Unit-VI REPRODUCTION
Chapter-2 Sexual Reproduction in Flowering Plants

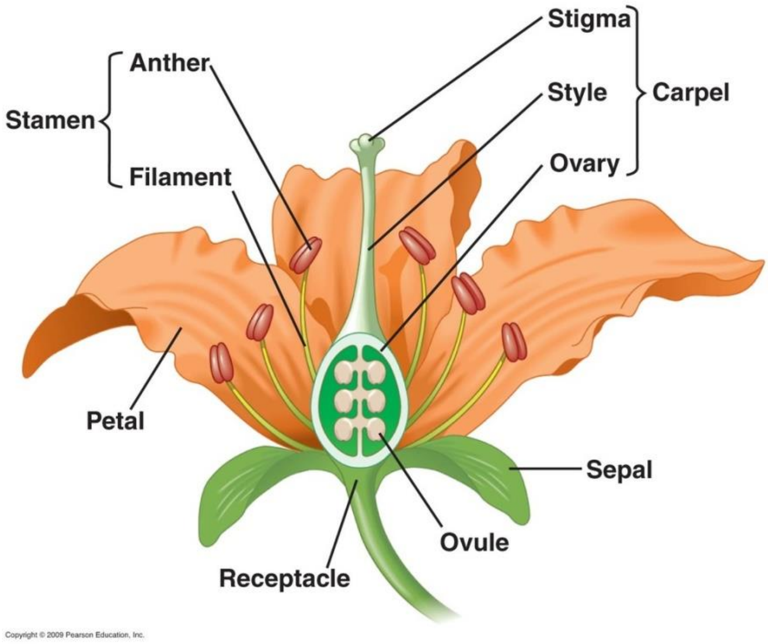
Flower – A Fascinating Organ of Angiosperms:

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.

According to Von Goethe ***flower is a modified shoot. "Flower is defined as highly condensed and modified reproductive shoot".***

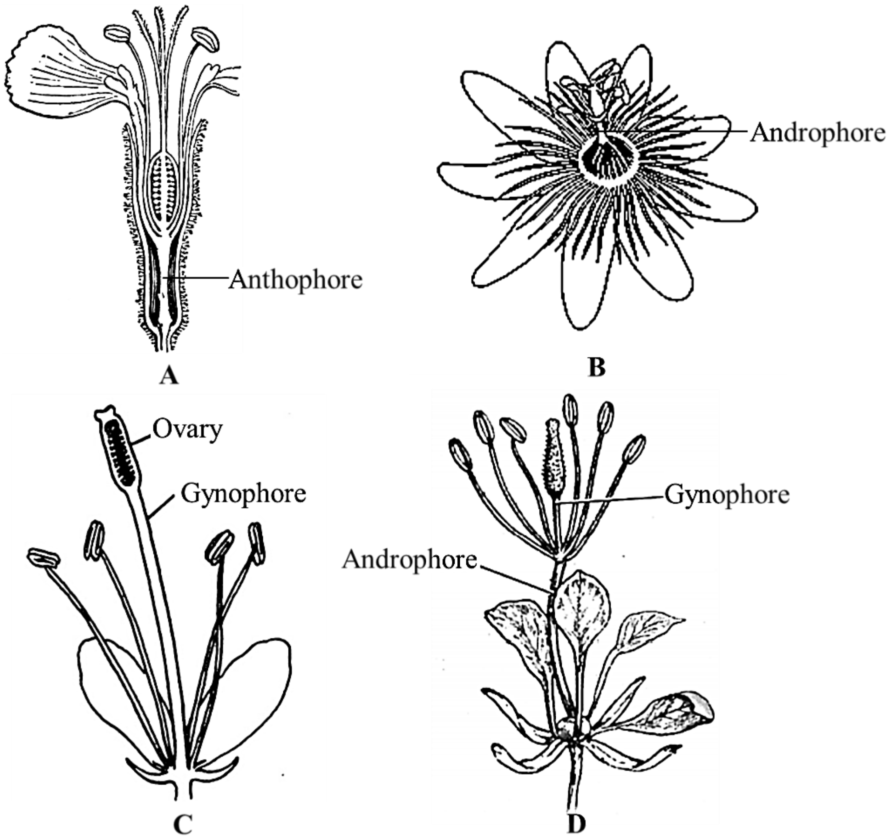
Flower has short or long flower stalk which is called ***pedicel***. The upper part of this swollen, spherical shaped or conical which is called the ***thalamus / receptacle***. Floral leaves are present on it. In a flower there are 4 different floral leaves namely; sepals, petals, stamens, and carpels.

The thalamus possesses 4 nodes with highly reduced internodes; at each node are present the modified floral leaves in the order calyx, corolla, androecium and gynoecium.



Sometimes the reduced internodes may grow in its length forming following structures;

a. **Anthophore (A)**: internode increases between calyx and corolla. Ex: *Silene*
b. **Androphore (B)**: internode increases between corolla and androecium. Ex: *Passiflora*
c. **Gynophore (C)**: internode increases between androecium and gynoecium. Ex: *Capparis*
d. **Gynandropore (D)**: if both androphore and gynophore are present in same flower. Also referred to as a*ndrogynophore*. Ex: *Cleome gynandra*, *Gynandropsis*.



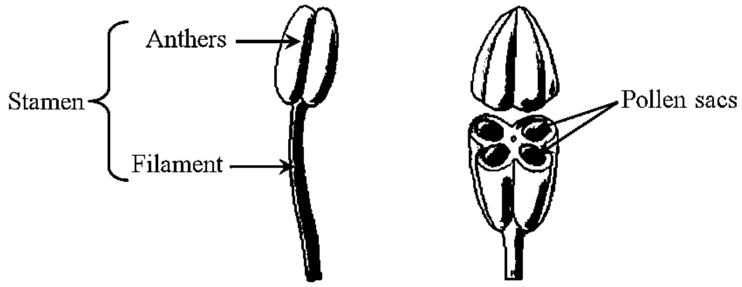
Pre-Fertilisation: Structures and Events:

- Several hormonal and structural changes are initiated which lead to the differentiation and further development of the floral primordium.
- Inflorescences are formed which bear the floral buds and then the flowers.
- In the flower the male and female reproductive structures, the androecium and the gynoecium differentiate and develop.

Stamen, Microsporangium and Pollen Grain:

- The stamen is referred to as *microsporophyll*. It is made up of two parts; *anther* and *filament*, connected by a *connective tissue*.
- The proximal end of the filament is attached to the thalamus or the petal of the flower. The number and length of stamens are variable in flowers of different species.
- A typical angiosperm anther is *bi-lobed* with each lobe having two theca. Hence are called *dithecous anthers*. Each anther lobe also has two microsporangia separated by a strip of sterile tissue.
- A few of them possess only one theca; hence, called *monothecous* (*Hibiscus, Moringa* etc.)
- The bi-lobed nature of an anther is very distinct in the transverse section of the anther. A typical dithecous anther is four-sided (tetragonal structure) consisting of four microsporangia located at the corners, two in each lobe (tetra-sporangiate anther).

- The microsporangia develop further and become *pollen sacs*. They extend longitudinally all through the length of an anther and are packed with pollen grains.

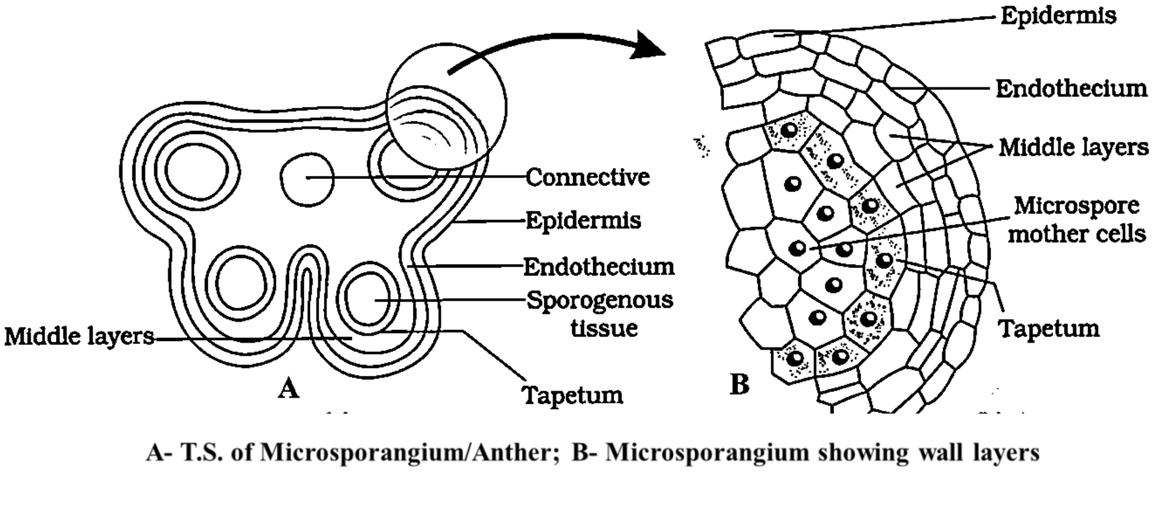


Structure of stamen

Structure of Microsporangium:

In a transverse section, a typical microsporangium/anther appears near circular in outline. It is generally surrounded by four wall layers- the *epidermis, endothecium, middle layers and the tapetum*.

a. **Epidermis**: It is the outermost layer of anther. It is uni-seriate and is protective in function.
b. **Endothecium**:
   - It is also uni-seriate layer. The outer walls of endothecial cells are thin while the inner and radial walls become thick due to the deposition of ***α- cellulose fibres***.
   - Callose bands are also present along the radial walls.
   - However, a small strip of endothecial cells are devoid of cellulose fibres and ***callose bands***, called ***stomium***. The anther dehisces at this region.
   - The ***hygroscopic nature*** of endothecial cells is the reason behind the dehiscence.
c. **Middle layer**:
   - This layer is 1-3 celled thick and is parenchymatous nature.
   - Middle layer is ephemeral (short lived) and is absent in a mature anther.
d. **Tapetum**:
   - It is a uniseriate ***nourishing layer***.
   - Cells of the tapetum possess dense cytoplasm and generally have more than one nucleus (***multinucleate***).
   - It absorbs food from the middle layers.



A- T.S. of Microsporangium/Anther; B- Microsporangium showing wall layers

There are two types of tapetum; amoeboid and glandular

1. **Amoeboid/ Invasive/ Periplasmodial**: The walls of this cells ***breakdown (degenerate)*** and form a protoplasmic mass. They absorb nutrients from middle layers and provide nutrition even after degeneration. It is found primitive angiosperms and is less common.
2. **Glandular/ Secretory/ Parietal**: The cells are intact and ***do not degenerate***. It is found in advanced angiosperms and is more common.

Microsporogenesis and Male Gametophyte:

When the anther is young, a group of compactly arranged homogenous cells called the sporogenous tissue occupies the centre of each microsporangium. As the anther develops, the cells of the sporogenous undergo meiotic divisions to form microspore tetrads.

The development of microspores from the diploid pollen mother cells by meiosis in the microsporangia is known as microsporogenesis.

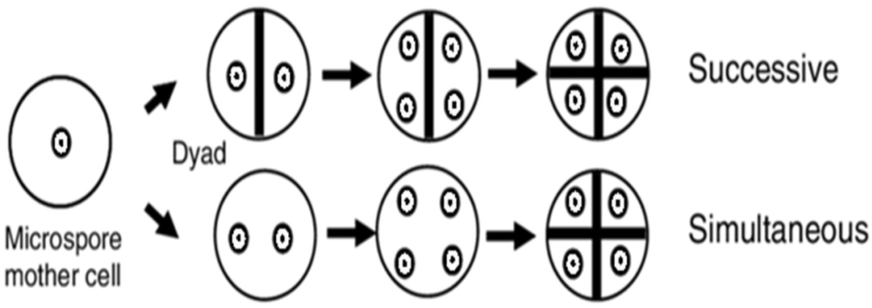
- The microspores develop from the **sporogenous tissue** of the archesporium. The sporogenous cells develop into the **pollen mother cells** (**microspore mother cells**). The pollen mother cells are **diploid** and they undergo **meiosis** to produce **microspore tetrads**.
- The microspore tetrads get separated to form the microspores, which are haploid. The separated microspores are now referred to as pollen grains.

The meiotic cytokinesis of microspore may be of following types;

i. <u>Successive type</u>:

- In this method, meiotic divisions are followed by immediate wall formation.
- Each pollen mother cell undergoes first meiotic division resulting in the formation of two nuclei.
- The nuclear division is followed by immediate wall formation. Thus, a dyad is formed.
- The two cells of the dyad undergo second meiosis, which is also followed by wall formation. As a result, a tetrad is formed.
- In this type, cell plate is formed from the centre and then extends centrifugally on both the sides.
- This type is common in monocots.

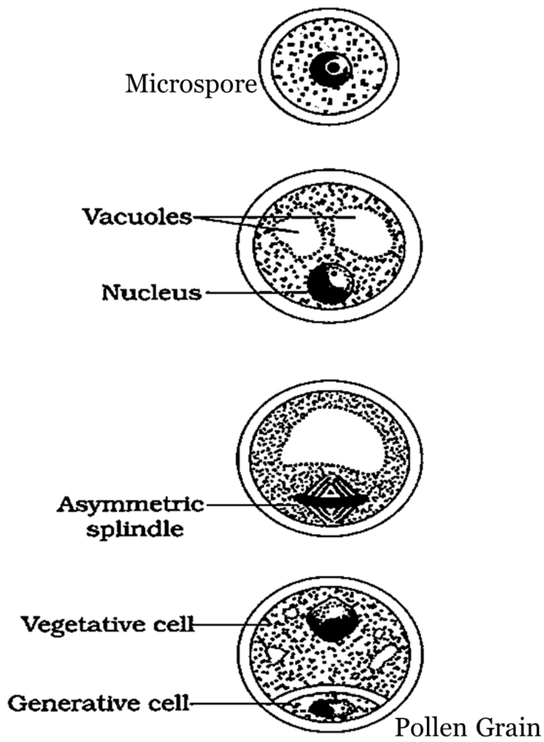
ii. <u>Simultaneous type</u>: In this type, walls are formed after the formation of four nuclei.



Microspore Tetrad

Pollen Grains:

- The pollen grains represent the **male gametophytes**.
- Pollen grains are generally spherical measuring about 25-50µm in diameter.
- It has a prominent two-layered wall. The hard outer layer called the **exine** is made up of ***sporopollenin*** which is one of the most resistant organic materials known. It can withstand high temperatures and strong acids and alkali. No enzyme that degrades sporopollenin is so far known. Pollen grains are well preserved as fossils because of the presence of sporopollenin.
- Pollen grain exine has prominent apertures called **germ pores** where sporopollenin is absent. Pollen tubes arise from these pores.
- The exine exhibits a fascinating array of patterns and designs.
- The inner wall of the pollen grain is **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.**
- The vegetative cell is bigger, has abundant food reserve and a large irregularly shaped nucleus.
- The generative cell is small and floats in the cytoplasm of the vegetative cell. It is spindle shaped with dense cytoplasm and a nucleus.
- In over **60%** of angiosperms, pollen grains are shed at this **2-celled stage**.
- In the remaining species, the generative cell divides mitotically to give rise to the two male gametes before pollen grains are shed (3-celled stage).
- When once they are shed, pollen grains have to land on the stigma before they lose viability if they have to bring about fertilisation.



Stages of Microspore maturing into Pollen Grain

- The period for which pollen grains remain viable is highly variable and to some extent depends on the prevailing temperature and humidity.
- In some **cereals** such as rice and wheat, pollen grains lose viability within **30 minutes** of their release.
- In some members of **Rosaceae, Leguminoseae/ Fabaceae** and **Solanaceae**, they maintain viability for **months**.

- It is possible to store pollen grains of a large number of species for years in **liquid nitrogen (-196°C)**. Such stored pollen can be used as **pollen banks**, similar to seed banks, in crop breeding programmes.

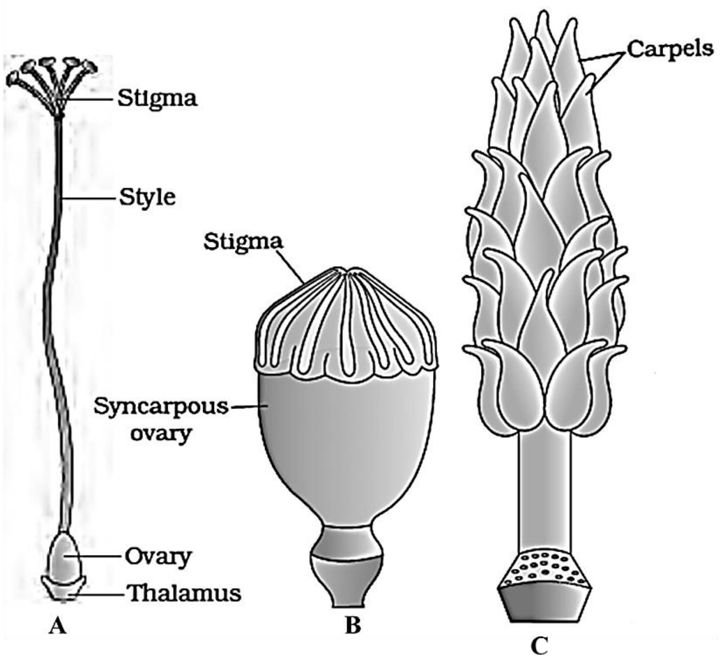
***(Note- Palynology**: The study of pollen grains and other spores, especially as found in archaeological or geological deposits.)*

Pollen Allergy: Pollen grains of many species cause severe allergies and bronchial afflictions (pain) in some people often leading to **chronic respiratory disorders**– asthma, bronchitis, etc. It may be mentioned that ***Parthenium*** (carrot grass) that came into India as a *contaminant* with imported wheat, has become ubiquitous in occurrence and causes pollen allergy. One of the causes for **Hay fever (allergic rhinitis)** is pollen grains of ***Ambrosia***.

Pollen grains as Food supplement: 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. Pollen consumption has been claimed to increase the performance of athletes and race horses.

The Pistil, Megasporangium (ovule) and Embryo sac

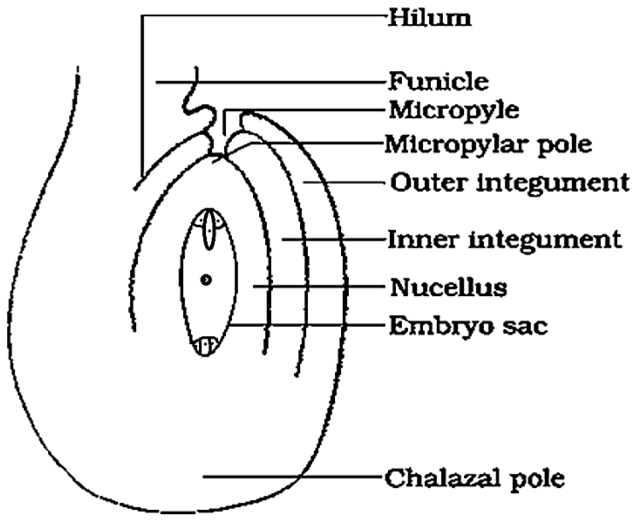
- The gynoecium represents the female reproductive part of the flower. The gynoecium may consist of a single pistil **monocarpellary** or may have more than one pistil **multicarpellary**.
- When there are more than one, the pistils may be fused together it is called **syncarpous** as in *Hibiscus*, Poppy etc. or may be free **apocarpous** as in *Michelia champaka*.
- 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**). The **placenta** (**a flattened, cushion-like structure**) is located inside the ovarian cavity.
- Arising from the placenta are the megasporangia, commonly called **ovules**.
- The number of **ovules in an ovary may be one** (**wheat, paddy, mango** etc.) to **many** (**papaya, water melon, orchids** etc.).



Multicarpellary Syncarpous ovary: A- *Hibiscus*; B- *Papaver* (Poppy)
Multicarpellary Apocarpous ovary: C- *Michelia*

Structure of Ovule (Megasporangium):

a. Each ovule is attached to the inner wall of the ovary (placenta) by a slender stalk called **funicle**.
b. The point of attachment of ovule to its funicle is called **hilum**. Thus, hilum represents the junction between ovule and funicle.
c. Each ovule is covered by one or two protective envelopes, called **integuments**.
d. If only one integument is present, the ovule is called ***unitegmic***, and if the ovule consists of two integuments, it is called ***bitegmic***. In some plants such as *Santalum* there is **no integument** hence the condition is called ***ategmic***.
e. Enclosed within the integuments is a mass of cells called the **nucellus**. Nucellus consists of living parenchymatous cells. Cells of the nucellus have abundant ***reserve food materials***. Located in the nucellus is the **embryo sac** or **female gametophyte**.



Structure of a typical Anatropous Ovule

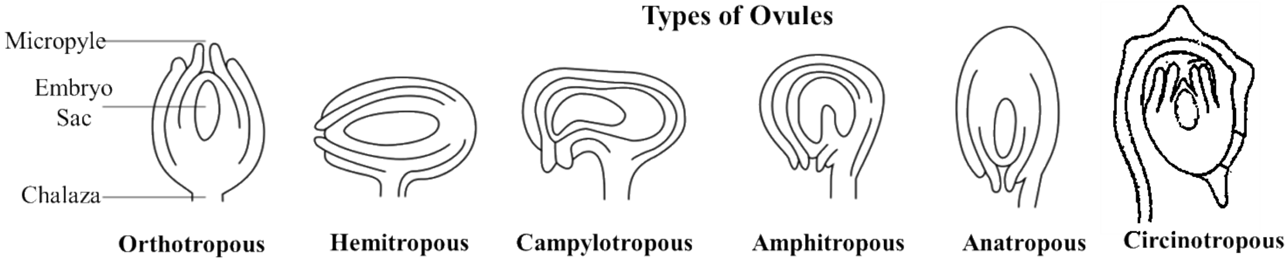
f. An ovule generally has a single embryo sac developed from a megaspore.The nucellus serves to cover and provide nutrition to the embryo sac (female gametophyte).
a. Integuments encircle the nucellus except at the tip where a small opening called the **micropyle** is organised

a. Each ovule has two distinct ends a micropylar end; it also called opening of ovule and a **chalazal** end the posterior end, opposite to micropyle.
b. In mature ovule, the female gametophyte or embryo sac is present at the centre. The embryo sac consists of egg cell (female gamete) synergid cells, antipodal cells and polar nuclei).

Types of Ovules:

1. **Orthotropous/Atropous ovule**: It is a **straight ovule**, where the micropyle, chalaza and the funiculus, all are in the same line. Ex: Most of Gymnosperms, Pepper etc.
2. **Hemianatropous/ Hemitropous ovule:** In this case the body of the ovule is **inverted only through 90°** with respect to funicle. As a result the funicle comes to lie at right angle to the nucellus. Micropyle and chalaza lie in the same plane. Ex: *Ranunculus*.
3. **Campylotropous ovule**: The body of the ovule is not completely inverted. The micropyle and chalaza do not lie in the same plane. However, the nucellus and embryo-sac remain straight. Ex: Cruciferae (Brassicaceae) Caryophyllaceae, Capparidaceae etc.
4. **Amphitropous ovule**: It is similar to campylotropous, but in this case the nucellus/embryo-sac etc. is **bent like horse shoe**. Ex: *Alisma*
5. **Anatropous ovule**: It is of the **most common type** of ovule present in more than 80% of angiosperm family. In this ovule, the funicle is long. The whole body of the ovule is inverted through 180°. As a result the micropyle comes close to the funicle. Ex: Asteraceae, Solanaceae, Malvaceae etc.
6. **Circinotropous ovule**: It is of a **very rare occurrence**. Here the body of the ovule is **bent through 360°,** so that it **takes a one complete turn**. Micropyle, chalaza, embryo sac, nucellus lie on same plane. Ex: *Opuntia*

Types of Ovules



Megasporogenesis:

The process of formation of megaspores from the megaspore mother cell is called ***megasporogenesis***. Ovules generally differentiate a single megaspore mother cell (MMC) in the micropylar region. It undergoes **meiosis** and **forms four haploid megaspores**.

In most of the angiosperms out of these 4 megaspores, **3 get degenerate** (to provide more nourishment to the remaining one). This method of embryo sac formation from a single megaspore is termed **monosporic development/ polygonum type**.

Here the functional megaspore is present towards chalazal end. Thus only one functional megaspore remains in the ovule. In some angiosperms bisporic or even tetrasporic embryo sac may also be present.

A megaspore is a haploid structure and represents the first cell of the female gametophyte. It develops to form fully mature embryo sac.

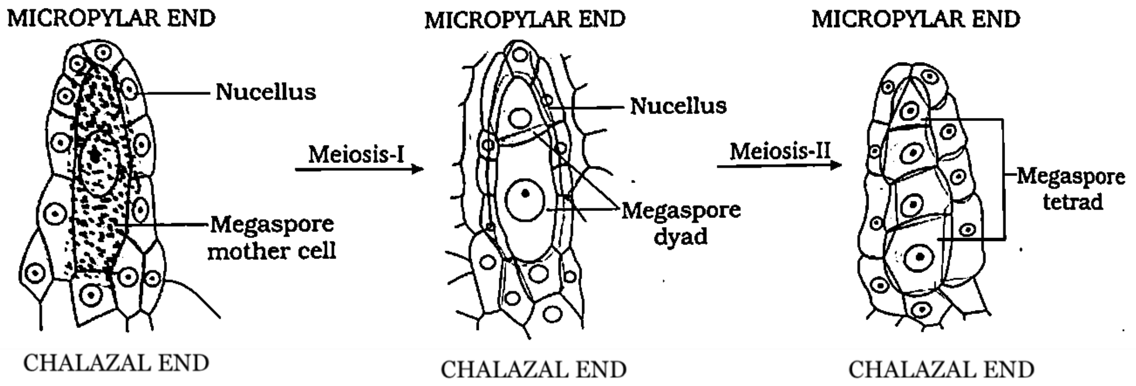
Formation of Female Gametophyte (Embryo Sac):

Female gametophyte is also called embryo sac. It develops from the functional megaspore. There are great variations in the development of embryo sac i.e. it may be monosporic, bisporic or tetrasporic. The development of a typical embryo sac is monosporic and is of the most common occurrence among angiosperms.

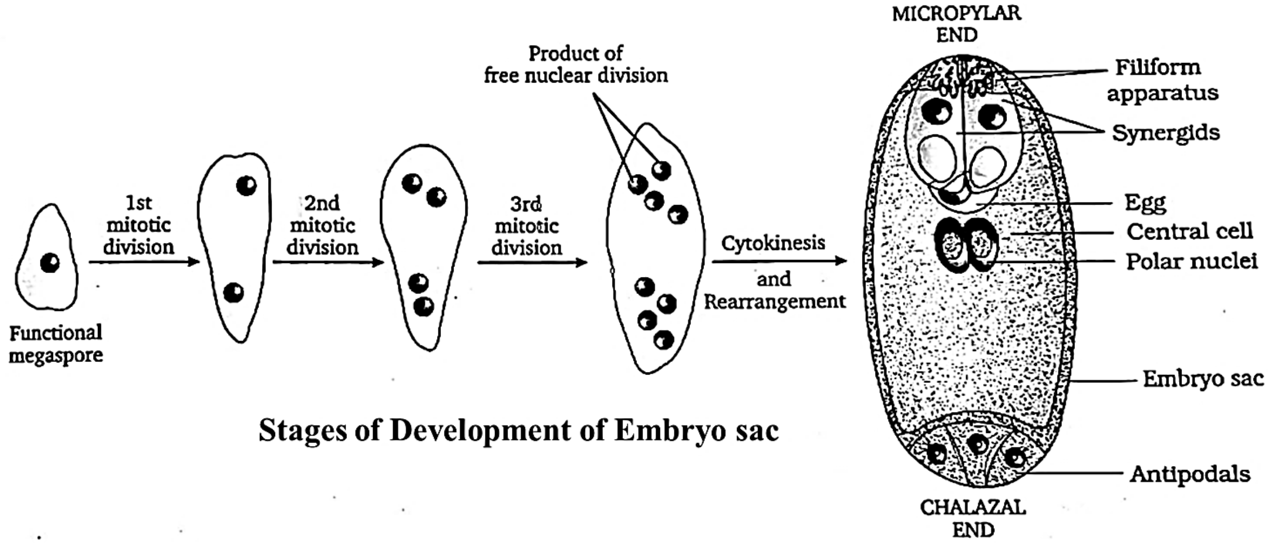
- The nucleus of the functional megaspore divides mitotically to form two nuclei which move to the opposite poles, forming the 2-nucleate embryo sac.
- Two more sequential mitotic nuclear divisions result in the formation of the 4-nucleate and later the 8-nucleate stages of the embryo sac.

Haploid megaspore →2 nuclei→4 nuclei→8 nuclei

- These mitotic 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 organisation of the typical female gametophyte or embryo sac.
- Of these 8 nuclei, 3 nuclei at micropylar end undergo cytokinesis, forming cell membrane and form egg apparatus. The egg apparatus contains **2 synergid cells** and **one egg cell** (female gamete).
- The **synergids/ helper cells** have special **cellular thickenings** at the micropylar tip called **filiform apparatus**, which play an important role in **guiding the pollen tubes** into the synergid
- Other three nuclei (at chalazal end) also undergo cytokinesis and form **3 antipodal cells.**
- One nucleus from each pole move towards the centre forming the **polar nuclei**/ **a large central cell**. The two nuclei may fuse later to form secondary fusion nucleus.
- This entire structure is called embryo-sac, which represents the **mature female gametophyte**. In a typical embryo sac **3+1+3 arrangement of cells** is observed.
- The mature female gametophyte (embryo-sac) consists of **8 nuclei** and **7 cells** (one egg cell. 2 synergids, 3 antipodal cells).



Stages of Megaspore Formation



Stages of Development of Embryo sac

Pollination

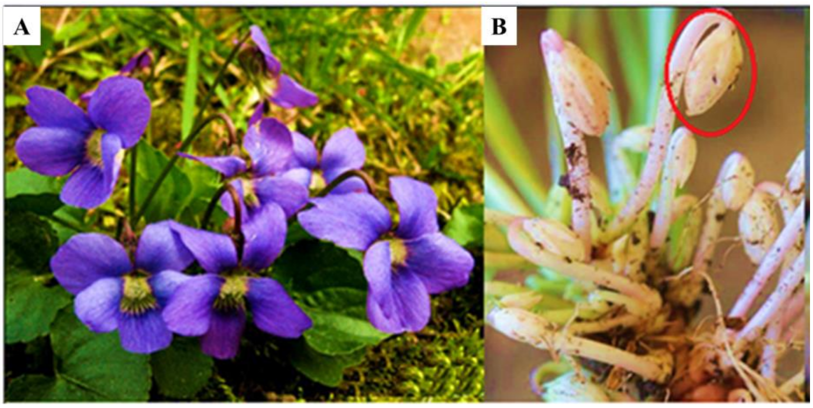
Transfer of pollen grains (shed from the anther) to the stigma of a pistil is termed pollination. It is of two main types; self-pollination and cross-pollination.

Self-Pollination:

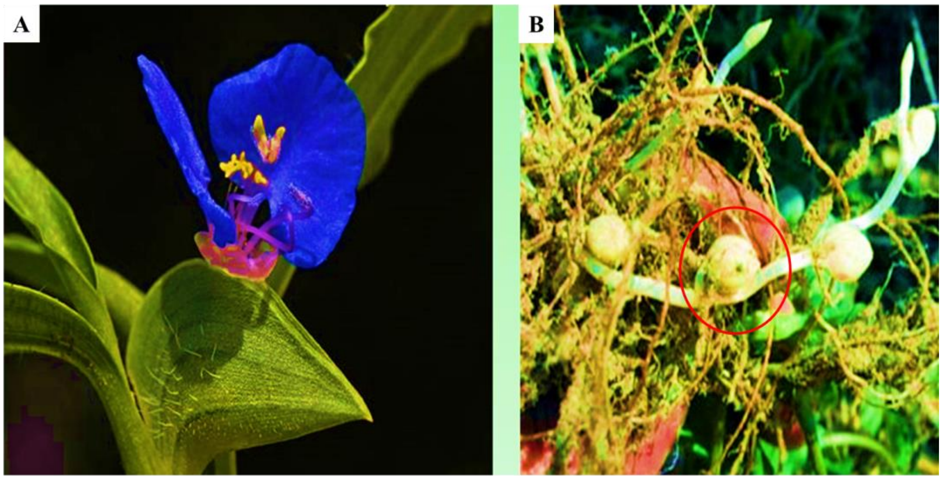
Transfer of pollen from anther of a flower to the stigma of the same flower (or flower of same plant) is called self-pollination. It can be two types, **autogamy** and **geitonogamy**

a. Autogamy:

- It is a type of self-pollination that is found only in **bisexual flower**. In this case, the stigma of a flower is pollinated by its own pollen.
- 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***, and ***Commelina*** produce two types of flowers – **chasmogamous** flowers which are similar to flowers of other species **with exposed anthers and stigma** (*Greek: chasmogamous= open marriage; named after the open arrangement of the of floral structures*), 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**.



Viola **(Common pansy): A- Chasmogamous flowers**
B- Cleistogamous flowers



Commelina**: A- Chasmogamous flower**
B- Cleistogamous flowers

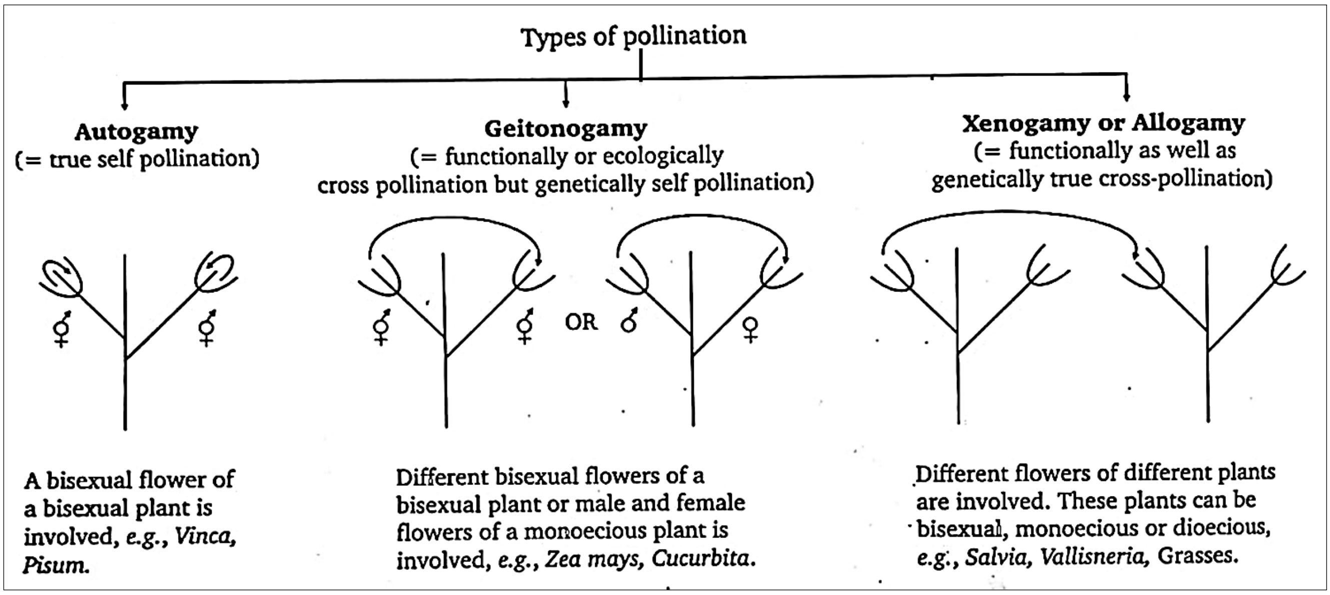
b. Geitonogamy:

- Transfer of pollen grains from the anther to the stigma of another flower of the same plant.
- 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.** Ex: Maize

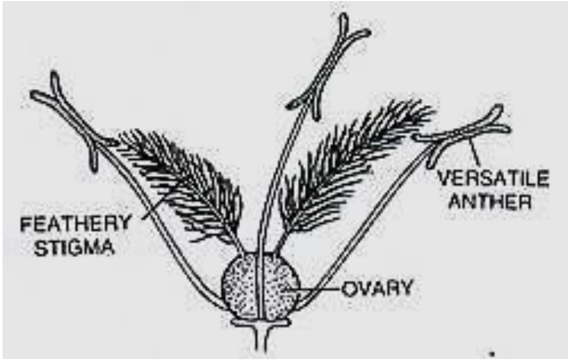
Xenogamy/Cross Pollination/Allogamy:
Transfer of pollen grains from anther to the stigma of a different plant. This is the only type of pollination which during **pollination brings genetically different types of pollen grains to the stigma. Pollination occurs due to pollinating agents**
Agents may be **abiotic** (non-living) or **biotic** (living). It is commonly seen in dioecious plant but very rarely in monoecious. Majority of plants use biotic agents for pollination. Only a small proportion of plants use abiotic agents.
Cross pollination is highly advantageous than self-pollination mainly in formation of new genotypes (varieties). Ex: **Grasses**, **Onion** etc.

Types of Cross Pollination:

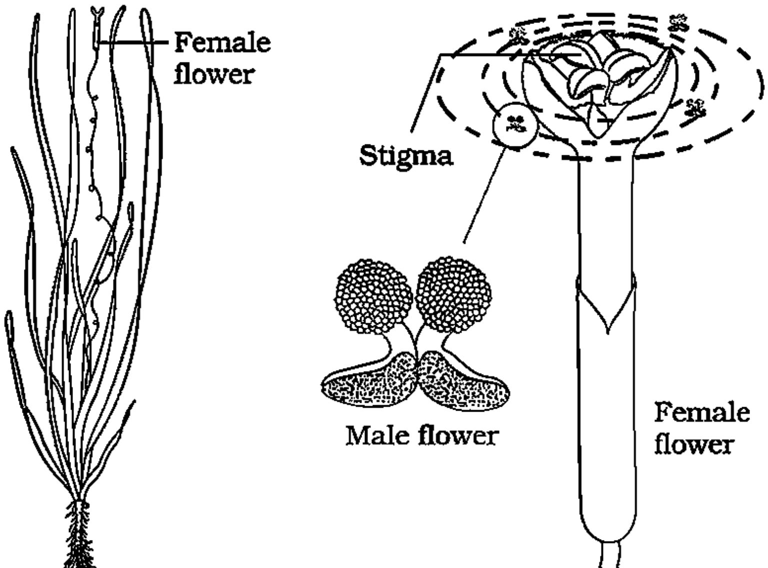
Pollination Type	Agent	Examples
1. Anemophily	Wind (Abiotic)	Grasses, Wheat, Paddy etc.
2. Hydrophily	Water (Abiotic)	*Vallisneria*, *Zostera*, etc.
3. Entomophily	Insects (Biotic)	Jasmine, Sunflower etc.
4. Zoophily:	Animals (Biotic)	
a. Ornithophily	Birds (Biotic)	*Musa*, *Hibiscus* etc.
b. Malacophily	Snails (Biotic)	*Lemna*, *Colocasia* etc.
c. Chiropterophily	Bats (Biotic)	Musa, Adansonia etc.
d. Elephophily	Elephants (Biotic)	*Rafflesia*



1. **Wind Pollination/Anemophily**:
   Anemophily refers to the pollination by wind (air). Wind pollinated flowers (primitive features) show following characters:
   a. Wind pollination also requires that the **pollen grains are light** and **non-sticky** so that they can be transported in wind currents.
   b. They often possess **well-exposed stamens** called **versatile anthers** (so that the pollens are easily dispersed into wind currents), and large often-**feathery stigma** called **plumose stigma** to easily trap air-borne pollen grains.
   c. Wind pollinated flowers often have a **single ovule in each ovary** and **numerous flowers** (inconspicuous and not showy) 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. Ex: Grasses, Paddy, Wheat etc.

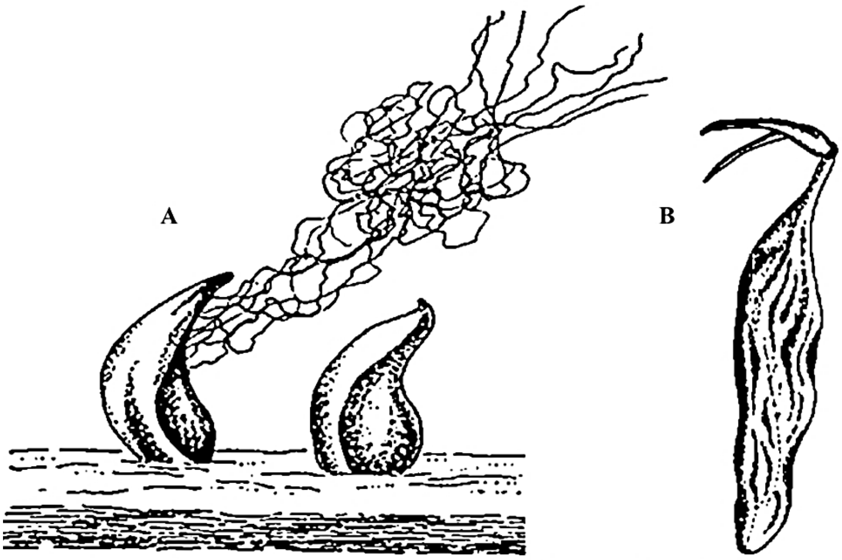


2. **Water Pollination/ Hydrophily**:
   a. Pollination by water is quite rare in flowering plants and is limited to about **30 genera**, mostly **monocotyledons**.
   b. Some examples of water pollinated plants are ***Vallisneria*** and ***Hydrilla*** which grow in fresh water and several **marine sea-grasses** such as ***Zostera***.
   c. **Not all aquatic plants use water for pollination**. In a majority of aquatic plants such as **water hyacinth (*Eichhornia*)** and **water lily (*Nymphaea*)**, the flowers emerge above the level of water and are **pollinated by insects or wind** as in most of the land plants.
   d. 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.
   e. They are carried passively by water currents some of them eventually reach the female flowers and the stigma.



Hydrophily in *Vallisneria*

   f. In another group of water pollinated plants such as **sea-grasses, female flowers remain submerged** in water and the pollen grains are released inside the water.
   g. **Pollen grains** in many such species are **long, ribbon like** and they are carried passively inside the water; some of them reach the stigma and achieve pollination.
   h. In most of the water-pollinated species, **pollen grains** are **protected** from wetting by a **mucilaginous covering**.



Zostera **(Sea-grass): A- Anthers releasing long ribbon-like pollens**
B- Pistil with bifid stigma

If hydrophily occurs completely under water then it is referred to as ***hypohydrophily*** as in ***Zostera*** or may occur on the water surface i.e. ***epihydrophily*** as in ***Vallisneria***.
In **anemophily** and **hydrophily pollen grains coming in contact with the stigma is a chance factor**. 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. Both wind and water pollinated **flowers are not very colourful** and **do not produce nectar**.

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, 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.

3. Insect pollination/ Entomophily:

a. Majority of insect-pollinated **flowers are large, colourful, fragrant** and **rich in nectar**.
b. When the flowers are small, a number of flowers are clustered into an inflorescence to make them conspicuous.
c. Animals are attracted to flowers by colour and/or fragrance.

d. The flowers pollinated by flies and beetles **secrete foul odours to attract** these animals.
e. To **sustain animal visits**, the flowers have to **provide rewards** to the animals. **Nectar** and **pollen grains** are the **usual floral rewards**.
f. For harvesting the reward(s) from the flower the animal visitor comes in contact with the anthers and the stigma.
g. The body of the animal gets a coating of **pollen grains**, which are generally **sticky** in animal pollinated flowers.
h. When the animal carrying pollen on its body comes in contact with the stigma, it brings about pollination.
i. In some species **floral rewards** are in **providing safe places to lay eggs**; an example is that of the **tallest inflorescence** of ***Amorphophallus*** (is about 6 feet in height).

***Amorphophallus* inflorescence**

Association of *Yucca* flower and Moth

j. A similar relationship exists between a **species of moth** and the plant ***Yucca*** where both species – 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.
   Examples for insect pollinated flowers: Jasmine, *Hibiscus,* Sunflower etc.

Outbreeding devices/Contrivances/ Adaptations for Cross-Pollination:

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**. Flowering plants have developed many devices to discourage self-pollination and to encourage cross-pollination.

1. Dichogamy: In some species, pollen release and stigma receptivity are not synchronised.

- Protandry: The pollen is released before the stigma becomes receptive Ex: Sunflower, *Jasminum* etc.
- Protogyny: Stigma becomes receptive much before the release of pollen. Ex: Rose, *Ficus etc.*

2. **Heterostyly**: 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. Ex: *Primula*, *Linum*, Jasmine, *Oxalis*, etc.

(Both 1 and 2 devices prevent autogamy).

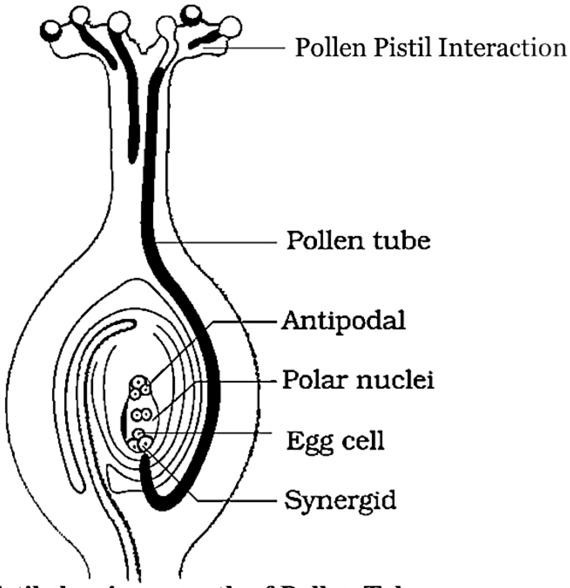
3. **Self-Incompatibility**: The third device **to prevent inbreeding** is self-incompatibility.
   This is a genetic mechanism and prevents self-pollen (from the same flower or other flowers of the same plant) from fertilising the ovules by inhibiting pollen germination or pollen tube growth in the pistil. Ex: *Passiflora*
4. **Uni-sexuality/ Dicliny**: Another device to prevent self-pollination is the **production of unisexual flowers**.
   - **a.** If both male and female flowers are present on the same plant such as **castor** and **maize** (**monoecious**), it **prevents autogamy but not geitonogamy**.
   - **b.** In several species such as **papaya**, male and female flowers are present on different plants i.e. each plant is either male or female (**dioecious**). This condition **prevents both autogamy and geitonogamy.**

Pollen-pistil Interaction:

Pollination does not guarantee the transfer of the right type of pollen (compatible pollen of the same species as the stigma). 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 recognise the pollen**, whether it 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 fertilisation.

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.

- The ability of the pistil to recognise the pollen followed by its acceptance or rejection is the result of a continuous dialogue between pollen grain and the pistil. This **dialogue is mediated by chemical components** of the pollen interacting with those of the pistil.
- 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 and reaches the ovary.



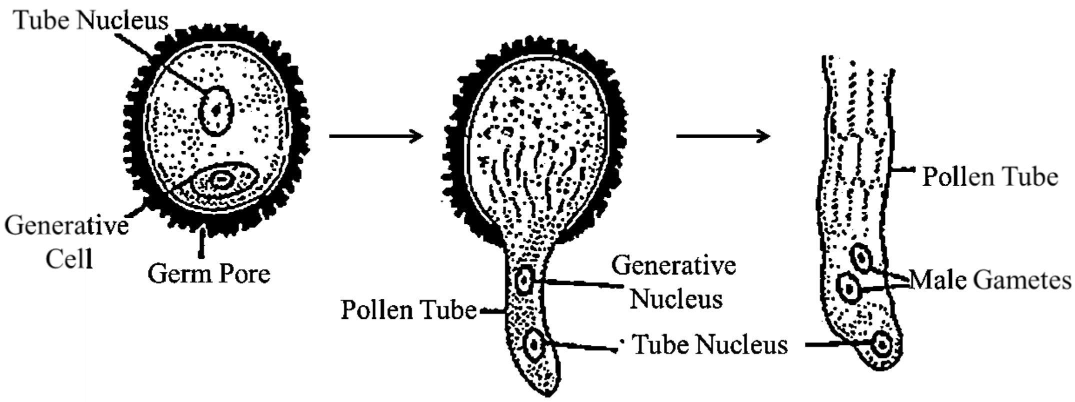
L.S. of Pistil showing growth of Pollen Tubes

- If pollen grains are shed at two-celled condition (a vegetative cell and a generative cell). Then 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.

Development of Male gametophyte:

Pollen grain is the first stage of male gametophyte development. A male gametophyte is developed soon after pollination. It involves following steps;

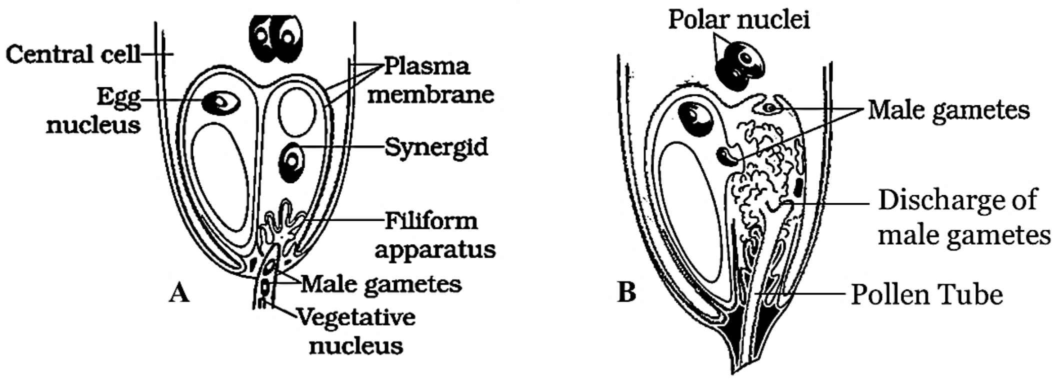
1. Formation of male gametes (sperm):
    - Only a right kind of spore germinates on the right kind of stigma, (i.e. for germination, both pollen and the stigma must be of the plants that belong to the same species or genus).
    - After pollination, the pollen grain undergoes first mitosis producing two cells, vegetative cell and a generative cell- **bi-celled stage**.
    - The vegetative cell is larger and is not involved in gamete formation. However, it **produces the pollen tube** of the male gametophyte and its nucleus **guides the gametes** towards the egg cell.
    - The generative cell is smaller and usually embeds inside the vegetative cell. The nucleus undergoes second mitosis producing **two male nuclei or sperm**.
2. Formation and growth of pollen tube:
    - The cytoplasm of the vegetative cell (tube cell) bulges out through germ pore, in the form of a tube, called pollen tube.
    - Pollen tube at the apex contains tube nucleus; which is in fact the nucleus of vegetative cell. Behind the tube nucleus, there are 2 male gametes (sperms).
    - The tube grows towards the ovule (megasporangium), making its way through the style.
    - This three celled stage represents the ***mature male gametophyte*** of angiosperm.
    - The male gametophyte of angiosperm is highly reduced, simple structure and is dependent wholly on the sporophyte.



Stages of Development of Male Gametophyte

Usually, a **single pollen tube** arises from one pollen grain. Such pollen grains are called ***monosiphonous***. However in some plants, pollen grains give rise to **many pollen tubes** and are called ***polysiphonous***. Now pollen tube makes its way through the style of carpel and moves towards the mature ovule containing female gametophyte (embryo sac) absorbing borate and calcium substances from style. This movement is a type of **chemotropism**.

- Pollen tube, after reaching the ovary, enters the ovule through the micropyle and then enters one of the synergids through the filiform apparatus.
- Many recent studies have shown that **filiform apparatus** present at the micropylar part of the synergids **guides the entry of pollen tube**.



A- Entry of pollen 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

- **All these events–from pollen deposition on the stigma until pollen tubes enter the ovule–are together referred to as pollen-pistil interaction**.
- 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, even in incompatible pollinations, to get desired hybrids.

<u>Pollen Germination Test</u>:

i. Dust the some pollen from flowers such as pea, chickpea, *Crotalaria*, balsam and *Vinca* on a glass slide containing a drop of sugar solution (about 10%).

ii. After about 15–30 minutes, observe the slide under the low power lens of the microscope.
iii. Pollen tubes coming out of the pollen grains are observed.

Artificial Hybridisation:

- It is one of the major approaches of 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.
- If the female parent bears **bisexual flowers**, **removal of anthers from the flower bud before the anther dehisces** using a pair of forceps is necessary. This step is referred to as **emasculation**.
- 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 re-bagged, and the fruits are 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 re-bagged.

Double Fertilisation:

The phenomenon of double fertilization was first reported by Strasburger (1884). The male gametes are brought to the egg present in female gametophyte by a **pollen tube**. This phenomenon is called ***siphonogamy*** which was discovered by G. B. Amici.

Discharge of male gametes (sperm):

- After entering one of the synergids, the pollen tube releases the two male gametes into the cytoplasm of the synergid.

Syngamy:

- 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, which gives rise to form an embryo

Triple fusion:

- 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**.
- The central cell after triple fusion becomes the **primary endosperm cell (PEC)**

Since two types of fusions, **syngamy** and **triple fusion** take place in an embryo sac the phenomenon is termed ***double fertilisation***, **an event unique to flowering plants** (**angiosperms**).

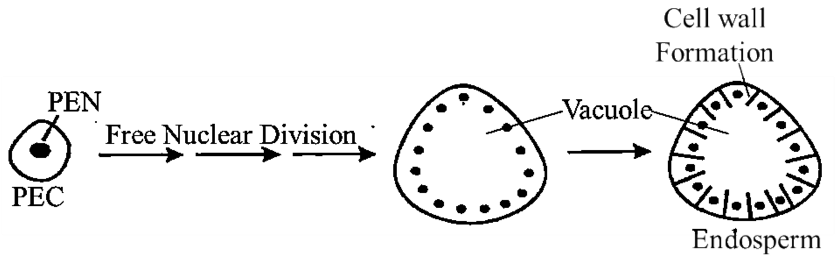
Post-Fertilisation: Structures and Events

After double fertilisation, events of endosperm and embryo development, maturation of ovule into seed and ovary into fruit, are collectively termed post-fertilisation events.

Endosperm:

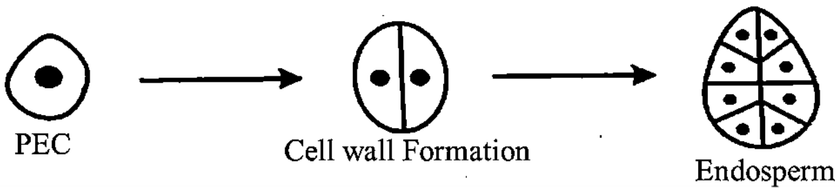
Endosperm is formed from the **primary endosperm nucleus** (**PEN**). Its formation starts before the formation of embryo. Primary endosperm nucleus is produced by **fusion of haploid polar nuclei** and **a haploid second male gamete**. The endosperm is thus **triploid** (**3n**). However, in some cases it may be **haploid** as in **Gymnosperms** which is a **pre-fertilization structure.**

- Endosperm development precedes embryo development.
- The primary endosperm cell divides repeatedly and forms a triploid endosperm tissue.
- The cells of this tissue are filled with reserve food materials (in the form of **starch granules, granules of proteins, or oils)** and are used for the nutrition of the developing embryo.
- **Nuclear Type**: In the most common type of endosperm development, the PEN undergoes **successive nuclear divisions** to give rise to free nuclei without wall formation. This stage of endosperm development is called **free-nuclear endosperm.** Ex**: Coconut** (*Cocos nucifera*) **water** from tender coconut, is nothing but free-nuclear endosperm (made up of thousands of nuclei), **Cotton** etc.



Development of Nuclear Endosperm

- **Cellular Type**: Here cell wall formation occurs and the endosperm becomes cellular. The number of free nuclei formed before cellularisation varies greatly.
  Ex**:** In **Coconut** the surrounding **white kernel** (**copra**) is the cellular endosperm.

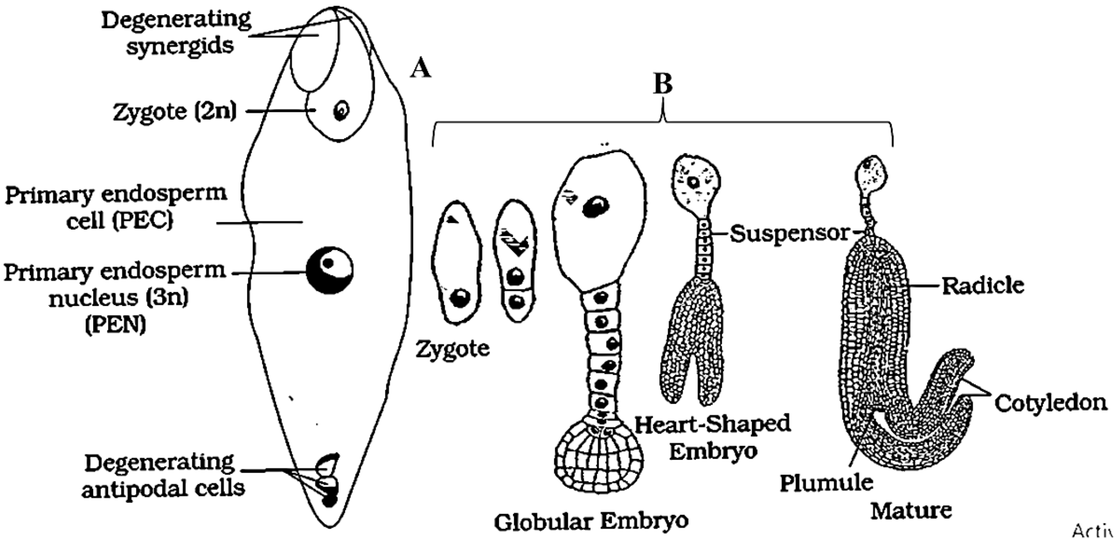


Development of Cellular Endosperm

- **Endosperm** may either be **completely consumed by the developing embryo** (Ex: Pea, groundnut, beans) before seed maturation or it may persist in the mature seed (Ex: Castor and coconut) and be used up during seed germination.

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.
- Though the seeds differ greatly, the early stages of embryo development (embryogeny) are similar in both monocotyledons and dicotyledons.
- The zygote gives rise to the **pro-embryo** and subsequently to the **globular, heart-shaped** and **mature embryo.**



A- Fertilised embryo sac showing zygote and PEN; B- Sequential stages of embryo development in dicots

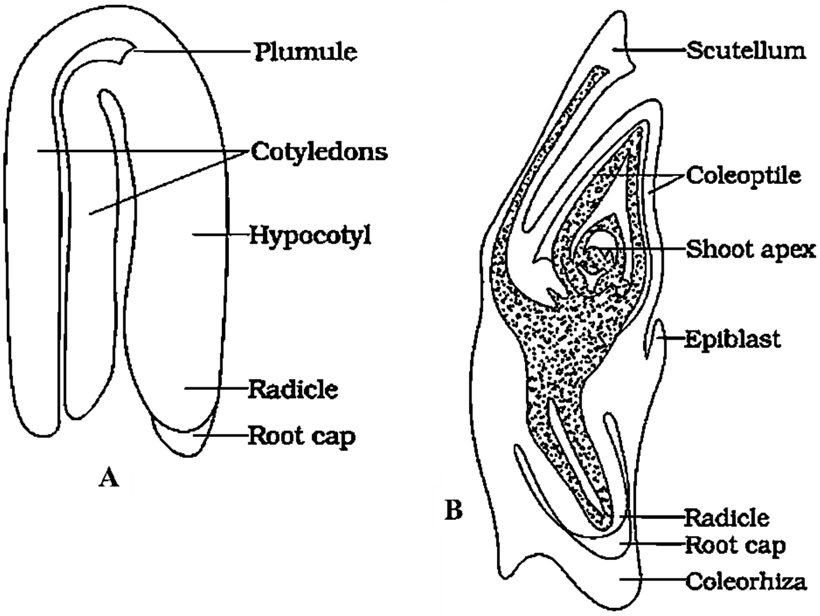
Dicot Embryo:

a. A typical dicotyledonous embryo consists of an embryonal axis (**tigellum**) and two cotyledons. The **cotyledons store up food material**
b. The portion of embryonal axis **above the level of cotyledons is the epicotyl**, which **terminates with the plumule or stem tip.** The plumule is crowned by some minute **young leaves (leaf primordia).**
c. The cylindrical **portion below the level of cotyledons is hypocotyl** that terminates at its **lower end in the radicle or root tip.**
d. The root tip is covered with a **root cap**.

Monocot Embryo:

a. Embryos of monocotyledons possess only **one cotyledon**.
b. In the **grass family** the **cotyledon is called scutellum** that is situated towards one side (**lateral**) of the embryonal axis like a shield.
c. At its **lower end, the embryonal axis** has the **radical and root cap enclosed** in an **undifferentiated sheath called coleorrhiza**.
d. The portion of the **embryonal axis above the level of attachment of scutellum** is the **epicotyl**.

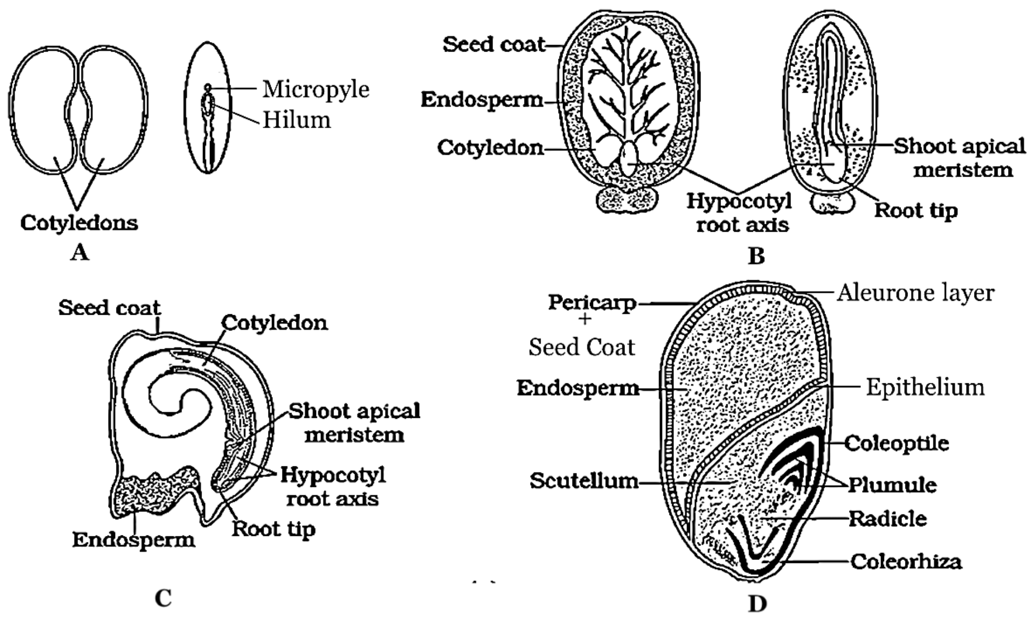
e. **Epicotyl** has a shoot apex and a few leaf primordia enclosed in a **hollow foliar structure, the coleoptile.**



A- Dicot Embryo; B- Monocot Embryo

Seeds:

a. In angiosperms, the seed is the **final product of sexual reproduction**.
b. It is often described as **a fertilised ovule**.
c. Seeds are formed inside fruits.
d. A seed typically consists of **seed coat, cotyledon** and **an embryo axis**.
e. The **cotyledons of the embryo** are simple structures, generally **thick** and swollen due to **storage of food reserves** (as in legumes).
f. Mature seeds may be either non-albuminous / ex-albuminous or may be albuminous.
   - **Non-albuminous seeds** have **no residual endosperm** as it is completely consumed during embryo development (Ex: Pea, groundnut). It is found mostly in dicots. **Orchids** (**monocots**) possess **ex-albuminous** seeds.
   - **Albuminous seeds retain a part of endosperm** as it is not completely used up during embryo development (Ex: Wheat, maize, barley). **Castor** (dicot) possesses **albuminous seeds**.
   - Occasionally, in some seeds such as **black pepper** and **beet**, **remnants of nucellus** are also **persistent**. This residual, **persistent nucellus is the *perisperm***.
g. **Integuments of ovules harden as tough protective seed coats**. It is made up of two layers the outer whitish one is the ***testa***, while the inner thin, hyaline and membranous covering is the ***tegmen***.
h. In dicot seed on one side of the seed coat **a narrow, elongated scar representing the point of attachment to stalk is distinctly seen, this is the hilum.**
i. The **micropyle remains as a small pore** in the seed coat. This facilitates entry of **oxygen** and **water into the seed during germination**.
j. As the seed matures, its water content is reduced and seeds become relatively **dry (10-15% moisture by mass**).



A- Structure of a Dicot (bean) Seed; B- Structure of Castor (dicot) seed; C- Structure of Onion (monocot) Seed; Structure of Monocot (maize) seed

k. The general **metabolic activity of the embryo slows down**. The embryo may enter **a state of inactivity called *dormancy***, or if favourable conditions are available (adequate moisture, oxygen and suitable temperature), they germinate.
l. Seeds offer several advantages to angiosperms. Firstly, since reproductive processes such as pollination and fertilisation are independent of water, seed formation is more dependable.
m. Also **seeds have better adaptive strategies for dispersal** to new habitats and help the species to colonise in other areas.
n. As they **have sufficient food reserves, young seedlings are nourished** until they are capable of photosynthesis on their own.
o. The **hard seed coat provides protection to the young embryo**.
p. Being products of sexual reproduction, **they generate new genetic combinations leading to variations.**
q. Seed is the **basis of our agriculture**.
r. **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. This period again varies greatly.
s. In a few species the seeds lose ***viability (ability to germinate)*** 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.
t. The viability of seeds may vary depending upon species and environmental conditions prevailing during seeds storage.

Plant	***Dormancy period***	***Place of Excavation***
1. Lupine, *Lupinus arcticus*	10,000 years	Arctic Tundra
2. Date palm, *Phoenix dactylifera*	2000 years	King Herod's palace near the Dead Sea.

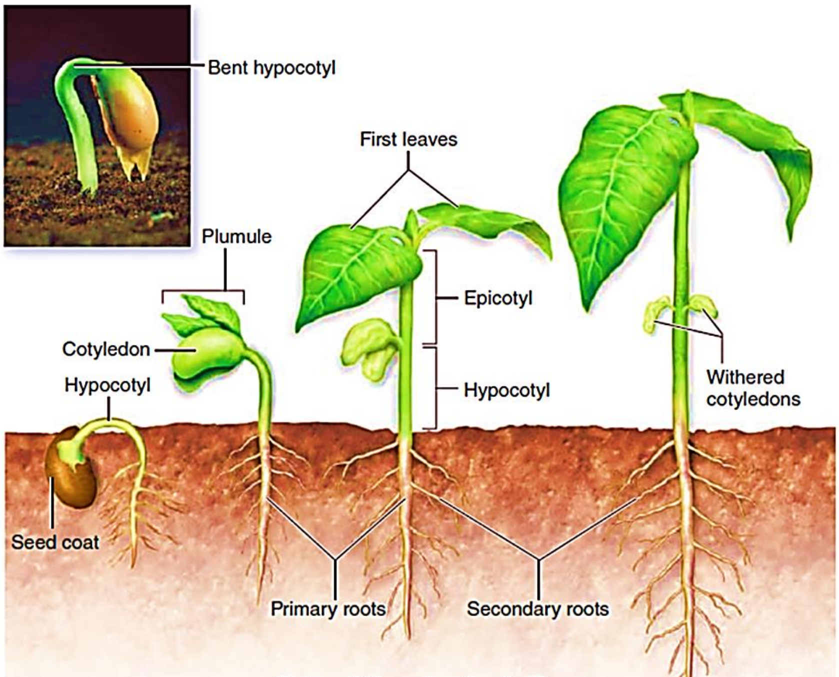
Seed Germination:

Seed germinates in favourable conditions. It absorbs water through micropyle and softens seed coat. The food present in seed gets mobilised by the activation of enzymes like amylase, lipase, protease and transported to embryo.

The radicle to grow first, followed by growth of either epicotyl or hypocotyl. After that plumule grows.

Seed germination can be of following types:

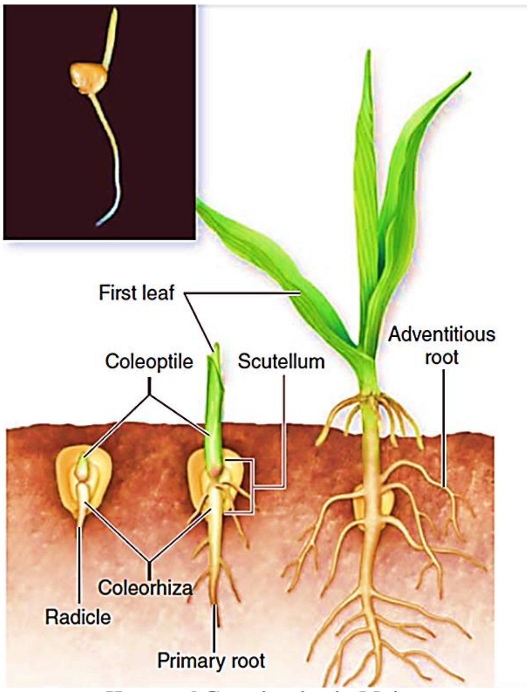
1. **Epigeal germination**: Here the cotyledons are pushed above the ground by the rapid ***elongation of hypocotyl***. The epicotyl stays the same length. Cotyledons soon turn green and start photosynthesising. Ex: Mung bean, Ricinus (castor), *Dolichos* (bean), *Helianthus* (sunflower) etc.



Epigeal Germination in Bean

2. **Hypogeal germination**: Here, the epicotyl elongates faster than hypocotyl at the time of seed germination. Thus the cotyledons remain inside the soil or may bring them just above the soil surface. They remain non-green, dry up gradually and fall off.
   Dicot seeds like pea, mango and most of the monocot seeds like maize, rice show hypogeal germination.

3. **Viviparous germination (Vivipary):** Germination of seeds inside the fruit, when it is still attached to the parent tree is called vivipary. It is a special type of seed germination occurring in plants that grow in sea coasts, i.e. Mangrove plants like *Avicennia*, *Rhizophora* etc



Hypogeal Germination in Maize

Did you know?

Orchid	*Smallest seed*	*12,50,000 seeds weighs around 1 gram.*
Double coconut (Lodoicea maldivica)	*Largest seed*	*One seed weighs between 15-30kgs*

Fruits:

- As ovules mature into seeds, **the ovary develops into a fruit**, i.e., the transformation of ovules into seeds and ovary into fruit proceeds simultaneously.
- The **wall of the ovary develops into the wall of fruit called *pericarp***. The pericarp is further divided into 3 layers; ***outer epicarp, middle mesocarp*** and ***inner endocarp***.
- The fruits may be **fleshy as in guava, orange, mango**, etc., or may be **dry, as in groundnut,** and **mustard,** etc**.**

Note:

Examples	***Type of fruit***	
1. Guava, Tomato, Brinjal etc.	*Berry*	
2. Mango, coconut etc.	*Drupe*	*Simple Fleshy Fruits*
3. Orange, lemon etc.	*Hesperidium*	
4. Ground nut	*Lomentum*	Simple dry dehiscent fruits
5. Mustard	*Siliqua*	

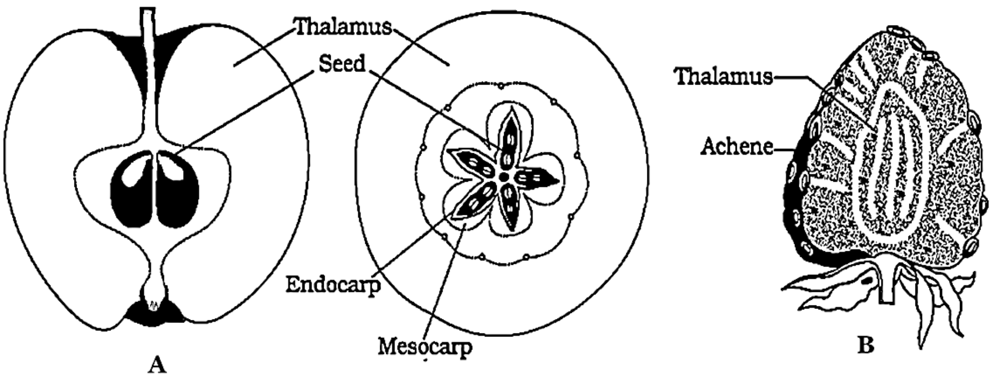
- Many fruits have evolved mechanisms for dispersal of seeds. For example in *Acer* (maple tree), *Ulmus* the ovarian wall is transformed into wings forming ***winged fruits*** called ***samara***. Similarly, in *Dandelion* the calyx being persistent is modified into hairy structure called ***pappus***, and the fruit is called ***cypsela***. This fruit ***disperses by parachute mechanism.***

- In most plants, by the time the fruit develops from the ovary, other floral parts degenerate and fall off.

False Fruits: In a few species such as apple, strawberry, cashew, etc., **the thalamus also contributes to fruit formation**. Such fruits are called ***false fruits/ pseudocarp***.

Note:

Examples	***Type of fruit***
1. Apple, Pear etc.	*Pome (Pseudocarp)*
2. Strawberry	*Etaerio of achenes (Aggregate Fruits) (Edible red part is thalamus)*
3. Cashew nut	*From ovary- Nut (Simple dry indehiscent fruit)* *From thalamus- fleshy false fruit*



False fruits: A- Apple; B- Strawberry

- Most fruits however **develop only from the ovary and are called *true fruits***.

Parthenocarpic Fruits: (Greek; *parthenos= virgin, karpos= fruit*)

The term parthenocarpy was first introduced by Noll in 1902. Later in 1939, Gustafsan successfully induced parthenocarpy in cucumber.

In a few species of plants **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** (auxins and gibberellins) and **such fruits are seedless**.

Fruits contain very large number of seeds. **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*.**

Apomixis (Greek = *"away from"* + *"mixing*")

Apomixis was defined by Hans Winkler as replacement of the normal sexual reproduction by asexual reproduction, without fertilization.

Some species of ***Asteraceae*** and ***Poaceae*** (***grasses)*** have evolved a special mechanism, to **produce seeds without fertilisation**, called ***apomixis***. Thus, **apomixis is a form of asexual reproduction that mimics sexual reproduction**.

The genetic nature of plants produced by apomixis is the same as that of parents and hence they can be called as clones

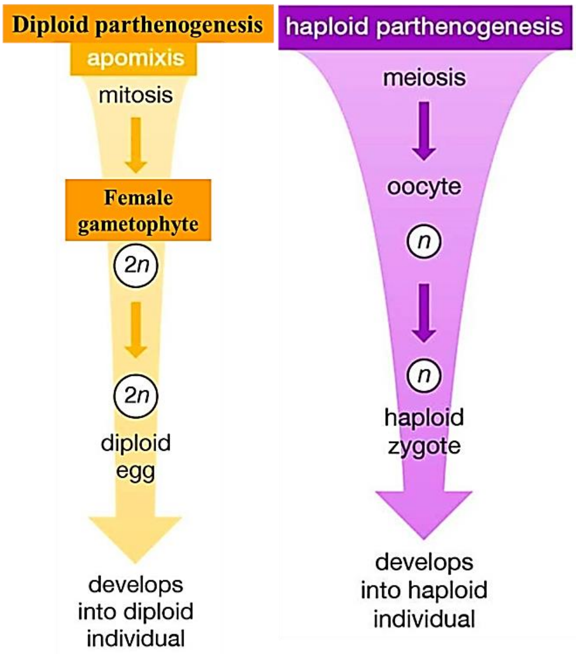
There are several ways of development of apomictic seeds.

a. **Apospory**: A **somatic cell in nucellus form an unreduced embryo sac** with a **diploid egg cell** formed without reduction division (meiosis) and develops into the embryo without fertilisation. Ex: Grasses
b. **Diplospory**: The **megaspore mother cell form an unreduced embryo sac** with a **diploid egg cell** formed without reduction division (meiosis) and develops into the embryo without fertilisation. Ex: Dandelion

Both are also referred to as ***diploid parthenogenesis.***

Parthenogenesis:

It refers to the formation of embryo from unfertilized egg or the female gametes. Hence the **progeny** produced will be **haploid**. In plants parthenogenesis is a **component process of apomixis**. It is also referred to as ***haploid parthenogenesis.***



Polyembryony

Antonie van Leeuwenhoek first described ***polyembryony*** in 1719 when the seed in ***Citrus*** was observed to have **two germinating embryos**. ***Occurrence of more than one embryo in a seed is referred to as polyembryony.***

In many species of ***Citrus*** and ***Mangifera 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. Such type of polyembryony is called ***adventive polyembryony*** which is a type of ***true polyembryony****.

*[**Note**: * True polyembryony is development of extra embryos from the cells of embryo sac (antipodal cell, synergids) or the cells surrounding embryo sac(nucellus and integuments)]*

Polyembryony observed in *Citrus* seed

Hybrid Varieties:

- Several of our food and vegetable crops are being extensively cultivated from hybrid varieties. 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 characters 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**.

Significance of Apomixis and its Utility:

- 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.

Don't compare your results to someone else's. You can never be another person.
You can only be a better version of yourself.
-Anonymous

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