyte; only one embryo reaches its maturity in a seed; embryo with usually two cotyledons enclosing the stem tip and a hard coleorhizae protecting root tip.

Cycas produces largest seeds in plant kingdom; seeds fleshy and red or brightly orange in colour and consisting of a thick integument (testa), a thin nucellus a massive endosperm and a straight embryo.

Pinus

Plants monoecious :

Female cones in groups of 1 to 4 on long shoot; development complete in about

three years; cone consists of an axis, which bears spirally arranged bract scales; a thick, woody, ovuliferous scale present in axil of each bract scale; ovules two in number and formed on upper surface of ovuliferous scale near its base; bract scale grows very slowly and remains quite small as compared to ovuliferous scale in mature cone; cone regarded as 'compound strobilus comparable with inflorescence (Florin, 1951).

Ovule consists of a single integument fused to nucellus except at apex; micropyle inwardly directed toward cone axis; diploid megasporocyte forms a linear tetrad of haploid megaspores by reductional division (meiosis); lowest cell becomes functional megaspore; free nuclear division of megaspore nucleus gives rise to about 2,000 nuclei; during course of an year, gametophyte becomes cellular; usually 3 (rarely 1 or 5) archegonia formed two weeks before fertilization; each archegonium consists of a short neck and a central cell; neck made up of two tiers of four cells; central cell forms a ventral canal cell and a large egg, the two separated by a definite wall.

Male cones formed in groups near the apex of long shoots; their development completes in one year; cone bears spirally arranged microsporophylls, each with two microsporangia on its lower surface; microsporangium dehisces by a longitudinal slit; reductional division of each diploid microspore mother cell results in formation of 4 haploid microspores; male gametophyte endosporic and undergoes partial development inside the microsporangium; microspore, at the time of shedding, has 4 nuclei/cells-2 prothallial cell, 1 tube nucleus/cell and a generative cell; microspores have two large lateral air sacs.

Pollination by wind and followed by a slow period of development of male gametophyte; generative cell divides into a sterile cell and a spermatogenous cell, latter forming two unequal non motile male gametes; fertilization occurs after about an year of pollination.

Zygote (2n) in its lower region forms 4 tiers of 4 cells each; upper two tiers not functional and degenerate; third tier or first embryonal segment (ES) elongates and undergoes further segmentation; several embryos formed from fourth tier or embryonal cells (EC) on account of cleavage resulting into cleavage polyembryony; only one embryo reaches maturity; embryo straight and with a radicle and plumule, the latter included within the cotyledons.

Each seed has a wing, which develops from upper surface of ovuliferous scale, mature seed consists of a seed coat, perisperm, kernel and embryo; seed coat develops from the middle stony layer of the integument.

Ephedra

Plants dioecious :

Female or megasporangiate cone (female inflorescence) consists of an axis (short shoot) bearing decussate bracts; most of lower bracts sterile; cone consists of two ovules (female flowers) one in the axil of each of upper bracts.

Ovule comprises a nucellus enclosed by two integuments (one integument and a perianth); lower half of inner integument fused to the nucellus but upper half remains free and prolongs into a long micropyle; micropylar tube projects freely out of strobilus at time of pollination.

Diploid megasporocyte (megaspore mother cell) produces a linear tetrad of haploid megaspores by meiotic division; lowest megaspore enlarges and produces cellular female gametophyte; free nuclear divisions of megaspore nucleus give rise to 256 (*E. trifurca*) or 512 (*E. foliata*) nuclei before wall formation begins; female gametophyte becomes cellular and forms 2 or 3 (rarely one) archegonia; archegonium develops from a single superficial cell dividing periclinally into a primary neck cell and a central cell; primary neck cell forms about 40 cells long neck and a central cell gives rise to a venter canal nucleus and an egg nucleus.

Microsporangiate shoots (male flowers) borne in cone or strobilus (compound inflorescence) consisting of several pairs of decussate bracts; lowest pairs of bracts sterile and flowers (or inflorescences) produced singly in axil of remaining fertile bracts.

Microsporangiate shoot consists of a pair of fused bracteoles (two lipped perianth) and a short axis (microsporangiophore or stamen or antherophore); axis single central and either unforked terminating in, depending upon the species, from one to eight microsporangia (anthers or synangia) of forked as in *E. distachya* and *E. intermedia* with two free axes (microsporangiophores or, as interpreted by Eames, microsporophylls), each bearing four microsporangia terminally; microsporangia possess 2 to 3 loculi, each opening by a terminal slit to release microspores (pollen grains).

Microspores haploid, unwinged and possessing a thick exine; four microspores formed by meiotic division of each diploid microsporocyte (microspore mother cell); male gametophyte endosporic; microspore shed from the microsporangium at five nucleate/celled stage consisting of two prothallial cells, a tube nucleus, a stalk or sterile cell and body or spermatogenous cell.

Pollination by drop mechanism; pollen tube emerges within a few hours of entry of microspores in pollen-chamber; body cell divides into two sperm nuclei and prothallial cells degenerate; pollen tube penetrates archegonium and, with rupture of its tip, tube nucleus, stalk cell nucleus and two sperm nuclei released; one sperm nucleus fuses with egg nucleus and results in formation of a diploid zygote; other male nucleus may fuse with the ventral canal nucleus (double fertilization) without resulting into embryo formation.

Zygote nucleus undergoes three divisions forming eight free diploid nuclei, which later become independent proembryonal cells: all of these cells may independently give rise to embryo showing precocious type of cleavage polyembryony; usually the lower 3 to 5 proembryonal cells develop; proembryonal cell divides to form a suspensor cell and an embryo initial, the latter is pushed down into female gametophyte by elongating suspensor; embryo initial forms embryo proper; only one embryo achieves full development in a seed.

Embryo prominent with two large cotyledons and embedded in female gametophyte; nucellus remains as a disorganized sheath of cells; inner integument consists of two layers of cells persisting at the micropylar end; outer integument consists of thick walled cells enclosing whole seed; seeds, without any resting period, even germinate inside the strobilus.

5.5. Economic Importance

Cycas :

Cycas, particularly *C. revoluta*, is grown as ornamental plant. Starch extracted from seeds and stem forms a useful item of food. Different parts of the plant have been found to be of medicinal value. Besides, various parts have been used miscellaneously from time to time by man.

Pinus :

Pinus is of high economic importance as source of soft-wood timber, wood, cellulose and turpentine. The seeds of *P. geradiana* are edible and are known as ‘chilgoza’. Packing boxes and match sticks are also manufactured trom the wood of the plant.

Ephedra :

Many species of Ephedra serve as a source of an important drug ephedrine used for the cure of asthma and hay fever.

PART

II

Chapter-1

Palaeobotany and *Rhynia* a Fossil Plant

Palaeobotany

1.1. Introduction

Palaeobotany is the study of fossil plants. The word 'FOSSIL' comes from the Latin verb *FODERE*, meaning to dig. But a fossil may be defined as anything which gives evidence that an organism once lived or existed in the geological past. Adolphe Brongniart is usually credited as the founder of Palaeobotany. Witham, Goeppert, Unger, Saporta, Ehingshausen, Schimper, Lesquereux, Williamson, Solms-Laubach, Heer, Nathorst, Knowlton, Berry, Scott, Zeiller, Seward and Sahni are some of the important names in the field of palaeobotanical researches. Earlier work on the Indian plant fossils was done by Oltokar Feistmantel and later by Birbal Sahni. Prof. Sahni has been considered as one of the foremost palaeobotanists of the world. He made masterly contributions in the field of Botany, Palaeobotany, Geology and Archaeology. His work on fossil plants was contributory to all pertinent branches of botany, as well as to stratigraphy, palaegeography and other lines of geological researches. Under his inspiring leadership gathered a band of devoted research workers (palaeobotanists) leading to the formation of an active school in palaeobotany at Lucknow. In 1946 Prof. Sahni and Mrs. Savitry Sahni founded the Palaeobotanical Society and the Institute of Palaeobotany at Lucknow. This institute now bears the name of the founder.

The study of fossil plants, technically known as palaeobotany, can be approached

from the view point of botany, wherein emphasis is on the plants, or from the geological angle in which the rock age containing the fossils is the primary concern.

The aims and objects of palaeobotany are not different from the botany of the living plants; the only difference is in the type of material worked upon and the techniques employed. Their concern is the interpretation of structure, morphology, distribution, phylogeny and ecology. One of the aims of palaeobotany is describing, naming and classifying plant fossils (reconstruction). To classify fossil plants is not only a difficult task but has many chances of errors as the palaeobotanist has to deal with the extinct genera and species and the material available for this is fragmentary and meagre.

The facts obtained from the study of fossil plants are of paramount importance for the bearing they have on the broader aspects of phylogeny and evolution. There has been a gradual succession of plant forms in the history of the earth. On account of evolutionary changes extending over hundreds of millions of years, some groups of plants have totally disappeared, while others and newer ones are now more numerous than ever before. Also there has been a gradual change from simple to more highly differentiated forms. Palaeobotany is essential to understand the relationships of the living plants with those long extinct. It discloses the phylogenetic or evolutionary relationships. Fossil plants are also of a great help in deciphering the climatic conditions of the geological past and most workers regard them as more trustworthy guides than animals.

1.2. Geological Eras

The history of the earth has been divided into four great eras: (1) Precambrian, (2) Palaeozoic, (3) Mesozoic, and (4) Cenozoic. Of these, the first or Precambrian era ended about 500×10^6 years ago and is characterized by scarcity of fossil records. These eras are further divided into periods (systems) and periods into epochs (series). The evolution of plant life through ages has been shown in Table 1. The age or time scale in the table is based on information from Bowen (1958) and the kind of vegetation is as mentioned by Sporne (1970).

Table 1. Geological eras with plant types through ages

ERA	PERIOD	EPOCH In Million (10^6) years	AGE In Million (10^6) years	PLANT TYPES
Cenozoic	Quaternary		1	Modern Vegetation
	Tertiary (upper)	Pliocene	10	Modern Vegetation
		Miocene	20	Modern Vegetation
	Tertiary (lower)	Oligocene	35	Modern Vegetation
		Eocene	50	Modern Vegetation
Mesozoic	Cretaceous	Upper	75	Modern Vegetation
		Lower	100	Dominance of Gymnosperms (Conifers and Bennettitales)
	Jurassic	Upper	130	
		Lower (Liassic)	140	Gymnosperms and Ferns forming luxuriant forests
	Triassic	Upper (Rhaetic)	160	
		Lower (Bunter)	180	Gymnosperms (Conifers and Palaeozoic - Bennettitales) forming sparse desert vegetation.
	Permian	Upper	190	
Paleozoic	Carboni-ferous	Upper (Coal Measures)	200	Early Gymnosperms; Tree-Lycopods; Calamites; Ferns forming tall swamp forests
		Lower	250	Early Gymnosperms; large Tree-Lycopods; Ferns
	Devonian	Upper	260	
		Middle	275	*Rhynia* in marshy localities
		Lower	300	Herbaceous marsh plants (*Psilophyton* and *Zosterphyllum*); some small shrubs.
	Silurian	Upper		
		Lower	350	Algae (marine)
	Ordovician		425	Algae (marine)
	Cambrian		500	Algae (marine); some land plants
Precam-brian	Precambrian			Fungi and Bacteria have been reported from rocks upto, 2,000 million years old.

Palaeobotanical researches have shown that though the Thallophyta were probably the starting point for all higher plant evolution, several of the higher types have evolved from this group independently of one another. The earliest organisms probably lived in water without free oxygen. They may have been similar to some one-celled plants of the present day which flourish in the absence of oxygen but themselves emit it, and in this way could have provided the atmosphere necessary for the development of animal life. The earliest records of life are probably 2800 million (2000 million according to Sporne) years old. These comprised the limestone nodules built up of thin layers of carbonate of lime, which may have been deposited by algae or bacteria.

About 350 million years back a big advancement took place in the plant form and structure, for the earliest known land plants were well adapted to life on land. Also sea weeds and other algae were still abundant in shallow seas. In the simplest known land plants there is little differentiation of body parts, the naked, dichotomously branching stem being tipped by simple sporangia (as in *Rhynia*).

About 250 million years back the plants grew in profusion in swamps and the landscape consisted of forests of tall, slender trees above a luxuriant undergrowth of fern-like plants, horsetails and creepers. During that period a new series of changes took place over the surface of the globe, which resulted in a redistribution of land and the sea and which was responsible for mountain building movements. At that time existed a great Southern Continent– Gondwana land – which included India, Australia, South America, Antarctica, South Africa and Medagascar. It was sometimes during that period that the great coal bearing formations of the world were formed. As the trees and other vegetations died, their leaves, branches and stems fell into the swamp, where they formed the peat. An almost continuous rain of pollen contributed in a significant measure to its formation. At intervals of varying lengths, subsidence caused the forest to be flooded by fresh or salt water which largely killed the plant life and formed a lake or lagoon in which sediments were laid down. So long as subsidence continued, sediments went on accumulating, and pressure and chemical changes gradually changed the buried peat into the familiar hard coal.

About 170-140 million years back the plant life was varied and abundant. The forests were of primitive conifers, cycads, ferns, tree-ferns and ginkgos (maiden-hair trees).

By the middle of the Cretaceous period the flowering plants (Angiosperms)

appeared all of a sudden.

In the later (upper) Cretaceous times the vegetation almost everywhere was essentially of a modern type. The diversity of earliest known flowering plants strongly suggests a long antecedent history, the records of which unfortunately have so far not been discovered.

About 70 million years ago, the floras had acquired a 'modern' aspect. Although ferns and conifers were common, the flowering plants were dominant.

Thus, we find that fossils unfold the vegetational history of the geological past, never witnessed by the human eye.

1.3. Process of fossilization

Ever since the formation of a solid crust of rock on the earth, the agents of denundation, namely water, snow and wind, have been continuously weathering it and breaking it into mineral particles. Through the agency of water these particles were carried to primitive lakes and seas, on the bottom of which they collected. In course of time thick deposits of sediments accumulated and at the great depths owing to pressure and higher temperature these were modified into stratified rocks. Along with the sediments, remains of animals and plants were deposited and buried, which with the passage of time changed in chemical composition and to a certain extent in shape, and are now found as fossils in the rocks.

The prime factors governing the extent of tissue preservation in fossil plants are (1) the types of tissues composing the plants, and (2) the conditions to which they were subjected preceding and during fossilization. A rapid burial in sediments is favourable to fossilization and fine sediments make better burial material as compared to coarse possession of hard body parts. Uniform temperature situations, quiet conditions of deposition and presence of highly mineralized ground waters are the other factors which favour fossilization.

1.4. Types of Fossils

The plants may be fossilized in various ways. The actual preservation is of rare occurrence and possible only when bacterial action and decay have been prevented. The following types of fossils have been described;

1. **Impression :** Most fossil plants occur in the form known as impression in which

no parts of the plant or organism remain, but where just the outline of its shape may still be seen. These are just imprints or impressions left by plants or their parts on fine-grained sediments such as silts and clays.

In the formation of this type of fossil, the organic material completely dissolves away leaving an impression which is a very faithful replica of the actual size and form of the plant.

2. **Compression or mummification :** A second type of plant fossil is the compression in which plant tissues get converted into coal and only a little structure can made out except for the cuticle of leaves and spores.

   Here, because of the weight of sediments above, the air and water contained in the tissues are pressed out and displaced, the plant materials undergo decomposition leaving only a residue of carbon to record the actual organism. This layer of carbon is normally devoid of any structure, although sometimes the cell pattern of the cutinized epidermis is retained.

3. **Cast :** The third type of plant fossil is the cast, which exhibits nothing of the original tissues of the plant, but is nevertheless valuable in showing their shape.

   Here, under certain conditions the plant material completely dissolves away before any great amount of compaction of sediments has taken place and thus leaves a cavity which later becomes filled up with percolating sediments or mineral matters which upon hardening form a cast.

4. **Petrifaction :** The most important kind of plant fossil, however, is the petrifaction in which the tissues are so well preserved by mineral substances (such as silica, carbonates of calcium and magnesium, iron pyrites) that almost every detail of cell wall is visible when sectioned, stained and observed under the microscope. The most beautiful petrifactions are those of silica.

   In these fossils, the original cell structure is retained by means of minerals in solution which infilterate into the tissues and crystallize in solid form (petrify) in the cell lumens and intercellular spaces, probably due to interaction between soluble mineral salts and certain compounds released during the partial disintegration of the cell walls.

1.5. Methods of Study of Fossils

The following are some of the important techniques for the study of fossils:

1. **Thin ground sections or slices :**

   This method is used for the study of petrifaction type of fossils. The rock is cut

into thin sections by means of stone cutting saw or machines. The section is then grinded until it becomes quite thin and transparent, making the microscopic study of the internal structure possible. This technique provides the fossil structure in an unchanged condition.

2. Film or peel technique :

This technique, described by Walton (1928), is quite excellent for the study of petrified specimens as it can provide the films serially. The rock is cut in the direction the film is required. Cutting is done by a rotating metallic disc with diamond pointed plate. Then, the surface of the rock is etched for a brief period in a suitable acid like hydrofluoric acid. The cell walls that remain projecting above the surface are then embedded in a film of cellulose acetate. This is peeled off from the rock and can be examined under the microscope as if it were a hand-cut section.

The film, thus obtained is more thin and transparent than the ground section. Also it is less expensive and quicker to prepare. The whole process takes no longer than ten minutes.

3. Maceration technique :

In case of compressions, a good deal of study is possible by maceration technique. From compressions, it is possible to get preparations of the cuticle, by oxidizing away the coaly substance with perchloric acid. The outlines of the epidermal cells, stomata, hairs, papillae etc can then be seen under the microscope.

This technique is also of immense importance in the study of spores and pollen grains. A variety of reagents have been used by different workers for maceration.

4. Transfer technique :

Compressions may also be studied by the employment of transfer techniques. It causes the least destruction of the fossil. The coaly layer representing the plant is transferred from the rock to a transparent base in such a manner that both the surfaces of plant material can be observed. The side of the rock consisting of fossils is cemented with the help of hot fused canada balsam on a glass slide. The other or exposed side of the rock is grinded on a glass plate with carborandum powder and water. Then the whole rock is moistened and coated with hot paraffin wax, which is removed after some time from the rock side leaving the glass side completely coated. This preparation is kept in a bath of hydrofluoric acid to remove mineral matter. Thus the silica of the rock gets dissolved and the fossil remains attached to glass slide. The exposed surface of the rock now

provides the view of the other side of the fossil. Thus both the surfaces of fossil can be observed. However, the specimen is usually dense and opaque.

1.6. Naming the Form Genera

It is very seldom that a plant is preserved all in one piece with its several parts attached and all the tissues intact. More or less dismemberment invariably takes place. Leaves, seeds and fruits become detached from the twigs on which they were produced and the stems break loose from the roots. The softer tissues decay completely. Hence, most fossils consist only of fragments of plants, which fossilized at different places. It may take many years to assign with certainty a particular kind of leaf to a particular kind of stem and so on. Thus, in the mean time, each fragment is described under a separate name, a form genus (artificial genus) without actually indicating the plant (natural genus) to which it belonged. ***Stigmaria*** (rhizophore) and ***Lepidostrobus*** etc are some such form genera which belonged to Lepidodendroids. In naming such form genera, usually a suffix is added to signify the plant part, e.g. **phyllum** for leaves; **dendron** for stem or tree trunk; **xylon** for woody part; **theca** for microsporangia; **stoma, spermum, carpon, carpus** for seed; **strobus** or **strobilus** for cone; and **pteris** for fern like stem or frond.

1.7. Reconstruction

It is the work of the palaeobotanist to reconstruct, as best as he can, from such fragments, the whole plant as it existed. Thus, fossil nomenclature is a complex system. An example of reconstruction is of plant *Lyginopteris oldhamia* (Potonie, 1899) *Calymmatotheca hoeninghausi* (Stur, 1897) is the name of the oldest discovered fragment of the reconstructed plant. Different parts of this plant were discovered at different times and given different names as follows :

Stems	:	*Lyginodendron oldhamium* and *Lyginopteris oldhamium*
Leaf	:	*Sphenopteris hoeninghausi*
Petiole	:	*Rachiopteris aspera*
Root	:	*Kaloxylon hookeri*
Stamen (pollen bearing organ)	:	*Crossotheca* sp., *Telangium* sp.
Seed cupule	:	*Calymmatotheca hoeninghausi*
Seed	:	*Lagenostoma* sp.

Chapter-2

Rhynia

2.1. Classification

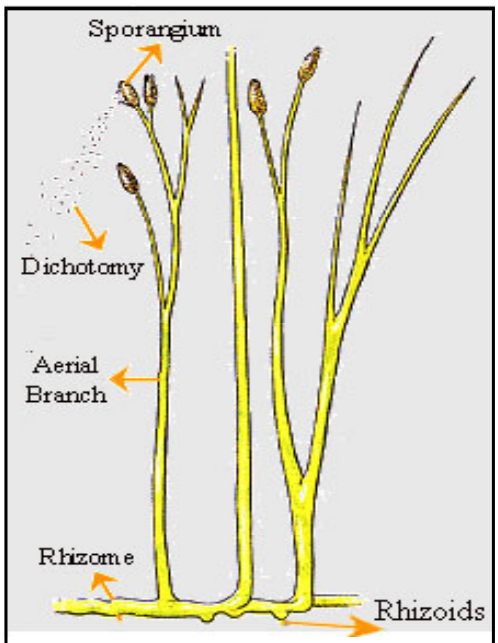
Psilophytopsida : Psilophytales; Rhyniaceae : *Rhynia*

2.2. Distribution and habitat :

Rhynia is an extinct vascular plant described by Kidston and Lang in 1917 from Middle Devonian rocks (red sandstone cherts or beds) at village Rhynie, Scotland.

The plant grew in marshy swamps or peaty habitat near volcanoes.

The petrified remains of the plants are found embedded in and impregnated with silica; the preservation of these specimens is excellent.



***Rhynia major* Sporophyte**

2.3. External features

R. major adult sporophyte had a dichotomously branched horizontal rhizome with groups of unicellular rhizoids at intervals. The tips of some rhizomes grew upwards as aerial stems (branches or axes), upto 50 cm in height and as much as 6 mm in diameter. The leafless aerial green photosynthetic stems also showed dichotomy and few of them terminated in sporangia.

R. gwynne-vaughani was a small plant of only 20 cm height. Over its surface, it had hemispherical projections developing into adventitious branches. Thus, besides branching dichotomously, the plant was able to branch adventitiously. The vascular

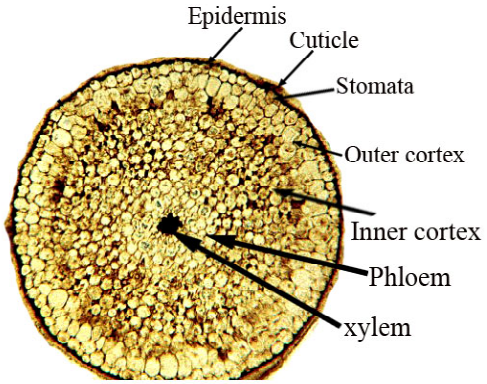
strand in adventitious branches was not connected with that in the main stem.

2.4. Vegetative Propagation

Probably, the adventitious branches were capable of developing into new plants, if detached from the parent aerial stem. Thus, they provided the means of vegetative propagation.

2.5. Anatomy

The internal structure of the aerial stem as well as the rhizome was essentially same and consisted of epidermal, fundamental and vascular tissue systems. On the outside of the axes was a well-defined epidermis with a thick cuticle on its outer surface. Stomata were present on the aerial stem but lacked in rhizome, which developed rhizoids.



***Rhynia* petrifaction stem T.S.**

Internally, the cortex was divisible into outer and inner regions the two often separated by a narrow zone of cells with dark contents. The outer cortex was narrow and made up of densely packed cells (1 to 4 cells in thickness) but the inner cortex was quite broad and had abundant inter cellular spaces with direct access to the stomata. The parenchymatous cells of the inner cortex probably served as the photosynthetic tissue. The vascular cylinder was slender and occupied the centre of the axes. It consisted of a cylinder of primary xylem surrounded by a cylinder of primary phloem. Thus, the stele was simple protostele (haplostele). The xylem consisted of tracheids with annular thickening and the phloem was made up of thin-walled cells with oblique end walls. The sieve plates have not been found.

2.6. Sporangia

The sporangia were produced singly on the apices of some of the aerial stems. They were oval or slightly cylindrical in shape and upto 3 mm long in *R.gwynne-vaughani* and as much as 12 mm long in *R.major*. The sporangial wall was massive,

above five cells in thickness, the innermost layer of which probably functioned as tapetum. The sporangial cavity contained within it a large number of spores arranged in tetrads. This suggests that spores were formed by meiosis and that the plant bearing them represented the sporophytic generation. All the spores were of the same size (homosporous).

The sporangium was without any special mechanism of dehiscence.

2.7. Gametophyte

The spores were small and tetrahedral with typical triradiate markings. All the spores were of one kind only.

Up to date the gametophyte of *Rhynia* is unknown Merker (1959) points out that some of the bits of the plant, recognized as rhizomes, could have been gametophyte. According to Pant (1961) *R. major* is a sporophyte and *R. gwynne-vaughani* may be a vascular gametophyte (as in *Psilotum*).

2.8. Phylogenetic importance of Rhynia:

The discovery, reconstruction and description of extinct plants (*Rhynia, Horneophyton* and others) of order Psilophytales is one of the most significant achievements of ***Palaeobotany*.**

Rhynia is one of the simplest and least specialized of known vascular plants. The sporophyte plant is believed to have been devoid of root. The aerial portion consisted of slender, leafless dichotomously branched axes or stem, some of which terminated in solilary thick-walled, homosporous sporangia. The vascular system of the axes was a simple haplostele, and consisted of a central slender strand of tracheids (xylem) surrounded by a cylinder of phloem. The extremely simple vascular system gives a clue as to the structure and arrangement of primitive conducting tissue in land plants.

Rhynia, on account of its simple organization, is of great phylogenetic importance. The discovery of *Rhynia* led to (1) the abandonment of the classical theory according to which there are three fundamental categories of plant organs (stems, leaves and roots), and (2) the development of new and far reaching theories of evolution. Thus, Zimmermann (1930) regarded *Rhynia* as the ideal starting point for his ‘telome theory’ according to which “all the vascular plants evolved from a

very simple leafless ancestral type, like *Rhynia*, made up of sterile and fertile axes (telomes)". However, Laclereq (1954) observed *Rhynia* was by no means the earliest land plant and was certainly not the ancestors of pteridophytes (Sporne, 1970). Irrespective of whether *Rhynia* is truly a primitive form or a reduced form of more complex land plants, it in its simplest and least specialized organization represents one of the significant 'stages' in the evolution of vascular plants.

2.9. Summary : *Rhynia*

Distribution :

Old Red Sandstone Cherts (Middle Devonian) of Rhynie, Scotland.

External Features :

Sporophyte plant herbaceous, rootless, leafless and differentiated into a creeping rhizome and erect aerial (photosynthetic) branches (stems or axes).

Anatomy :

Axes (Rhizome as well as aerial portion) differentiated into epidermis, cortex and stele; cortex with outer and inner zones; stele, a simple protostele or haplostele; occasionally, central tracheids of xylem smaller than surrounding tracheids.

Sporangia:

Terminal on aerial stem (cauline); of one kind only (homosporous), oval or slightly cylindrical; sporangial wall about five layered, innermost forming the epidermis; indehiscent; many spores in a sporial cavity; spores of one kind only; small and tetrahedral.

Gametophyte :

Not known.

Phylogeny :

Rhynia in its simplest organization represents a significant stage in the evolution of land plants.

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पुण्य स्मृति

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