

GYMNOSPERMS, TAXONOMY OF ANGIOSPERMS AND ANATOMY

BLOCK-I-GYMNASPERMS

**Unit-1: Distribution, General Characteristics, Classification
and Economic Importance of Gymnosperms**

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INTRODUCTION

The word Gymnosperm, "*Gymnos*" = *necked* and "*Sperma*" means *seeds* was first used by Theophrastus, a pupil of Aristotle in his famous book "*Enquiry into Plants*". He used this term in all those plants having unprotected (without covering) seeds.

On the basis of their seeds with or without covering are grouped into two major categories namely- Angiosperms and Gymnosperms. Thus the plants or Spermatophyta is divided into two sub groups Angiosperms and Gymnosperms.

The ovules of gymnosperms have freely exposed before and after fertilization while in case of angiosperms where (*Angios* = *Vessels* and *Sperma* = *Seeds*) the ovules are enclosed within the carpel. Thus due to this, the angiosperms are considered as the most advanced type of organisms in plant kingdom. Comparatively to angiosperms, the gymnosperms are less advanced; they have some specific characteristic features as-

GENERAL CHARACTERS OF GYMNOSPERMS

- ❑ They are slow growers and lacks vegetative means of reproduction such as by cuttings, layering etc.
- ❑ They are unable to grow under varied habitats means they are able to grow on some specific habitats and conditions.
- ❑ They have limited means of dispersal of seeds and can be dispersed only by wind, animals or by human beings.
- ❑ Most of the gymnosperms are terrestrial or land loving and unable to grow in aquatic habitats except a few.
- ❑ They lack vessels in xylem (with few exceptions) and companion cells in phloem.
- ❑ Most of the gymnosperms are unisexual, thus due to absence of bisexuality, chances of self- pollination reduces, and
- ❑ As wind is the main source of pollination hence maximum amount of pollen grains are wasted.

MORPHOLOGY OF VEGETATIVE ORGANS

The living gymnosperms including, tall trees, shrubs and climbers includes approximately 70 genera and 725 species.

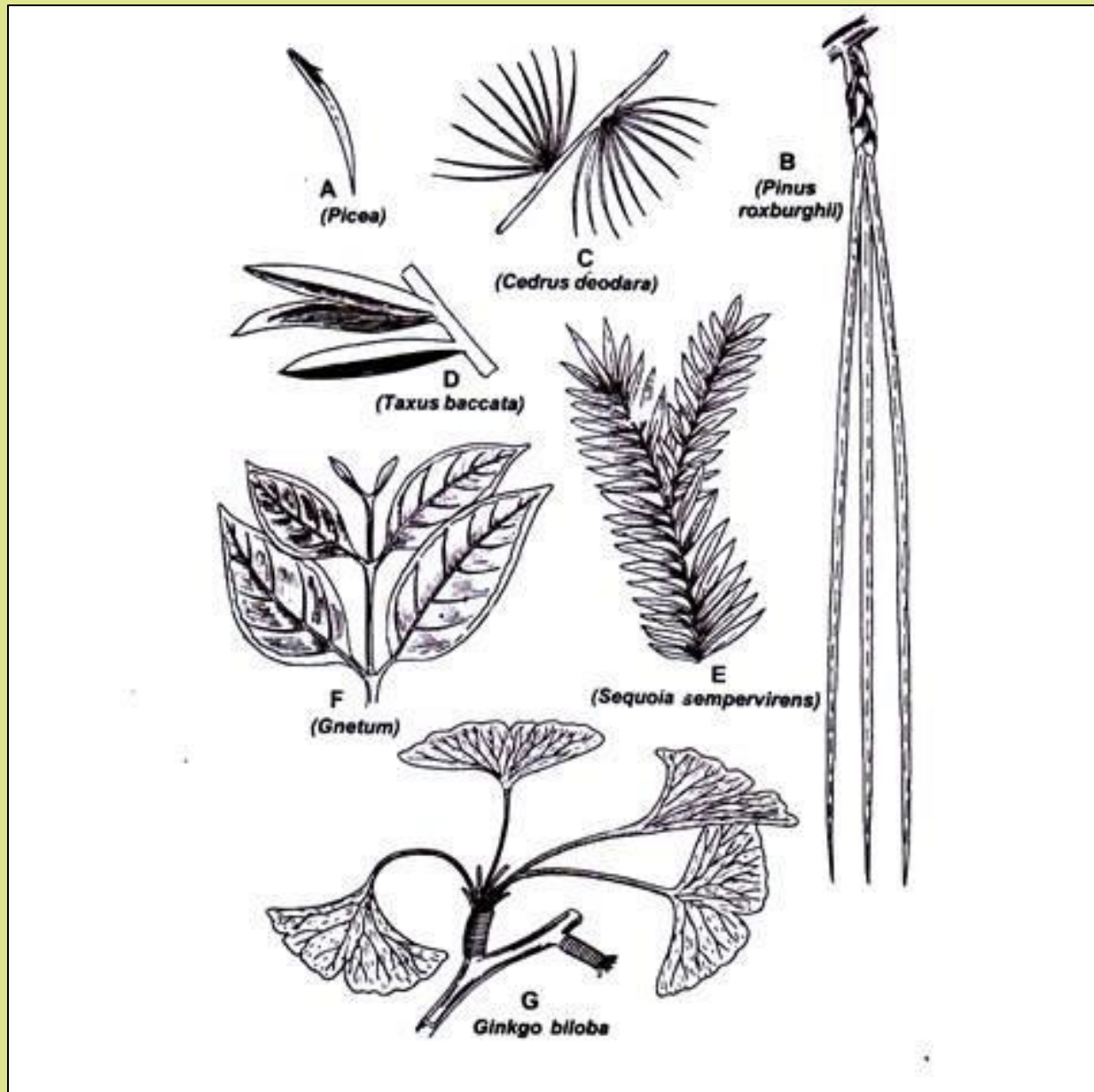
There are complete absence of herbs and climbers. Vegetative propagation is not reported in this group but only bulbils are known in some *Cycas* as means of vegetative propagation. Generally they possess tap root but sometimes mycorrhizal and corolloid roots (*Pinus* and *Cycas* respectively) are present in some genera.

Stem: The stem may be aerial, erect, unbranched (e.g. *Cycas*, *Zamia*) or aerial, erect branched (e.g. *Pinus*, *Cedrus* etc.). In gymnosperms the branches may be of two types on the basis of their branching system.

They may be either- two types as in *Pinus*- i) the long shoots and ii) the dwarf shoots at their apices and collectively known as spurs.

Leaf: Gymnosperms bears both microphyllous and megaphyllous leaves. The microphyllous leaves are large and well- developed and their vascular supply always leaves a leaf- gap in the stem stele is another characteristic feature of gymnosperms. The leaves may be simple or compound and vary in shape, size and form, as a minute scale leaf to several feet long megaphylls (e.g. in *Cycas*). Gymnosperms show great diversity in leaf venation, it may be parallel (*Welwitschia*), reticulate (*Gnetum*) or even dichotomous (*Ginkgo*). The leaves are always evergreen and mostly possess resin canals as in *Pinus*, *Cedrus* and *Abies*. The leaves of Gnetales lack resin passages but *Gnetum* possess latex tubes.

Leaf Arrangements: The arrangement of leaves may be whorled (*Cedrus*), opposite or decussate (*Gnetum*, *Ephedra* etc.) or spirally arranged (*Taxus*, *Podocarpus* etc.). Conifers usually have sunken stomata. The shape of leaves may also vary from triangular (*Pinus roxburghii*), semi-circular (*Pinus sylvestris*), bifid or circular (*Pinus microphylla*), and bifacial leaflet of *Cycas*, *Zamia*, and *Gnetum* leaves). Likewise leaves the system and arrangement of vascular bundles also shows great variations in gymnosperms. In a young stem the ring of discrete vascular bundles. The leaf base remains permanently merismatic while the tip drying off.



Vegetative organs (leaf) of some gymnosperms

Due to secondary growth gymnosperms possess primary and secondary wood. The secondary wood is the characteristic feature of cycadophyta. The wood is porous, soft and more parenchymatous in nature, while pycnoxylic wood is the characteristic feature of coniferophyta; the wood is compact and narrow medullary rays, xylem lacks wood vessels except in *Ephedra*, *Gnetum* etc. The xylem is usually endarch or mesarch in stem while it may be exarch in roots. The vascular bundles are conjoint, collateral, endarch and open in gymnosperms.



CLASSIFICATION

The group Gymnosperms is a very large class which includes both living and fossil forms. Due to ample records of fossil forms the classification has become somewhat complicated. Several workers have classified Gymnosperms differently from time to time among them the important ones are as follows.

The pioneer workers in this field are Coulter and Chamberlain (1917) divided the gymnosperms directly into seven orders viz.

1. Cycadofilicals,
2. Bennettiales,
3. Cycadales,
4. Cordaitales,
5. Ginkgoales,
6. Coniferales and
7. Gnetales.

Jefferey (1917) recognizes two classes among gymnosperms as follows-

A. Class Arachigymnospermae- It includes all those gymnosperms that resemble ferns from their general appearance and anatomy. They possess motile spermatozoids. He divided this class into five orders-

- 1 Order Pteridospermae- it includes all extinct forms, primitive and that lived in Paleozoic period.
2. Order Cycadeodea- It includes all extinct forms.
3. Cycadales- Includes extinct and living forms.
4. Order Cordaitales- Includes all extinct forms.
5. Order Ginkgoales- Includes extinct and single living genera.

B. Metagymnospermae -i) plants of this class possess simple leaves and have no resemblance to the ferns.

ii) Possess non- motile male gametes, the pollen grains grow into a pollen tube. It includes two orders-

1 Order Coniferales- It includes living genera e.g. *Pinus, Cedrus, Taxus, Podocarpus, Taxodium* etc. also includes fossil genera.

2 Order Gnetales- Includes *Ephedra, Gnetum and Welwitschia* and many fossil genera.

On the basis of composition of wood the gymnosperms were divided into two classes-

i) Metaxylic- when possess porous wood and loose texture.

ii) Pycnoxylic- When the wood was compact

The former includes Cycadales, Cycadeiodales and Cycadofilicales while the latter includes Cordaitales, Ginkgoales, Coniferales and Gnetales. This classification was given by Soward (1919).

However, Chamberlain in 1934 divided the gymnosperms into two classes which were further divided into orders with their respective characters such as-

- A. Class Cycadophyta-** i) Most of the plants of this group are unbranched, stems are stumpy.
- ii) Male cones large and compact with simple sporophylls bear large ovule.
- iii) Anatomically the stems have wide cortex and monoxyle wood.

This class includes three orders-

- a) Cycadofilicales- Includes extinct forms and fossils.
- b) Cycadeoidales- Includes both living and fossil forms.
- c) Cycadales- Includes both living and fossil forms.

B. Class- Coniferophyta- i) profusely branched stem is the characteristic feature of this group.

- ii) Leaves simple and the foliage given leaf like appearance.
- iii) Both the strobili- male and female are compact and bear complex sporophylls.
- iv) Wood is pycnoxylic.

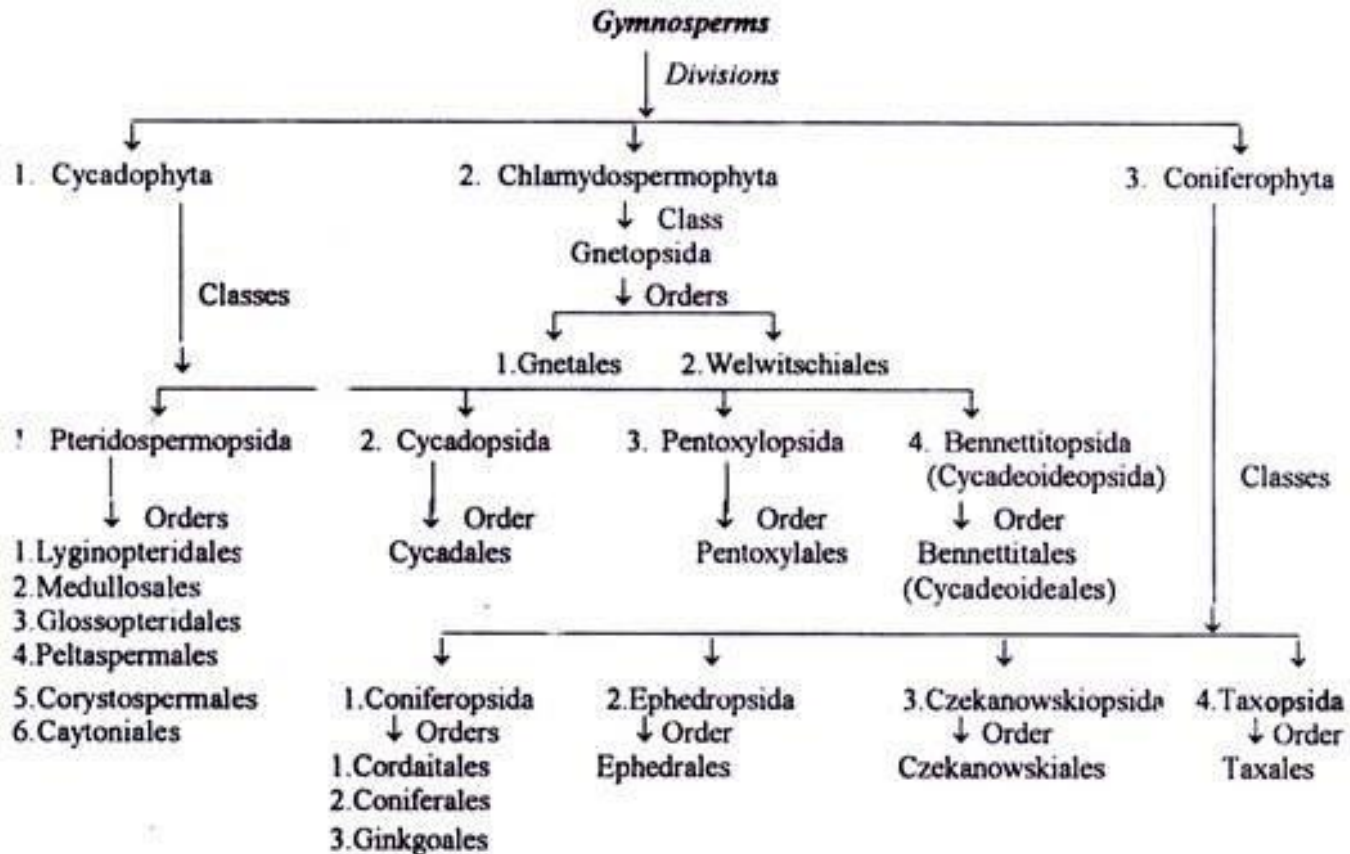
It includes four orders-

- a. Cordaitales- It Includes extinct order.
- b. Ginkgoales- It includes extinct and only one living representative- *Ginkgo biloba*.
- c. Coniferales- It includes both extinct and living forms.
- d. Gnetales- Includes both living and extinct forms.

D. D. Pant (1957) has proposed a classification of Gymnosperms in which the group is divided into three divisions

- a) Cycadophyta
- ii) Chlamydospermatophyta and
- iii) Coniferophyta

An outline of Pant's (1957) scheme of classification of gymnosperms is as follows:



After that Andrew (1961) another renowned scientist classified Gymnosperms and divided it into six divisions as-

i) Pteridospermatophyta

ii) Cycadophyta.

iii) Ginkgophyta

iv) Coniferophyta.

v) Gnetophyta and

vi) Gymnosperms of uncertain affinities.

K. R. Sporne in 1965 classified Gymnosperms in his book namely "*The Morphology of Gymnosperms*" based on Pilger and Melchior (1954) classification-

Gymnosperms- divided into three divisions

1. Cycadopsida 2. Coniferopsida and 3. Gnetopsida

These divisions further divided into orders-

1. Division Cycadopsida-

Order 1. Pteridospermales- Families-(7)-1. Lyginopteridaceae-
(Lyginopteris)

2- Medulosaceae (Medulosa)

3- Calamopteridaceae (Calamopitys)

4- Glossopteridaceae (Glossopteris)

5- Peltospermaceae (Xylopteris)

6- Corystospermaceae (Xylopteris)

7-Caytoniaceae (Caytonia)

Order 2. Bennettitales - Families (3) 1- Williamsoniaceae (Williamsonia)

2. Wielandiellaceae (Wielandiella)

3. Cycadeoideaceae (Cycadeidea)

Order 3. Pentoxylaes -Family(1) 1. Pentoxylaceae (Pentoxylon), Sahnia)

Order 4. Cycadales-Family(2)

1. Cycadaceae (Cycas, Zamia etc.)
2. Nilssoniaceae (Nilssononia)

2. Division Coniferopsida

Order 1. Cordaitales –Families (3)

1. Ertophytaceae (Eristophyton)
2. Cordaitaceae (Cordaites)
3. Poroxylaceae (Poroxylon)

Order 2. Coniferales –Families (9)

1. Lebachiaceae (Lebachia)
2. Voltziaceae (Voltziopsis)
3. Palissyaceae (Palissya)
4. Pinaceae (Pinus, Abies, Picea)
5. Taxodiaceae (Taxodium)
6. Cupressaceae (Cupressus)
7. Podocarpaceae (Podocarpus)

8. Cephalotaxaceae (Cephalotaxus)

9. Araucariaceae (Araucaria, Agathis)

Order 3. Taxales- Family (1) Taxaceae (Taxus, Torreya)

Order 4. Ginkgoales.-Families (2) 1. Trichopteryaceae (Trichopteryx)

2. Ginkgoaceae (Ginkgo)

3.Division Gnetopsida

Order 1. Gnetales.- Families (3)

1. Gnetaceae (Gnetum)

2. Welwitschiaceae (Welwitschia)

3. Ephedraceae (Ephedra)

Recently (1980) Taylor classified Gymnosperms in six divisions as

1. Progymnospermophyta,
2. Pteridospermophyta.
3. Cycadophyta.
4. Cycadophyta.
5. Ginkgophyta.
6. Coniferophyta.

Thus after reviewing the different theories and outlines of classification of Gymnosperms adopted by different works from time to time it shows that there are great controversies regarding the classification of Gymnosperms. But even then the last and the most important classification may be taken as correct one for studies.

Stewart (1983) placed Progymnosperpsida, Gymnospermopsida and Gnetopsida as distinct classes under the division Tracheophyta, the vascular plants of kingdom Plantae. These three classes were further divided as-

Kingdom Plantae-

Division Tracheophyta

Class - 1. Progymnospermopsida

Order - A. Aneunophytales

B. Aracheopteridales

C. Protopityles

Class 2. Gymnospermopsida

Order - A. Pteridospermales

B. Cycadales

C. Cytoniales

D. Glossopteridales

E. Pentoxylales

F. Gzekanowskiales

G. Gimkgoales

H. Cordaitales

I. Voltziales

K. Coniferales

L. Taxales

Class 3. Gnetopsida

- Order A. Gnetales
- B. Ephedrales
- C. Welwitschiales.

Birbal Sahni (1920 a), based on morphological nature of ovule bearing organ and axial or foliar nature of ovules divided gymnosperms into two major groups- Stachyspermae (ovules arise on the axial organ or stem) spread over orders- Cordaitales, Ginkgoales, Coniferales, Taxales and Cycadales and Cycadofilicales as Phyllospermae (ovules borne on leaves).

Gymnospermae-

1. Phyllospermae

- A. Cycadofilicales
- B. Bennettitales
- C. Cycadales and
- D. Taxales.

2. Stachyspermae

- A. Cordaitales
- B. Ginkgoales
- C. Coniferales.

Christenhusz et al., (2011) proposed a new classification and linear sequence of the extant gymnosperms based on molecular and morphological phylogenetic studies. They divided all extant gymnosperms into 4 sub classes, 8 orders and 12 families as follows-

- Sub Class I. Cycadidae Order A. Cycadales
 - Family 1. Cycadaceae Family 2. Zamiaceae
- Sub Class II Ginkgoidae Order B. Ginkgoales
 - Family 3. Ginkgoaceae
- Sub Class III Gnetidae Order C. Welwitschiales
 - Family 4. Welwitschiaceae
- Order D. Gnetales
 - Family 5. Gnetaceae
- Order E. Ephedrales
 - Family 6. Ephedraceae
- Sub class IV Pinidae Order F. Pinales
 - Family 7. Pinaceae

Order G. Araucariales

Family8. Araucariaceae

Family9. Podocarpaceae

Order H. Cupressales

Family10. Sciadopityaceae

Family11. Cupressaceae

Family12. Taxaceae.

DISTRIBUTION

Certain groups of gymnosperms are entirely extinct, while others are present in living as well as in fossil forms with primitive features. Still there are some groups chiefly within living gymnosperms that extend throughout the temperate, tropical and even in arctic zones. Most of the gymnosperms are evergreen xerophytes.

The total number of living gymnosperms in the world is approximately number seventy genera and 725 species. A total of 16 genera and 53 species were reported from India (M. B. Raizada and K. C. Sahni, 1960).

Maheshwari listed only 14 genera. This lesser number of representatives is mainly due to their habitat as gymnosperms are mainly dwellers of temperate regions in India and such climate was afforded only by the Himalayas, They form extensive forests and grow luxuriantly in the various Himalayan ranges that is why most of the gymnosperms are distributed in eastern and western Himalayas besides in some other regions of India.

There are six living orders of gymnosperms and out of them four are represented in India. These include- Cycadales, Coniferales, Ephedrales and Gnetales. The Cycadales are represented by 4 species of *Cycas* in India.

Gymnosperms are very poorly represented in the Indian flora. In the vast peninsular India they are represented by a few species of *Cycas*, *Podocarpus*, and *Gnetum*. However, in the extra peninsular Himalayas and in some extent in the connected ranges of Kashmir, Assam, and Arunachal Pradesh gymnosperms represented only by conifers and covering extensive tract of forest land.

Among gymnosperms, different groups of this category i.e. Cycads, Conifers, Ginkgoales, and Gnetales the most frequently and densely populated group is the Coniferales. This group as we know is represented by *Pinus*, *Cedrus*, *Abies*, *Larix*, *Picea*, *Cupressus*, *Tsuga*, *Juniperous*, *Taxus*, *Araucaria*, *Thuja*, *Podocarpus*, *Cephalotaxus* are common.

Conifers are found predominantly in the Himalayas and are particularly rich in the north-west Himalayas (Uttarakhand, Kashmir, Himachal Pradesh etc.).

Their distribution is generally governed by altitude and generally ranges from 1800- 3300 meters asl. While some species of *Pinus* (*P. insularis* 700-1,850 m asl and *P. merkusii* (150- 600 m asl.) are reported from Khasya region of Assam and on the hillocks in East Bengal respectively).

Among Cycads only *Cycas* occurs in India and the genus is represented by four species viz. *C. circinalis*, *c. beddomei*, *C. pectinata* and *C. rumphii*, beside this another species *C. revolute*, which is a native of Japan is commonly cultivated in Indian gardens.

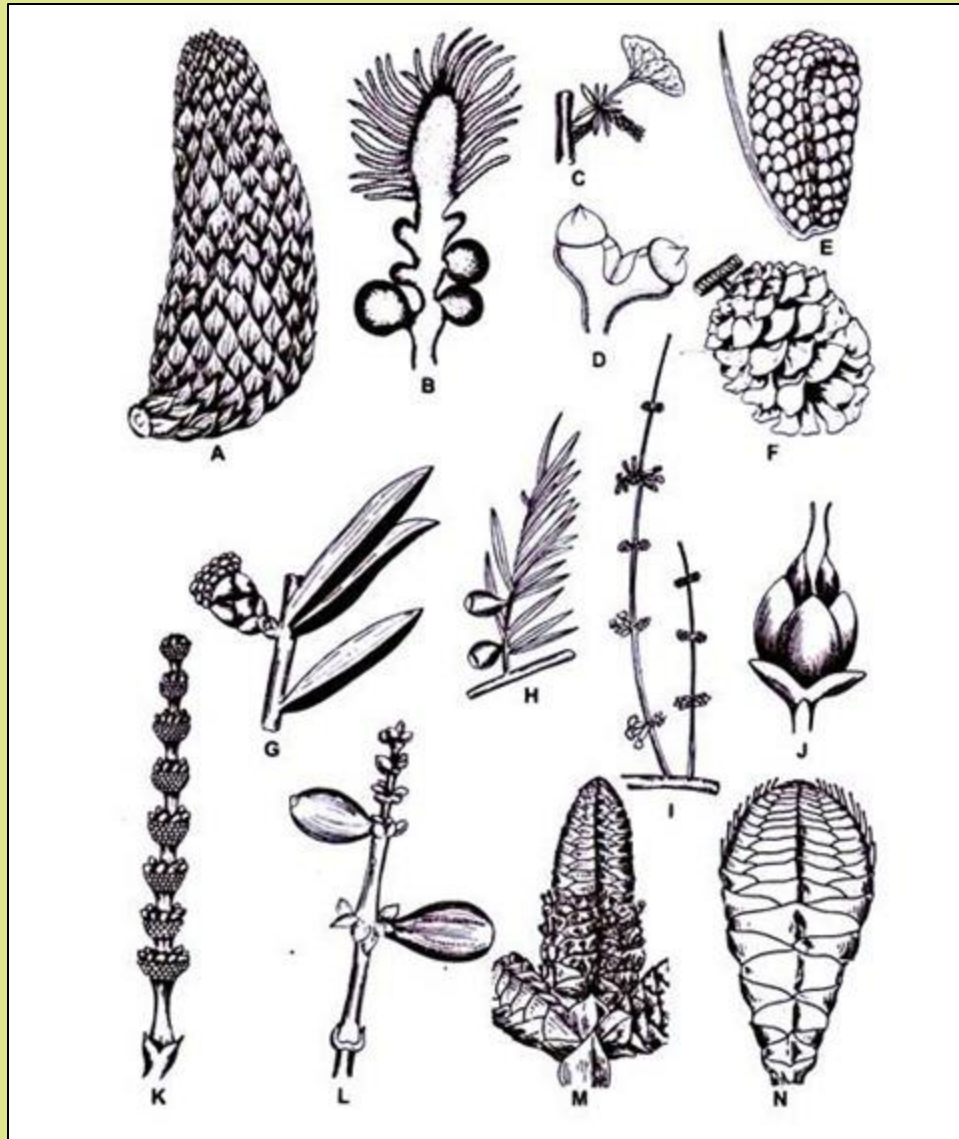
Species of *Zamia*, *Macrozamia*, *Encephalartos* and *Stangeria* are exotics and occasionally cultivated in Indian gardens. Similarly a few plants of *Ginkgo biloba*, a native of China, occur in Indian under cultivation in gardens.

Gnetales are represented in India by a number of species of *Ephedra* and *Gnetum*. Out of seven species of *Ephedra* only one (*E. foliate*) occurs in the plains of Rajasthan and Punjab while rest six are confined to the north-west Himalayan regions.

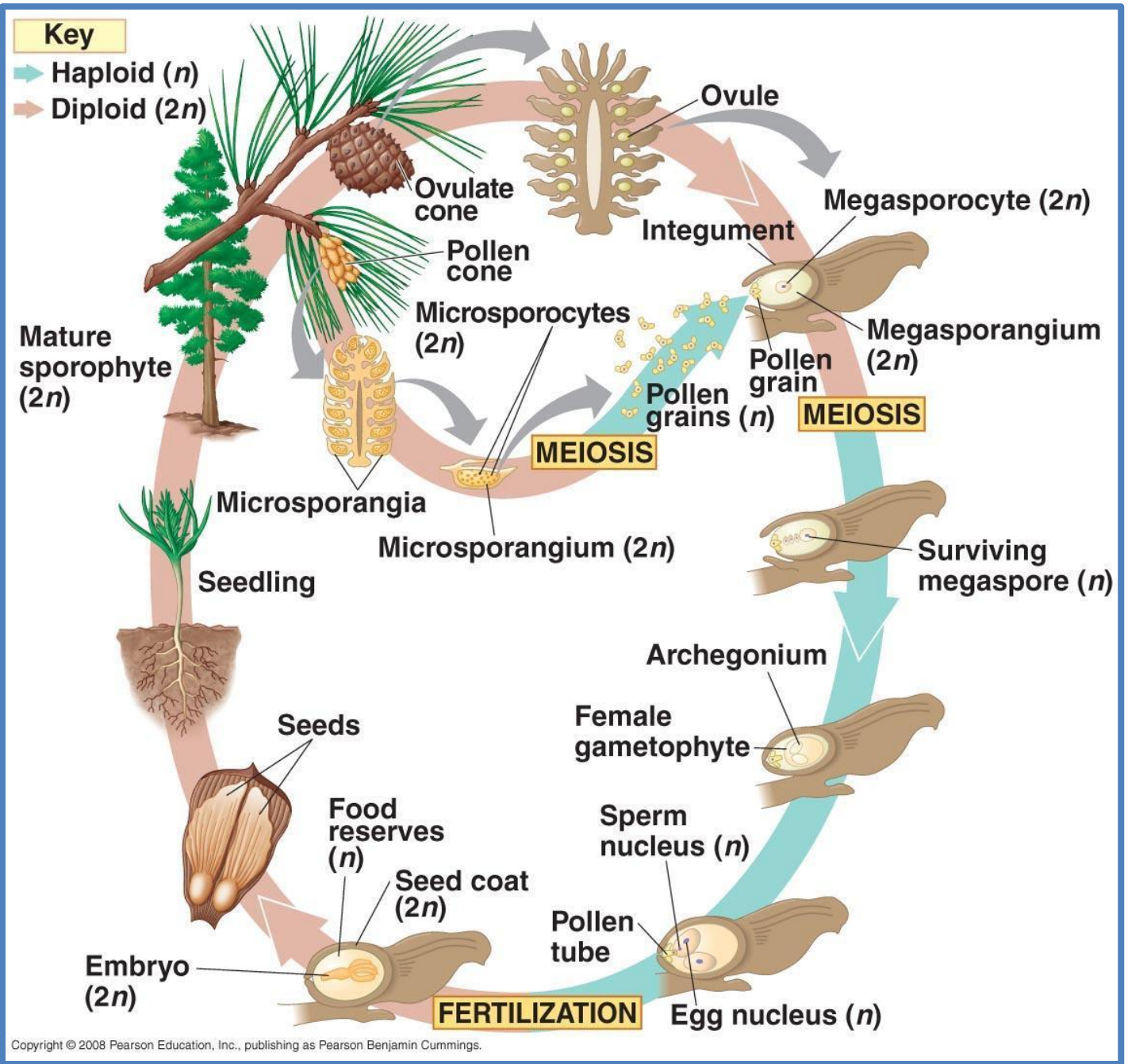
REPRODUCTION

Gymnosperms possess two different types of spores and hence refers as hetrosporous. The microspores are smaller while another spore larger in size called megaspore. These two kinds of spores on germination produce two different kinds of gametophytes. The microspore or pollen grains produce male gametophyte, while the larger megaspore produces female gametophyte, bears two or more archegonia or female sex organs. These spores are produced within the leafy structures or sporangia that borne on sporophylls, spirally arranged along an axis to form compact strobili or cones.

The microsporangiata or male strobili bearing microsporophyll and microsporangia while the megasporangiata or female strobili bear megasporophylls with ovules or microsporangia. The two types of cones or strobili may be borne on same tree as in *Pinus* or on different trees like in *Cycas* and *Ginkgo*. The microsporangium contains numerous small microspores whereas the megasporangium contains only one larger megaspore. Both the spores i.e. microspore and megaspores are haploid and develop as a result of meiosis or reduction division in the respective spore mother cells. They are the primary structures of the male and female gametophytes respectively.

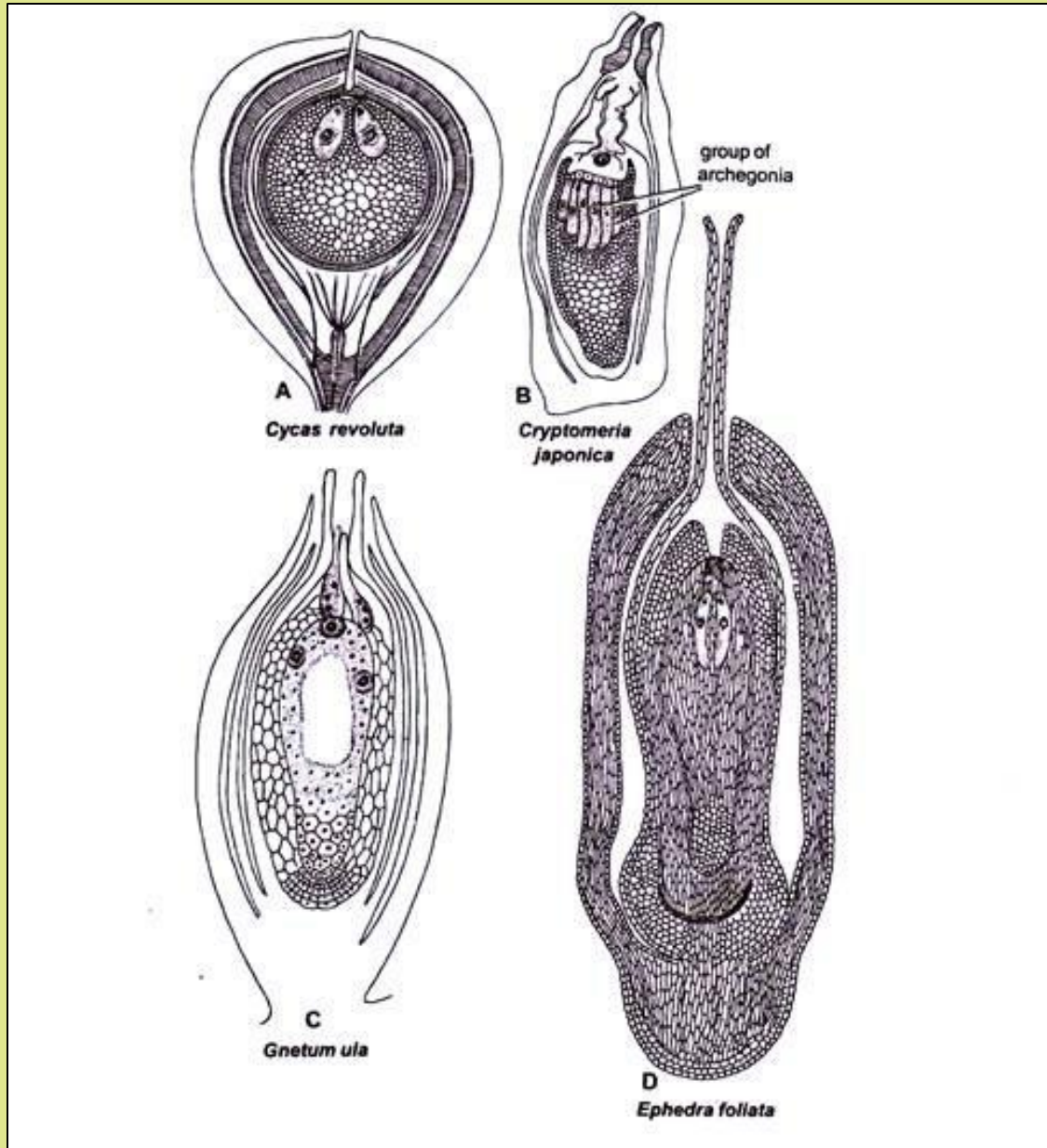


Male and female cones/strobili of Cycas(A,B), Ginkgo(C,D), Pinus (E,F), Taxus (G,H), Ephedra (I,J), Gnetum (K,L) and Welwitschia(M,N)



In gymnosperms the gametophytes are endosporic i.e. they develop within or inside the respective spore wall. In general the strobili or cones are of varying shapes and sizes in different species. Their position also varies from plant to plant. Among gymnosperms, the microsporangiate or male cones are largest and arise singly at the apex of male plant.

Female gametophyte or ovule: As per discoveries the ovules of gymnosperms are without any covering or naked and are borne on usually spirally arranged megasporophylls around a central axis. The ovules are generally sessile. Among gymnosperms, ovules of *Cycas* are the largest among the plant kingdom. In a ovule there is a megasporangium or nucellus enclosed in a parenchymatous mass of cells. The nucellus encloses a single diploid megaspore mother cell that undergoes meiosis and forms 4 haploid mother cells arranged in linear tetrad form. Out of these 4 only one, usually the lower one remains functional and the rest ones degenerate. The functional megaspore enlarges and undergoes free nuclear division and results into large number of free nuclei. This transforms into young gametophyte that has developed within the megaspore.



Ovules is some gymnosperms

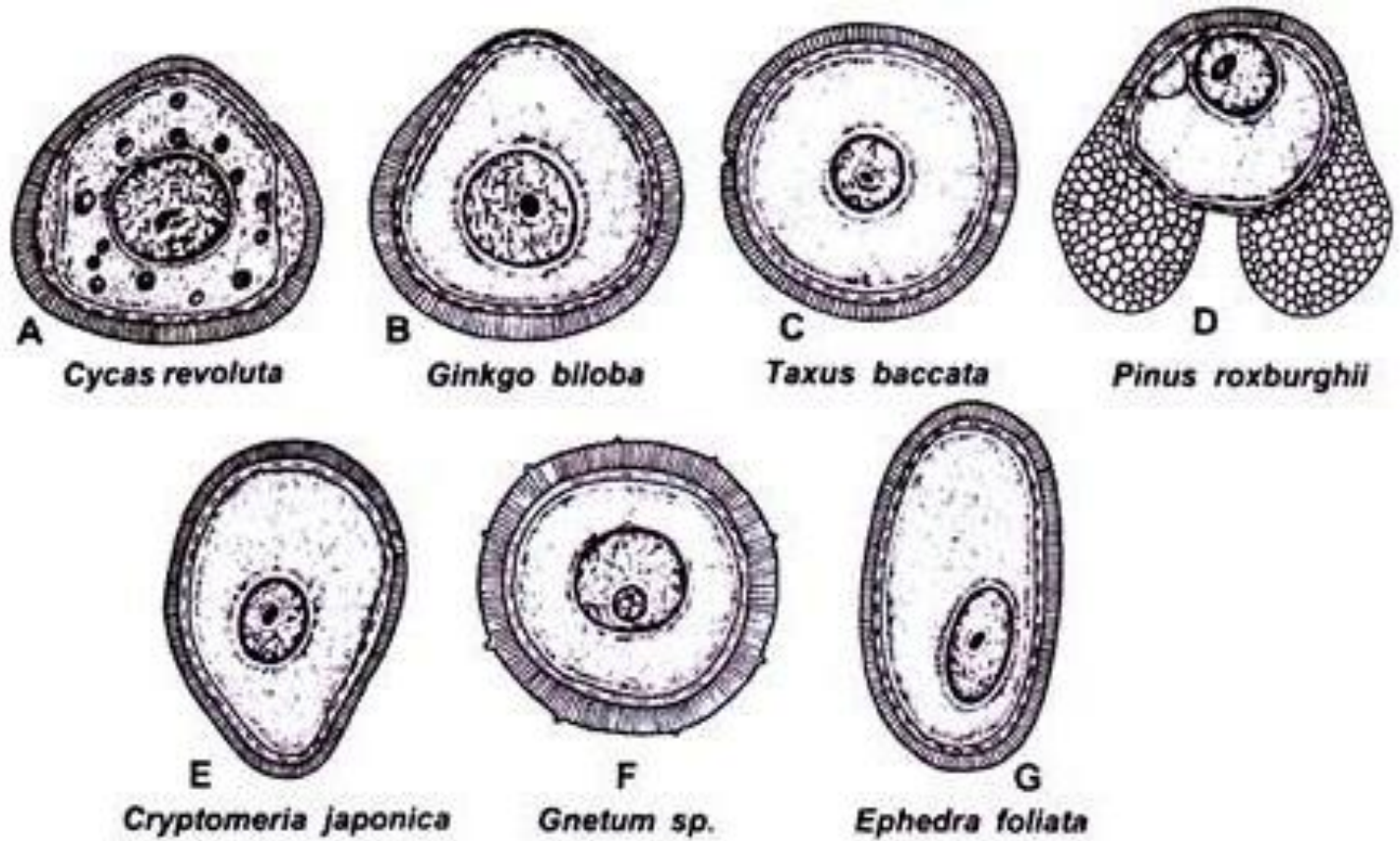
The nucellus now covered by a single massive layer or integument grow around and leaving a small pore at one end known as micropylar end. Thus the new megasporangium integumented is called ovule. Now around each free nuclei a centripetal wall formation starts and it continues till the whole female gametophyte becomes cellular.

In gymnosperms, a single ovule consists of one middle stony layer covered by inner and outer fleshy layer. The apical region of the nucellus forms a pollen chamber by degeneration consisting the semi-germinated pollen grains or microspores. These megaspores remain in the chamber till further growth, towards the micropylar end the female prothallus develops two or more archegonia. Depending upon species the archegonia have a short or long neck made up of 2, 4, and 8 cells, in *Cycas*, *Taxus* and *Biota* respectively. This develops into megaspore mother cell which further undergoes free nuclear divisions.

Afterwards nuclear divisions the cell wall formation starts as a result of which the female gametophyte become a cellular structure. The female gametophyte or prothallus get differentiated into upper reproductive region, middle storage region and the lower basal haustorial region.

Ultimately most of the cells abort and only one remain and matures. Generally in gymnosperms the female gametophyte has cellular tissue at its lower end while on its upper end a few free nuclei remains without wall formation and acts as eggs. After fertilization this apex end however, becomes cellular (exceptional in *Welwitschia*).

Microspores: In gymnosperms the pollen grains or microspores are unicellular and haploid structures. They differ in shape and sizes in different groups of gymnosperms. They may be tetrahedral with a definite polarity due to the thicker exine towards the base (e.g. *Cycas*) and uniaperturate, may be almost spherical and uniaperturate (*Ginkgo*), may be winged (saccate), uniaperturate with reticulate exine (*Abies pindrow*, *Cedrus deodara*, *Pinus roxburghii* and *P. wallichiana*, *Picea smithiana* etc.) whereas in *Ephedra* the pollen grains are inaperturate elongate with plicate exine surface. *E. foliata* showing parallel ridges along the long axis of grains the pollen grains possess two tiny (sac like) structures the extremities however, in other species sacs are almost absent. (Figs. ovules of gymnosperms, archegonia of gymnosperms). Based on studies it is suggested there is a gradual reduction in the wings or sacs and ultimately resulted in non-winged pollen grains as reported in *Ephedra*.



Pollen grains in gymnosperms

Male Gametophyte: The male gametophytes in gymnosperms are endosporic in nature and show variations regarding their release from sporangia, the number of male prothallial cells (they complete their development partly in the microsporangium and partly in the pollen chamber of the ovule), size and motility of male gametes and their time of formation and discharge. In different groups of gymnosperms differs in their morphology. In lower gymnosperms- cycadaceous micro gametophytes there is one male prothallus cell that divides into a large sterile cell or stalk cell and a body cell or a spermatogenous cell and a tube nucleus. They are arranged in a linear row. The body cell again divides into two multiciliate male gametes. In all Cycads the pollen tube is formed and is more haustorial in nature than a sperm carrier. While in *Microcycas* the stalk cell divides into 10 or 11 body cells or spermatogenous cells. These all cells divide to produce 20 or 22 spermatozoids. Contrary to this in *Ceratozamia* there are 4 spermatozoids. Generally in Gymnosperms the generative cell divides into stalk cell and body cell except in *Cycas revolute*, where it is divided anticlinally. In case of Coniferales, different families of this group show slight variations in the sequence of micro- gametophyte development, although the major event shows similarities.

In Pinaceae family the nucleus of microspore divide twice by periclinal walls and cut off three cells- two male prothallus cells and one antheridial cell. The latter divides periclinally and forms a tube cell and a generative cell. The grains are liberated at this four celled stage (two prothallus cells, one tube cell and one generative cell). Again the generative cell undergoes periclinal division and forms a stalk cell and a body cell. All these cells lie in an axial row. The semi germinated pollen grains may germinate immediately or after a month. The pollen tube may start branching on entering the nuecllus, then the tube nucleus migrates into one of the branches of pollen grain and moves to the tip, while the generative cell remain within the spore wall and divides into stalk cell and body cell between the pollination period of the year or in the following spring, these two moves into the pollen tube. Simultaneously about a week before fertilization, the body cell divides into two non-motile, unequal size male gametes. There is difference in opinion regarding the male gamete. According to some workers the two male gametes are as two nuclei of binucleate sperm cells, whereas others regard them as two sperm cells. Sometimes the generative cell divides before pollination, in some genera *e.g. Abies, Cedrus, Picea, and Larix* etc. In *Abies* the cell sometimes divides into two male gametes before pollination or shortly after pollination.

However, Chawdhury (1960) have been reported equal male gametes in *Cedrus*. The period between pollination and fertilization varies in different members of Pinaceae. It is longest in *Pinus* ranges up to one year, up to nine months in *Cedrus*, 4-5 weeks in *Abies* and a few days in *Picea*. Similarly the number of prothallial cells also varies in different species of gymnosperms.

In *Abies balsamea* formation of 3 or 4 prothallial cells have been reported by Hitchinson (1915). While in Taxodiaceae the microgametes lack prothallial cell and divides into a generative cell and a tube cell before pollination. Further the generative cell divides into stalk cell and body cell after pollination. In family Cupressaceae too prothallial cells are absent, here the pollen grains directly acts as antheridial cell and may divide into generative cell and tube cell before pollination. Based on studies, in *Cupressus semipervirens* the body cells divides into 4- 20 male gametes, contrary to this in *C. fusiberus* only two male gametes are produced. Among gymnosperms, the Araucariaceae are unique in producing many prothallial cells the two non- motile male gametes are equal in size. In the members of Podocarpaceae the number of male prothallial cells may be 1- 8 in *Podocarpus*, 3-6 in *Dacrydium* and 1-3 in *Phyllocladus*. While in *Pherosphaera* the male prothallial cell is absent.

In Cephalotaxaceae there is no prothallial cell in any species of *Cephalotaxus*. Whereas in *Taxus* there are no male prothallial cells. The male gametes are unequal in size. In *Ephedra* the cells of male gametophyte arranged in a single axial row including two prothallial cells, a stalk cell, a body cell and a tube cell. Out of the two prothallial cells one is without a cell wall and is thus called prothallial nucleus. After pollination the body cell divides into two male gametes. Contrary to this in *Gnetum* there is only one prothallial cell, a tube nucleus and a generative nucleus. Further division takes place after pollination while at that time the pollen grain contains only three nuclei. The generative nucleus divides into two male gametes. In *Welwitschia* there is no prothallial cell and the released grain contains a tube nucleus and a generative nucleus. Based on above discussion on the general characteristics of male gametophyte in gymnosperms following points emerge

1) The Cycadales, Ginkgoales, Coniferales and *Ephedra* among Gnetales all have the same cellular cell organization of the micro gametophytes including the tube cell, the stalk cell and the male gamete except one difference for the formation of prothallial cell.

2) In case of Araucariaceae and Podocarpaceae formation of a very large number of prothallial cells they developed secondarily at the base of the microspore, may be dealt as a later evolutionary development. This condition is not reported in any living or fossil gymnosperms or nor among lower heterotrophic tracheophytes.

3) In another specific ontogenetic feature is the orientation of the division of spermatogenous cell which produces the stalk cell and the body cell, (e. g. *Ginkgo*), *Araucariaceae*, *Podocarpaceae* and *Cycas revoluta* and in some species of *Ephedra*. The division wall is anticlinal while in other Cycads and Pinaceae the division wall is periclinal and the two cells are superimposed.

4) Beside this in *Microcycas* the stalk cell which is sterile divides and gives rise to additional spermatogenous cell or body cell.

5) While in some other gymnosperms i.e., *Cupressus* and sometimes in *Juniperus* more than two male gametes are produced. This feature may be related with the presence of large number of archegonial complex.

POLLINATION AND FERTILIZATION

In gymnosperms the medium of pollination is wind; it results in the transfer of semi-germinated pollen grains on the micropyle of the ovule. In most of the gymnosperms, the pollen grains are caught into a pollination drop selected by micropylar end of the ovule. After drying of pollination drop the microspores in semi-germinated stage are drawn into the ovule. Just after the drawing of the microspores in the microgametophyte the micropyle closes. A distinct pollen chamber is formed at the apex of the nucellus and receives the microgametophytes on pollination as in some gymnosperms (*Cycas*, *Ginkgo*, *Ephedra* etc.)

While in Conifers and other gymnosperms the semi-germinated pollen grains come in direct contact with the nucellus beak. Contrary to this in the palaeozoic gymnosperms now extinct the pollen chambers contained liquid filled cavities in which the motile sperms were liberated due to the dehiscence of the microspore wall. In general in all the living gymnosperms, the microspores by division produce pollen tube as a tubular outgrowth that grows through the nucellar tissue. In Cycads and *Ginkgo* the pollen tubes mainly acts as the haustorial organs and grows

for long time (several months) into the nucellar tissue and absorb food and supply it to the micro gametophyte at the grain end or at the lower end of the pollen tube. The pollen tube bursts during fertilization and liberation of multiciliate male gametes along with some liquid in the cavity above the mega gametophyte. At that time the sperms swims to the archegonial neck and enters into the archegonia and only one of them fuses with the egg or oosphere and form the diploid zygote or oospore.

In the conifers the pollen tube plays an important role of sperm carrier. The male gamete along with stalk and tube nucleus migrate to tip of the pollen tube. The tube grows through the nucellar tissue, reaches to the archegonial tube enters through it and after bursting liberates the male gametes. Among them, one fuses with the egg to form a diploid zygote. This specific process of fertilization is termed as *Siponogamous*.

However, in Cycadofilicales, Bennettitales and Cordaitales, the extinct orders of gymnosperms did not produce pollen tubes and sperms were liberated directly into the pollen chamber. This process is known as **Zooidogamous**.

In case of *Welwitschia* the female gametophyte gives out tubular prolongation that meets the pollen tips fertilization takes place after the intervening wall dissolves. In *Welwitschia* and *Gnetum* there are no archegonia.

EMBRYOLOGY: In different groups of gymnosperms embryogeny differs in different stages. It also differs in living and fossil forms. In living or present day gymnosperms the first phase in embryo development is the free nuclear divisions except in *Gnetum*, *Welwitschia* and *Sequoia semipervirens*. While it is completely absent in angiosperms and other tracheophyta.

Just after free nuclear division, wall formation begins and the embryo transformed into cellular form. Later it differentiated into a suspensor, radicle, hypocotyl, plumule and cotyledons. When the shoot end of the embryo is directed away from the micropylar end of the ovule, that type of embryo development or embryogeny is called “**Endosporic**”.

Polyembryony is the characteristic and significant feature of gymnosperms. This is possible as more than one archgonia are fertilized and so more than one zygote are formed. These zygotes later developed into embryos, but one of them succeeded in developing into a complete embryo. Comparatively to Cycades, in Conifers there is a "*Cleavage Polyembryony*". As reported earlier that in conifers only four nuclei formed, so in this case all the four cells of the young embryo separates after wall formation and develop into 4 embryos, but only one completes further development while others abort.

In *Thuja* no cleavage Polyembryony reported and only one embryonal initial develops into an embryo. No free nuclear division is reported in *Sequoia semipervirens* and the zygote divided first by a transverse wall and forming two cells which divided further by other longitudinal walls to form four cells. All these cells may function as embryo initial and give rise to filamentous embryo.

In majority of conifers the zygote develops four free nuclei and later because of further divisions and wall formation results in forming a "*Proembryo*" with a four celled distal embryonal tier, middle suspensor tier and upper rosette tier (*Pinus, Cycas, Tsuga* etc.)

While in other gymnosperms as in *Abies*, *Picea* and *Larix* the rosette tier disappears at a later stage. In further developmental stages the lower embryo tier develops into all the organs at a later stage. The suspensor tier develops into additional embryos. While the upper most tier ends are in open contact with the egg cytoplasm. This end is apparently active in transmission of nutrients to the growing embryos.

The number of cotyledons varies in different species even in the same species. It is 10 in *Pinus roxburghii*, *P. banksiana*- 3-6, *P. contorta*- 2-8, *P. sabiniana*-7-8.

Cleavage Polyembryony is not reported in *Araucaria angustifolia* the member of Araucariaceae. In this species 32-45 free nuclei are formed. Later by polar elongation wall formation is accompanied. The cells at the distal end develop into enlarged cap cells. The central cells develop into embryo and those situated towards the micropylar end give rise to suspensor. There is complete absence of "*Cleavage Polyembryony*".

In case of Cupressaceae the genus *Actinostrobus* shows Cleavage Polyembryony and show somewhat different pattern of development. Here 4 free nuclei are formed. Wall formation results in forming 4 cells among which two vertically placed cells below archegonial neck and two transversally placed cells below.

The lower cells divide once to form four embryonic initials while the upper cells do not divide further. The lower ones are polarized in a transverse plane and each of them forms a small distal initial cell and a large suspensor cell and forms four small embryonal cells and four large suspensor cells that elongate considerably.

Hence show cleavage polyembryony. The rosette tier and upper tier is not formed in this case. The embryo has two cotyledons. The embryonal cells are binucleate in the Podocarpaceae. While the number of binucleate cells and the pro-suspensor cell varies with species and genera. The embryo has two cotyledons.

Development of embryo in Gnetales is different than above mentioned cases. Among Gnetales in *Ephedra trifurea* the zygote nucleus divides into eight free nuclei of unequal size distributed unevenly in the protoplasm. Three to five of these nuclei become enclosed individually by irregular wall which become globular later. All these globular cells is pro-embryo or is an example of proembryony. Later the globular pro-embryo develops into an embryo with the massive embryonal mass at the distal end and a number of suspensors. In *Ephedra foliate* exceptionally there is only one suspensor tube.

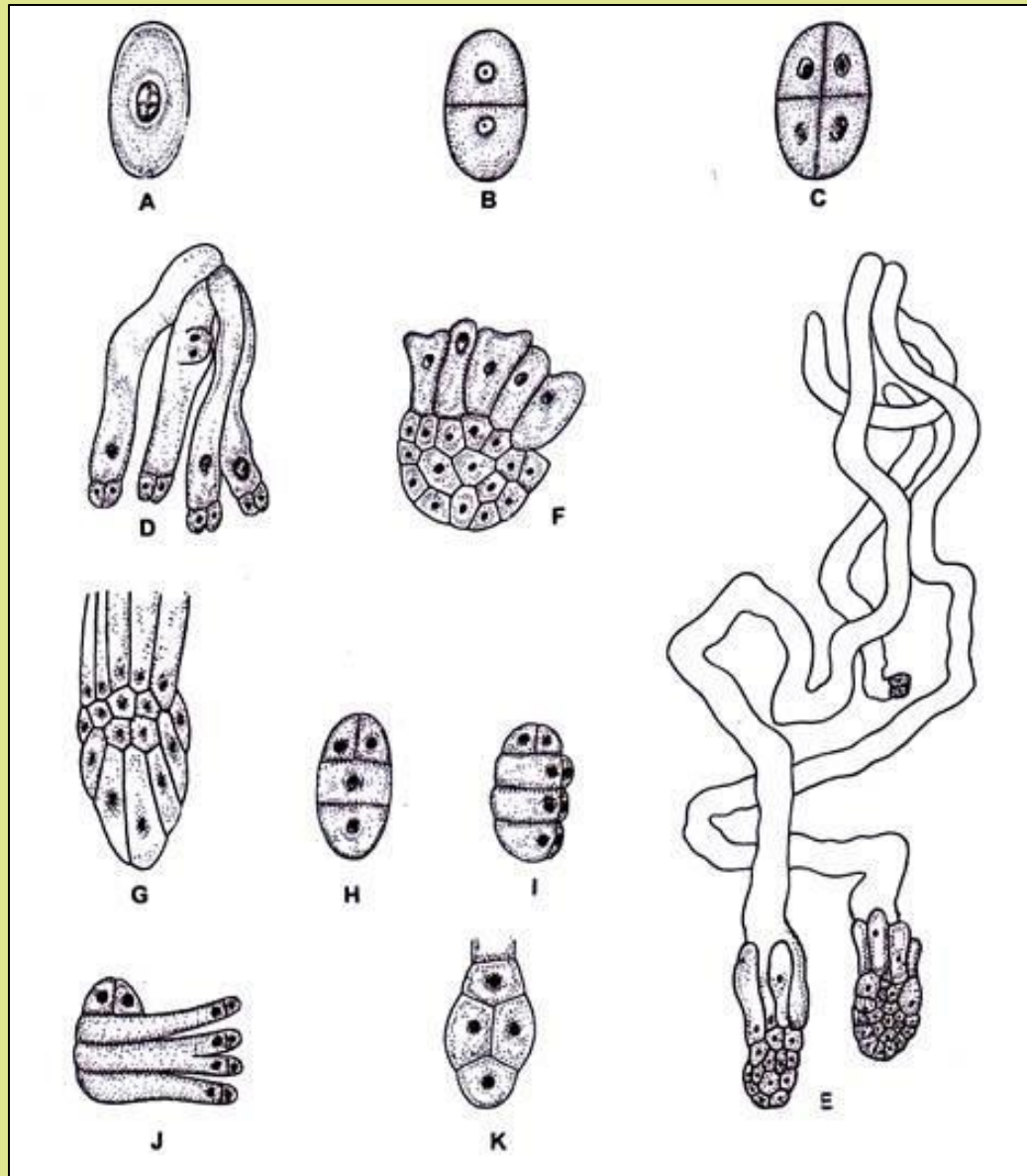
In *Welwitschia* embryo developed differently in this case the zygote elongates and divides into different parts- an upper elongated primary suspensor and a distal embryonal cell, later it divides to form an apical wall. The outer mass of this apical mass are called inner cortical ring and are situated adjacent to the primary suspensor. The outer cortical ring is formed later containing elongate around the suspensor. Thus the primary suspensor cell is now surrounded by two layers of 8- 16 cells. Later by division of these cells more layers are added around these. At the distal end the cells form cap cells while those in the middle develop into embryo.

Comparatively to this embryo development in *Gnetum* is quite different. In this case free nuclear division is not found and the zygote divides and develops into a two celled body that gives out elongated and tube like suspensors. These suspensor cells may branch and all have a distal, densely granulose embryonal cell. Further these terminal cells develop into an embryo out of which only one reaches maturity. In *Gnetum* embryo development is completed after the detachment of the seed.

On the basis of comparative studies of embryonal development in gymnosperm, it is concluded that there is no close relationship or resemblances between the embryogeny of pteridophytes, gymnosperms and angiosperms. This suggests parallel evolution among these groups rather than evolved from a common ancestor. However, the gymnosperms embryo share some common features with other embryos-

1. Axial development of embryo.
2. Early determination of polarity.
3. A conspicuous meristematic distal pole.

These similarities point out the possibility of a common ancestry of gymnosperms with other vascular plants.



Embryogeny of Sequoia semipervirens (A-E); Proembryos of Araucaria angustifolia (F-G); Early embryogeny of Actinostrobus pyramidalis (H-K).

SEED FORMATION: After fertilization, the structure developing from fertilized ovule and its consequent enlargement is known as seed. The zygote develops into an embryo while the endosperm persists as a nutritive tissue, whereas the nucellus becomes disorganized (or serves as nurse cells for developing embryo) or it may remain in the form of dry tissue at the micropylar end of the seed known as nucellar cup.

In gymnosperms the inner fleshy layer called the tegmen, may persist as a thin layer of seed coat. The middle stony layer later changes into a hard layer called the testa, which mechanically protected the female gametophyte and the embryo. Development of seed may vary in different species of gymnosperms. In *Cycas* and *Taxus* the outer fleshy layer develops into scarlet red and fleshy outermost seed coat.

In *Gnetum* the seed develops before the embryo completes its development. In *Taxus* a fleshy aril develops from the basal cup-shaped structure. Except *Cycas* and *Ginkgo*, the seeds of all gymnosperms remain dormant for some time. While in these two genera the seeds germinate immediately, they lose their viability when fall on moist substratum.

In gymnosperms the seed represents two sporophytic and one gametophytic generation. Different parts of a seed of gymnosperms represents different generations.

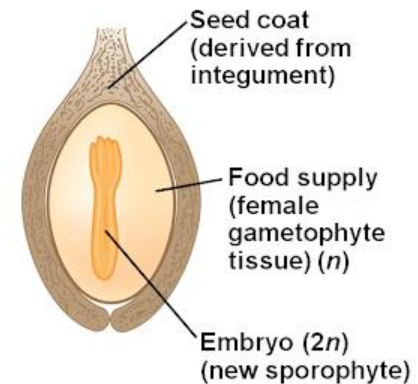
1) The young embryo represents the new sporophytic generation.

2) The seed coat represents the old sporophytic generation and

3) The endosperm represents the gametophytic generation.

In most of the genera of gymnosperm the germination of seed is epigeal means the cotyledons come above ground except in *Ginkgo* where the cotyledons remain embedded in the endosperms. While in *Ephedra trifurcate* *Vivipary* has been reported. All the gymnosperms represent *heterogenous alternation of generation*.

From ovule to seed in a gymnosperm



(c) Gymnosperm seed

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ECONOMIC IMPORTANCE OF GYMNOSPERMS

Gymnosperms are of great economic importance in nature and have many economic importance for human beings. It gives valuable wood, resin, essential oils, gums, paper, turpentine, medicines, food, ornamentals and miscellaneous items.

Gymnosperms are frequently used in parks, gardens because of their evergreen habit and symmetrical appearance. The trees are used for timber, building construction, resin, paper manufacturing etc. They are also used in medicines, perfumes, varnishes, paints and essential oils. While roasted seeds of *Ginkgo* are eaten at least in China and Japan, to promote digestion and diminishes the effect of drinking wine. Seeds of *Pinus gerardiana* (chilgoja) used as dry fruit. Seed kernels of *Gnetum ula* yield an oil for illumination and massage in rheumatism. Bark of *Taxus baccata* is used as main ingredient of famous *Bhatia tea*.

FOOD: In some parts of India, Malaya, Philippines and Indonesia, young succulent leaves of various species of *Cycas* are cooked and eaten as vegetable. The famous “*Sago*” starch is obtained from the stem / seeds of *Cycas* and used as food. This stem starch obtained from *Macrozamia spiratis* is an important source of food for poultry, dairy

animals and pigs. The seeds of *Cycas* are used as paste and eaten as cakes in Nicobar Island.

GREEN MANURE: Leaves of *Cycas* are rich in nitrogen and used as green manure for rice, sweet potato and sugarcane.

MEDICINE: Leaf extract of *Ginkgo biloba* is useful in the treatment of cerebral insufficiency and vertigo.

ORNAMENTAL: *Ginkgo biloba* and *Cycas* species are grown as an avenue tree and in gardens also for beautification. These trees are preferred especially due to their slow growth, evergreen nature and beautiful symmetry.

TIMBER: Conifers and Taxales are most important genera of gymnosperms significantly important to produce high quality, straight grained, light colored, high weight and strong wood in comparison to their weight. They are suitable for making cabinets and furniture due to their strength and durability. The wood of *Abies* is light and termite free. It also has pleasant scent smell and used for packing cases, match wood, wood wool, aircraft work, plywood, light camp furniture and also used as household materials. *Juniperus* wood is fragrant, reddish brown and rarely damaged by insects. *Cedrus* wood is also durable, oily, fragrant, insect repellent and rot resistant.

The wood of *Taxus* is strong, oily, elastic, close-grained, fragrant and very durable with smooth glossy surface. Beside this, wood of *Araucaria cunningghana* used for plywood manufacture.

RESIN: Conifers exudated resins, this help the wood resistant to decay. Conifers are the major resin yielders of the world. These resins evaporate their oil and became harder which makes them invaluable in paints, varnishes, paper sizing, medicines and liquors industries.

CANADA BALSAM: A resin obtained from *Abies balsamea* which has a very high refractory index approximately that of glass. Due to this property it is extremely suitable as amounting medium for microscopic objects and as cements for uses in optical work.

ESSENTIAL OILS: All conifers young branches and adherent leaves provide essential oils. *Himalayan Cedar oil* (*Cedrus deodara*) and *Red Cedar Wood* (*Juniperus virginiana*) are used cleaning tissues in histological work and also use with the oil immersion lens of the microscope. The oil obtained from *Cedrus atlantica* possess medicinal properties and used against bronchitis, tuberculosis, skin diseases and gonorrhoea. The essential oils are used extensively in preparation of deodorants, room sprays, disinfectants, perfumery and medicine etc.

FATTY OILS: Many conifer seeds are rich in fatty oils. The oil from the seeds of *Pinus cembra* and *Torreya nucifera* is edible and also used for paints. The Tail Oil obtained as a by product from sulphate process of cooking conifer wood for making Kraft paper is used in paints, soaps, linoleum, emulsifiers etc.

PHARMACEUTICALS: The leaves of *Taxus baccata* are used in asthma, bronchitis, hiccough, epilepsy and for indigestion. *Taxol* (from *Taxus brevifolia*) is found effective against ovarian cancer, breast cancer, and melanoma and colon cancer. *Ephedra* is the source of a valuable drug *Ephedrine* obtained from *E. equisetina*, *E. gerardiana*, *E. major*, *E. sinica*, *E. intermedia* and *E. nebrodensis*. It is used against cold, respiratory disorder and hay fever. An aromatic beverage, known as *Mormon tea* is also brewed from the species of *Ephedra* in south western United State.

AMBER: It is a fossil, water insoluble tree resin which was secreted by the now extinct pine, (*P. succinifera*). It is yellow, brown to black, hard and brittle with an aromatic odor.

GLOSSARY

1. **AMBER:** It is a fossil, water insoluble tree resin, secreted by now extinct pine (*P. succinifera*), yellow, brown and black in color and hard, brittle with aromatic odor.
2. **ARIL:** Fleshy and hairy outgrowth of seed or fertilized ovule regarded as modified outer integument.
3. **EPIGEAL:** Describing germination of seed where cotyledons are raised above the ground surface by considerable elongation of hypocotyl.
4. **EMBRYO:** Young individual formed after fertilization.
5. **ENDOSPORIC:** Gametophyte describing a gametophyte that develops within the spore.
6. **GAMETOPHYTE:** vegetative structure representing gamete producing generation in the life cycle of plant. It arises from germination of haploid spore.
7. **GENERATIVE CELL:** One of the cells found in pollen tube of seed plants. In gymnosperms it gives rise to a body cell and a stalk cell.
8. **GREEN MANURE:** Any fast growing, inexpensive crop sown towards the end of season to be ploughed into the soil after a while. It is green so that it may increase soil manure on decomposition.

9. GUM: Any substance that swells in water to form gels or sticky solutions.

10. HETROMORPHIC ALTERNATION OF GENERATION: Type of alternation of generation where morphologically different gametophytic and sporophytic generations alternate with each other to complete the sexual life cycle of organism.

11. HETEROSPORY: Plants producing different types of spores by a species.

12. HYPOCOTYL: Region of stem that is derived from part of the embryo lying between cotyledons and radicle.

13. HYPOGEAL: Type of seed germination in which cotyledons remain buried in the ground even after germination.

14. LIVING FOSSIL: Any present day species that resembles some characteristics to extinct organism (only *Ginkgo biloba*).

15. OVARY: The swollen, rounded basal portion of angiospermic carpel that contains ovule.

16. POLLEN CHAMBER: A cavity at the micropylar end of nucellus in some gymnosperms into which pollen grains settle after the pollination and mature there prior to germination.

17. PRO- EMBRYO: Term referring to young plant individual formed

after fertilization not before its differentiation into embryo and suspensor tissue.

18. POLYEMBRYONY: Condition of formation of more than one embryo in one ovule which may develop by division of one fertilized zygote (cleavage polyembryony) or may develop asexually from somatic tissue along with sexual embryo (adventitive polyembryony).

19. PROTHALLUS: Free living gametophyte of certain lower vascular plants. Female gametophyte of gymnosperms is sometimes termed a prothallus.

20. SPOROPHYLL: A modified leaf that bears sporangia

21. SPOROPHYLL: Individual, usually of diploid phase of life cycle that is formed from the fusion product of two gametes by mitosis and throughout and reproduces by spores which germinate in haploid in life cycle.

22. SYMPHYTOGAMOUS: When the male gamete along with tube and stalk nucleus migrate to the tip of the pollen tube, which grows through the nucellar tissue and reaches to archegonial neck and pierces through it, bursts and then liberates the male gametes out of these one fuses with egg to form a zygote (e.g. Pinus).

23 TEGMEN: In a zygote the inner fleshy layer in gymnospermic seed

may persist as a thin layer of seed coat.

24. TESTA: The middle stony layer changes into a hard layer called testa in gymnosperm seeds.

25 VIVIPARY: Phenomenon of differentiation of young plants or bulbils at the floral axis (instead of flowers) phenomenon of germination of seeds or spores in situ on the maternal plant even before its release, common in mangrove plants.

26. XYLEM: A type of vascular tissue which serves mainly to translocate water and solutes.

27. ZOOIDOGAMOUS: Some extinct orders of gymnosperms did not produce pollen tube and the sperms were liberated directly into the pollen chamber (e.g. Cycadofilicales, Bennettitales and Cordaitales).

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