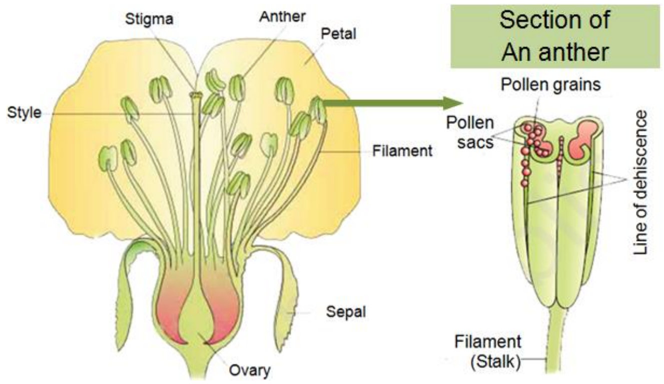
2. SEXUAL REPRODUCTION IN FLOWERING PLANTS

All flowering plants (angiosperms) show sexual reproduction. Flowers are the sites of sexual reproduction.

PRE-FERTILISATION: STRUCTURES & EVENTS

- Several hormonal and structural changes result in differentiation and development of the floral primordium.
- Inflorescences bear the floral buds and then the flowers.

STRUCTURE OF A FLOWER



A typical flower has 2 parts: **Androecium & Gynoecium.**

Androecium (whorl of Stamens)

It is the male reproductive part of the flower.

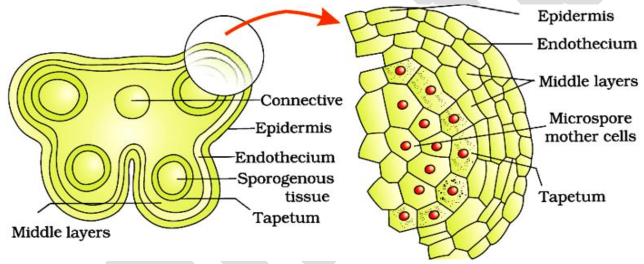
It consists of a whorl of **stamens.** Their number and length are variable in different species.

A stamen has 2 parts:

a. Filament: Long and slender stalk. Its proximal end is attached to the thalamus or the petal of the flower.

b. Anther: Terminal and typically **bilobed.** Each lobe has 2 thecae **(dithecous).** Often a longitudinal groove runs lengthwise separating the theca.

Transverse section of anther:



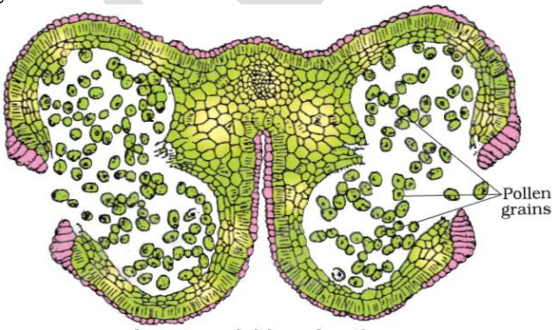
- The anther is a tetragonal structure consisting of four **microsporangia** located at the corners.
- Each lobe consists of two microsporangia.
- The microsporangia develop to **pollen sacs.** They extend longitudinally all through the length of an anther and are packed with pollen grains.

Structure of a microsporangium:

- A typical microsporangium is near circular in outline.
- It is surrounded by four wall layers– the **epidermis, endothecium, middle layers & tapetum.**
- The outer 3 layers give protection and help in dehiscence of anther to release the pollen.
- The **tapetum** (innermost layer) nourishes the developing pollen grains.
- Cells of the tapetum contain dense cytoplasm and generally have more than one nucleus.
- When the anther is young, a group of compactly arranged homogenous cells **(sporogenous tissue)** occupies the centre of each microsporangium.

Microsporogenesis:

- As the anther develops, each cell of sporogenous tissue undergo meiotic divisions to form **microspore tetrads** (microspores are arranged in a cluster of four cells). Each one is a potential **pollen (microspore mother cell).**
- The formation of microspores from a pollen mother cell (PMC) through meiosis is called **microsporogenesis.**
- As the anthers mature and dehydrate, the microspores dissociate from each other and develop into **pollen grains.**
- Each microsporangium contains thousands of pollen grains. They are released with the dehiscence of anther.



A mature dehisced anther

Pollen grain (male gametophyte):

Generally spherical. 25-50 µm in diameter. Cytoplasm is surrounded by a plasma membrane.

A pollen grain has a two-layered wall: **exine** and **intine.**

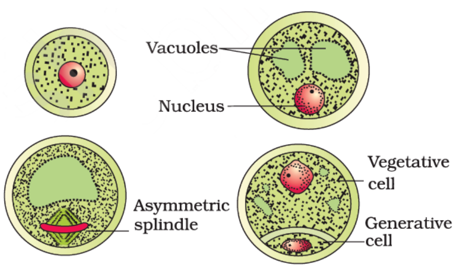
- **Exine:** The hard outer layer. Made up of **sporopollenin** (highly resistant organic material). It can withstand high temperature and strong acids and alkali. Enzymes cannot degrade sporopollenin.

  Exine has apertures called **germ pores** where sporopollenin is absent.

  Pollen grains are preserved as fossils due to the presence of sporopollenin. Exine exhibits patterns and designs.
- **Intine:** The inner wall. It is a thin and continuous layer made up of **cellulose** and **pectin.**

A matured pollen grain contains 2 cells:

- **Vegetative cell:** It is bigger, has abundant food reserve and a large irregularly shaped nucleus.
- **Generative cell:** It is small and floats in the cytoplasm of the vegetative cell. It is spindle shaped with dense cytoplasm and a nucleus.



Stages of a microspore maturing into a pollen grain

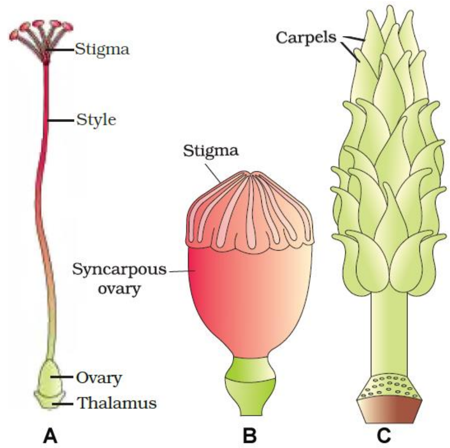
- In over 60% of angiosperms, pollen grains are shed at the 2-celled stage. In others, the generative cell divides mitotically to give rise to the two male gametes before pollen grains are shed (3-celled stage).
- The shed pollen grains have to land on the stigma before they lose viability. The viability period of pollen grains is variable. It depends on temperature and humidity.
- Viability of pollen grains of some cereals (rice, wheat etc.) is 30 minutes. Some members of Leguminoseae, Rosaceae & Solanaceae have viability for months.

Economic importance of pollen grains:

- These are rich in nutrients. Pollen tablets are used as food supplements. Pollen tablets & syrups increase performance of athletes and race horses.
- Pollen grains can be stored for years in liquid nitrogen (-196^{0}C). They are used as pollen banks, similar to seed banks, in crop breeding programmes.
- Pollen grains of some plants (e.g. *Parthenium* or carrot grass) are allergic for some people. It leads to chronic respiratory disorders – asthma, bronchitis, etc.

Gynoecium (Pistil)

- It represents the female reproductive part of the flower.
- It may consist of a single pistil (**monocarpellary**) or more than one pistil **(multicarpellary).**
- In **multicarpellary**, the pistils may be fused together (**syncarpous**) or free (**apocarpous**).

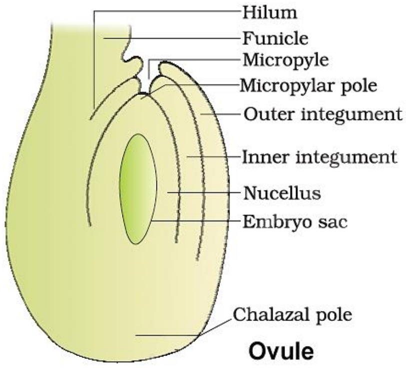


A. *Hibiscus* pistil.
B. Multicarpellary, syncarpous pistil of *Papaver*.
C. Multicarpellary, apocarpous gynoecium of *Michelia*

- Each pistil has three parts:
  - **Stigma:** It is a landing platform for pollen grains.
  - **Style:** It is an elongated slender part beneath the stigma.
  - **Ovary:** It is the basal bulged part of the pistil. Inside the ovary is the **ovarian cavity** (**locule)** in which the **placenta** is located. Arising from the placenta are the **ovules (megasporangia).** The number of ovules in an ovary may be one (wheat, paddy, mango etc.) to many (papaya, water melon, orchids etc.).

Megasporangium (Ovule):

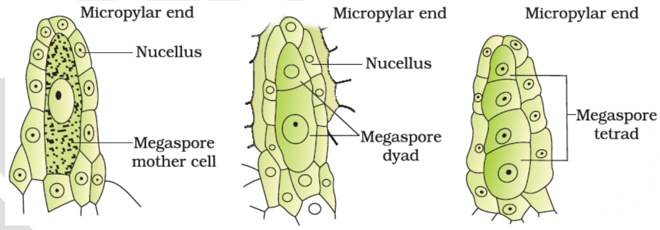
- It is a small structure attached to the placenta by means of a stalk **(funicle)**. The junction where the body of ovule and funicle fuse is called **hilum.**
- Each ovule has one or two protective envelopes called **integuments.** Integuments encircle the ovule except at the tip where a small opening (**micropyle)** is present.
- Opposite the micropylar end is the **chalaza** (basal part).
- Enclosed within the integuments, there is a mass of cells called **nucellus**. Its cells contain reserve food materials.
- Located in the nucellus is the **embryo sac (female gametophyte)**. An ovule generally has a single embryo sac formed from a megaspore through meiosis.



Ovule

Megasporogenesis:

- It is the formation of megaspores from the **megaspore mother cell (MMC)**.
- Ovules generally differentiate a single megaspore mother cell in the micropylar region of the nucellus. It is a large cell containing dense cytoplasm and a prominent nucleus.
- The MMC undergoes meiotic division. It results in the production of 4 **megaspores**.

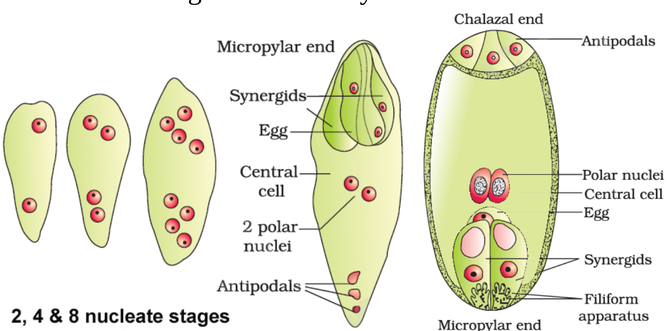


Female gametophyte (embryo sac):

- In a majority of flowering plants, one of the megaspores is **functional** while the other three degenerate.
- The **functional megaspore** develops into the **female gametophyte.** This method of embryo sac formation from a single megaspore is termed **monosporic** development.

Formation of the embryo sac:

- The nucleus of the functional megaspore divides mitotically to form two nuclei. They move to the opposite poles, forming **2-nucleate** embryo sac.
- The nuclei again divide two times forming **4-nucleate** and **8-nucleate** stages of the embryo sac.



2, 4 & 8 nucleate stages embryo sac & a mature embryo sac

Mature embryo sac

- These divisions are strictly free nuclear, i.e. nuclear divisions are not followed immediately by cell wall formation.
- After the 8-nucleate stage, cell walls are laid down leading to the organization of the typical **female gametophyte** or **embryo sac**.
- 6 of the 8 nuclei are surrounded by cell walls and organized

into cells. Remaining 2 nuclei (polar nuclei) are situated below the egg apparatus in the large **central cell.**

Distribution of the cells within the embryo sac:

A typical mature embryo sac is **8-nucleate** and **7-celled**.

- 3 cells are grouped at the **micropylar end** and form **egg apparatus**. It consists of 2 **synergids** and one **egg cell**.
- Synergids have special cellular thickenings at the **micropylar tip** called **filiform apparatus.** It helps to guide the pollen tubes into the synergid.
- 3 cells at the **chalazal end** are called the **antipodals**.
- The large **central cell** has two **polar nuclei.**

Pollination

- It is the transfer of pollen grains from the anther to the stigma of a pistil.
- Some external agents help the plants for pollination.

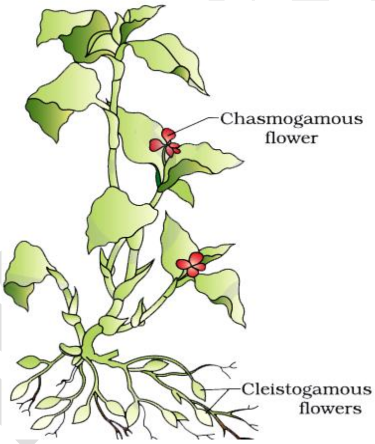
Depending on the source of pollen, pollination is 3 types.

a. Autogamy (self-pollination): In this, pollen grains transfer from the anther to stigma of the same flower.

In flowers with exposed anthers & stigma, complete autogamy is rare. Autogamy in such flowers requires synchrony in pollen release and stigma receptivity. Also, anthers & stigma should lie close to each other.

Plants like *Viola* (common pansy), *Oxalis* & *Commelina* produce 2 types of flowers:

- **Chasmogamous flowers:** They are similar to flowers of other species with exposed anthers and stigma.
- **Cleistogamous flowers:** They do not open at all. Anthers & stigma lie close to each other. They are autogamous. When anthers dehisce in the flower buds, pollen grains come in contact with stigma for pollination. Cleistogamous flowers produce assured seed-set even in the absence of pollinators.



b. Geitonogamy: In this, pollen grains transfer from the anther to the stigma of another flower of the same plant. It is functionally cross-pollination involving a pollinating agent. But it is genetically similar to autogamy since the pollen grains come from the same plant.

c. Xenogamy: In this, pollen grains transfer from anther to the stigma of a different plant. It brings genetically different pollen grains to the stigma.

Agents of Pollination

1. Abiotic agents (wind & water)

Pollination by wind (anemophily):

- More common abiotic agent.
- Wind pollinated flowers often have a single ovule in each ovary and numerous flowers packed into an inflorescence.
- E.g. Corncob – the tassels are the stigma and style which wave in the wind to trap pollen grains. Wind-pollination is quite common in grasses.
- **Ways for effective pollination:**
  - The flowers produce enormous amount of pollen.
  - The pollen grains are light and non-sticky so that they can be transported in wind currents.
  - They often possess well-exposed stamens (for easy dispersion of pollens into wind currents).
  - Large, feathery stigma to trap air-borne pollen grains.

Pollination by water (hydrophily):

- It is quite rare. It is limited to about 30 genera, mostly monocotyledons. E.g. *Vallisneria* & *Hydrilla* (fresh water), *Zostera* (marine sea-grasses) etc..
- As against this, water is a regular mode of transport for the male gametes among the lower plants. It is believed, particularly for some bryophytes & pteridophytes, that their distribution is limited because of the need for water for the transport of male gametes and fertilisation.
- In *Vallisneria*, the female flower reaches the surface of water by the long stalk and the male flowers or pollen grains are released on to the surface of water. They are carried by water currents and reach the female flowers.
- In sea grasses, female flowers remain submerged in water. Pollen grains are long and ribbon like. They are carried inside the water and reach the stigma.
- The pollen grains of most of the water-pollinated species have a mucilaginous covering to protect from wetting.
- Not all aquatic plants use hydrophily. In most of aquatic plants (water hyacinth, water lily etc.), the flowers emerge above the level of water for entomophily or anemophily.
- Wind and water pollinated flowers are not very colourful and do not produce nectar.

2. Biotic agents (animals)

- Majority of flowering plants use animals as pollinating agents. E.g. Bees, butterflies, flies, beetles, wasps, ants, moths, birds (sunbirds & humming birds) bats, primates (lemurs), arboreal (tree-dwelling) rodents, reptiles (gecko lizard & garden lizard) etc.
- Pollination by insects **(Entomophily),** particularly bees is more common.
- Often flowers of animal pollinated plants are specifically adapted for a particular species of animal.
- **Features of insect-pollinated flowers:**
  - Large, colourful, fragrant and rich in nectar. Nectar & pollen grains are the floral rewards for pollination.
  - When the flowers are small, they form inflorescence to make them visible.
  - The flowers pollinated by flies and beetles secrete foul odours to attract these animals.
  - The pollen grains are generally sticky.
- When the animal comes in contact with the anthers and the stigma, its body gets pollen grains. When it comes in contact with the stigma, it results in pollination.
- Some plants provide safe places as floral reward to lay eggs.

E.g. *Amorphophallus* (It has the tallest flower of 6 feet).

A moth species and the plant *Yucca* cannot complete their life cycles without each other. The moth deposits its eggs in the locule of ovary. The flower gets pollinated by moth. The larvae come out of the eggs as seeds start developing.

- Many insects consume pollen or nectar without bringing about pollination. They are called **pollen/nectar robbers.**

Outbreeding Devices:

Hermaphrodite flowers can undergo self-pollination. Continued self-pollination results in inbreeding depression. To avoid **self-pollination** and encourage **cross-pollination,** there are some devices in plants:

a. Avoiding synchronization: Here, the pollen is released before the stigma becomes receptive or stigma becomes receptive before the release of pollen. It prevents autogamy.

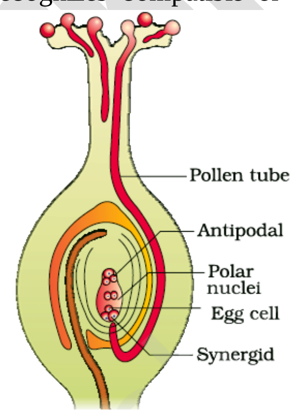
b. Arrangement of anther & stigma at different positions: This also prevents autogamy.

c. Self-incompatibility: It is a genetic mechanism to prevent self-pollen (from the same flower or other flowers of the same plant) from fertilization by inhibiting pollen germination or pollen tube growth in the pistil.

d. Production of unisexual flowers: If male & female flowers are present on the same plant (i.e., monoecious, e.g. castor & maize), it prevents autogamy but not geitonogamy. In dioecious plants (e.g. papaya), male and female flowers are present on different plants **(dioecy).** This prevents both autogamy and geitonogamy.

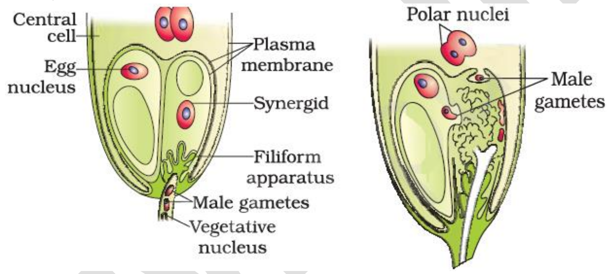
Pollen-pistil Interaction:

- It is a process in which pistil recognizes compatible or incompatible pollen through the chemical components produced by them.
- If the pollen is **compatible** (right type), the pistil accepts it and promotes post-pollination events. Pollen grain germinates on the stigma to produce a pollen tube through one of the germ pores. The contents of pollen grain move into the pollen tube. Pollen tube grows through the tissues of stigma and style and reaches the ovary.



Longitudinal section of a flower showing growth of pollen tube

- If the pollen is **incompatible (wrong type),** the pistil rejects pollen by preventing pollen germination on the stigma or the pollen tube growth in the style.
- In some plants, pollen grains are shed at **2-celled condition** (a vegetative cell & a generative cell). In such plants, the generative cell divides and forms the two male gametes during the growth of pollen tube in the stigma.
- In plants which shed pollen in the **3-celled condition,** pollen tubes carry 2 male gametes from the beginning.
- Pollen tube reaches the **ovary,** then enters the **ovule** through **micropyle** and then enters one of the **synergids** through the **filiform apparatus.** The filiform apparatus present at the micropylar part of the synergids guides the entry of pollen tube.



a) Entry of tube into a synergid (b) Discharge of male gametes into a synergid and the movements of the sperms, one into the egg and the other into the central cell

- A plant breeder can manipulate pollen-pistil interaction, even in incompatible pollinations, to get desired hybrids.

Artificial hybridisation:

- It is a crop improvement programme in which desired pollen grains are used for pollination.
- This is achieved by following techniques:
  - **Emasculation:** Removal of anthers from the bisexual flower bud of female parent before the anther dehisces.
  - **Bagging:** Here, emasculated flowers are covered with a suitable bag (made up of butter paper) to prevent contamination of its stigma with unwanted pollen.

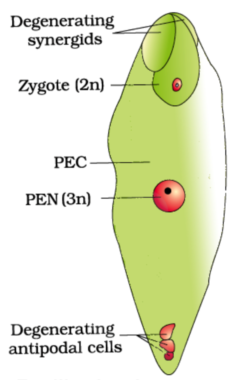
    When the stigma attains receptivity, mature pollen grains collected from anthers of the male parent are dusted on the stigma. Then the flowers are rebagged and allowed to develop the fruits.
- For unisexual flowers, there is no need for emasculation. Female flower buds are bagged before the flowers open. When the stigma becomes receptive, pollination is carried out using the desired pollen and the flower rebagged.

DOUBLE FERTILISATION

- After entering one of the synergids, the pollen tube releases the 2 male gametes into the cytoplasm of the synergid. One male gamete moves towards the egg cell and fuses with its nucleus **(syngamy)**. This forms the **zygote** (a diploid cell).
- The other male gamete moves towards the two polar nuclei located in the central cell and fuses with them to produce a triploid **primary endosperm nucleus (PEN).** As it involves fusion of 3 haploid nuclei, it is called **triple fusion.**
- Since 2 types of fusions (syngamy & triple fusion) take place in an embryo sac, it is called **double fertilisation.**

It is an event unique to flowering plants.

- The central cell after triple fusion becomes the **primary endosperm cell (PEC)** and develops into the **endosperm** while the zygote develops into an **embryo.**



Fertilized embryo sac

POST- FERTILISATION: STRUCTURES & EVENTS

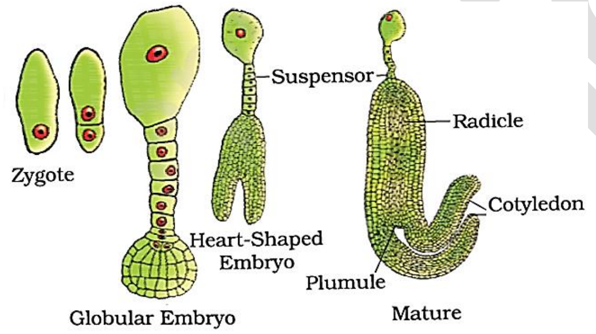
Post-fertilisation events: Endosperm & embryo development, maturation of ovule(s) into seed(s) & ovary into fruit.

Endosperm development

- The primary endosperm cell divides repeatedly and forms a **triploid endosperm tissue.**
- Endosperm cells are filled with reserve food materials. They are used for **nutrition** of the developing embryo.
- In common endosperm development, the PEN undergoes successive nuclear divisions to give rise to free nuclei. This stage is called **free-nuclear endosperm.** The number of free nuclei varies greatly.
- The endosperm becomes cellular due to the cell wall formation. The tender **coconut water** is a **free-nuclear endosperm** (made up of thousands of nuclei) and the surrounding **white kernel** is the **cellular endosperm.**

Embryo development

- Embryo develops at the micropylar end of the embryo sac where the zygote is situated.
- Most zygotes divide only after the formation of certain amount of endosperm. This is an adaptation to provide nutrition to the developing embryo.
- Though the seeds differ greatly, the **embryogeny** (early embryonic developments) is similar in monocots & dicots.
- The zygote gives rise to the **proembryo** and subsequently to the **globular, heart-shaped** and **mature embryo**.



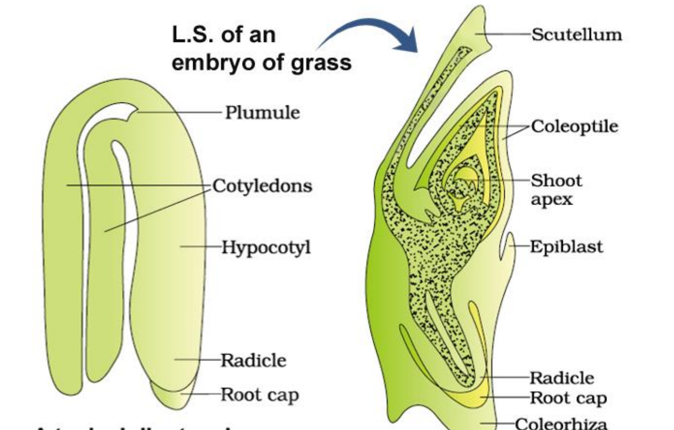
Stages in embryo development in a dicot

Dicotyledonous embryo

- It has an **embryonal axis** and 2 **cotyledons.**
- The portion of embryonal axis above the level of cotyledons is the **epicotyl,** which terminates with the **plumule (stem tip).**
- The cylindrical portion below the level of cotyledons is **hypocotyl** that terminates with the **radicle (root tip).** The root tip is covered with a **root cap.**

Monocotyledonous embryo

- They possess only one cotyledon.
- In the grass family, the cotyledon is called **scutellum.**
- It is situated lateral to the embryonal axis. At its lower end, the embryonal axis has the radicle and root cap enclosed in **coleorrhiza** (an undifferentiated sheath).
- Portion of embryonal axis above the level of attachment of scutellum is the epicotyl. It has a shoot apex and a few leaf primordia enclosed in **coleoptile** (a hollow foliar structure).



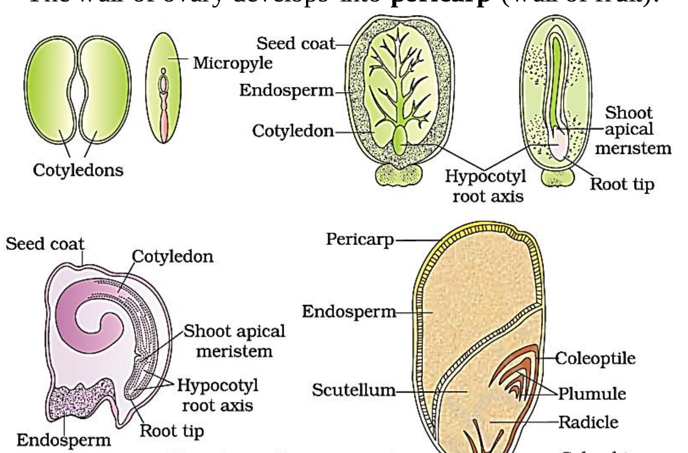
A typical dicot embryo

Seed from Ovule

- Seed is the fertilized ovule formed inside fruits. It is the final product of sexual reproduction.
- It consists of **seed coat(s), cotyledon(s) & an embryo axis.**
- The cotyledons are simple, generally thick and swollen due to storage food (as in legumes).
- Mature seeds are 2 types:
  - **Non-albuminous seeds:** have no residual endosperm as it is completely consumed during embryo development (e.g., pea, groundnut, beans).
  - **Albuminous seeds**: retain a part of endosperm as it is not completely used up during embryo development (e.g., wheat, maize, barley, castor, coconut, sunflower).
- Occasionally, in some seeds (black pepper, beet etc.) remnants of nucellus are also persistent. It is called **perisperm.**
- Integuments of ovules harden as tough protective seed coats. It has a small pore (micropyle) through which O_2 & water enter into the seed during germination.
- As the seed matures, its water content is reduced and seeds become dry (10-15 % moisture by mass). The general metabolic activity of the embryo slows down. The embryo may enter a state of inactivity **(dormancy).** If favourable conditions are available (adequate moisture, oxygen and suitable temperature), they germinate.

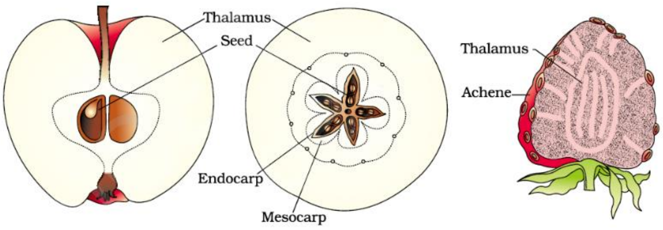
Fruit from Ovary

- The ovary develops into a fruit. Transformation of ovules into seeds and ovary into fruit proceeds simultaneously.
- The wall of ovary develops into **pericarp** (wall of fruit).



Structure of some seeds

- The fruits may be **fleshy** (e.g. guava, orange, mango, etc.) or **dry** (e.g. groundnut, mustard etc.).
- Fruits are 2 types:
  - **True fruits:** In most plants, the fruit develops only from the ovary and other floral parts degenerate and fall off. They called **true fruits.**
  - **False fruits:** In this, the thalamus also contributes to fruit formation. E.g. apple, strawberry, cashew etc.



False fruits of apple and strawberry

- In some species fruits develop without fertilisation. Such fruits are called **parthenocarpic fruits.** E.g. Banana.
- Parthenocarpy can be induced through the application of growth hormones. Such fruits are seedless.

Advantages of seeds:

- Since pollination and fertilisation are independent of water, seed formation is more dependable.
- Seeds have better adaptive strategies for dispersal to new habitats and help the species to colonize in other areas.
- They have food reserves. So young seedlings are nourished until they are capable of photosynthesis.
- The hard seed coat protects the young embryo.
- Being products of sexual reproduction, they generate new genetic combinations leading to variations.
- Dehydration and dormancy of mature seeds are crucial for storage of seeds. It can be used as food throughout the year and also to raise crop in the next season.

Viability of seeds after dispersal:

- In a few species the seeds lose viability within a few months. Seeds of many species live for several years.
- Some seeds can remain alive for hundreds of years. The oldest is that of a lupine (*Lupinus arcticus*) excavated from Arctic Tundra. The seed germinated and flowered after an estimated record of 10,000 years of dormancy.
- 2000 years old viable seed is of the date palm (*Phoenix dactylifera*) discovered during the archeological excavation at King Herod's palace near the Dead Sea.

APOMIXIS AND POLYEMBRYONY

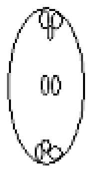
- **Apomixis** is the production of seeds without fertilisation. E.g. Some species of *Asteraceae* and grasses.
- It is a form of asexual reproduction that mimics sexual reproduction.
- **Development of apomictic seeds:** In some species, the diploid egg cell is formed without reduction division and develops into the embryo without fertilisation.
  In many species (e.g. many *Citrus* & *Mango* varieties) some of the nucellar cells surrounding the embryo sac divide, protrude into the embryo sac and develop into the embryos. In such species each ovule contains many embryos. Occurrence of more than one embryo in a seed is called **polyembryony**.

Importance of apomixis in hybrid seed industry

- If the seeds collected from hybrids are sown, the plants in the progeny will segregate and lose hybrid characters.
- Production of hybrid seeds is costly. Hence the cost of hybrid seeds is also expensive for the farmers.
- If the hybrids are made into apomicts, there is no segregation of characters in the hybrid progeny. Then the farmers can keep on using the hybrid seeds to raise new crop year after year.

MODEL QUESTIONS

1. Observe the relationship of the first two and fill in the blanks.
   (a) Radicle : coleorrhiza Plumule : ....
   (b) m.m.c : microspore mother cell PEN : ....
   (c) 2n : zygote 3n : ....
   (d) Intine : Pectin Exine : ....
   (e) Female gametophyte: Embryo sac Male gametophyte: ....
2. In Angiosperms, the zygote is diploid while the endosperm in triploid. Discuss the events leading to the formation of diploid zygote and triploid endosperm.
3. Emasculation and bagging are two important steps in artificial hybridization. State the importance of both the processes in artificial hybridization.
4. The Petal of an angiosperm possesses 22 chromosomes. State the ploidy and chromosome number of the following structures supposed to be seen in the plant.
   (a) Coleoptile (b) Perisperm (c) Endosperm
   (d) Generative cell (e) Globular Embryo (f) Endosperm
5. Group the following parts into n, 2n, 3n
   Egg, synergids, PEN, pollen, embryo, nucellus, integuments, endosperm
6. Differentiate (a) Perisperm and Pericarp (b) Epicotyl and Hypocotyl
7. Observe the diagram



   (a) What is the structure shown here?
   (b) How many nuclei were in its younger stage?
   (c) What are the upper three nuclei together called?
8. “People prefer seedless fruits than seeded ones.” Name a process concerned with development of seedless fruits.
9. Production of unisexual flowers in coconut prevents only autogamy, but in papaya it prevents both autogamy & geitonogamy. Justify.
10. Ibin says that “Apomixis is a boon to hybrid seed industry” Evaluate this statement and write your opinion.
11. Continuous self-pollination result in breeding depression in plants. List out devices by which cross pollination is encouraged in nature.
12. Apple is called a false fruit.
   (a) Give reason (b) Which part of the flower forms the fruit?
13. Tender coconut has liquid endosperm inside it. But, when matured it has solid endosperm.
   (a) Mention the function of endosperm
   (b) Give the functional difference between liquid endosperm and solid endosperm.