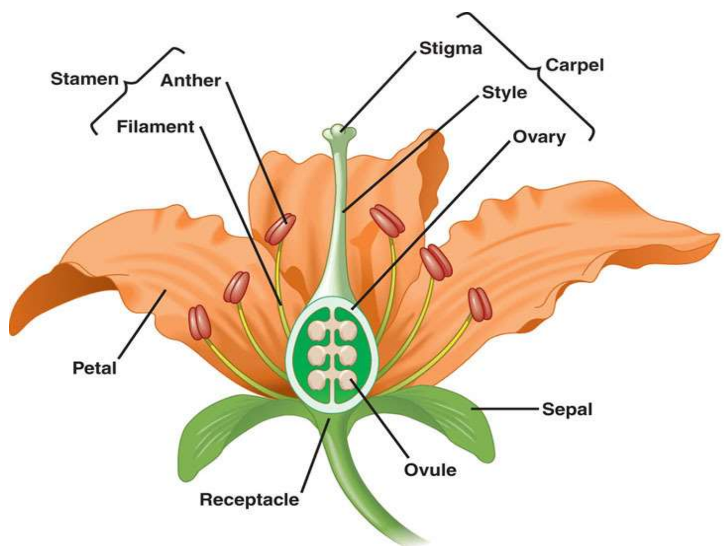
CHAPTER 2
SEXUAL REPRODUCTION IN FLOWERING PLANTS
PART 1

FLOWER – A FASCINATING ORGAN OF ANGIOSPERMS:

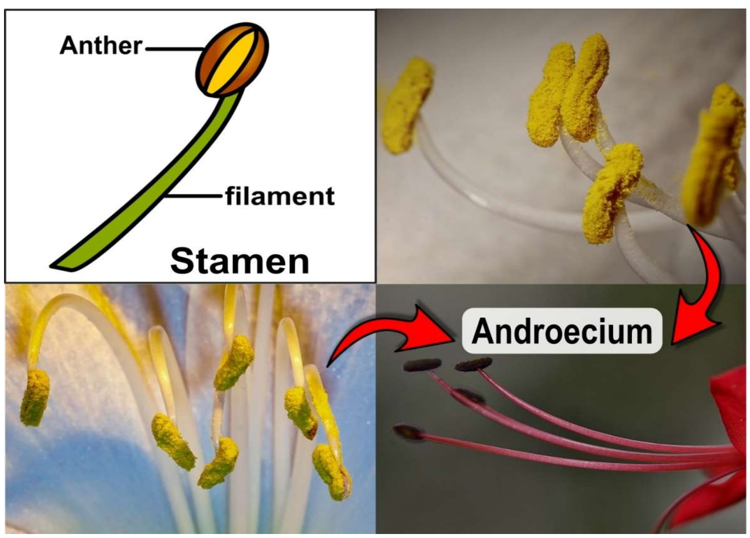
- Human beings have had an intimate relationship with flowers since time immemorial.
- Flowers are objects of aesthetic, ornamental, social, religious and cultural value – they have always been used as symbols for conveying important human feelings such as love, affection, happiness, grief, mourning, etc.
- Have you heard of **floriculture** – what does it refer to?
- Floriculture is the science and practice of growing, harvesting, storing, designing and marketing flowering plants.
- To a biologist, flowers are morphological and embryological marvels and the sites of sexual reproduction.
- Stamen and Pistil are the two most important unit of sexual reproduction.

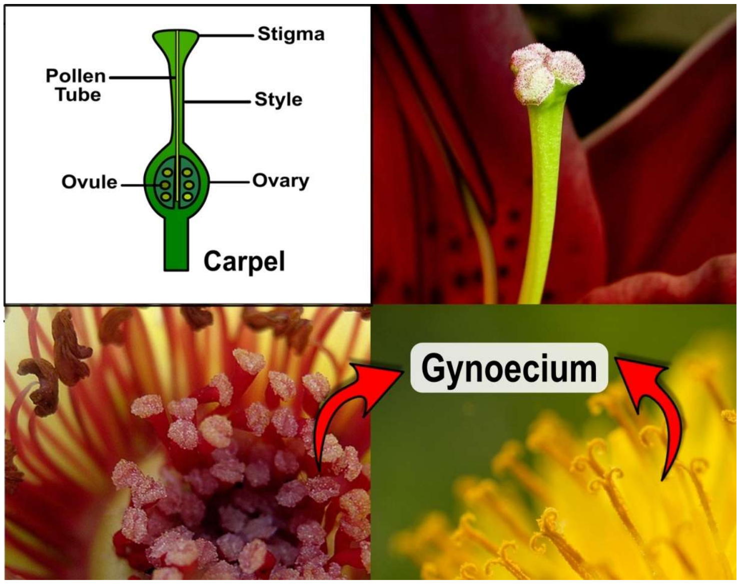


Parts of a Flower

PRE-FERTILISATION - STRUCTURES AND EVENTS:

- The events which occur before the fertilization are called **pre-fertilization events**.
- During this process several hormonal and structural changes occur which lead to the differentiation and further development of the floral primordium.
- In embryology, floral primordium refers to the formation of little buds at the end of stems from which flower will be developed.
- **Inflorescences** are formed which bear the floral buds and then the flowers.
- In the flower, the **androecium** (male reproductive part) and the **gynoecium** (female reproductive part) differentiate and develop to form male and female gametophyte.
- The androecium consists of a whorl of stamens representing the male reproductive organ and the gynoecium represents the female reproductive organ.





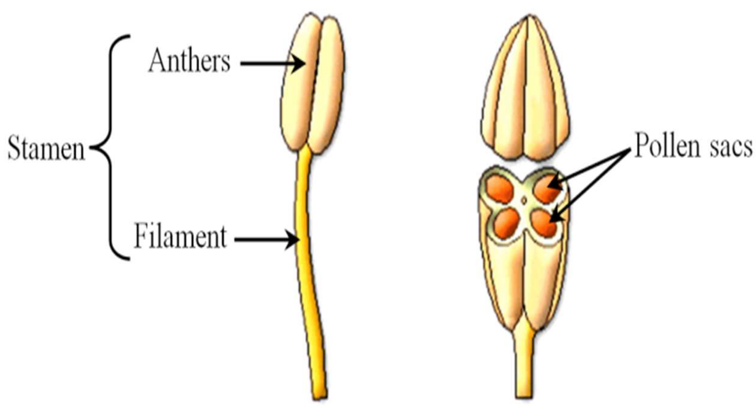
- Different events and structures involved in pre-fertilization are discussed below.

Development of Male Gametophyte

- Development of male gametophyte involves the study of following:

Stamen

- It is the male reproductive unit of angiosperm.
- It consists of two parts.
- (i) The long and slender stalk called the **filament**.
- (ii) The terminal, generally bilobed structure called **anther**.



- The proximal end of the filament is attached to the thalamus or the petal of the flower (epipetalous).
- The number and length of stamens are variable in flowers of different species.

Structure of Anther

- A typical angiosperm anther is **bilobed** with each lobe having two theca (chamber), i.e., they are **dithecous** (two chambered).
- The theca are separated by a longitudinal groove running lengthwise.
- In a cross section, the anther is a four-sided (tetragonal) structure consisting of **four microsporangia** located at the corners, two in each lobe.
- Later, the microsporangia develop and become **pollen sacs**.
- They extend longitudinally all through the length of an anther and are packed with **pollen grains**.

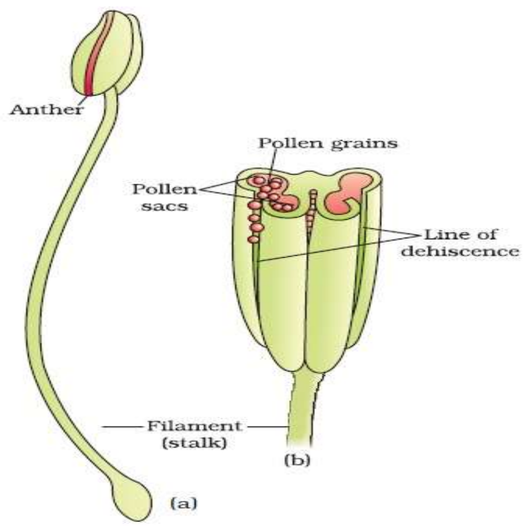
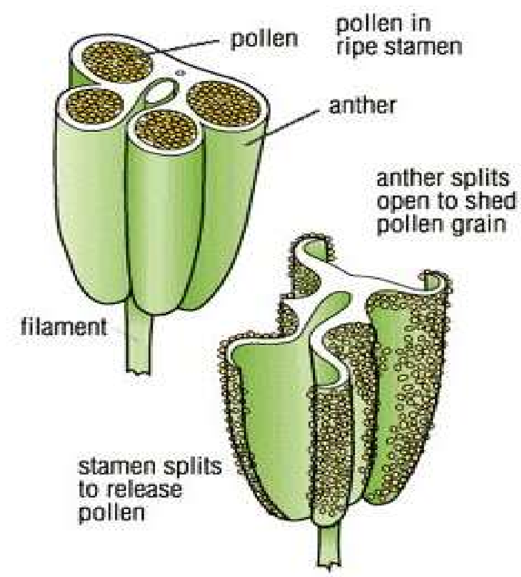


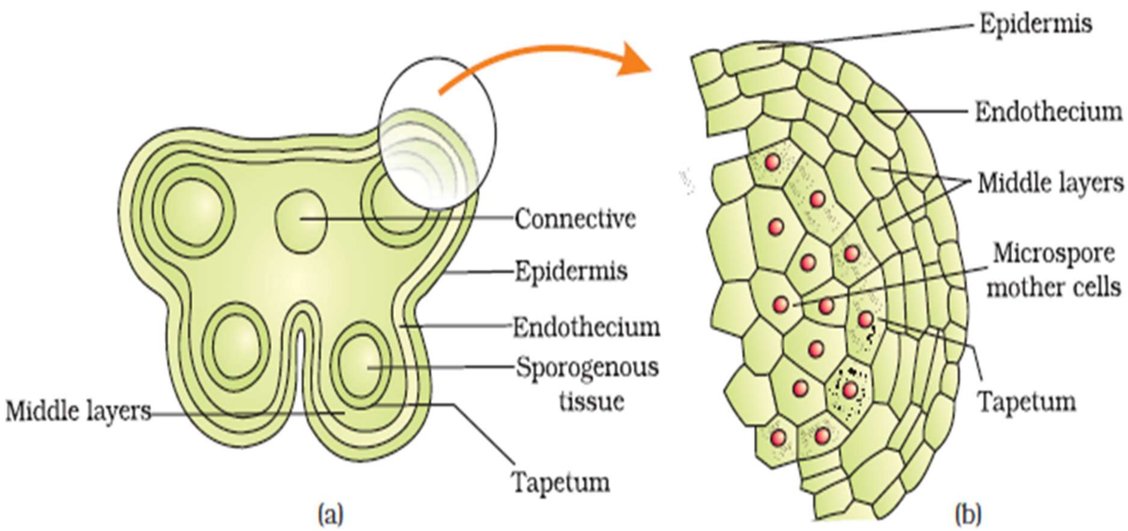
Figure 2.2 (a) A typical stamen; (b) three–dimensional cut section of an anther



Structure of microsporangium:

- A typical microsporangium is surrounded by four wall layers i.e., the **epidermis**, **endothecium**, **middle layers** and the **tapetum**.
- The outer three wall layers perform the function of protection and help in dehiscence of anther to release the pollen grains.
- Dehiscence is the spontaneous opening at maturity of a plant structure, such as a fruit, anther, or sporangium, to release its contents.
- **Tapetum** nourishes the developing microspores or pollen grains.
- Thus, tapetum is important for the nutrition and development of pollen grains, as well as a source of precursors for the pollen coat.
- The cells of tapetum are usually bigger and normally have more than one nucleus per cell.

- When the anther is young, a group of compactly arranged homogeneous cells called the **sporogenous tissue** occupies the centre of each microsporangium.



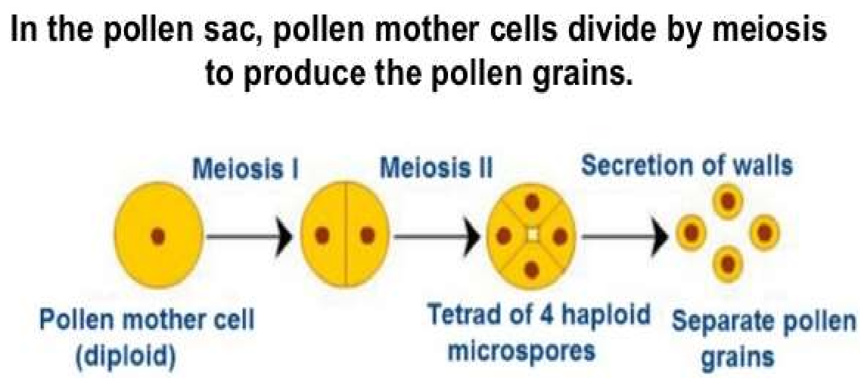
(a) T.S. of a Young Anther
(b) Enlarged view of Microsporangium showing four wall layers

- As the sporogenous cells/tissues undergo mitosis, the nuclei of tapetal cells also divide.
- Sometimes, this mitosis is not normal due to which many cells of mature tapetum become multinucleate
- Thus, *tapetal cells* are syncitium (*cells* having more than one nucleus)

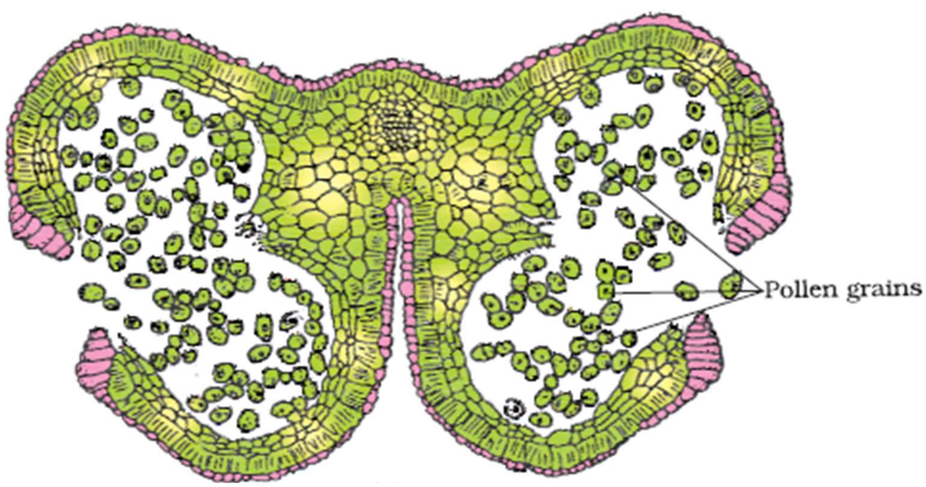
Microsporogenesis:

- Each cell of the sporogenous tissue is a potential Pollen Mother Cell (PMC) or microspore mother cell and can give rise to **microspore tetrad**.
- As the anther develops, the cells of the sporogenous tissue undergo meiotic divisions to form microspore tetrads.
- As each cell of the sporogenous tissue is capable of giving rise to a microspore tetrad, each one is a potential pollen or microspore mother cell.
- The process of formation of microspore from a pollen mother cell through the process of meiosis is called **microsporogenesis**.
- The microspores, as they are formed, are arranged in a cluster of four cells–the microspore tetrad.
- The word tetrad means" four" which states that it has four cells.
- They are formed by the meiosis in microspore mother cell.

- After meiosis 1 the number of cells is two and after the meiosis 2 the number of cells is 4.
- As the anthers mature and dehydrate, the microspores dissociate from each other and develop into pollen grains.



- Inside each microsporangium several thousands of microspores or pollen grains are formed that are released with the dehiscence of anther.



A mature dehisced anther releasing pollen grains

Male Gametophyte - Pollen grain:

- The pollen grains represent the **male gametophytes**.
- It is a haploid, uninucleate and minute, produced in large numbers by meiosis in the microspore mother cell.
- They vary in their size, shape, colour design etc., from species to species.
- Pollen grains are generally spherical measuring about 25-50 micrometers in diameter.
- It has a prominent two-layered wall called **sporodem**.

- The hard outer layer is called **exine** and is made up of **sporopollenin.**
- It is one of the most resistant organic material known.
- It can withstand high temperatures and strong acids and alkali.
- No known enzyme can degrade sporopollenin.
- Thus, pollens are well-preserved as fossils.
- Pollen grains have prominent distal apertures called **germ pores** where sporopollenin is absent.
- The inner wall of the pollen grain is called the **intine.**
- It is a thin and continuous layer made up of **cellulose** and **pectin**.
- The cytoplasm of pollen grain is surrounded by a plasma membrane.
- When the pollen grain is mature it contains two cells, the **vegetative cell** and **generative cell**.

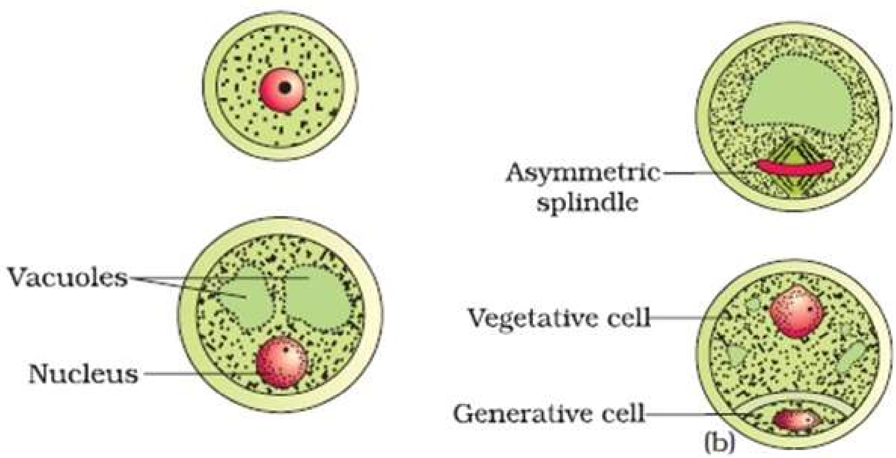
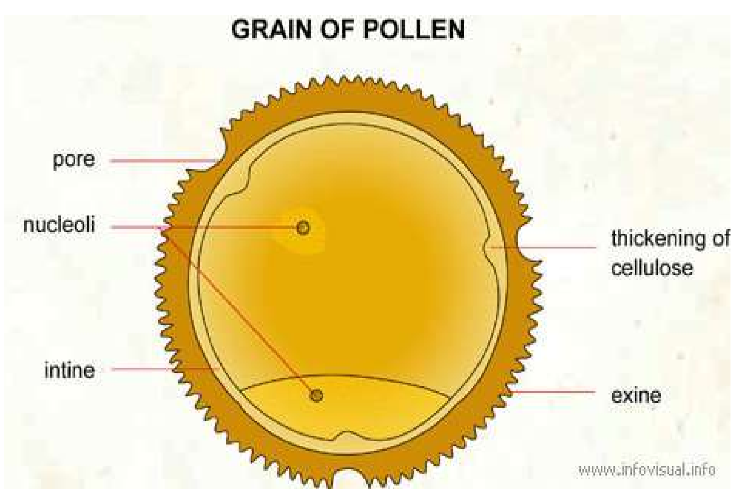


Figure 2.5 (a) Enlarged view of a pollen grain tetrad; (b) stages of a microspore maturing into a pollen grain



- The vegetative cell is bigger, has abundant reserve food material and a large irregularly shaped nucleus.
- Whereas the generative cell is small, spindle-shaped and floats in the cytoplasm of the vegetative cell.
- It has dense cytoplasm and a relatively small nucleus.
- Pollen grains are generally shed at this two-celled stage in over 60 per cent of angiosperms
- In the remaining species, the generative cell divides mitotically and gives rise to two male gametes before pollen grains are shed (3-celled stage).
- Pollen grains of many species cause severe allergies and bronchial infections in some people often leading to chronic respiratory disorders – asthma, bronchitis, etc.
- It may be mentioned that *Parthenium* or carrot grass that came into India as a contaminant with imported wheat, has become ubiquitous (wide-spread) in occurrence and causes pollen allergy.
- Pollen grains are rich in nutrients.
- It has become a fashion in recent years to use pollen tablets as food supplements.
- In western countries, a large number of pollen products in the form of tablets and syrups are available in the market and used to increase the performance of athletes and race horses.

Figure 2.6 Pollen products

- Viability of pollen depends on temperature and humidity.

- How long do you think the pollen grains retain viability?
- In some cereals such as rice and wheat, pollen grains lose viability within 30 minutes of their release, and in some members of Rosaceae, Leguminoseae and Solanaceae, they maintain viability for months.
- Once pollen grains are shed, pollen grains have to land on the stigma before they lose viability if they have to bring about fertilization.
- You may have heard of storing semen/ sperms of many animals including humans for artificial insemination.
- It is possible to store pollen grains of a large number of species for years in liquid nitrogen ($-196^{0}C$).
- Such stored pollen can be used as pollen banks, similar to seed banks, in crop breeding programmes.

Development of Female Gametophyte

- To have a clear understanding of female gametophyte development, we need to study about three important structures namely, Pistil or Gynoecium, Ovule or Megasporangium and Embryo Sac or Female Gametophyte.

Pistil or Gynoecium:

- The pistil or gynoecium represents the female reproductive part of the flower.
- It may consist of a single pistil (monocarpellary), two carpels (bicarpellary), three carpels (tricarpellary) or many pistil (multicarpellary).
- When there are more than one, the pistils may be fused together (syncarpous) as in *Papaver*, *Solanum* or may be free (apocarpous) as in *Michelia*, rose etc.

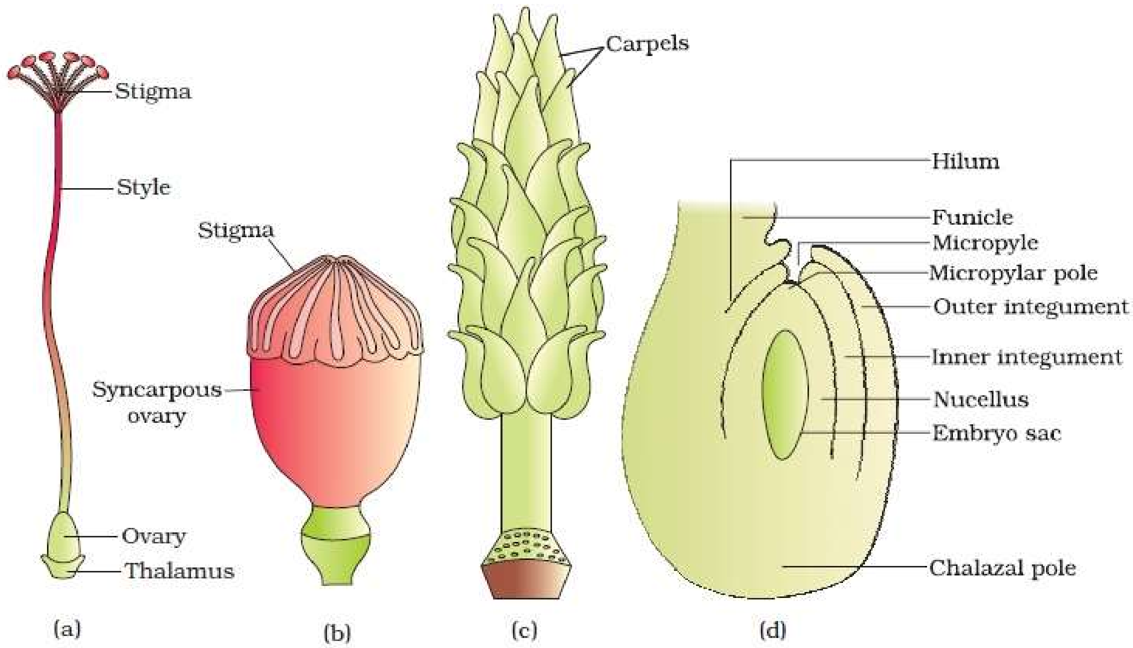
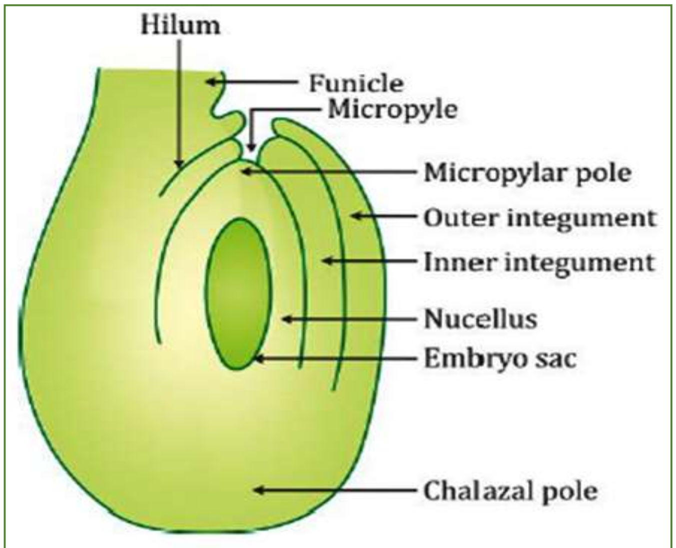


Figure 2.7 (a) A dissected flower of *Hibiscus* showing pistil (other floral parts have been removed); (b) Multicarpellary, syncarpous pistil of *Papaver*; (c) A multicarpellary, apocarpous gynoecium of *Michelia*; (d) A diagrammatic view of a typical anatropous ovule

- Each pistil has three parts, the **stigma**, **style** and **ovary**.
- The stigma serves as a landing platform for pollen grains.
- The style is the elongated slender part beneath the stigma.
- The basal bulged part of the pistil is the ovary.
- Inside the ovary is the **ovarian cavity** (**locule**) in which placenta is located.
- Megasporangia or ovules arise from placenta.
- The number of ovules in an ovary may be one (wheat, paddy, mango) to many (papaya, water melon, orchids).

Megasporangium (Ovule):

- The ovule is an integumented megasporangium within which the meiosis and megaspore formation takes place.
- It is attached to the placenta by means of a stalk called **funicle**.
- The junction between an ovule and funicle is called **hilum**, which later appears as a scar on the seed
- Each ovule has one or two protective envelopes called **integuments**, which encircle the ovule except at the tip where small opening called **micropyle** is present.

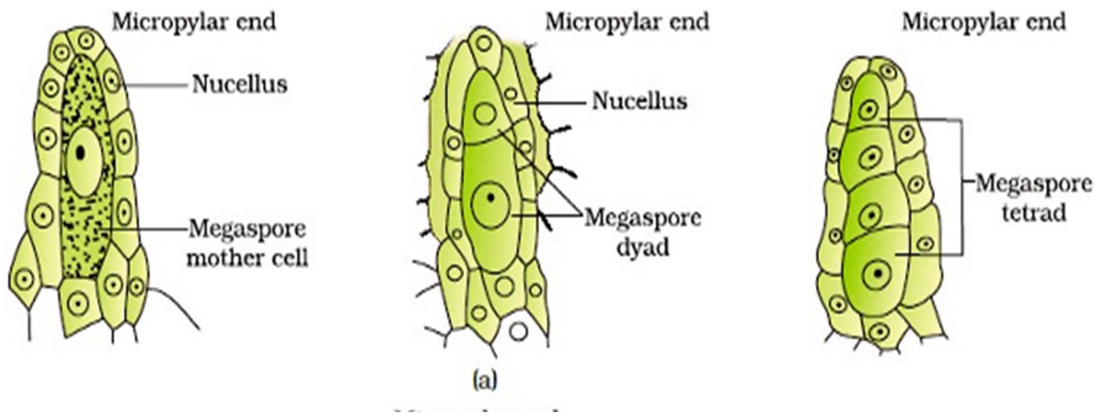


A Typical Anatropous Ovule

- The basal part of an ovule just opposite to the micropylar end is the **chalaza**.
- Enclosed within the integuments is a mass of cells called the **nucellus**.
- Cells of the nucellus have abundant reserve food materials.
- Located in the nucellus is the **embryo sac** or **female gametophyte**.
- An ovule generally has a single embryo sac formed from a megaspore.

Megasporogenesis:

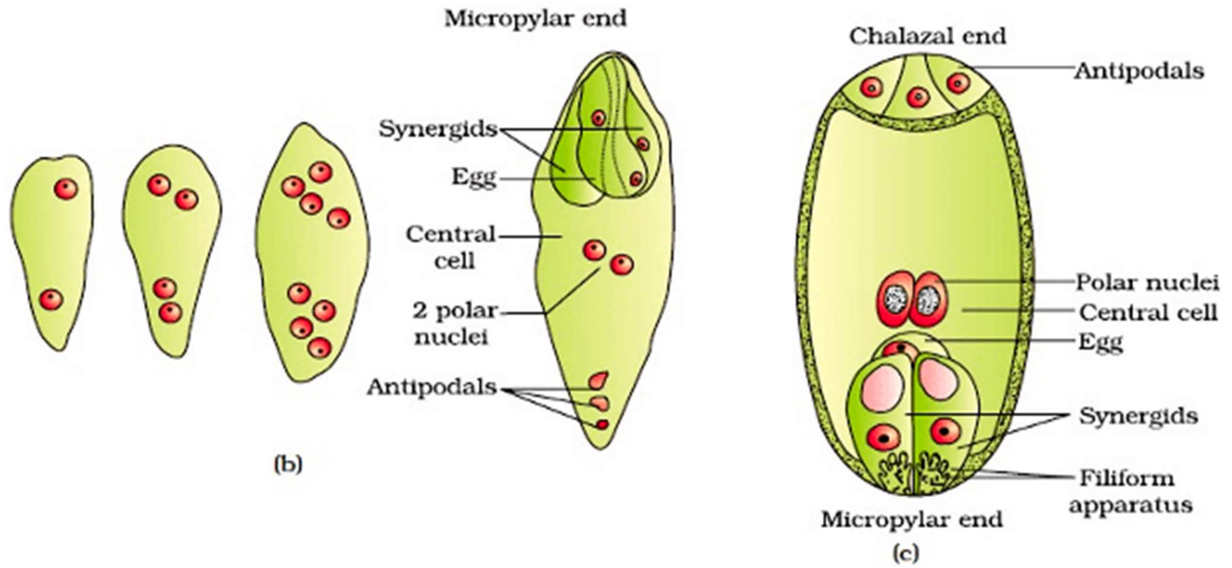
- The process of formation of megaspores from the megaspore mother cell or MMC is called **megasporogenesis**.
- It occurs inside the nucellus of developing ovule of angiosperms.
- The process begins very early when nucellus is not completely surrounded by the integuments.
- The MMC (a large cell containing dense cytoplasm and a prominent nucleus) enlarges in size and divides by meiosis.
- It first divides transversely into two cells called **megaspore dyad**.
- These two cells again divide transversely and as a result, a linear row of four haploid cells is produced which is called **megaspore tetrad**.
- Thus, megasporogenesis results in the production of four megaspores.



Megasporogenesis - Part of ovule showing a large megaspore mother cell, a dyad and a tetrad of megaspores

Female Gametophyte (Embryo Sac):

- In a majority of flowering plants, one of the megaspores is functional while the other three degenerate.
- Only the functional megaspore develops into the female gametophyte (embryo sac).
- This method of embryo sac formation from a single megaspore is termed **monosporic development**.
- What will be the ploidy of the cells of the nucellus, MMC, the functional magaspore and female gametophyte?
  - **Nucellus – Diploid (2n)**
  - **Megaspore Mother Cell (MMC) – Diploid (2n)**
  - **Functional Megaspore – Haploid (n)**
  - **Female Gametophyte – Haploid (n)**
- Following are the different stages in the development of female gametophyte.
- The nucleus of the functional megaspore divides mitotically to form two nuclei which move to the opposite poles, forming the 2-nucleate embryo sac.
- Two more sequential mitotic nuclear divisions result in the formation of the 4-nucleate and later the 8-nucleate stages of the embryo sac.
- These mitotic divisions are strictly free nuclear, that is, 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.



(b) Different stages in the development of Embryo sac
(c) Diagramatic representation of a mature embryo sac

- Observe the distribution of cells inside the embryo sac.
- Six of the eight nuclei are surrounded by cell walls and organized into cells.
- There is a characteristic distribution of the cells within the embryo sac.
- **Three cells** are grouped together **at the micropylar end** and constitute the **egg apparatus**.
- Thus, the egg apparatus consists of **two synergids** and **one egg cell**.
- The synergids have special cellular thickenings at the micropylar tip called **filiform apparatus**, which play an important role in guiding the pollen tubes into the synergid.
- **Three cells** of the **chalazal end** and are called the **antipodals**.
- The large central cell is formed by the fusion of **two polar nuclei**.
- Thus, a typical angiosperm embryo sac or female gametophyte at maturity consists of eight nuclei and seven cells.

POLLINATION

- The transfer of pollen grains from the anther of the stamen to the stigma of a carpel/pistil is termed **pollination.**
- Flowering plants have evolved an amazing array of adaptations to achieve pollination.
- They make use of external agents to achieve pollination.

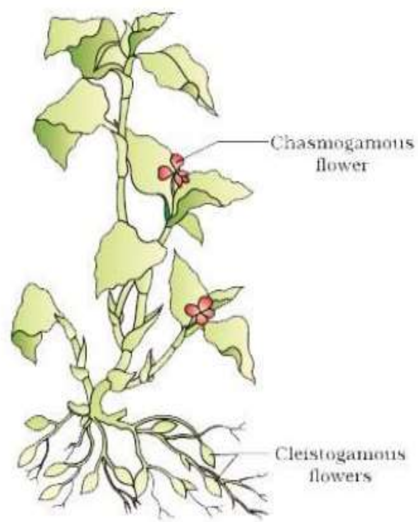
- Pollination can basically be divided into two types:
  - **Self pollination** and
  - **Cross pollination.**
- The transfer of pollen from the anther to the stigma of the same flower or another flower on the same plant is called self-pollination.
- The transfer of pollen from the anther of a flower on one plant to the stigma of a flower on another plant is called cross pollination.
- Self pollination can be further be divided into two types:
  - **Autogamy** and
  - **Geitonogamy.**
- Cross pollination is also known as **Xenogamy.**
- Thus, depending upon the source of pollen grains, pollination is of three types:
  - **Autogamay,**
  - **Geitonogamy** and
  - **Xenogamy**.

(i) Autogamy:

- It is a type of self pollination in which pollen grains from the anthers of a flower are transferred to the stigma of the same flower.
- E.g., wheat, rice, pea etc.
- In a normal flower which opens and exposes the anthers and the stigma, complete autogamy is rather rare.
- Autogamy in such flowers requires synchrony in pollen release and stigma receptivity and also, the anthers and the stigma should lie close to each other so that self-pollination can occur.
- Some plants such as *Viola* (common pansy), *Oxalis*, *Commelina*, peanut (*Arachis hypogaea*) etc., produce two types of flowers – **chasmogamous flowers** which are similar to flowers of other species with exposed anthers and stigma, and **cleistogamous flowers** which do not open at all.
- In such flowers, the anthers and stigma lie close to each other.

- When anthers dehisce in the flower buds, pollen grains come in contact with the stigma to effect pollination.
- Thus, cleistogamous flowers are invariably autogamous as there is no chance of cross-pollen landing on the stigma.
- Cleistogamous flowers produce assured seed-set even in the absence of pollinators.

- **chasmogamous flowers and Cleistogamous flowers :**

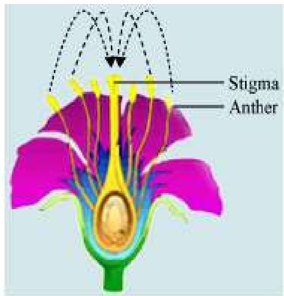
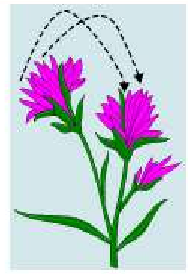


- Do you think that cleistogamy is advantageous or disadvantageous to the plant?
- Why?
- It is advantageous because this type self-pollination does not require external agent.
- It preserves useful characters of the parent individual.
- The *plant* can propagate itself under unfavourable conditions.
- It helps in producing pure lines.
- The *disadvantage* is that there is self pollination due to which the chances of variation and evolution of genetically superior *plants* is reduced.

(ii) Geitonogamy:

- It is a kind of self pollination where the pollen grains from the anther of a flower are transferred to the stigma of another flower of the same plant.
- It usually occurs in plants which show monoecious condition, e.g., *Cucurbita*

- Although geitonogamy is functionally cross-pollination involving a pollinating agent, genetically it is similar to autogamy since the pollen grains come from the same plant.

(a) Type I	(b) Type II
	
It occurs within the same flower. Pollen from the anther is transferred to stigma of the same flower.	It occurs between two flowers of the same plant. Pollen from the anther of one flower is transferred to stigma of another flower in the same plant.

(iii) Xenogamy (Cross-pollination):

- It involves the transfer of pollen grains from anther of one plant to the stigma of a different plant.
- This is the only type of pollination which brings genetically different types of pollen grains to the stigma during pollination. E.g., papaya, maize etc.

Out-breeding Devices:

- Majority of flowering plants produce hermaphrodite flowers and pollen grains are likely to come in contact with the stigma of the same flower.
- Continued self-pollination result in **inbreeding depression**.
- **Inbreeding** is the production of offspring from the mating or breeding of individuals or organisms that are closely related genetically.
- **Inbreeding depression** is the reduced biological fitness in a given population as a result of inbreeding, or breeding of related individuals.
- Flowering plants have developed many devices to discourage self-pollination and to encourage cross-pollination.
- In some species, **pollen release and stigma receptivity are not synchronized.**
- Either the pollen is released before the stigma becomes receptive or stigma becomes receptive much before the release of pollen.

- In some other species, **the anther and stigma are placed at different positions** so that the pollen cannot come in contact with the stigma of the same flower.
- Both these devices prevent autogamy.
- The third device to prevent inbreeding is **self-incompatibility**.
- This is a genetic mechanism and prevents self-pollen (from the same flower or other flowers of the same plant) from fertilizing the ovules by inhibiting pollen germination or pollen tube growth in the pistil.
- Another device to prevent self-pollination is the **production of unisexual flowers.**
- If both male and female flowers are present on the same plant such as castor and maize **(monoecious**), it prevents autogamy but not geitonogamy.
- In several species such as papaya, male and female flowers are present on different plants, that is each plant is either male or female **(dioecious**).
- This condition prevents both autogamy and geitonogamy.

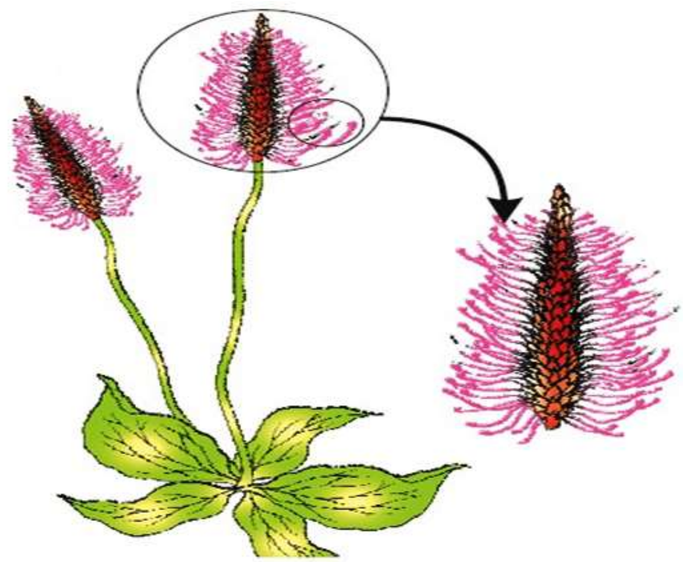
Agents of Pollination:

- The agents responsible for pollination in angiosperms has been grouped into two main categories; **abiotic agents** (winds and water) and **biotic agents** (animals).
- Majority of plants use biotic agents for pollination.
- Only a small proportion of plants use abiotic agents.
- Pollen grains coming in contact with the stigma is a chance factor in both wind and water pollination.
- To compensate for this uncertainties and associated loss of pollen grains, the flowers produce enormous amount of pollen when compared to the number of ovules available for pollination.

Adaptation for Wind Pollination:

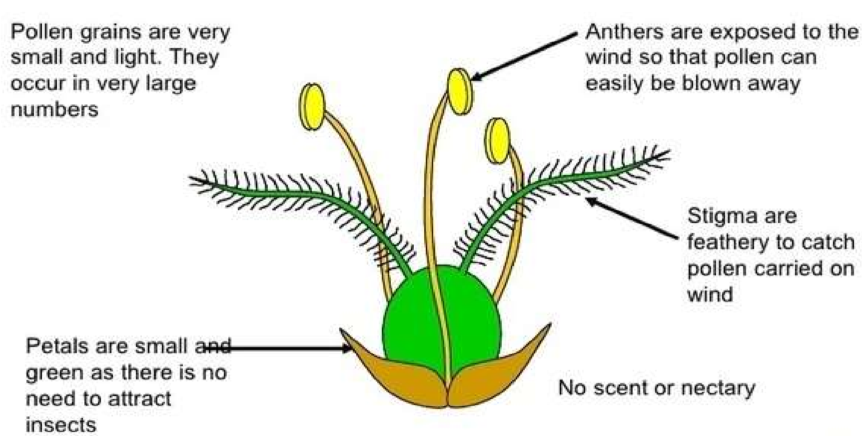
- Wind pollination is also termed as **anemophily** and is the most common amongst abiotic pollinations.
- The adaptations of wind pollinated flowers are as follows:
- Flowers are small, colourless, inconspicuous and nectarless.
- The anthers are well exposed for the easy dispersal of pollen grains.

- Pollen grains are small, light and non-sticky so that they can be transported in wind currents.
- The stigmas are large, hairy and feathery or branched to catch the air-borne pollen grains.
- Wind pollinated flowers often have a single ovule in each ovary and numerous flowers packed into an inflorescence; a familiar example is the corn cob – the tassels you see are nothing but the stigma and style which wave in the wind to trap pollen grains.
- Common examples of wind pollinated flowers are grasses, sugarcane, bamboo, coconut etc.



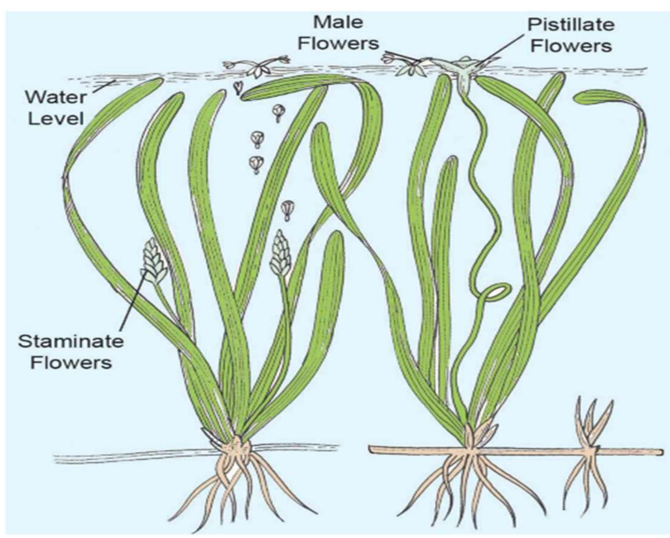
A wind-pollinated plant showing compact inflorecence and well-exposed stamens

Wind-pollinated flowers are different in structure because they do not have to attract insects to them but do need to be exposed to the wind.



Adaptations for Water Pollination:

- Pollination by water is also termed as **hydrophily**.
- Pollination by water is quite rare in flowering plants and is limited to about 30 genera, mostly monocotyledons.
- It is very common in lower plant groups such as algae, bryophytes and pteridopytes.
- Some examples of water pollinated plants are *Vallisneria* and *Hydrilla* which grow in fresh water and several marine sea-grasses such as *Zostera*.
- 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 passively by water currents; some of them eventually reach the female flowers and the stigma.
- In plants such as sea grasses, female flowers remain submerged in water and the pollen grains are released inside the water.
- In such species, pollen grains are long, ribbon like and are carried passively inside the water to reach the stigma and achieve pollination.



Vallisneria

- The other adaptations found in water pollinated flowers are as follows:
- Flowers are small, colourless, inconspicuous, odourless and nectarless.
- The stigmas are long and sticky.
- Pollen grains are protected from getting wet by mucilaginous covering.
- Not all aquatic plants use water for pollination.

- In a majority of aquatic plants such as water hyacinth and water lily, the flowers emerge above the level of water and are pollinated by insects or wind as in most of the land plants.
- Both wind and water pollinated flowers are not very colourful and do not produce nectar.
- *What would be the reason for this?*

Pollination by Animals:

- Pollination by animals is termed as **Zoophily**.
- Majority of flowering plants use a range of animals as pollinating agents.
- Bees, butterflies, flies, beetles, wasps, ants, moths, birds (sunbirds and humming birds) and bats are the common pollinating agents.
- Among the animals, insects, particularly bees are the dominant biotic pollinating agents.
- Even larger animals such as some primates (lemurs), arboreal (tree-dwelling) rodents (mice, rats and squirrels), or even reptiles (gecko lizard and garden lizard) have also been reported as pollinators in some species.
- Often flowers of animal pollinated plants are specifically adapted for a particular species of animal.

Adaptations for Insect Pollination:

- Insect pollination is also returned as **entomophily**.
- The adaptations of insect pollinated flowers are as follows.
- Majority of insect-pollinated flowers are large, colourful, fragrant and rich in nectar.
- When the flowers are small, a number of flowers are clustered into an inflorescence to make them conspicuous.
- Animals are attracted to flowers by colour and/or fragrance.
- The flowers pollinated by flies and beetles secrete foul odours to attract these animals.
- To sustain animal visits, the flowers have to provide rewards to the animals.
- **Nectar** and **pollen grains** are the usual floral rewards for the insect pollinators.

- For harvesting the reward(s) from the flower the animal visitor comes in contact with the anthers and the stigma.
- The body of the animal gets a coating of pollen grains, which are generally sticky in animal pollinated flowers.
- When the animal carrying pollen on its body comes in contact with the stigma, it brings about pollination.
- In some species floral rewards are in providing safe places to lay eggs; an example is that of the tallest flower of *Amorphophallus* (the flower itself is about 6 feet in height).
- In plant *Yucca,* moth and the plant cannot complete their life cycles without each other.
- The moth deposits its eggs in the locule of the ovary and the flower, in turn, gets pollinated by the moth.
- The larvae of the moth come out of the eggs as the seeds start developing.
- Many insects may consume pollen or the nectar without bringing about pollination.
- Such floral visitors are referred to as **pollen/nectar robbers**.

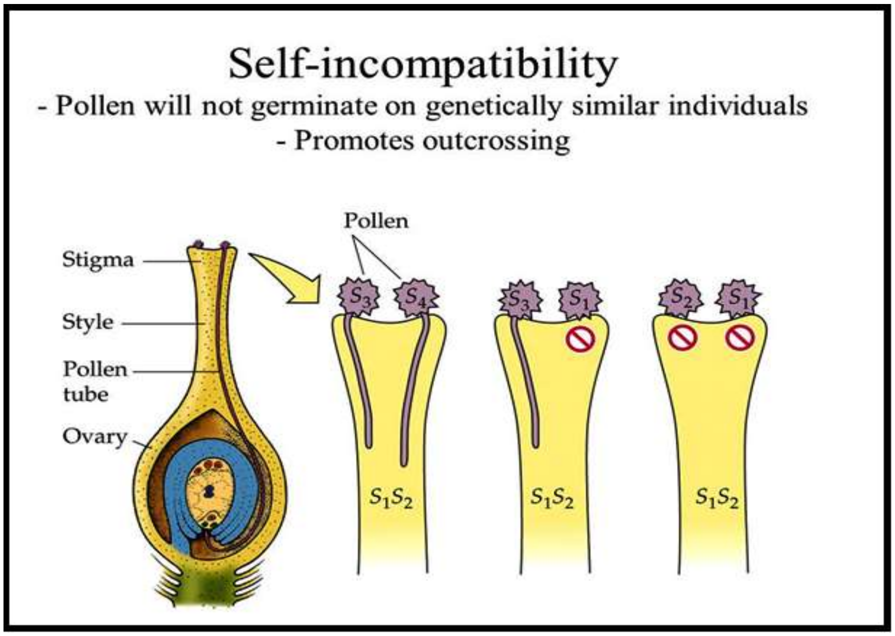
Yucca Moth

POLLEN-PISTIL INTERACTION:

- The events from the deposition of pollen on the stigma till the entry of pollen tube into the ovule are collectively called **pollen-pistil interaction**.
- It is an essential step in fertilization of angiosperms and depends on compatibility and incompatibility of pollen and pistil.
- It is a dynamic process involving pollen recognition followed by inhibition or promotion of pollen.
- It includes the following steps.

Recognition of Compatible Pollen:

- Pollination does not guarantee the transfer of the right type of pollen.
- Often, pollen of the wrong type, either from other species or from the same plant (if it is self-incompatible), also land on the stigma.
- The pistil has the ability to recognize, whether the pollen is of the right type (compatible) or of the wrong type (incompatible).
- If it is of the right type, the pistil accepts the pollen and promotes post-pollination events that lead to fertilization.
- If the pollen is of the wrong type, the pistil rejects the pollen by preventing pollen germination on the stigma or the pollen tube growth in the style.
- It is the result of continuous dialogue mediated by chemical components of the pollen interacting with those of the pistil.
- After recognizing the correct pollen, pistil promotes post-fertilization events that lead to fertilization.
- It is only in recent years that botanists have been able to identify some of the pollen and pistil components and the interactions leading to the recognition, followed by acceptance or rejection.



Growth of a Pollen Tube:

- After compatible pollination, the pollen grain germinates on the stigma to produce a pollen tube through one of the germ pores.
- The contents of the pollen grain move into the pollen tube.
- Pollen tube grows through the tissues of the stigma and style by secreting the enzymes that digest them.

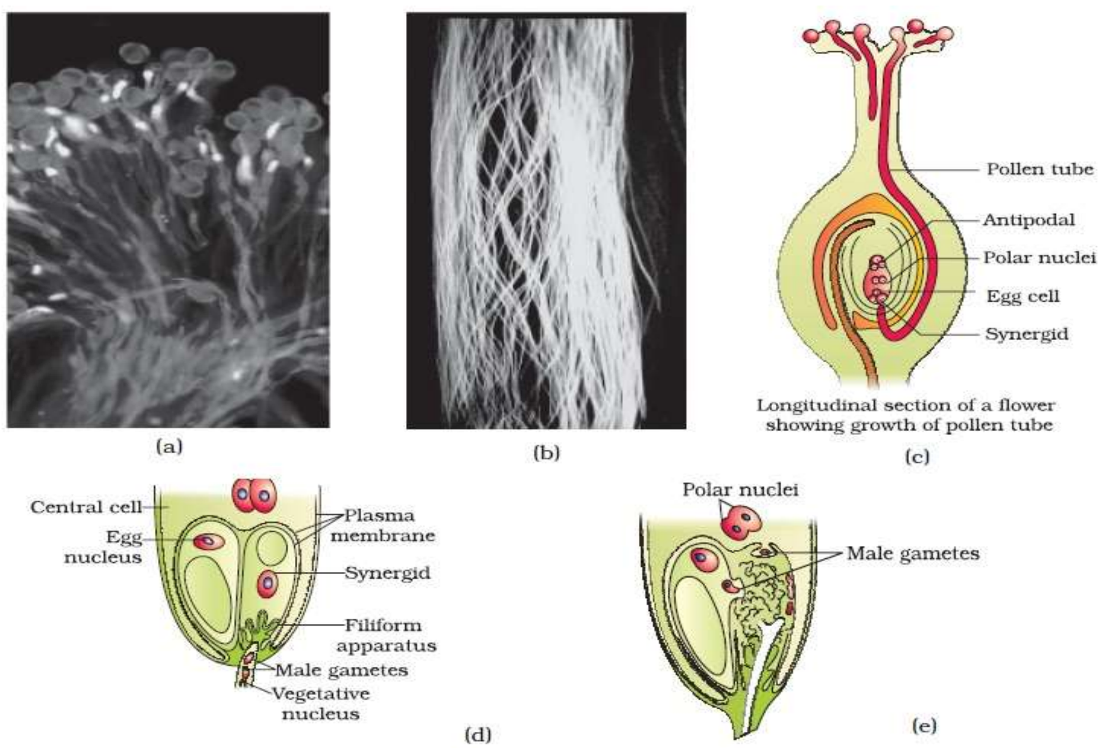


Figure 2.12 (a) Pollen grains germinating on the stigma; (b) Pollen tubes growing through the style; (c) L.S. of pistil showing path of pollen tube growth; (d) enlarged view of an egg apparatus showing entry of pollen tube into a synergid; (e) Discharge of male gametes into a synergid and the movements of the sperms, one into the egg and the other into the central cell

- We have learnt earlier that in some plants, pollen grains are shed at two-celled condition (a vegetative cell and 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 three-celled condition, pollen tubes carry the two male gametes from the beginning.

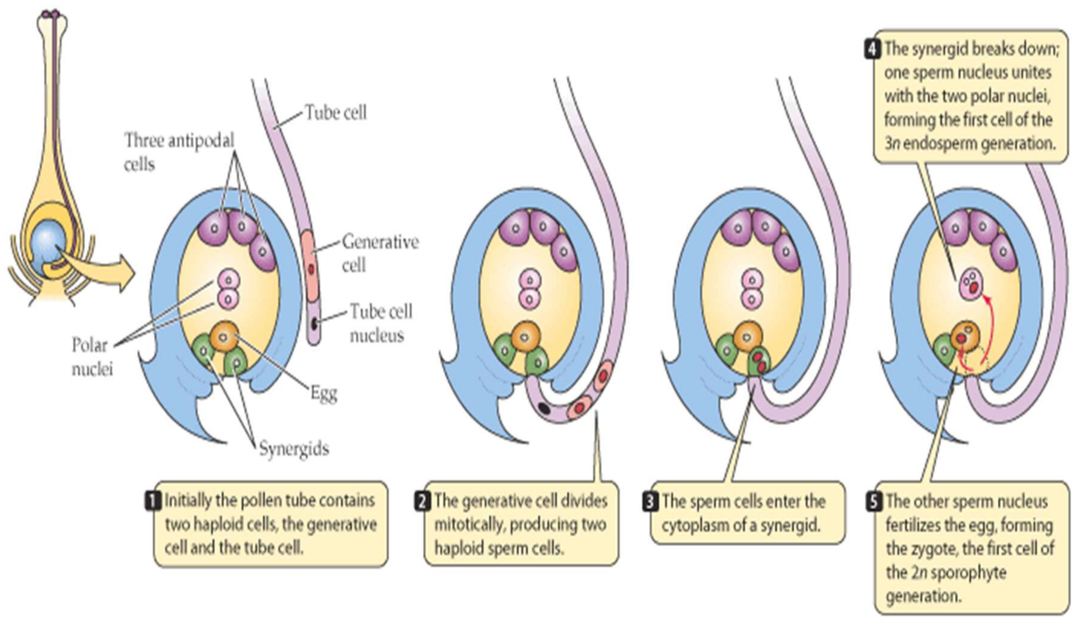
Entry of Pollen Tube into the Ovule:

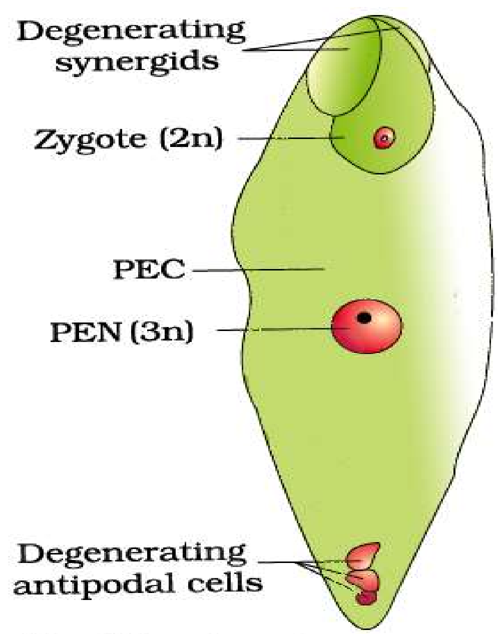
- After reaching the ovary, the pollen tube enters the ovule through the micropyle and then enters one of the synergids through the filiform apparatus.
- The filiform apparatus present at the micropylar part directs the growth of pollen tube by secreting some chemical substances.
- All these events–from pollen deposition on the stigma until pollen tubes enter the ovule–are together referred to as **pollen-pistil interaction**.
- You can easily study pollen germination by dusting some pollen from flowers such as pea, chickpea, balsam and *Vinca* on a glass slide containing a drop of sugar solution (about 10 per cent).
- After about 15–30 minutes, observe the slide under the low power lens of the microscope.
- You are likely to see pollen tubes coming out of the pollen grains.

DOUBLE FERTILISATION:

- After entering one of the synergids, the pollen tube releases the two male gametes into the cytoplasm of the synergid.
- One of the male gametes moves towards the egg cell and fuses with its nucleus thus completing the **syngamy**.
- This results in the formation of a diploid cell, the zygote.
- 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 this involves the fusion of three haploid nuclei it is termed **triple fusion.**
- Since two types of fusions, syngamy and triple fusion take place in an embryo sac the phenomenon is termed **double fertilization**, 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

- As pointed out earlier, pollen-pistil interaction is a dynamic process involving pollen recognition followed by promotion or inhibition of the pollen.
- The knowledge gained in this area would help the plant breeder in manipulating pollen-pistil interaction to get desired hybrids.
- A plant breeder is interested in crossing different species and often genera to combine desirable characters to produce commercially 'superior' varieties.
- **Artificial hybridization** is one of the major approaches of crop improvement programme.

Artificial Hybridization:

- It is the corssing of different species and often genera to combine desirable characters to produce commercially superior varieties.
- It has been used by the plant breeders for crop improvement programme.
- In such crossing experiments it is important to make sure that only the desired pollen grains are used for pollination and the stigma is protected from contamination (from unwanted pollen).
- This is achieved by **emasculation** and **bagging** techniques.

(i) Emasculation

- In this method, the anther is removed from the bud before it dehisces using a pair of forceps.
- It is mainly done when the female parent bears bisexual flowers.

(ii) Bagging

- Emasculated flowers have to be covered with a bag of suitable size, generally made up of butter paper, to prevent contamination of its stigma with unwanted pollen.
- This process is called **bagging**.
- When the stigma of bagged flower attains receptivity, mature pollen grains collected from anthers of the male parent are dusted on the stigma, and the flowers are rebagged, and the fruits allowed to develop.
- If the female parent produces unisexual flowers, there is no need for emasculation.
- The 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.

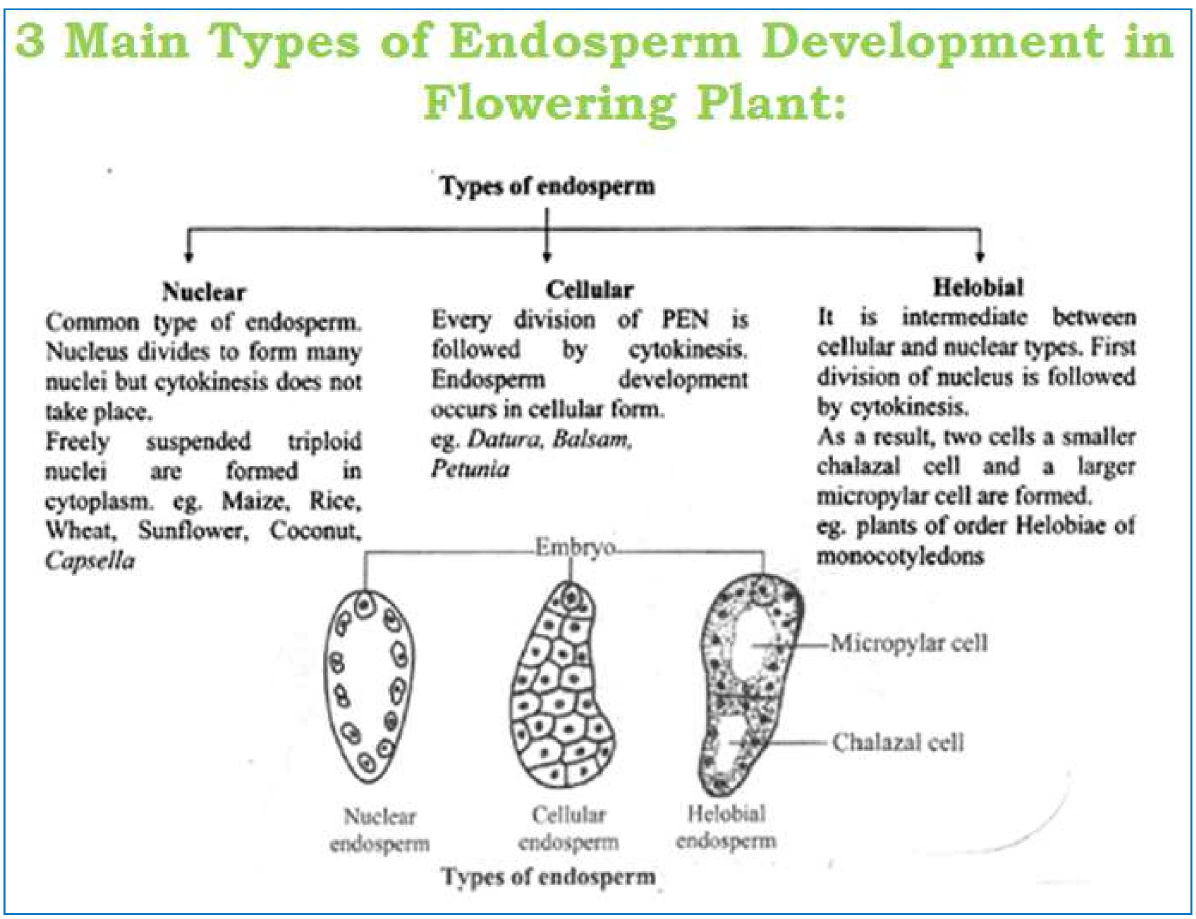
POST FERTILISATION: STRUCTURES AND EVENTS:

- The major post-fertilization events include development of endosperm and embryo, maturation of ovules into seeds and ovary into fruit.
- These events take place soon after the double fertilization.

Development of Endosperm:

- Endosperm development precedes embryo development.

- The process takes place in the following steps.
- **(i)** The primary endosperm cell divides repeatedly and forms a triploid endosperm tissue.
- The cells of this tissue are filled with reserve food materials and are used for the nutrition of the developing embryo.
- **(ii)** The PEN undergoes successive free nuclear divisions to give rise to free nuclei.
- At this stage, it is called **free-nuclear endosperm.**
- **(iii)** After this cell wall formation occurs from the periphery and proceeds towards the centre and the endosperm becomes cellular.
- The coconut water from tender coconut that you are familiar with, is nothing but free-nuclear endosperm (made up of thousands of nuclei) and the surrounding white kernel is the cellular endosperm.
- Endosperm may either be completely consumed by the developing embryo (e.g., pea, groundnut, beans) before seed maturation or it may persist in the mature seed (e.g. castor and coconut) and be used up during seed germination.



Development of Embryo:

- Embryo develops at the micropylar end of the embryo sac where the zygote is situated.
- Most zygotes divide only after certain amount of endosperm is formed.
- This is an adaptation to provide assured nutrition to the developing embryo.
- In majority of angiosperms, the zygote divides by an asymmetric mitotic division and generated two cells with two different fates.
- (i) A smaller daughter cell with dense cytoplasm is situated towards the chalazal pole.
- It is called the **terminal cell** or **apical cell**.
- Another comparatively larger daughter cell situated towards the micropylar end is called **basal cell**.
- This cell divides transversely and gives rise to **suspensor cells**.
- The zygote gives rise to the **pro-embryo** and subsequently to the **globular**, **heart-shaped** and **mature embryo**.
- Though the seeds differ greatly, the early stages of embryo development (**embryogeny**) are similar in both monocotyledons and dicotyledons.
- Figure 2.13 depicts the stages of embryogeny in a dicotyledonous embryo.

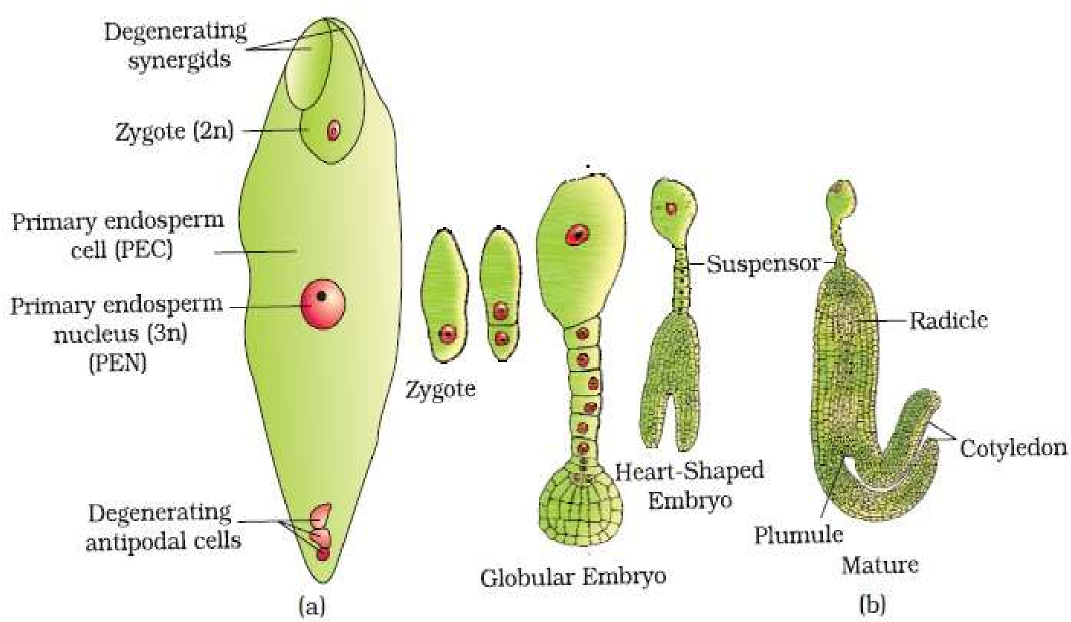


Figure 2.13 (a) Fertilised embryo sac showing zygote and Primary Endosperm Nucleus (PEN); (b) Stages in embryo development in a dicot [shown in reduced size as compared to (a)]

Structure of Dicot Embryo:

- A typical dicotyledonous embryo consists of an **embryonal axis** and two **cotyledons**.
- The portion of embryonal axis above the level of cotyledons is the **epicotyl**, which terminates with the **plumule** or stem tip.
- The cylindrical portion below the level of cotyledons is **hypocotyl** that terminates at its lower end in the **radicle** or root tip.
- The root tip is covered with a root cap.
- E.g., mango, apple, radish, rose etc.

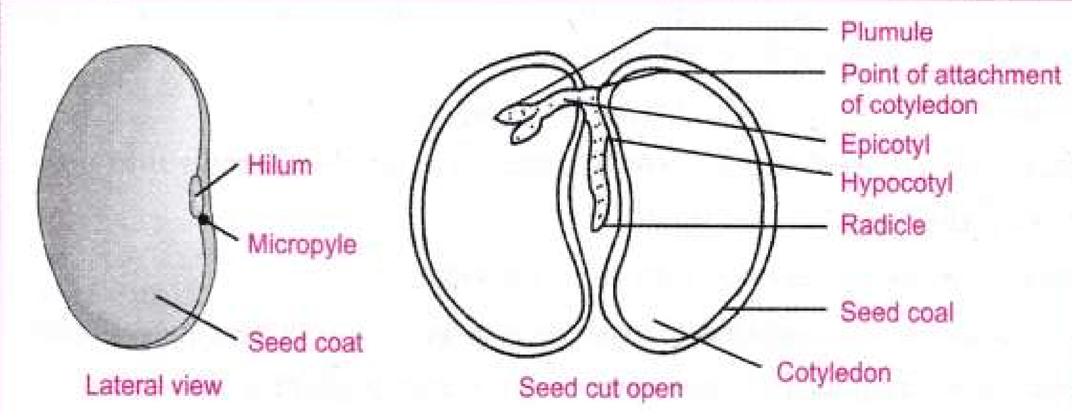
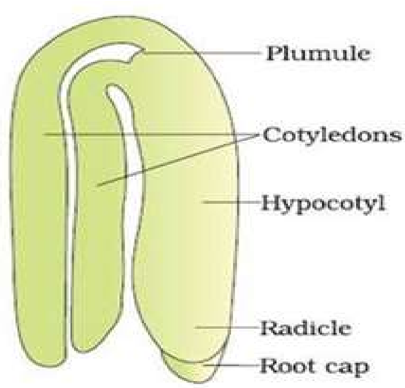


Fig. Red kidney bean seed



A Typical Dicot Embryo

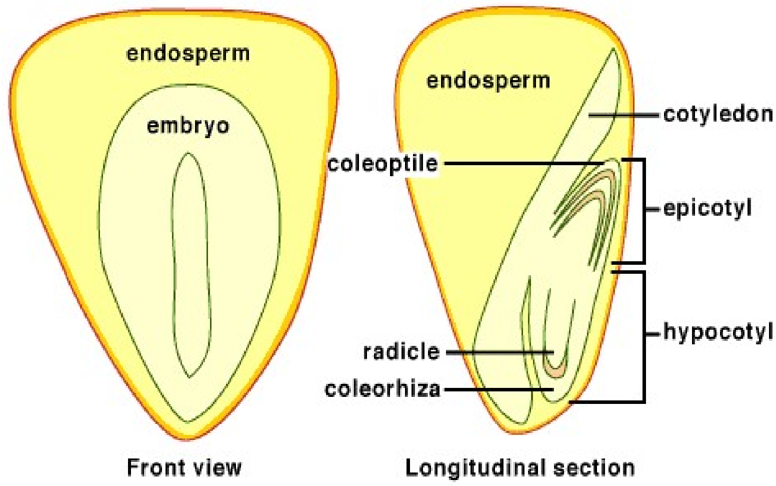
Structure of Monocot Embryo of Grass:

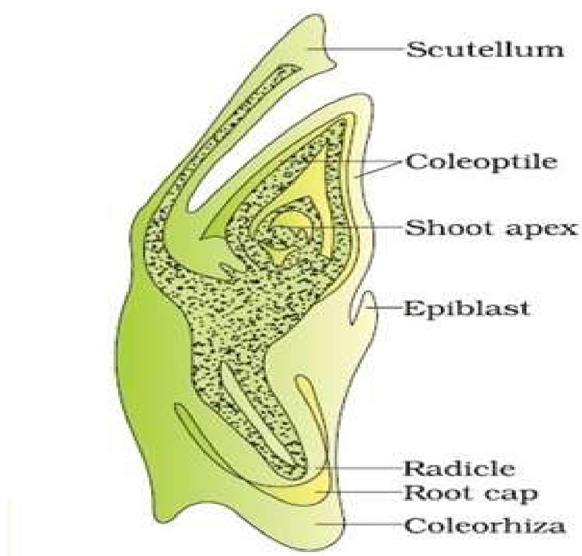
- Embryos of monocotyledons possess only one cotyledon at one end of the embryonal axis and this cotyledon is called **scutellum.**
- At the lower end, the embryonal axis has the radicle and root cap enclosed in an undifferentiated sheath called **coleorrhiza**.

➢ The portion of the embryonal axis above the level of attachment of scutellum is the **epicotyl**.

➢ Epicotyl has a shoot apex and a few leaf primordia enclosed in a hollow foliar structure, the **coleoptile**.

➢ E.g., Grass, bamboo, palm, banana etc.





Monocot Embryo of Grass

Development of Seed from Ovule:

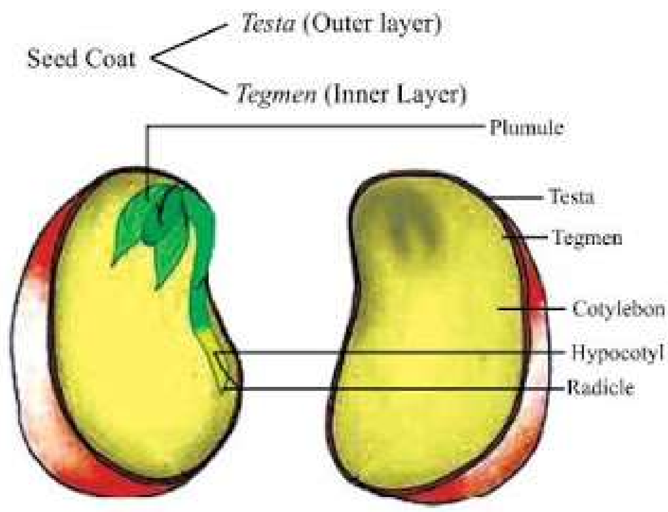
➢ In angiosperms, the seed is the final product of sexual reproduction.

➢ It is often described as a **fertilized ovule**.

➢ Seeds are formed inside fruits.

Structure of a Seed:

- A typical seed consists of seed coat, cotyledon and an embryonal axis.
- The seed coat is often double layered, formed by integuments.
- The outer integument forms the outer hard seed coat called **testa** and inner integument forms the inner seed coat called **tegmen**.
- The **cotyledons** (embryonic leaves or seed leaves) are generally thick and swollen with food materials.
- These are one or two in number and rich in reserve food material.
- **Micropyle** remains as a small opening found on the seed coat which facilitates the entry of water and oxygen into the seed.



- As the seed matures, its water content is reduced and seed become relatively dry (10-15% moisture by mass).
- The **hilum** marks the point of attachment to the stalk or funicle.
- Sometimes, the general metabolic activity of the embryo slows down and it may enter into a state of inactivity called **dormancy**.
- When favourable conditions are available, the seed germinates into plants.

Types of Seeds:

- Depending upon the presence or absence of endosperm seeds may be **non-albuminous** or **albuminous**.
- Non-albuminous seeds have no residual endosperm as it is completely consumed during embryo development.
- E.g., beans, pea, groundnut.

- Albuminous seeds retain a part of endosperm as it is not completely used up during embryo development.
- E.g., wheat, maize, barley, coconut, castor.
- In some seeds such as black pepper and beet, remains of nucellus called **perisperm** is also persistent.
- The major differences between monocot and dicot seeds are:

Advantages of Seeds:

- The following are the advantages of seeds.
- They are the basis of our agriculture.
- Can you imagine agriculture in the absence of seeds, or in the presence of seeds which germinate straight away soon after formation and cannot be stored?
- Dehydration and dormancy of mature seeds are crucial for storage of seeds which can be used as food throughout the year and also to raise crop in the next season.
- The stored food in seeds supports the growth of seedlings till they become nutritionally independent.
- The hard seed coat provides protection to the young embryo.
- Being products of sexual reproduction, they generate new genetic combinations leading to variations.
- Seeds are adapted for dispersal to form new plant colonies.
- How long do the seeds remain alive after they are dispersed?
- This period again varies greatly.
- In a few species the seeds lose viability within a few months.
- Seeds of a large number of species live for several years.
- Some seeds can remain alive for hundreds of years.
- There are several records of very old yet viable seeds.
- The oldest is that of a lupine (a genus of flowering plants in the legume family, Fabaceae) *Lupinus arcticus* excavated from Arctic Tundra.
- The seed germinated and flowered after an estimated record of 10,000 years of dormancy.

- A recent record of 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.

Seed Dispersal:

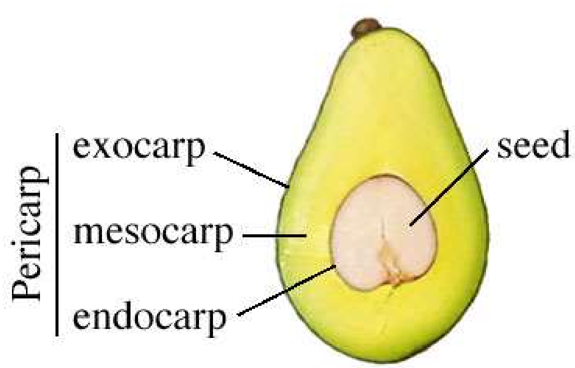
- It is the movement or transport of seeds away from the parent plant.
- This allows seeds to spread in a large geographical area.

Significance of Seed Dispersal:

- Seed dispersal is important because if the seeds are not dispersed, many germinating seedlings will grow very close to the parednt plant.
- This results in competition between every one of the seedlings as well as with parent plant.
- The competition is for light, water and nutrients.
- Since, all of these are important for plants to grow, the growth of plant is affected.

Formation of Fruit from Ovary:

- A fruit is formed after fertilization as a result of cell division and differentiation in the ovary, i.e., a ripened ovary forms a fruit.
- The wall of the ovary develops into the fruit wall called **pericarp**.
- Pericarp is having three layers, namely epicarp, mesocarp and endocarp.
- Pericarp protects the seeds and helps in their dispersal.



- The fruits may be fleshy as in guava, orange, mango, etc., or may be dry, as in groundnut, and mustard.
- *Is there any relationship between number of ovules in an ovary and the number of seeds present in a fruit?*

- Yes, *there* is a *relationship between* the *number* of *ovules* in an *ovary* and the *number* of *seed present* in a *fruit*.
- If there is one ovule, there will be one seed.
- If there is more than one ovule, there will be more than one seed in the fruit.
- Ovules in the ovary become seeds when the ovary is developing into a fruit.
- So, since some plants like mango are uni-ovulate (have one ovule), have one seed.
- Some fruits like papaya, watermelon have many ovules and hence after the ovary mature into a fruit, the ovules will turn into seeds and hence the fruits will have many seeds.
- It all depends on the number of ovules in the ovary.
- Normally one egg is present in a normal angiospermic embryo sac, and one embryo sac in each ovule; ovule number vary according to the plant; ovary number and flower number also vary accordingly.
- Can you think of some plants in which fruits contain very large number of seeds.
- Some *fruits* that have *multiple seeds* are Strawberry, Jack *fruit*, Water melon, Musk melon, Orange, Grape, Pineapple, Pomegranate, Custard Apple, Passion *fruit*, Sweet Lime etc.
- Orchid fruits are one such category and each fruit contain thousands of tiny seeds.
- Similar is the case in fruits of some parasitic species such as *Orobanche* and *Striga***.**
- *Orobanche or* Broomrapes are aggressive root parasitic weeds, which attack strategic food crops, such as legumes and vegetables,
- *Striga* is a parasitic weed of cereal crops.
- Have you seen a tiny seed of Ficus?
- How large is the tree of Ficus developed from that tiny seed.
- How many billions of seeds does each Ficus tree produce?
- Can you imagine any other example in which such a tiny structure can produce such a large biomass over the years?
- Pine trees and maples produce small seeds that can be carried on the wind, yet these small seeds grow into large trees.

Types of Fruits:

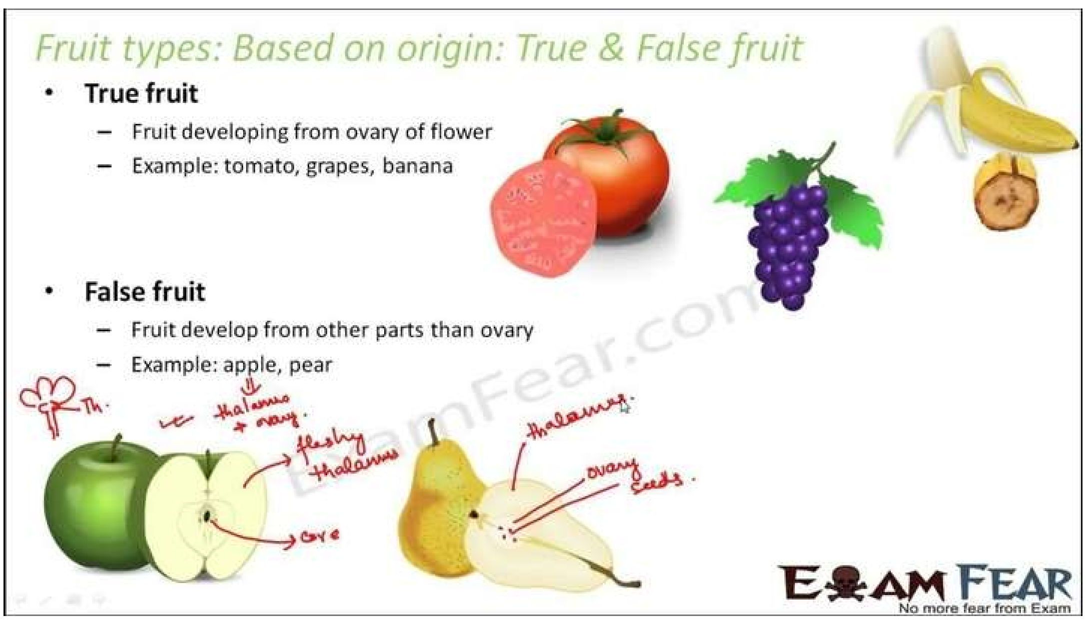
- On the basis of formation of fruits, they are of two types – **true fruits** and **false fruits.**

True fruits:

- In most plants, the fruits develop only from the ovary and by the time the other floral parts degenerate and fall off.
- The fruits developed from ovary of a flower and not associated with any non-carpellary part are called true fruits.
- E.g., mango, grape, tomato etc.

False Fruits:

- On the other hand, in a few species such as apple, strawberry, cashew, etc., the thalamus also contributes to fruit formation.
- Thus, the fruits developed from ovary along with other accessory floral parts like thalamus are called false fruits.
- Examples of false fruits are apple, pear, cashew, strawberry etc.



Parthenocarpic Fruits:

- In some species of plants fruits develop without fertilization.
- Such fruits are called parthenocarpic fruits.
- Examples are banana, grape, orange etc.
- This type of formation of fruits without fertilization is called **parthenocarpy**.

- Parthenocarpy can be induced through the application of growth hormones and such fruits are seedless.
- Although in most of the species, fruits are the results of fertilisation, there are a few species in which fruits develop without fertilisation.
- Such fruits are called **parthenocarpic fruits**.
- Banana is one such example.
- Parthenocarpy can be induced through the application of growth hormones and such fruits are seedless.

Some Special Mechanisms of Reproduction:

- Although seeds, in general are the products of fertilization, a few flowering plants such as some species of *Asteraceae* and grasses, have evolved a special mechanism, to produce seeds or even embryos without fertilization (or from unfertilized egg).
- Three such mechanisms include:
  - **(i) Apomixis**
  - **(ii) Polyembryony** and
  - **(iii) Parthenocarpy**

1. Apomixis:

- Apomixis is a form of asexual reproduction that mimics sexual reproduction and produces seeds without fertilization.
- It does not involve formation of zygote through the gametic fusion.
- It occurs in some species of Asteraceae and grasses.
- There are several ways of development of apomictic seeds.
- In some species, the diploid egg cell is formed without reduction division and develops into the embryo without fertilization.
- More often, as in many *Citrus* and *Mango* varieties some of the nucellar cells surrounding the embryo sac start dividing, protrude into the embryo sac and develop into the embryos.
- In such species each ovule contains many embryos.
- The genetic nature of plants produced by apomixis is the same as that of parents and hence they can be called as clones.

- Hybrid varieties of several of our food and vegetable crops are being extensively cultivated.
- Cultivation of hybrids has tremendously increased productivity.
- One of the problems of hybrids is that hybrid seeds have to be produced every year.
- If the seeds collected from hybrids are sown, the plants in the progeny will segregate and do not maintain hybrid characters.
- Production of hybrid seeds is costly and hence the cost of hybrid seeds becomes too expensive for the farmers.
- If these 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 and he does not have to buy hybrid seeds every year.
- Because of the importance of apomixis in hybrid seed industry, active research is going on in many laboratories around the world to understand the genetics of apomixis and to transfer apomictic genes into hybrid varieties.

2. Polyembryony:

- Occurrence of more than one embryo in a seed is referred to as **polyembryony.**
- In gymnosperms, poly embryony can occur due to cleavage of growing embryo.
- It occurs in some species of citrus (orange and lemon), onion, groundnut and mango varieties.

3. Parthenocarpy:

- The production and development of seedless fruit is calle parthenocarpy.
- It is of teo types, vegetative and stimulative.
- In vegetative parthenocarpy, the seedless fruits can develop without the stimulus of pollination. Eg., Pear
- In stimulative parthenocrpy, the stimulus of pollination is required without actual process of fertilization. Eg., Grapes

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