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BIOLOGY

NCERT CLASS XII

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Chapter 1

SEXUAL REPRODUCTION IN FLOWERING PLANTS

Angiosperms (or **flowering plants**) are the most advanced terrestrial plants. All flowering plants perform **sexual reproduction**. During their sexual life cycle, flowering plants alternate between diploid *sporophytic phases* and haploid *gametophytic phases*. The haploid gametophytic body produces **gametes**, whereas the diploid sporophytic body produces **meiospores** (or *sexual spores*). Let us understand the processes of sexual reproduction in flowering plants, where **flowers** serve as the site for these processes.

1.1 Flower – A fascinating organ of angiosperms

The most distinguishing feature of flowering plants is the presence of *flowers*. Flowers have great aesthetic, ornamental, social, economic, religious, and cultural value for humans. The branch of *horticulture* concerned with growing and marketing flowers and ornamental plants is called **floriculture**. In angiospermic plants, flowers serve as the **reproductive units**. A typical flower has four types of *floral leaves* arranged in four whorls on the **thalamus**. These are **calyx**, **corolla**, **androecium** and **gynoecium**. These four whorls are divided into two groups:

- Accessory non-reproductive whorls (include **calyx** and **corolla**)
- Essential reproductive whorls (include **androecium** and **gynoecium**).

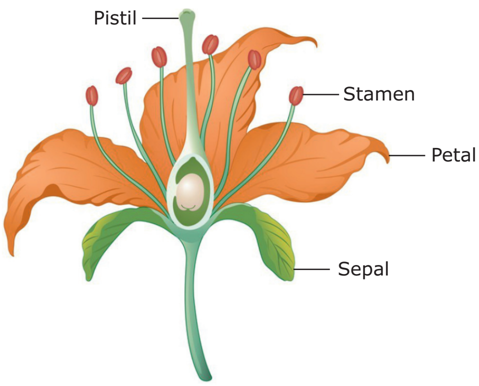


Figure 1.1 A typical flower structure. The part of the flower stalk to which the flower parts are attached is termed the receptacle. A typical flower has four whorls. From the outside in, the whorls are the sepals (collectively, the calyx); the petals (collectively, the corolla); the stamens (collectively, the androecium); and the carpels (collectively, the gynoecium).

A flower having all four floral components (calyx, corolla, androecium and gynoecium) is called **complete flower**, whereas a flower lacking one or more of the four components is called **incomplete flower**. The accessory non-reproductive parts of the flower are called **perianth**, includes both *calyx* and *corolla*. The **calyx** is the outer perianth of the flower. The individual units of the calyx are called **sepals**. It is generally green and leaf like and protects the flower bud. The **corolla** is the inner perianth of the flower. The individual units of the corolla are **petals**. The petals are generally large, brightly coloured and may have fragrance and help in pollination by attracting insects.

The essential reproductive parts of flower are *androecium* and *gynoecium*. The **androecium** is the microspore (pollen) producing male reproductive organ of a flower. The individual units of androecium are **stamens** (or **microsporophyll**). The **gynoecium** or **pistil** is the megaspore producing female reproductive organ of a flower. The individual units of gynoecium are **carpels** (or **megasporophyll**). The gynoecium is made up of one or more carpels. On the basis of the number of carpels, the gynoecium can be **simple** (or **monocarpellary**) or **compound** (or **multicarpellary**).

Simple gynoecium is made up of only one carpel, such as in the pea.

Compound gynoecium is made up of two or more carpels, such as in the mustard. The multicarpellary condition can be **syncarpous** (carpels are fused, such as in *Papaver*) or **apocarpous** (carpels are free, such as in *Michelia*).

Flower sex refers to the presence or absence of male and female parts within a flower. A flower having both stamens and carpels is called **perfect** or **bisexual** flower. *Most flowers are bisexual flowers*. Some flowers are **imperfect** or **unisexual** flower, having only stamens or carpels. When only stamens are present, it is said to be a **staminate** (male) flower and when only carpels are present, it is said to be a **pistillate** (female) flower. The presence of bisexual flower is likely the primitive character in angiosperms.

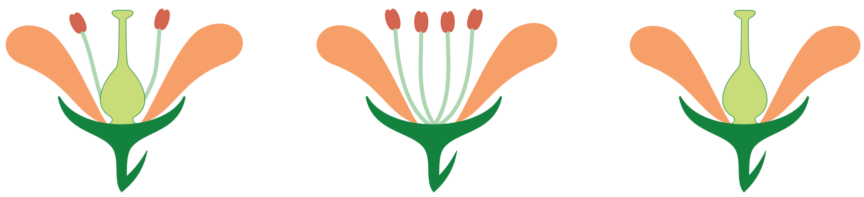


Figure 1.2 Flower sex – Bisexual flowers possess both stamens and carpels, while unisexual flowers can be categorized as either pistillate (female), where only carpels develop, or staminate (male), where only stamens develop.

Plant sex refers to the presence and distribution of perfect or imperfect flowers on individual plant of a species. Flowering plants can be *hermaphrodite*, *monoecious* and *dioecious*. A **hermaphroditic** plant contains only bisexual flowers. A **monoecious** plant contains both staminate and pistillate unisexual flowers on the single plant. A **dioecious** plant bears either staminate or pistillate unisexual flowers on separate plants, meaning each plant is either a male or female plant.

1.2 Pre-fertilization structures and events

What is a flower? We can define a flower, a *reproductive structure*, as modified reproductive shoots that develop through the transition from the *vegetative meristem* to the *floral meristem*. This transformation involves hormonal and structural changes, including the formation of inflorescences, which carry the floral buds that eventually bloom into flowers. Within a typical flower, the male (**androecium**) and female (**gynoecium**) reproductive structures differentiate and develop. The androecium consists of **stamens**, the *male reproductive organs*, while the gynoecium consists of **carpels**, the *female reproductive organs*. This intricate process ensures successful plant reproduction.

1.2.1 Stamen, microsporangium and pollen grain

The individual units of the *androecium* are *stamens* (microsporophylls). A **stamen** has two parts: the long and slender stalk called the **filament** and the terminal structure called the **anther**. The number and length of stamens vary in flowers of different species. A typical anther consists of *two lobes* (thecae) and is called **dithecal**. Each lobe contains two **microsporangia**. Thus, a typical anther is of the **tetrasporangiate type**, consisting of four microsporangia. The microsporangia develop further and become **pollen sacs**.

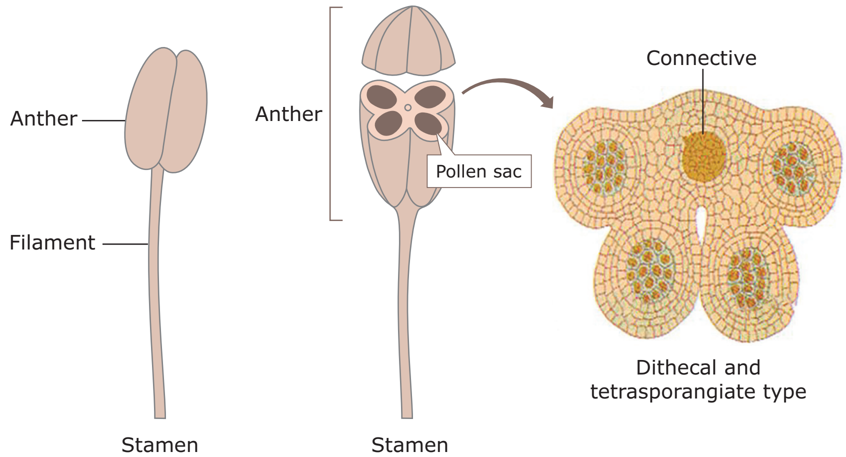


Figure 1.3 A typical anther is dithecal, meaning it consists of two thecae. Each theca contains two microsporangia, also known as pollen sacs. The tissue interconnecting the two thecae is termed the connective, to which the filament is attached.

Microsporangium

In a transverse section, a typical microsporangium is surrounded by four wall layers: an **epidermis**, an **endothecium**, 2 or 3 **middle layers**, and a **tapetum**. The epidermis, endothecium, and middle layers perform the protective function and aid in the dehiscence of the anther to release the pollen grains. The **tapetum** is the innermost layer of the anther wall. It supplies nutrients to the developing pollen grains and also plays an important role in pollen wall formation. The tapetum cells possess dense cytoplasm and generally have more than one nucleus. In tapetal cells, a multinucleate condition arises if the division of the tapetal cell nucleus (i.e. *karyokinesis*) is not followed by *cytokinesis*. When the anther is young, at the center of each microsporangium, there is a group of tightly packed homogeneous cells known as **sporogenous cells** (derived from *archesporial cells*). These sporogenous cells eventually differentiate into **microspore mother cells** (or *microsporocytes*), which produce microspores through meiosis.

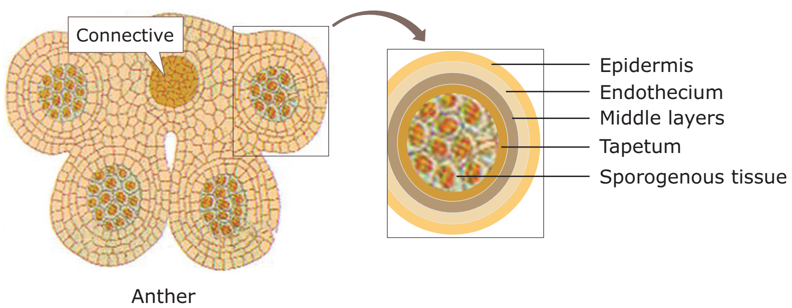


Figure 1.4 Transverse section of a young anther. Four wall layers, the epidermis, endothecium, middle layers and the tapetum surround the microsporangium. Cells of the sporogenous tissue lying in the center of the microsporangium, undergo meiosis to form microspores.

Microsporogenesis

The process of spore formation is called **sporogenesis**. The formation of the **microspores** is termed **microsporogenesis**. It occurs within the pollen sacs (i.e. microsporangia). The sporogenous cells function as **microspore mother cells** (also called **pollen mother cells**, **PMC**). Each PMC, through a meiotic division, gives rise to a group of four *haploid* microspores. The aggregates of four microspores are referred to as **microspore tetrads**. As the anthers mature and dehydrate, the microspores dissociate from each other and develop into **pollen grains**. Inside each microsporangium, several thousands of pollen grains are formed, which are released with the dehiscence of the anther.

Sporogenous cell (2n) → **Pollen mother cell** (2n) → (Meiosis) **Microspores** (n) → (Maturation) **Pollen grains** (n)

Pollen grain: Microspores, after their release from the tetrads, are referred to as **pollen grains**. Pollen grains from different species show a variety of sizes, shapes, colors, and designs. Pollen grains are generally spherical, measuring about 25-50 micrometers in diameter. The wall typically consists of an *exine* and an *intine*. The **exine**, which is the hard outer layer, is composed of **sporopollenin**, a highly resistant organic material. Sporopollenin can withstand high temperatures, strong acids, and alkalis, and so far, no enzyme capable of degrading it has been discovered. The hardness of the exine is an evolutionary adaptation that serves multiple protective functions, ensuring the successful dispersal and germination in diverse and challenging environments. The pollen grain has apertures or pores called **germ pores**. Sporopollenin is absent at the germ pores. The pollen tube emerges through these germ pores during germination. The inner wall of the pollen grain is called the **intine**. It is a thin and continuous layer made up of *cellulose* and *pectin* (**pecto-cellulosic**). The cytoplasm of the pollen grain is surrounded by a plasma membrane.

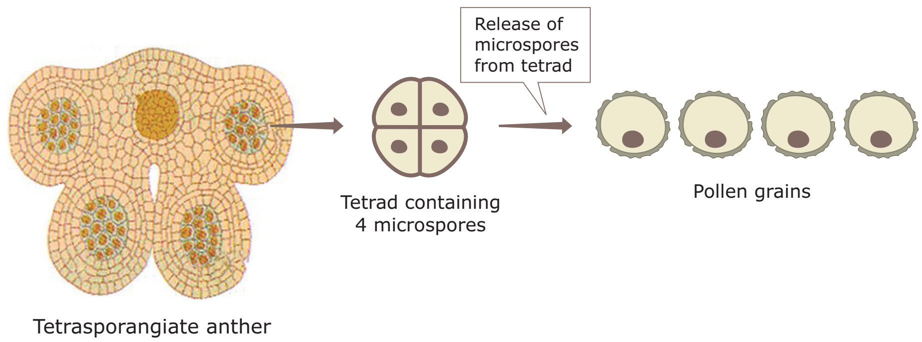


Figure 1.5 A typical anther is tetrasporangiate, meaning it contains four microsporangia. Within these microsporangia, pollen grains develop. The cells of the sporogenous tissue located in the center of the microsporangium undergo meiosis (microsporogenesis) to produce tetrads of microspores. These individual microspores then mature into pollen grains.

The pollen grain is the **male gametophyte**. The formation of the male gametophyte is called **microgametogenesis**. Each male gametophyte consists of two haploid cells: a small **generative cell** and a large **tube cell** (also known as the **vegetative cell**). The *vegetative cell* contains food reserves and a large, irregularly shaped nucleus. The *generative cell* floats in the cytoplasm of the vegetative cell. It is spindle shaped with dense cytoplasm and a nucleus. In over 60 percent of angiosperms, pollen grains are shed at this **2-celled stage**. In the remaining species, the generative cell undergoes mitotic division to produce the two non-motile male gametes before pollen grains are shed (**3-celled stage**). When viable and compatible pollen grains come into contact with the stigma, they germinate.

After being released from the anther, the period for which pollen grains remain viable is highly variable and to some extent depends also on the external environmental conditions (such as temperature and humidity). For instance, in certain cereals like *rice* and *wheat*, pollen grains lose their viability within a short span of 30 minutes after release. On the other hand, in certain plant families such as Rosaceae, Leguminoseae, and Solanaceae, pollen grains can remain viable for several months. It is also possible to store pollen grains of a large number of species for years in liquid nitrogen (–196°C), a method called **cryopreservation**. Such stored pollen can be used as **pollen banks**, similar to seed banks, in crop breeding programmes.

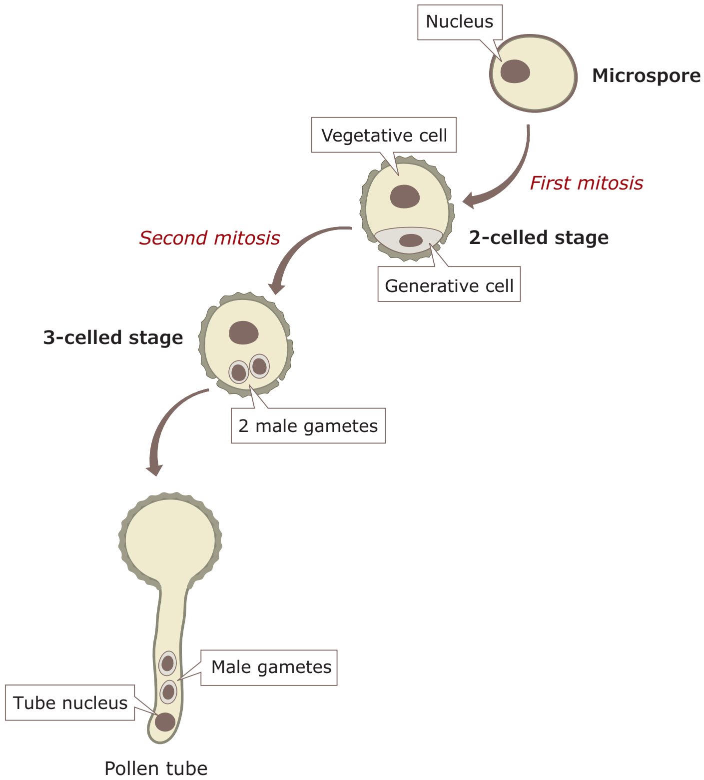


Figure 1.6 The stages of microspore maturation into a pollen grain. During the maturation process, individual microspores undergo a transformation, leading to the formation of pollen grains. These pollen grains serve as the male gametophyte. The process of male gametophyte formation is known as microgametogenesis. Each male gametophyte is composed of two haploid cells: a small generative cell and a larger vegetative cell. The generative cell undergoes mitotic division to produce the two non-motile male gametes. Pollen grains can shed at either the 2-celled stage or the 3-celled stage. In the 2-celled stage, the pollen grains consist of the generative cell and the vegetative cell. On the other hand, in the 3-celled stage, the pollen grains contain the vegetative cell, and the two non-motile male gametes.

Pollen grains from various species have the potential to cause severe allergies and respiratory disorders, including chronic conditions such as *asthma* and *bronchitis*. One notable example is ***Parthenium***, commonly known as **carrot grass**, which has become a prevalent source of pollen allergies in India. Interestingly, *Parthenium* was introduced to India as a contaminant with imported wheat.

In recent years, there has been a growing trend of using pollen as a food supplement due to its rich nutrient content. It has also been claimed that consuming pollen enhances the performance of athletes and race horses.

1.2.2 Pistil, megasporangium and embryo sac

The **pistil** or **gynoecium** represents the *female reproductive* part of the flower. The individual units of gynoecium are **carpels** (**megasporophyll**). Each *carpel* has three parts: the *stigma*, *style* and *ovary*.

Ovary: It is the swollen basal part of the carpel that contains one or more *ovules*, also called **megasporangia**. The chamber within the ovary that bears the ovule(s) is known as the **ovarian cavity** or **locule**. The number of ovules in an ovary can vary, ranging from one (found in wheat, paddy, and mango) to many (found in papaya, watermelon, and orchids). The ovules remain attached to the tissue of the ovary within the ovarian cavity called the **placenta**. The arrangement of ovules within the ovary is referred to as **placentation**. After fertilization, the ovules develop into *seeds*, and the ovary matures into a *fruit*.

Stigma: It is attached to the style and is responsible for receiving the pollen grains during pollination.

Style: It is the elongated and slender part of the carpel that connects the ovary to the stigma.

Ovule

The *ovule* (or **megasporangium**) is located within the ovary and serves as the site for *megaspore* formation. It is a complex structure consisting of the nucellus, one or two integuments, and funiculus. **Integuments** act as protective envelopes. If an ovule possesses two integuments, it is referred to as **bitegmic**. On the other hand, if an ovule has only one integument, it is known as **unitegmic**. The mass of cells enclosed within the integuments, which contains large reserve food materials, is called the **nucellus**. The stalk connecting the ovule to the placenta is called the **funiculus**. The point of contact between the ovule and the funiculus is called **hilum**. The ovule exhibits distinct polarity with two ends: the *micropylar end* and the *chalazal end*. At the micropylar end, which is located at the tip of the ovule, there is a small opening called the **micropyle**. The micropyle serves as a passage for pollen tubes to enter the ovule during the process of fertilization. On the other hand, the chalazal end represents the basal part of the ovule called **chalaza**. It is situated opposite to the micropylar end.

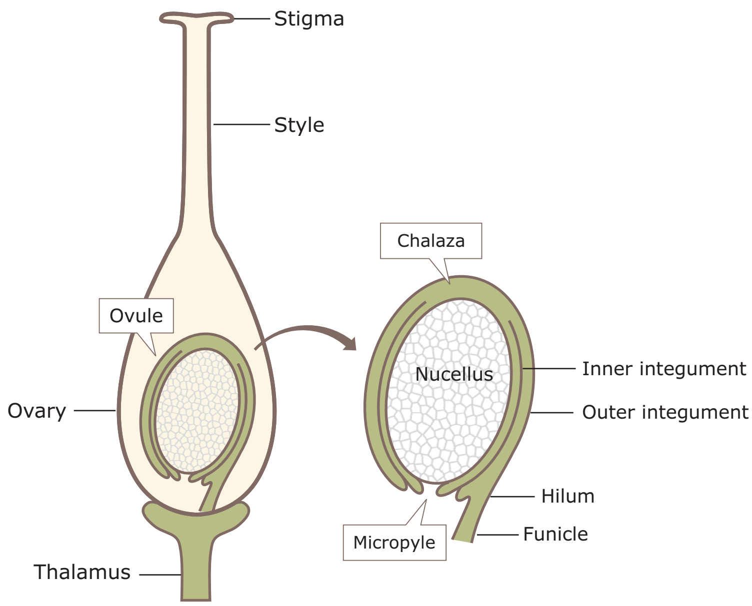


Figure 1.7 The pistil has three parts – the stigma, style and the ovary. Ovules are present within the ovary. The ovules have a stalk called funicle, protective integument(s), and an opening called micropyle. The central tissue within the ovule is called the nucellus, which plays a crucial role in the development and nourishment of the embryo sac. The point of contact between the ovule and the funiculus is referred to as the hilum. The ovule displays clear polarity, characterized by two distinct ends: the micropylar end and the chalazal end.

Megasporogenesis

The process of megaspore formation within the ovule is known as **megasporogenesis**. Megasporogenesis involves three main events: the formation of the megaspore mother cell, meiosis to produce haploid megaspores, and the selection of a megaspore to develop into the female gametophyte. Within the nucellus, a single cell enlarges and transforms into the **archesporial cell**. Typically, in the micropylar region of the nucellus, the archesporial cell directly differentiates into a single **megaspore mother cell** (or **megasporocyte**). This megaspore mother cell is a large cell with dense cytoplasm and a prominent nucleus. It undergoes meiotic division, resulting in the formation of a **linear tetrad** comprising four megaspores. In most angiospermic plants, three of the four megaspores degenerate, while the one farthest from the micropyle survives and develops into the embryo sac (or female gametophyte). This type of embryo sac formation from a single megaspore is referred to as **monosporic** megasporogenesis, as only one of the four megaspores contributes to the female gametophyte. Angiosperms also exhibit two other patterns of megasporogenesis known as *bisporic* and *tetrasporic*.

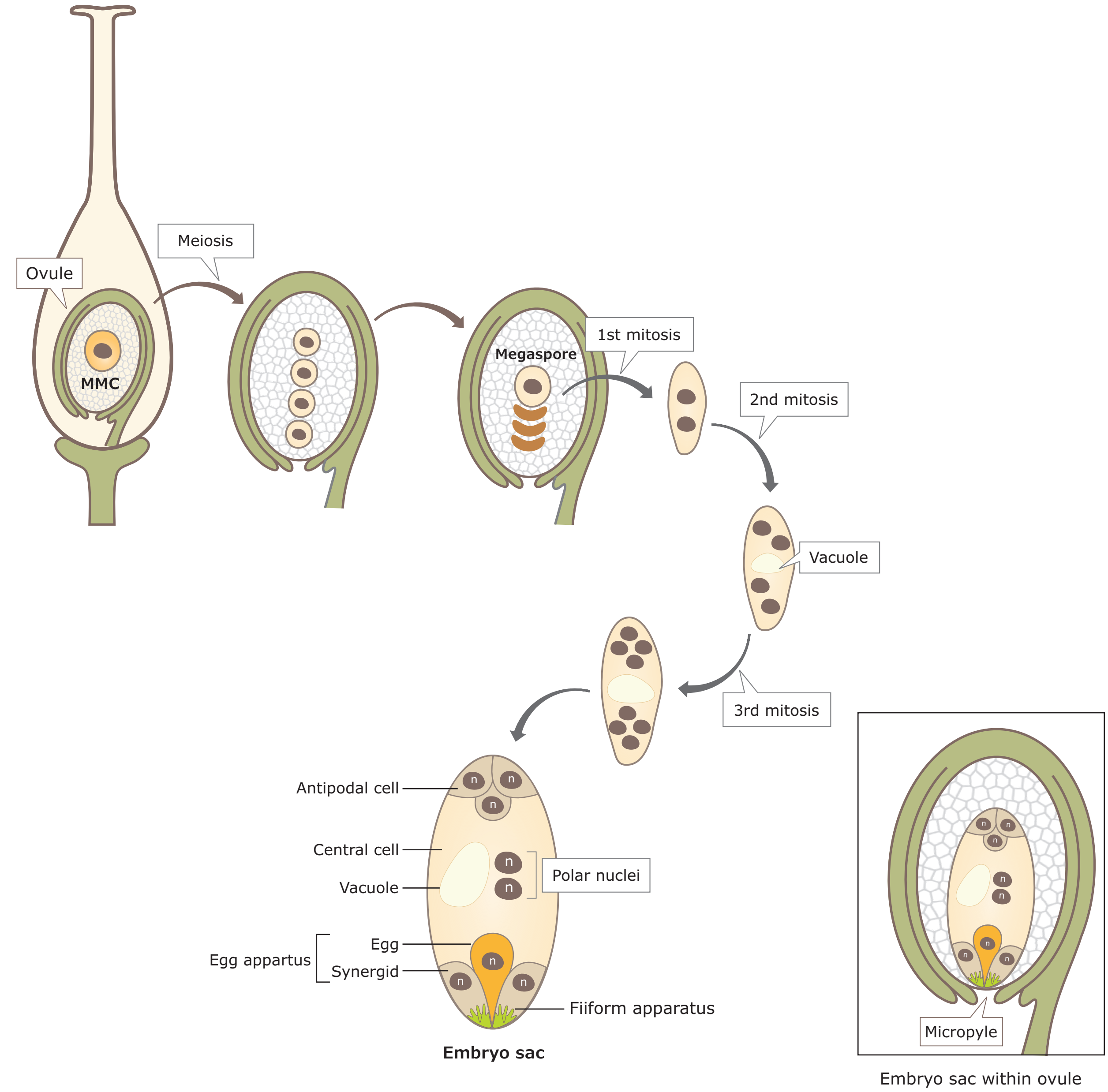
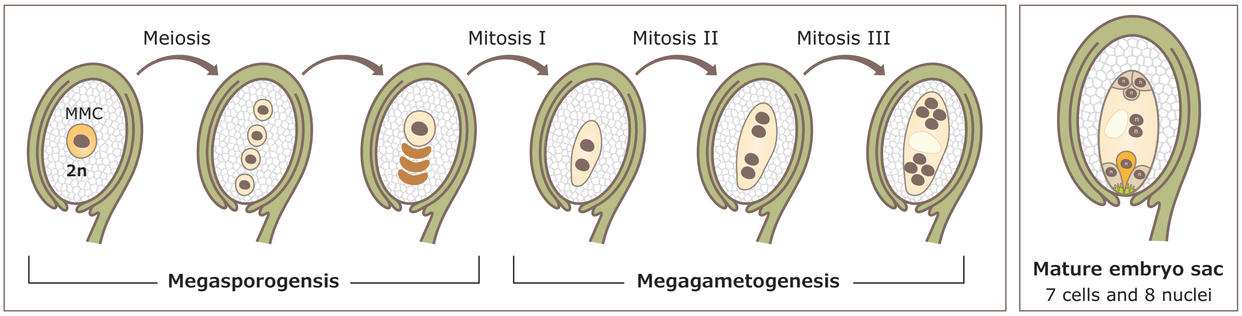


Figure 1.8 Megasporogenesis and megagametogenesis. A cell of the archesporium, the megaspore mother cell (MMC) divides meiotically and one of the megaspores forms the embryo sac (the female gametophyte). The mature embryo sac is 7-celled and 8-nucleate. At the micropylar end is the egg apparatus consisting of two synergids and an egg cell. At the chalazal end are three antipodals. At the centre is a large central cell with two polar nuclei.

Female gametophyte

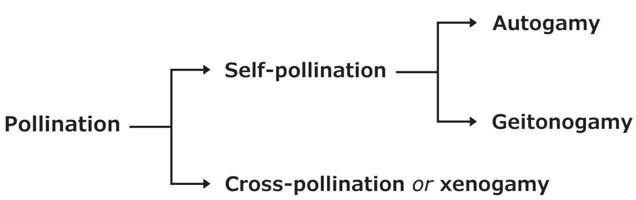
The **embryo sac** represents the *female gametophyte*, and its formation is known as **megagametogenesis**. During this process, the nuclei of the megaspore undergo three consecutive *mitotic divisions*, resulting in an eight-nucleated embryo sac. The first mitotic division produces two nuclei that move to opposite poles, forming a **2-nucleate** embryo sac. Two more sequential divisions lead to the formation of the **4-nucleate** and, eventually, the **8-nucleate** embryo sac. These divisions occur without immediate cell wall formation, known as *free nuclear divisions*. After the 8-nucleate stage, cellular organization takes place. Six of the eight nuclei are enclosed within cells, while the remaining two nuclei, called **polar nuclei**, reside in the large **central cell**.

The cells within the embryo sac are distributed in a characteristic pattern. At the micropylar end, three cells constitute the **egg apparatus**, which consists of two **synergids** and one **egg cell**. The synergids possess special cellular thickenings called **filiform apparatus** at the micropylar tip, which aid in guiding pollen tubes into the synergid. Three cells are located at the chalazal end and are known as **antipodal cells**. The large central cell, as mentioned earlier, contains two polar nuclei. Thus, a mature embryo sac, despite being 8-nucleated, consists of seven cells. The eight-nucleated cell is organized into the **seven-celled** embryo sac. This pattern of megasporogenesis and megagametogenesis is referred to as the **polygonum type**.



1.2.3 Pollination

The male and female gametes in flowering plants are produced in the pollen grain and embryo sac, respectively. As both types of gametes are *non-motile*, they must be brought together for fertilization to occur. How is this achieved? This objective is accomplished through the process of **pollination**, which involves the transfer of pollen grains from the anther to the stigma of a pistil. Depending on the source of pollen, pollination can be divided into two types – **self-pollination** and **cross-pollination** (also called **xenogamy**).



Self-pollination (also called **inbreeding** or **selfing**) can occur through two processes: *autogamy* and *geitonogamy*.

In **autogamy**, pollination is completed within the same flower, involving the transfer of pollen grains from the anther to the stigma of the same flower. For autogamy to occur, the flowers must be bisexual, containing both male and female reproductive structures. Certain natural conditions, such as *cleistogamy*, ensure self-pollination. **Cleistogamy** is a condition in which the flowers (called **cleistogamous flowers**) do not open at all, making them invariably autogamous as there is no chance for cross-pollination. In nature, the majority of flowers are **chasmogamous**, in contrast to cleistogamous flowers. *Chasmogamous flowers* open at maturity, exposing their anthers and stigma to facilitate pollination. Some plants, such as *Viola* (common pansy), *Oxalis*, and *Commelina*, produce both types of flowers - *chasmogamous* as well as *cleistogamous* flowers.

If pollen grains are transferred from the anther to the stigma of another flower on the same plant, it is known as **geitonogamy**. Functionally, geitonogamy is considered cross-pollination, but genetically, it is similar to autogamy since the pollen grains come from the same plant.

Cross-pollination (or **xenogamy**) refers to the transfer of pollen from the flower of one plant to the flower of another genetically unrelated plant of the same species.

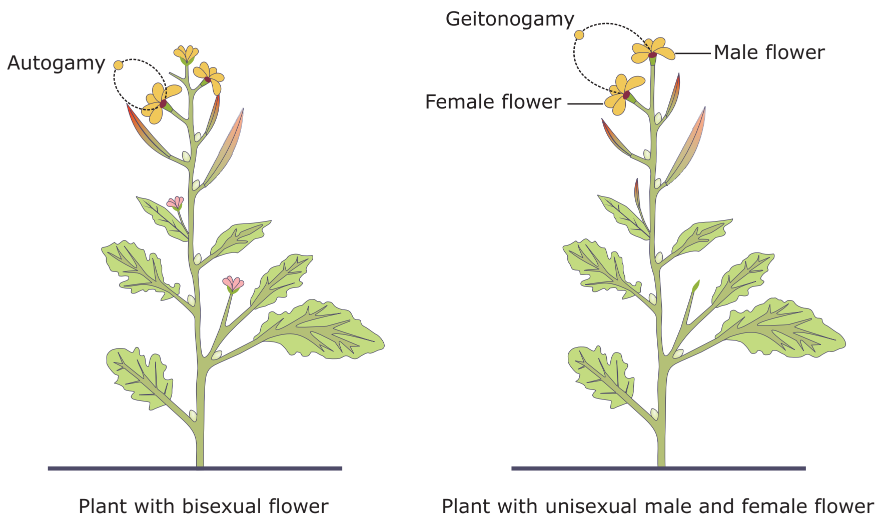


Figure 1.9 Self-pollination can take place through two distinct processes: autogamy and geitonogamy. In autogamy, pollen grains are transferred from the anther to the stigma of the same flower. On the other hand, geitonogamy involves the transfer of pollen grains from the anther to the stigma of another flower on the same plant.

Some authors classify pollination into two categories: *autogamy* and *allogamy*. **Autogamy** refers to pollination within a flower, i.e. self-pollination, while **allogamy** involves pollination between different flowers. Furthermore, allogamy is subdivided into **geitonogamy** (pollination between different flowers on the same plant) and **xenogamy** (pollination between flowers of different plants of same species).

Agents of pollination

Pollination is mediated through the assistance of **pollinating agents**. These agents can be either *biotic* (such as animals) or *abiotic* (such as wind and water). The majority of plants rely on biotic agents for pollination, while only a small fraction employs abiotic agents.

Abiotic-pollinating agents

When pollinating agents are abiotic, such as ***wind*** or ***water***, the contact between pollen grains and the stigma occurs by chance. To compensate this uncertainty, these plants produce a large number of pollen grains as compared to the number of available ovules for pollination. Among abiotic pollinating agents, **wind pollination** (or **anemophily**) is more prevalent. Wind-pollinated flowers possess specific characteristics:

- They are small in size, lack bright colors, and do not produce nectar.
- Each ovary typically contains a single ovule.
- Flowers are often packed in an inflorescence, which helps to increase the chances of capturing airborne pollens.
- They produce lightweight and non-sticky pollen grains, enabling them to be carried by wind currents.
- The stamens are generally exposed to air currents, facilitating the easy dispersal of pollen into the air.
- The stigmas are often large and feathery, aiding in the capture of airborne pollen grains.

Wind-pollination is quite common in grasses. A familiar example is the **corn cob**. Corn plants are *monoecious*, meaning they have both male and female flowers on the same plant. They produce male flowers on a terminal **tassel** and female flowers on lateral **ears**. However, both male and female flowers initially develop as bisexual flowers. During development, the female parts of the male flowers and the male parts of the female flowers abort. This results in the development of unisexual male and female flowers. In NCERT, the tassels are incorrectly described as female parts (stigmas and styles) to trap pollen grains.

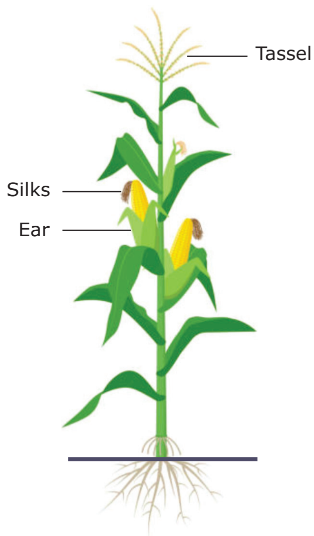


Figure 1.10
Corn plants are classified as monoecious, which means they bear both male and female flowers on the same plant. The male flowers are produced on a terminal tassel, while the female flowers emerge on lateral ears.

Pollination by water (**hydrophily**) is rare in flowering plants. Water pollination occur in aquatic plants with flowers either at or under the water surface. They include both freshwater plants, such as ***Vallisneria*** and ***Hydrilla***, and marine water plants, such as seagrasses ***Zostera***. Just like air-pollinated plants, flowers of water-pollinated plants tend to lack bright colors and do not produce nectar. Additionally, many water-pollinated species have evolved mechanisms to safeguard their pollen grains from getting wet, often by employing a protective mucilaginous coating.

In ***Vallisneria***, hydrophilous pollination occurs on the water surface. *Vallisneria* species grow submerged at the bottom of freshwater bodies. Female flowers develop underwater and are brought to the water surface by the elongation of their slender peduncle. Male flowers also develop underwater but detach from the plant when mature. These male flowers rise to the water surface, where the sepals open, exposing the stamens. The dispersed male flowers on the water surface aggregate around a female flower, and pollination occurs when a stamen contacts the stigma. After pollination, the peduncle of the female flower coils up tightly, retracting the pollinated flower underwater.

Figure 1.11
In *Vallisneria*, the female flowers reach the surface of the water by a long stalk, and the male flowers are released onto the water's surface. The male flowers are carried passively by water currents and come in contact with the female flowers. Pollination occurs when a stamen contacts the stigma.

In **seagrasses**, the female flowers remain submerged in water and the pollen grains are released inside the water. Pollen grains are carried passively inside the water; some of them reach the stigma and complete pollination. Not all aquatic plants use water for pollination. In many aquatic plants, such as **water hyacinth** and **water lily**, the flowers emerge above the water's surface and are pollinated by insects or wind, just like most land plants.