PLANT REPRODUCTION

Chapter

INTRODUCTION

Plants have developed various strategies, both sexual and asexual, to ensure reproductive success. Plants have evolved different reproductive strategies for the continuation of their species. Some plants reproduce sexually while others reproduce asexually, in contrast to animal species, which rely almost exclusively on sexual reproduction. Plant sexual reproduction usually depends on pollinating agents, while asexual reproduction is independent of these agents. Flowers are often the showiest or most strongly-scented part of plants. With their bright colors, fragrances, and interesting shapes and sizes, flowers attract insects, birds, and animals to serve their pollination needs. Other plants pollinate via wind or water; still others self-pollinate.

Asexual Reproduction

Vegetative reproduction is a type of asexual reproduction. Other terms that apply are vegetative propagation, clonal growth, or vegetative multiplication. Vegetative growth is enlargement of the individual plant, while vegetative reproduction is any process that results in new plant "individuals" without production of seeds or spores. It is both a natural process in many, many species as well as a process utilized or encouraged by horticulturists and farmers to obtain quantities of economically-valuable plants. In this respect, it is a form of cloning that has been carried out by humanity for thousands of years and by plants for hundreds of millions of years.

Sexual Reproduction and The Flower

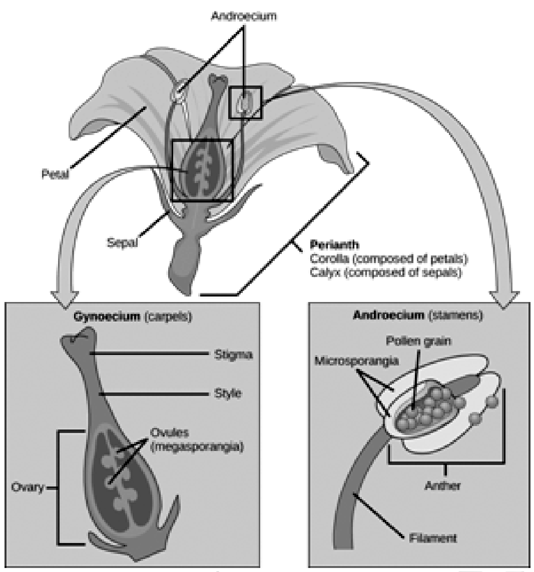
The flower is the reproductive organ of plants classified as angiosperms. All plants have the means and corresponding structures for reproducing sexually. The basic function of a flower is to produce seeds through sexual reproduction. Seeds are the next generation, serving as the primary method in most plants by which individuals of the species are dispersed across the landscape. Actual dispersal is, in most species, a function of the fruit (a structural part that typically surrounds the seed).

Sexual Reproduction in Angiosperms

Angiosperms may be monoecious or dioecious and undergo sexual reproduction . The lifecycle of angiosperms follows the alternation of generations. In the angiosperm, the haploid gametophyte alternates with the diploid sporophyte during the sexual reproduction process of angiosperms. Flowers contain the plant's reproductive structures.

Flower Structure

A typical flower has four main parts, or whorls: the calyx, corolla, androecium, and gynoecium . The outermost whorl of the flower has green, leafy structures known as sepals, which are collectively called the calyx, and help to protect the unopened bud. The second whorl is comprised of petals, usually brightly colored, collectively called the corolla. The number of sepals and petals varies depending on whether the plant is a monocot or dicot. Together, the calyx and corolla are known as the perianth. The third whorl contains the male reproductive structures and is known as the androecium. The androecium has stamens with anthers that contain the microsporangia. The innermost group of structures in the flower is the gynoecium, or the female reproductive component(s). The carpel is the individual unit of the gynoecium and has a stigma, style, and ovary. A flower may have one or multiple carpels.

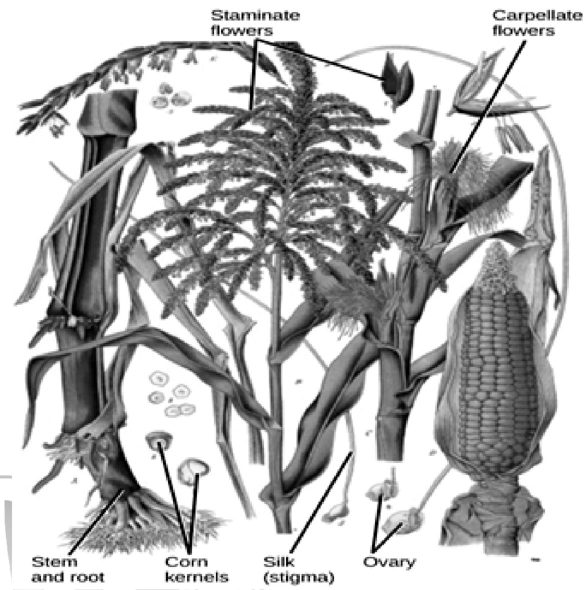


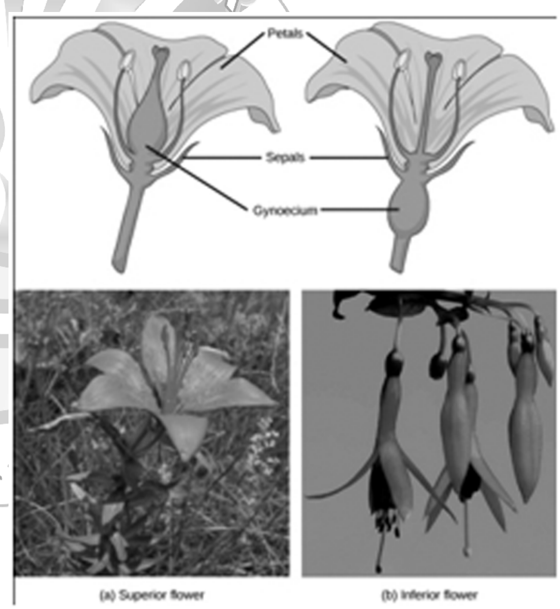
Structures of the Flower

If all four whorls are present, the flower is described as complete. If any of the four parts is missing, the flower is known as incomplete. Flowers that contain both an androecium and a gynoecium are called perfect, androgynous, or hermaphrodites. There are two types of incomplete flowers: staminate flowers contain only and androecium; and carpellate flowers have only a gynoecium.

Staminate and Carpellate Flowers

If both male and female flowers are borne on the same plant (e.g., corn or peas), the species is called monoecious (meaning "one home"). Species with male and female flowers borne on separate plants (e.g., C. papaya or Cannabis)are termed dioecious, or "two homes." The ovary, which may contain one or multiple ovules, may be placed above other flower parts (referred to as superior); or it may be placed below the other flower parts (referred to as inferior).

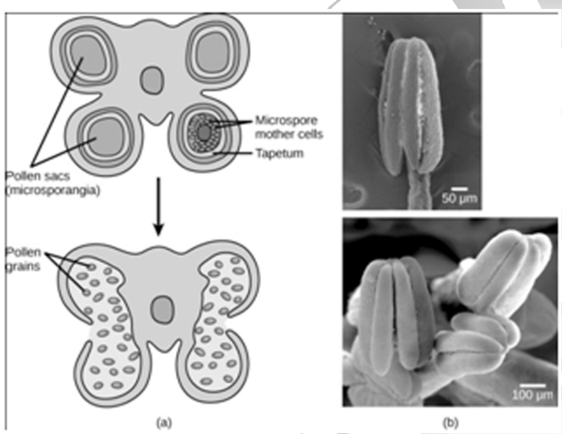




Superior and Inferior Flower

Male Gametophyte

The male gametophyte develops and reaches maturity in an immature anther. In a plant's male reproductive organs, development of pollen takes place in a structure known as the microsporangium . The microsporangia, usually bi-lobed, are pollen sacs in which the microspores develop into pollen grains. Within the microsporangium, the microspore mother cell divides by meiosis to give rise to four microspores, each of which will ultimately form a pollen grain . An inner layer of cells, known as the tapetum, provides nutrition to the developing microspores, contributing key components to the pollen wall. Mature pollen grains contain two cells: a generative cell and a pollen tube cell. The generative cell is contained within the larger pollen tube cell. Upon germination, the tube cell forms the pollen tube through which the generative cell migrates to enter the ovary. During its transit inside the pollen tube, the generative cell divides to form two male gametes.

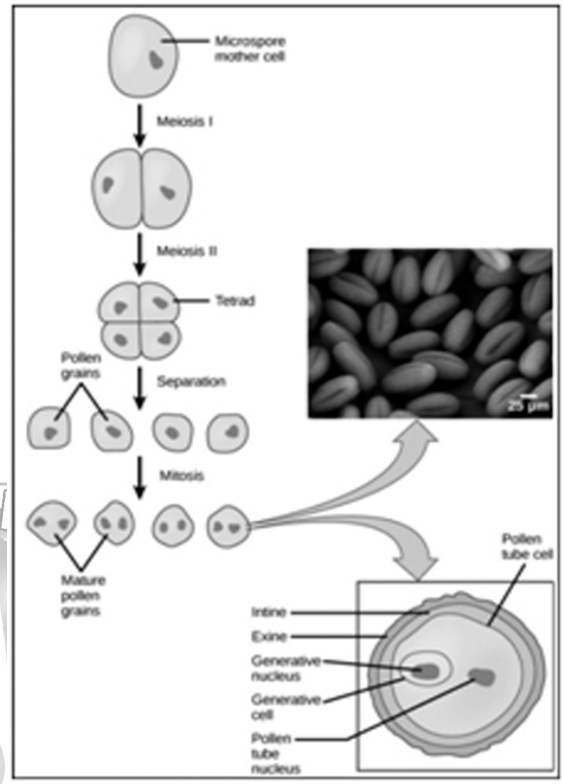


Microsporangium

Upon maturity, the microsporangia burst, releasing the pollen grains from the anther. Each pollen grain has two coverings: the exine (thicker, outer layer) and the intine . The exine contains sporopollenin, a complex waterproofing substance supplied by the tapetal cells. Sporopollenin allows the pollen to survive under unfavorable conditions and to be carried by wind, water, or biological agents without undergoing damage.

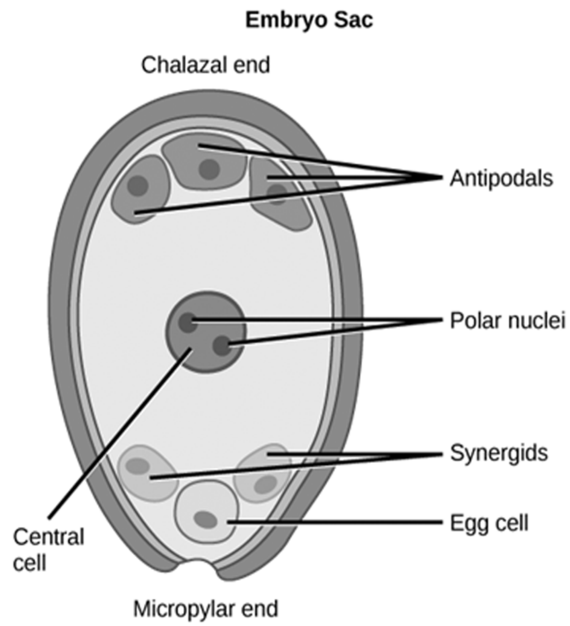
Female Gametophyte (Embryo Sac)

The overall development of the female gametophyte has two distinct phases. First, in the process of megasporogenesis, a single cell in the diploid megasporangium undergoes



Pollen Grain Structure

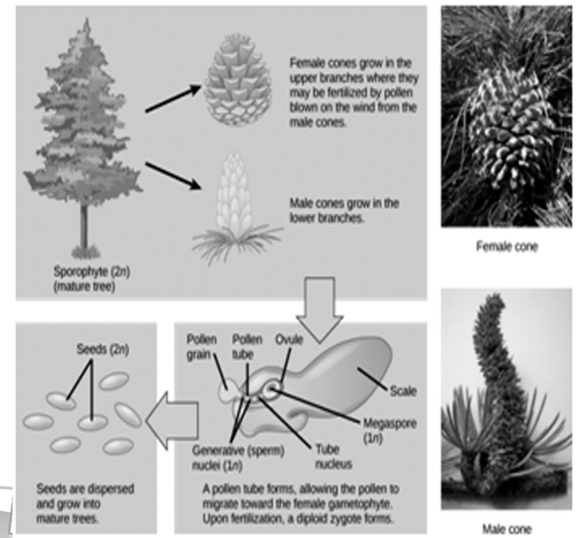
meiosis to produce four megaspores, only one of which survives. During the second phase, megagametogenesis, the surviving haploid megaspore undergoes mitosis to produce an eight-nucleate, seven-cell female gametophyte, also known as the megagametophyte, or embryo sac. The polar nuclei move to the equator and fuse, forming a single, diploid central cell. This central cell later fuses with a sperm to form the triploid endosperm. Three nuclei position themselves on the end of the embryo sac opposite the micropyle and develop into the antipodal cells, which later degenerate. The nucleus closest to the micropyle becomes the female gamete, or egg cell, and the two adjacent nuclei develop into synergid cells . The synergids help guide the pollen tube for successful fertilization, after which they disintegrate. Once fertilization is complete, the resulting diploid zygote develops into the embryo; the fertilized ovule forms the other tissues of the seed.



A double-layered integument protects the megasporangium and, later, the embryo sac. The integument will develop into the seed coat after fertilization, protecting the entire seed. The ovule wall will become part of the fruit. The integuments, while protecting the megasporangium, do not enclose it completely, but leave an opening called the micropyle. The micropyle allows the pollen tube to enter the female gametophyte for fertilization.

Sexual Reproduction in Gymnosperms

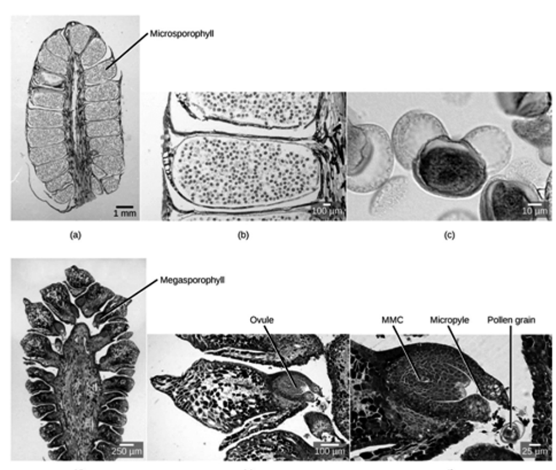
Gymnosperms produce both male and female gametophytes on separate cones and rely on wind for pollination. As with angiosperms, the life cycle of gymnosperms is also characterized by alternation of generations. In conifers such as pines, the green leafy part of the plant is the sporophyte; the cones contain the male and female gametophytes . The female cones are larger than the male cones and are positioned towards the top of the tree; the small, male cones are located in the lower region of the tree. Because the pollen is shed and blown by the wind, this arrangement makes it difficult for a gymnosperm to self-pollinate.



Conifer life cycle

Male Gametophyte

A male cone has a central axis on which bracts, a type of modified leaf, are attached. The bracts, known as microsporophylls, are the sites where microspores will develop . The microspores develop inside the microsporangium. Within the microsporangium, cells known as microsporocytes divide by meiosis to produce four haploid microspores. Further mitosis of the microspore produces two nuclei: the generative nucleus and the tube nucleus. Upon maturity, the male gametophyte (pollen) is released from the male cones and is carried by the wind to land on female cones.



Male and female gametophytes

Female Gametophyte

The female cone also has a central axis on which bracts known as megasporophylls are present . In the female cone, megaspore mother cells are present in the megasporangium. The megaspore mother cell divides by meiosis to produce four haploid megaspores. One of the megaspores divides to form the multicellular female gametophyte, while the others divide to form the rest of the structure. The female gametophyte is contained within a structure called the archegonium.

Reproductive Process

Upon landing on the female cone, the tube cell of the pollen forms the pollen tube, through which the generative cell migrates towards the female gametophyte through the micropyle. It takes approximately one year for the pollen tube to grow and migrate towards the female gametophyte. The male gametophyte containing the generative cell splits into two sperm nuclei, one of which fuses with the egg, while the other degenerates. After fertilization of the egg, the diploid zygote is formed, which divides by mitosis to form the embryo. The scales of the cones are closed during development of the seed. The seed is covered by a seed coat, which is derived from the female sporophyte. Seed development takes another one to two years. Once the seed is ready to be dispersed, the bracts of the female cones open to allow the dispersal of seed; no fruit formation takes place because gymnosperm seeds have no covering.

Angiosperms Versus Gymnosperms

Gymnosperm reproduction differs from that of angiosperms in several ways. In angiosperms, the female gametophyte in the ovule exists in an enclosed structure, the ovary; in gymnosperms, the female gametophyte is present on exposed bracts of the female cone and is not enclosed in an ovary. Double fertilization is a key event in the life cycle of angiosperms, but is completely absent in gymnosperms. The male and female gametophyte structures are present on separate male and female cones in gymnosperms, whereas in angiosperms, they are a part of the flower. Finally, wind plays an important role in pollination in gymnosperms because pollen is blown by the wind to land on the female cones. Although many angiosperms are also wind-pollinated, animal pollination is more common.

POLLINATION-AND-FERTILIZATION

Plants can transfer pollen through self-pollination; however, the preferred method is cross-pollination, which maintains genetic diversity.

Pollination

In angiosperms, pollination is defined as the placement or transfer of pollen from the anther to the stigma of the same or a different flower. In gymnosperms, pollination involves pollen transfer from the male cone to the female cone. Upon transfer, the pollen germinates to form the pollen tube and the sperm that fertilize the egg.

Self-Pollination and Cross-Pollination

Pollination takes two forms: self-pollination and cross-pollination. Self-pollination occurs when the pollen from the anther is deposited on the stigma of the same flower or another flower on the same plant. Cross-pollination is the transfer of pollen from the anther of one flower to the stigma of another flower on a different individual of the same species. Self-pollination occurs in flowers where the stamen and carpel mature at the same time and are positioned so that the pollen can land on the flower's stigma. This method of pollination does not require an investment from the plant to provide nectar and pollen as food for pollinators. These types of pollination have been studied since the time of Gregor Mendel. Mendel successfully carried out self-pollination and cross-pollination in garden peas while studying how characteristics were passed on from one generation to the next. Today's crops are a result of plant breeding, which employs artificial selection to produce the present-day cultivars. An example is modern corn, which is a result of thousands of years of breeding that began with its ancestor, teosinte. The teosinte that the ancient Mesoamericans originally began cultivating had tiny seeds, vastly different from today's relatively giant ears of corn. Interestingly, though these two plants appear to be entirely different, the genetic difference between them is minuscule.

Genetic Diversity

Living species are designed to ensure survival of their progeny; those that fail become extinct. Genetic diversity is, therefore, required so that in changing environmental or stress conditions, some of the progeny can survive. Self-pollination leads to the production of plants with less genetic diversity since genetic material from the same plant is used to form gametes and, eventually, the zygote. In contrast, cross-pollination leads to greater genetic diversity because the male and female gametophytes are derived from different plants. Because cross-pollination allows for more genetic diversity, plants have developed many ways to avoid self-pollination. In some species, the pollen and the ovary mature at different times. These flowers make self-pollination nearly impossible. By the time pollen matures and has been shed, the stigma of this flower is mature and can only be pollinated by pollen from another flower. Some flowers have developed physical features that prevent self-pollination. The primrose employs this technique. Primroses have evolved two flower types with differences in anther and stigma length: the pin-eyed flower and the thrum-eyed flower. In the pin-eyed flower, anthers are positioned at the pollen tube's halfway point, and in the thrum-eyed flower, the stigma is found at this same location. This allows insects to easily cross-pollinate while seeking nectar at the pollen tube. This phenomenon is also known as heterostyly. Many plants, such as cucumbers, have male and female flowers located on different parts of the plant, thus making self-pollination difficult. In other species, the male and female flowers are borne on different plants, making them dioecious. All of these are barriers to self-pollination; therefore, the plants depend on pollinators to transfer pollen. The majority of pollinators are biotic agents such as insects (bees, flies, and butterflies), bats, birds, and other animals . Other plant species are pollinated by abiotic agents, such as wind and water.

Pollination by Insects

Plants have developed adaptations to promote symbiotic relationships with insects that ensure their pollination.

Bees

Bees are perhaps the most important pollinator of many garden plants and most commercial fruit trees . The most common species of bees are bumblebees and honeybees. Since bees cannot see the color red, bee-pollinated flowers usually have shades of blue, yellow, or other colors. Bees collect energy-rich pollen or nectar for their survival and energy needs. They visit flowers that are open during the day, are brightly colored, have a strong aroma or scent, and have a tubular shape, typically with the presence of a nectar guide. A nectar guide includes regions on the flower petals that are visible only to bees, which help guide bees to the center of the flower, thus making the pollination process more efficient. The pollen sticks to the bees' fuzzy hair; when the bee visits another flower, some of the pollen is transferred to the second flower. Recently, there have been many reports about the declining population of honeybees. Many flowers will remain unpollinated, failing to bear seeds if honeybees disappear. The impact on commercial fruit growers could be devastating.

Flies

Many flies are attracted to flowers that have a decaying smell or an odor of rotting flesh. These flowers, which produce nectar, usually have dull colors, such as brown or purple. They are found on the corpse flower or voodoo lily (Amorphophallus), dragon arum (Dracunculus), and carrion flower (Stapleia, Rafflesia). The nectar provides energy while the pollen provides protein. Wasps are also important insect pollinators, pollinating many species of figs.

Butterflies and Moths

Butterflies, such as the monarch, pollinate many garden flowers and wildflowers, which are usually found in clusters. These flowers are brightly colored, have a strong fragrance, are open during the day, and have nectar guides. The pollen is picked up and carried on the butterfly's limbs. Moths, on the other hand, pollinate flowers during the late afternoon and night. The flowers pollinated by moths are pale or white and are flat, enabling the moths to land. One well-studied example of a moth-pollinated plant is the yucca plant, which is pollinated by the yucca moth. The shape of the flower and moth have adapted in a way to allow successful pollination. The moth deposits pollen on the sticky stigma for fertilization to occur later. The female moth also deposits eggs into the ovary. As the eggs develop into larvae, they obtain food from the flower and developing seeds. Thus, both the insect and flower benefit from each other in this symbiotic relationship. The corn earworm moth and Gaura plant have a similar relationship.

Pollination by Bats, Birds, Wind, and Water

Non-insect methods of pollination include pollination by bats, birds, wind, and water. Plants have developed specialized adaptations to take advantage of non-insect forms of pollination. These methods include pollination by bats, birds, wind, and water.

Pollination by Bats

In the tropics and deserts, bats are often the pollinators of nocturnal flowers such as agave, guava, and morning glory. The flowers are usually large and white or pale-colored so that they can be distinguished from their dark surroundings at night. The flowers have a strong, fruity, or musky fragrance and produce large amounts of nectar. They are naturally-large and wide-mouthed to accommodate the head of the bat. As the bats seek the nectar, their faces and heads become covered with pollen, which is then transferred to the next flower.

Pollination by Birds

Many species of small birds, such as hummingbirds and sun birds, are pollinators for plants such as orchids and other wildflowers . Flowers visited by birds are usually sturdy and are oriented in a way to allow the birds to stay near the flower without getting their wings entangled in the nearby flowers. The flower typically has a curved, tubular shape, which allows access for the bird's beak. Brightly-colored, odorless flowers that are open during the day are pollinated by birds. As a bird seeks energy-rich nectar, pollen is deposited on the bird's head and neck and is then transferred to the next flower it visits. Botanists determine the range of extinct plants by collecting and identifying pollen from 200-year-old bird specimens from the same site.

Pollination by Wind

Most species of conifers and many angiosperms, such as grasses, maples, and oaks, are pollinated by wind. Pine cones are brown and unscented, while the flowers of wind-pollinated angiosperm species are usually green, small, may have small or no petals, and produce large amounts of pollen. Unlike the typical insect-pollinated flowers, flowers adapted to pollination by wind do not produce nectar or scent. In wind-pollinated species, the microsporangia hang out of the flower, and, as the wind blows, the lightweight pollen is carried with it . The flowers usually emerge early in the spring before the leaves so that the leaves do not block the movement of the wind. The pollen is deposited on the exposed feathery stigma of the flower.

Pollination by Water

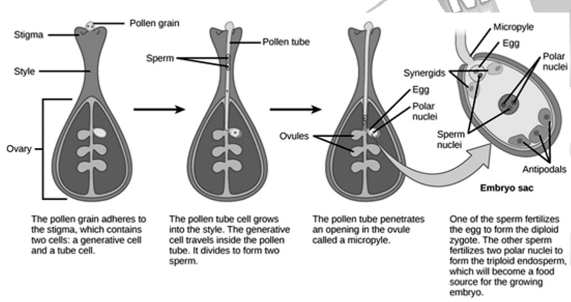
Some weeds, such as Australian sea grass and pond weeds, are pollinated by water. The pollen floats on water. When it comes into contact with the flower, it is deposited inside the flower.

Pollination by Deception

Orchids are highly-valued flowers, with many rare varieties. They grow in a range of specific habitats, mainly in the tropics of Asia, South America, and Central America. At least 25,000 species of orchids have been identified. Flowers often attract pollinators with food rewards, in the form of nectar. However, some species of orchid are an exception to this standard; they have evolved different ways to attract the desired pollinators. They use a method known as food deception, in which bright colors and perfumes are offered, but no food. Anacamptis morio, commonly known as the green-winged orchid, bears bright purple flowers and emits a strong scent. The bumblebee, its main pollinator, is attracted to the flower because of the strong scent, which usually indicates food for a bee. In the process, the bee picks up the pollen to be transported to another flower. Other orchids use sexual deception . Chiloglottis trapeziformis emits a compound that smells the same as the pheromone emitted by a female wasp to attract male wasps. The male wasp is attracted to the scent, lands on the orchid flower, and, in the process, transfers pollen. Some orchids, like the Australian hammer orchid, use scent as well as visual trickery in yet another sexual deception strategy to attract wasps. The flower of this orchid mimics the appearance of a female wasp and emits a pheromone. The male wasp tries to mate with what appears to be a female wasp, but instead picks up pollen, which it then transfers to the next counterfeit mate.

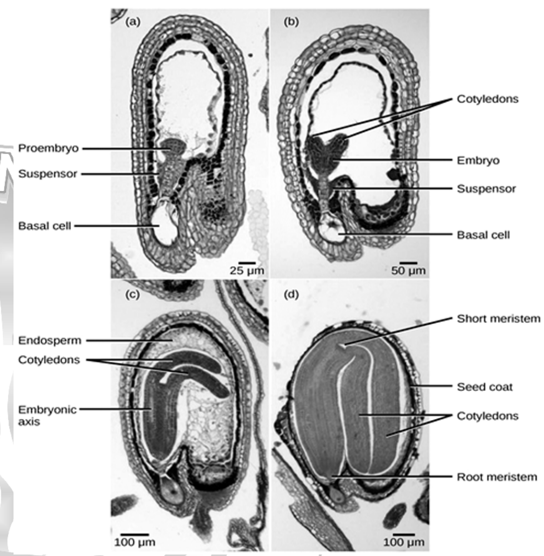
Double Fertilization

Angiosperms undergo two fertilization events where a zygote and endosperm are both formed. After pollen is deposited on the stigma, it must germinate and grow through the style to reach the ovule. The microspores, or the pollen, contain two cells: the pollen tube cell and the generative cell. The pollen tube cell grows into a pollen tube through which the generative cell travels. The germination of the pollen tube requires water, oxygen, and certain chemical signals. As it travels through the style to reach the embryo sac, the pollen tube's growth is supported by the tissues of the style. During this process, if the generative cell has not already split into two cells, it now divides to form two sperm cells. The pollen tube is guided by the chemicals secreted by the synergids present in the embryo sac; it enters the ovule sac through the micropyle. Of the two sperm cells, one sperm fertilizes the egg cell, forming a diploid zygote; the other sperm fuses with the two polar nuclei, forming a triploid cell that develops into the endosperm. Together, these two fertilization events in angiosperms are known as double fertilization . After fertilization is complete, no other sperm can enter. The fertilized ovule forms the seed, whereas the tissues of the ovary become the fruit, usually enveloping the seed.



Double fertilization

After fertilization, embryonic development begins. The zygote divides to form two cells: the upper cell (terminal cell) and the lower cell (basal cell). The division of the basal cell gives rise to the suspensor, which eventually makes connection with the maternal tissue. The suspensor provides a route for nutrition to be transported from the mother plant to the growing embryo. The terminal cell also divides, giving rise to a globular-shaped proembryo. In dicots (eudicots), the developing embryo has a heart shape due to the presence of the two rudimentary cotyledons. In non-endospermic dicots, such as Capsella bursa, the endosperm develops initially, but is then digested. In this case, the food reserves are moved into the two cotyledons. As the embryo and cotyledons enlarge, they become crowded inside the developing seed and are forced to bend. Ultimately, the embryo and cotyledons fill the seed, at which point, the seed is ready for dispersal . Embryonic development is suspended after some time; growth resumes only when the seed germinates. The developing seedling will rely on the food reserves stored in the cotyledons until the first set of leaves begin photosynthesis.



Embryo development

Development of the Seed

Monocot and dicot seeds develop in differing ways, but both contain seeds with a seed coat, cotyledons, endosperm, and a single embryo.

Parts of a Seed

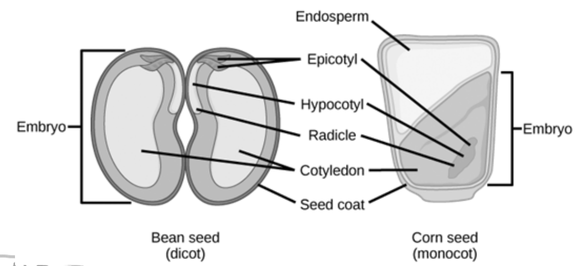
The seed, along with the ovule, is protected by a seed coat that is formed from the integuments of the ovule sac. In dicots, the seed coat is further divided into an outer coat, known as the testa, and inner coat, known as the tegmen. The embryonic axis consists of three parts: the plumule, the radicle, and the hypocotyl. The portion of the embryo between the cotyledon attachment point and the radicle is known as the hypocotyl. The embryonic axis terminates in a radicle, which is the region from which the root will develop.

Seed Growth

In angiosperms, the process of seed development begins with double fertilization and involves the fusion of the egg and sperm nuclei into a zygote. The second part of this process is the fusion of the polar nuclei with a second sperm cell nucleus, thus forming a primary endosperm. Right after fertilization, the zygote is mostly inactive, but the primary endosperm divides rapidly to form the endosperm tissue. This tissue becomes the food the young plant will consume until the roots have developed after germination. The seed coat forms from the two integuments or outer layers of cells of the ovule, which derive from tissue from the mother plant: the inner integument forms the tegmen and the outer forms the testa. When the seed coat forms from only one layer, it is also called the testa, though not all such testae are homologous from one species to the next. In gymnosperms, the two sperm cells transferred from the pollen do not develop seed by double fertilization, but one sperm nucleus unites with the egg nucleus and the other sperm is not used. Sometimes each sperm fertilizes an egg cell and one zygote is then aborted or absorbed during early development. The seed is composed of the embryo and tissue from the mother plant, which also form a cone around the seed in coniferous plants such as pine and spruce. The ovules after fertilization develop into the seeds.

Food Storage in the Seed

The storage of food reserves in angiosperm seeds differs between monocots and dicots . In monocots, the single cotyledon is called a scutellum; it is connected directly to the embryo via vascular tissue. Food reserves are stored in the large endosperm. Upon germination, enzymes are secreted by the aleurone, a single layer of cells just inside the seed coat that surrounds the endosperm and embryo. The enzymes degrade the stored carbohydrates, proteins, and lipids. These products are absorbed by the scutellum and transported via a vasculature strand to the developing embryo.

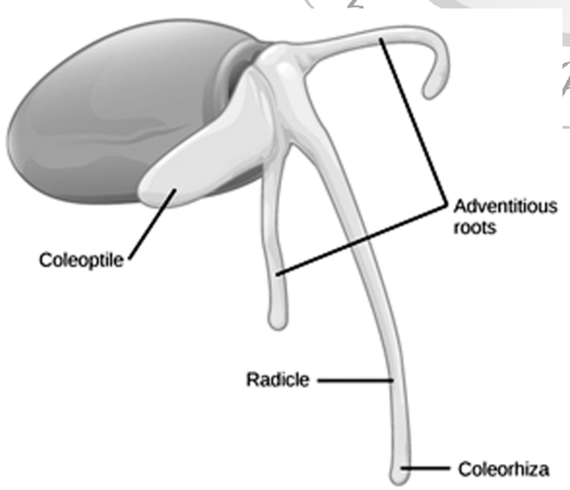


Monocots and dicots

In endospermic dicots, the food reserves are stored in the endosperm. During germination, the two cotyledons act as absorptive organs to take up the enzymatically-released food reserves, similar to the process in monocots. In non-endospermic dicots, the triploid endosperm develops normally following double fertilization, but the endosperm food reserves are quickly remobilized, moving into the developing cotyledon for storage.

Seed Germination

Upon germination in dicot seeds, the epicotyl is shaped like a hook with the plumule pointing downwards; this plumule hook persists as long as germination proceeds in the dark. Therefore, as the epicotyl pushes through the tough and abrasive soil, the plumule is protected from damage. Upon exposure to light, the hypocotyl hook straightens out, the young foliage leaves face the sun and expand, and the epicotyl continues to elongate. During this time, the radicle is also growing and producing the primary root. As it grows downward to form the tap root, lateral roots branch off to all sides, producing the typical dicot tap root system. In monocot seeds, the testa and tegmen of the seed coat are fused. As the seed germinates, the primary root emerges, protected by the root-tip covering: the coleorhiza. Next, the primary shoot emerges, protected by the coleoptile: the covering of the shoot tip. Upon exposure to light, elongation of the coleoptile ceases and the leaves expand and unfold. At the other end of the embryonic axis, the primary root soon dies, while other, adventitious roots emerge from the base of the stem . This produces the fibrous root system of the monocot. Depending on seed size, the time it takes a seedling to emerge may vary. However, many mature seeds enter a period of dormancy marked by inactivity or extremely-low metabolic activity. This period may last for months, years, or even centuries. Dormancy helps keep seeds viable during unfavorable conditions. Upon a return to optimal conditions, seed germination takes place. These conditions may be as diverse as moisture, light, cold, fire, or chemical treatments. Scarification, the softening of the seed coat, presoaking in hot water, or passing through an acid environment, such as an animal's digestive tract, may also be needed.



Monocot seeds

Development of Fruit and Fruit Types

Fruits are categorized based on the part of the flower they developed from and how they release their seeds. After fertilization, the ovary of the flower usually develops into the fruit. Fruits are generally associated with having a sweet taste; however, not all fruits are sweet. The term "fruit" is used for a ripened ovary. In most cases, flowers in which fertilization has taken place will develop into fruits, while unfertilized flowers will not. The fruit encloses the seeds and the developing embryo, thereby providing it with protection. Fruits are diverse in their origin and texture. The sweet tissue of the blackberry, the red flesh of the tomato, the shell of the peanut, and the hull of corn (the tough, thin part that gets stuck in your teeth when you eat popcorn) are all fruits. As the fruit matures, the seeds also mature. Fruits may be classified as simple, aggregate, multiple, or accessory, depending on their origin . If the fruit develops from a single carpel or fused carpels of a single ovary, it is known as a simple fruit, as seen in nuts and beans. An aggregate fruit is one that develops from numerous carpels that are all in the same flower; the mature carpels fuse together to form the entire fruit, as seen in the raspberry. A multiple fruit develops from an inflorescence or a cluster of flowers. An example is the pineapple where the flowers fuse together to form the fruit. Accessory fruits (sometimes called false fruits) are not derived from the ovary, but from another part of the female gametophyte, such as the receptacle (strawberry) or the hypanthium (apples and pears). Fruits generally have three parts: the exocarp (the outermost skin or covering), the mesocarp (middle part of the fruit), and the endocarp (the inner part of the fruit). Together, all three are known as the pericarp. The mesocarp is usually the fleshy, edible part of the fruit; however, in some fruits, such as the almond, the endocarp is the edible part. In many fruits, two, or all three of the layers are fused, and are indistinguishable at maturity. Fruits can be dry or fleshy. Furthermore, fruits can be divided into dehiscent or indehiscent types. Dehiscent fruits, such as peas, readily release their seeds, while indehiscent fruits, like peaches, rely on decay to release their seeds.

Fruit and Seed Dispersal

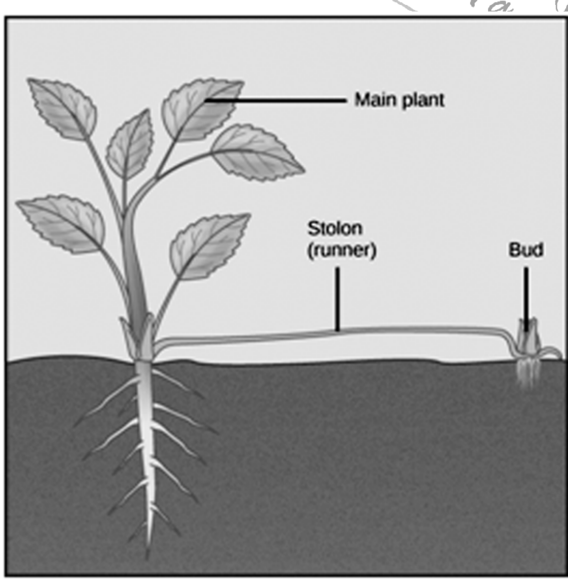
Some fruits can disperse seeds on their own, while others require assistance from wind, water, or animals. The fruit has a single purpose: seed dispersal. Seeds contained within fruits need to be dispersed far from the mother plant so that they may find favorable and less-competitive conditions in which to germinate and grow. Some fruits have built-in mechanisms that allow them to disperse by themselves, whereas others require the help of agents such as wind, water, and animals. Modifications in seed structure, composition, and size aid in dispersal. Wind-dispersed fruit are lightweight and may have wing-like appendages that allow them to be carried by the wind. Some have a parachute-like structure to keep them afloat. Some fruits, such as the dandelion, have hairy, weightless structures that are suited to dispersal by wind . Seeds dispersed by water are contained in light and buoyant fruit, giving them the ability to float. Coconuts are well known for their ability to float on water to reach land where they can germinate. Similarly, willow and silver birches produce lightweight fruit that can float on water. Animals and birds eat fruits; seeds that are not digested are excreted in their droppings some distance away. Some animals, such as squirrels, bury seed-containing fruits for later use; if the squirrel does not find its stash of fruit, and if conditions are favorable, the seeds germinate. Some fruits have hooks or sticky structures that stick to an animal's coat and are then transported to another place. Humans also play a major role in dispersing seeds when they carry fruits to new places, throwing away the inedible part that contains the seeds. All of the above mechanisms allow for seeds to be dispersed through space, much as an animal's offspring can move to a new location. Seed dormancy allows plants to disperse their progeny through time: something animals cannot do. Dormant seeds can wait months, years, or even decades for the proper conditions for germination and propagation of the species.

ASEXUAL REPRODUCTION

Plants can reproduce asexually, without the fertilization of gametes, by either vegetative reproduction or apomixis. Many plants are able to propagate themselves using asexual reproduction. This method does not require the investment required to produce a flower, attract pollinators, or find a means of seed dispersal. Asexual reproduction produces plants that are genetically identical to the parent plant because no mixing of male and female gametes takes place. Traditionally, these plants survive well under stable environmental conditions when compared with plants produced from sexual reproduction because they carry genes identical to those of their parents. Plants have two main types of asexual reproduction: vegetative reproduction and apomixis. Vegetative reproduction results in new plant individuals without the production of seeds or spores. Many different types of roots exhibit vegetative reproduction . The corm is used by gladiolus and garlic. Bulbs, such as a scaly bulb in lilies and a tunicate bulb in daffodils, are other common examples of this type of reproduction. A potato is a stem tuber, while parsnip propagates from a taproot. Ginger and iris produce rhizomes, while ivy uses an adventitious root (a root arising from a plant part other than the main or primary root), and the strawberry plant has a stolon, which is also called a runner. Some plants can produce seeds without fertilization. Either the ovule or part of the ovary, which is diploid in nature, gives rise to a new seed. This method of reproduction is known as apomixis. An advantage of asexual reproduction is that the resulting plant will reach maturity faster. Since the new plant is arising from an adult plant or plant parts, it will also be sturdier than a seedling. Asexual reproduction can take place by natural or artificial (assisted by humans) means.

Natural and Artificial Methods of Asexual Reproduction

Plants can undergo natural methods of asexual reproduction, performed by the plant itself, or artificial methods, aided by humans. Natural methods of asexual reproduction include strategies that plants have developed to self-propagate. Many plants, such as ginger, onion, gladioli, and dahlia, continue to grow from buds that are present on the surface of the stem. In some plants, such as the sweet potato, adventitious roots or runners (stolons) can give rise to new plants . In Bryophyllum and kalanchoe, the leaves have small buds on their margins. When these are detached from the



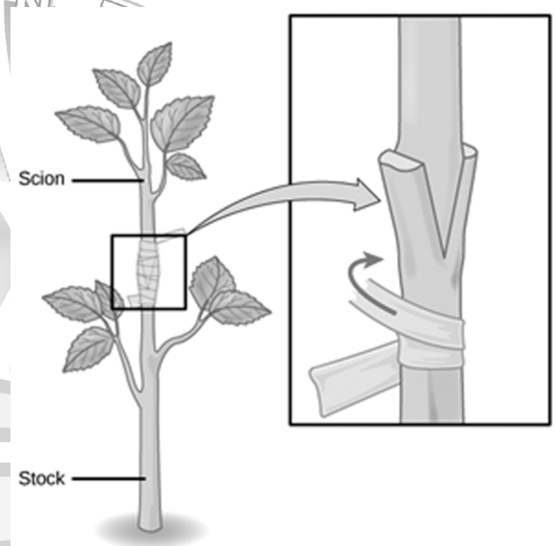
Runners: asexual reproduction

plant, they grow into independent plants; they may also start growing into independent plants if the leaf touches the soil. Some plants can be propagated through cuttings alone.

Artificial Methods of Asexual Reproduction

Artificial methods of asexual reproduction are frequently employed to give rise to new, and sometimes novel, plants. They include grafting, cutting, layering, and micropropagation.

Grafting



Grafting

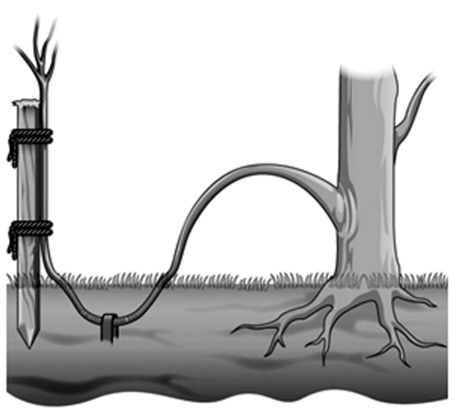
Grafting has long been used to produce novel varieties of roses, citrus species, and other plants. In grafting, two plant species are used: part of the stem of the desirable plant is grafted onto a rooted plant called the stock. The part that is grafted or attached is called the scion . Both are cut at an oblique angle (any angle other than a right angle), placed in close contact with each other, and are then held together. Matching up these two surfaces as closely as possible is extremely important because these will be holding the plant together. The vascular systems of the two plants grow and fuse, forming a graft. After a period of time, the scion starts producing shoots, eventually bearing flowers and fruits. Grafting is widely used in viticulture (grape growing) and the citrus industry. Scions capable of producing a particular fruit variety are grafted onto root stock with specific resistance to disease.

Cutting

Plants such as coleus and money plant are propagated through stem cuttings where a portion of the stem containing nodes and internodes is placed in moist soil and allowed to root. In some species, stems can start producing a root even when placed only in water. For example, leaves of the African violet will root if kept undisturbed in water for several weeks.

Layering

Layering is a method in which a stem attached to the plant is bent and covered with soil . Young stems that can be bent easily without any injury are the preferred plant for this method. Jasmine and bougainvillea (paper flower) can be propagated this way. In some plants, a modified form of layering known as air layering is employed. A portion of the bark or outermost covering of the stem is removed and covered with moss, which is then taped. Some gardeners also apply rooting hormone. After some time, roots will appear; this portion of the plant can be removed and transplanted into a separate pot.



Layering

Micropropagation

Micropropagation (also called plant tissue culture) is a method of propagating a large number of plants from a single plant in a short time under laboratory conditions. This method allows propagation of rare, endangered species that may be difficult to grow under natural conditions, are economically important, or are in demand as disease-free plants. To start plant tissue culture, a part of the plant such as a stem, leaf, embryo, anther, or seed can be used. The plant material is thoroughly sterilized using a combination of chemical treatments standardized for that species. Under sterile conditions, the plant material is placed on a plant tissue culture medium that contains all the minerals, vitamins, and hormones required by the plant. The plant part often gives rise to an undifferentiated mass, known as a callus, from which, after a period of time, individual plantlets begin to grow. These can be separated; they are first grown under greenhouse conditions before they are moved to field conditions.

Plant Life Spans

The life cycles and life spans of plants vary and are affected by environmental and genetic factors. The length of time from the beginning of development to the death of a plant is called its life span. The life cycle, on the other hand, is the sequence of stages a plant goes through from seed germination to seed production of the mature plant. Some plants, such as annuals, only need a few weeks to grow, produce seeds, and die. Other plants, such as the bristlecone pine, live for thousands of years . Some bristlecone pines have a documented age of 4,500 years. Even as some parts of a plant, such as regions containing meristematic tissue (the area of active plant growth consisting of undifferentiated cells capable of cell division) continue to grow, some parts undergo programmed cell death (apoptosis). The cork found on stems and the water-conducting tissue of the xylem, for example, are composed of dead cells.

Annuals, Biennial, and Perennials

Plant species that complete their life cycle in one season are known as annuals, an example of which is Arabidopsis, or mouse-ear cress. Biennials, such as carrots, complete their life cycle in two seasons. In a biennial's first season, the plant has a vegetative phase, whereas in the next season, it completes its reproductive phase. Commercial growers harvest the carrot roots after the first year of growth and do not allow the plants to flower. Perennials, such as the magnolia, complete their life cycle in two years or more.

Monocarpic and Polycarpic Plants

In another classification based on flowering frequency, monocarpic plants flower only once in their lifetime; examples of monocarpic plants include bamboo and yucca. During the vegetative period of their life cycle (which may be as long as 120 years in some bamboo species), these plants may reproduce asexually, accumulating a great deal of food material that will be required during their once-in-a-lifetime flowering and setting of seed after fertilization. Soon after flowering, these plants die. Polycarpic plants form flowers many times during their lifetime. Fruit trees, such as apple and orange trees, are polycarpic; they flower every year. Other polycarpic species, such as perennials, flower several times during their life span, but not each year. By this method, the plant does not require all its nutrients to be channeled towards flowering each year.

Genetics and Environmental Conditions

As is the case with all living organisms, genetics and environmental conditions have a role to play in determining how long a plant will live. Susceptibility to disease, changing environmental conditions, drought, cold, and competition for nutrients are some of the factors that determine the survival of a plant. Plants continue to grow, despite the presence of dead tissue, such as cork. Individual parts of plants, such as flowers and leaves, have different rates of survival. In many trees, the older leaves turn yellow and eventually fall from the tree. Leaf fall is triggered by factors such as a decrease in photosynthetic efficiency due to shading by upper leaves or oxidative damage incurred as a result of photosynthetic reactions. The components of the part to be shed are recycled by the plant for use in other processes, such as development of seed and storage. This process is known as nutrient recycling. However, the complex pathways of nutrient recycling within a plant are not well understood The aging of a plant and all the associated processes is known as senescence, which is marked by several complex biochemical changes. One of the characteristics of senescence is the breakdown of chloroplasts, which is characterized by the yellowing of leaves . The chloroplasts contain components of photosynthetic machinery, such as membranes and proteins. Chloroplasts also contain DNA. The proteins, lipids, and nucleic acids are broken down by specific enzymes into smaller molecules and salvaged by the plant to support the growth of other plant tissues. Hormones are known to play a role in senescence. Applications of cytokinins and ethylene delay or prevent senescence; in contrast, abscissic acid causes premature onset of senescence.

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