STRUCTURE, DEVELOPMENT AND REPRODUCTION IN FLOWERING PLANTS

Flower, Sexual and Vegetative Reproduction, and Significance of Seed

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Reproduction is a process of producing offspring and a means of self-perpetuation. All living beings are characterized by reproduction. The modes of reproduction vary according to individual species and surrounding conditions. Both asexual and sexual reproduction occur in the life cycle of plants and the reproductive details vary from group to group. In lower organisms, reproduction may be by fragmentation, division of cell or budding, whereas in higher organisms it may be with the help of fully developed sex organs. In higher plants, reproduction is either without the involvement of sex organs or fusion of gametes (asexual) or with the involvement of sex organs-stamen and pistil (sexual). Some plants show special modes of reproduction namely apomixis, polyembryony, etc. In this chapter you will study various processes involved in the reproduction of flowering plants.

In flowering plants, there are two main modes of reproduction: (i) asexual or vegetative reproduction and (ii) sexual reproduction. In vegetative reproduction, the offspring are produced from the somatic cells, whereas in sexual reproduction there is fusion of male and female gametes. In the former case the somatic cells may be from root, stem, leaf or even buds of leaf and flower whereas in sexual reproduction the gametes from male and female organs of the flower are fused to produce a zygote.

FLOWER

The outstanding characteristic of angiosperms is the flower—a shoot of determinate growth in which internodes are highly reduced and leaves function as different floral parts. At the time of floral initiation the shoot apex transforms into floral apex. The floral axis which bears floral organs is known as receptacle. The receptacle consists of several shortened nodes closely brought together by the suppression of internodes. In a typical flower both fertile and sterile appendages are borne on the receptacle (Fig. 1).

Fig. 1. The main parts of a flower

Flowers show a great deal of variation in size, colour, shape and insertion of different floral whorls. In angiosperms, duckweed (Wolffia microscopica) bears smallest flowers (about 0.1mm in diameter) whereas Rafflesia bears largest flowers (about 1 meter in diameter).
Both sterile and fertile appendages are borne on the floral receptacle in distinct whorls consisting of calyx, corolla, androecium and gynoecium. A flower containing all four whorls—sepals, petals, stamens and carpels is called a complete flower. Flowers lacking one or more whorls are incomplete flowers. All complete flowers are perfect flowers because they contain both stamens and carpels. Imperfect flowers contain either stamens or carpels, making them male or female flowers, respectively. If a flower has both the stamens and the carpels it is designated as bisexual or hermaphroditic and if found separately, the flower is known as unisexual. A flower is said to be neuter or sterile, if it has no functional stamens or carpel. If the male and female flowers are found on the same plant, it is monoecious (e.g. Ricinus) but if on separate plants, it is dioecious (e.g. Cannabis). Some plants are polygamous as they bear both unisexual and bisexual flowers (e.g. Mangifera).

The outermost whorl of a flower forms the calyx, a collection of modified leaves called sepals. The second whorl is made up of petals, collectively forming the corolla of the flower. Petals are variously coloured and fragrant. The whorl immediately inside the petals is a collection of stamens—modified leaves that form the flower’s male reproductive organs. Most stamens have a long, slender stalk, the filament, and a swollen end called the anther. Pollen grains are produced inside the anther lobes in regions called pollen sacs (microsporangia). When pollen is mature, the anthers split open, releasing the pollen.

The gynoecium is composed of the female reproductive parts of the flower, called carpels. These carpels are also modified leaves. Some flowers have only one carpel (monocarpellary), others have more than one carpel (bi-, tri or multicarpellary). Each separate carpel, or each unit of fused carpels, is called a pistil. The pistil has three parts: ovary, style and stigma. The enlarged bottom part of the pistil is called ovary. The ovary bears its locule or locules the ovules in which the female gametophyte develops. The style of the pistil connects the stigma with the ovary. The stigma is sticky area of the pistil to which pollen grains adhere.

**Functions:**

1. The sepals protect the flower bud during its development.
2. Many flowers have nectaries-glands that secrete sugary nectar. These flowers attract animals and “reward” them for transferring pollen grains with a stream of nutritious nectar.

**STRUCTURE OF ANThER AND PISTIL**

**Microsporangium**

Stamen, the male reproductive unit, is made up of the anther and the filament (Fig. 2A). In majority of angiosperms, a typical anther consists of four elongated microsporangia (Fig. 2B, C). At maturity, the two sporangia of each side become confluent owing to the breakdown of the partition wall between them. Usually each anther lobe consists of two microsporangia (dithecoous) but in some taxa (e.g. Moringa) each anther lobe has only one microsporangium (monothecous).
A very young anther comprises a homogenous mass of cells bound by a well-defined epidermis. During its development the anther assumes a four-lobed appearance. The archesporial cells differentiate in the hypodermal region at four corners. The archesporial cells soon undergo periclinal divisions giving rise to the primary parietal cells on the outer side and primary sporogenous cells on the inner (Fig. 3A-B). The cells of the parietal layer undergo a series of periclinal and anticlinal divisions to form 2-5 concentric layers of anther wall (Fig. 3C-E). The primary sporogenous cells, either directly or after a few mitoses, function as microspore mother cells. Schematic representation of the ontogeny of anther wall layers is given in figure 4.

The mature anther wall consists of epidermis, endothecium, middle layers and tapetum (Fig. 3E). In mature anther epidermal cells are generally stretched and flattened. The cells of endothecium develop fibrous thickenings at maturity. The layer of cells lying beneath the middle layers is tapetum. The cells of the tapetum are densely cytoplasmic and surround the sporogenous cells completely. The tapetum is of two
types: amoeboid and secretory tapetum. The former is characterized by an early breakdown of the inner and radial walls of its cells. In Secretory type, the tapetal cells remain in their original position throughout the microspore development. The tapetum is a highly active layer of cells investing the sporogenous tissue and helps in the nutrition of the developing microspores. It also plays an important role in the formation of pollen wall. During development, the cells of tapetum and middle layer degenerate and in a mature anther only epidermis and endothecium persist (Fig. 5A-F).

The sporogenous cells may directly function as microspore mother cells (also called pollen mother cells, PMCs or meiocytes; Fig. 5A) or they may undergo a few mitoses to add up to their number before entering meiosis. The microspore mother cells possess thin cellulosic walls and are usually uninucleate. The MMCs are interconnected with the tapetal cells through plasmodesmata. With the entry of PMCs into meiosis the connections between the tapetal cells and the PMCs are broken and the walls of the PMCs become thicker by the deposition of callose (β-1,3-glucan). Concurrently with the deposition of callose, the plasmodesmatal connections between the PMCs are replaced by massive cytoplasmic channels (Fig. 5B). The massive cytoplasmic channels provide passage for the movement of cytoplasmic contents from one cell to the other. After the completion of meiosis, the callose wall is rapidly broken down and the microspores are released into the anther locule (Fig. 5C-F).

The aggregate of four microspores are referred to as microspore tetrads. Occurrence of more than four spores in a tetrad is called polyspor. In Asclepiadaceae and Orchidaceae all the pollen grains of a sac are united in a single compact mass called pollinium.
Fig. 5 A-F. Diagrammatic representation of pollen development. A. Differentiation of wall layers. B. Formation of syncytium by the development of cytoplasmic channels. C. Isolation of individual microspore mother cells by callose wall. D. Tetrad of microspores. Individual microspores are enclosed by a callose. E. Release of microspores by dissolution of callose wall. Middle layers have degenerated. D. Mature 2-celled pollen. Tapetum is degenerated and endothecium has developed thickenings.
The mature anther dehisces by means of slits or pores. These microspores after formation of wall are called pollen grains (Figs. 5F). The pollen wall is distinguishable in to two layers. The inner layer, called intine, is thin and made up of pectin and cellulose, whereas the outer layer is tough, and often with spinous outgrowth known as exine. The exine is made up of a complex substance, called sporopollenin (sporopollenin is derived from oxidative polymers of the carotenoids and carotenoid esters) which makes the pollen grains extremely resistant to chemical and biological degradation. At certain places, the exine is very thin or missing, giving an appearance of a pore, called the germ pore. There are usually three germ pores in dicots and one in monocots.

**Development of the Male gametophyte**

The microspore is the first cell of the gametophytic generation. During gametogenesis, the nucleus of microspore divides mitotically to produce a bigger vegetative cell and a smaller generative cell (Fig. 6A,B). The generative cell is initially attached to the wall of the pollen grain but later comes to lie freely in the cytoplasm of the vegetative cell.

Before the start of pollen mitosis, the nucleus of microspore is displaced from the centre toward one side of the cell. At this stage, the cytoplasm between the nucleus and the wall, on the side where vegetative cell is to be cut becomes highly vacuolated. Initially, the cytoplasm of the vegetative cell and that of the generative cell are separated by two plasma-membranes (Fig. 6B). The wall of the generative cell is soon formed in between the two cell membranes and adjoins the intine (innermost layer of pollen wall) on either side of the generative cell (Fig. 6C). The wall of the generative cell grows inwards between the plasmalemma of the generative cell and the intine (Fig. 6D) until the two ends of the wall meet and fuse and the cell is finally pinched off. Soon the wall of the generative cell disappears and the cytoplasm of the generative cell remains enclosed in two plasm membranes, its own and the detached invagination of the plasmalemma of the vegetative cell (Fig. 6E). After its formation, the generative cell separates from the intine and moves to a position where it is completely enclosed by the vegetative wall (Fig. 6E). The sperm cells are formed by mitotic division of the generative cell (Fig. 6F).

In a mature anther, the tapetum degenerates while the outer endothelial cells become fibrous (Fig. 5F). At this stage, the dehiscence of the anther takes place and the pollen grains are released. At this stage, the dehiscence of anther takes place and the pollen grains are released. The pollen grains are shed either at bi-celled or tri-celled stage. After reaching the stigma, the intine grows out through a germ pore into a slender pollen tube. The life of male gametophyte is very short as compared to that of the sporophyte.
Megasporangium

A typical pistil consists of a basal swollen part (ovary), a stalk (style) and a terminal receptive disc (stigma). Inside the ovary, there are one or more ovules or megasporangia. The main body of the ovule consists of the parenchymatous tissue, the nucellus, with one or two protective coverings or integuments. The ovule is attached to the placenta by means of a small or elongated stalk known as funiculus. The integuments surround the nucellus all around except at the apex leaving a narrow passage, called the micropyle. The base of the nucellus which is not easy to delimit because it merges with the bases of the integument is called chalaza (Fig. 7).
The ovule at first arises as a primordium on the placenta in the cavity of the ovary (Fig. 8A). Localised divisions in the hypodermal layers of placenta give rise to small dome-shaped structures. Owing to the meristematic activity of the cells of ovular primordia, the protuberances become prominent and constitute the nucellus. The nucellus consists of a group of unspecialized nutrient rich cells which divide mitotically to form an oval mass. The initials of the two integuments arise at the base of the nucellus, and surround it all around except at the apex leaving a single tiny opening, the micropyle (Fig. 8B-D). The whole structure is called an ovule and is lifted clear of the placenta by a stalk or funicle (Fig. 8E). Different types of ovules found in angiosperms are shown in figure 9A-F.
Development of the Female Gametophyte

The primary archesporial cell behaves directly as megaspore mother cell (mmc) or divides to form outer primary parietal cell and inner primary sporogenous cell which later functions as megaspore mother cell. This cell divides meiotically to form four megaspores (Fig. 10A-C). The four megaspores are arranged in a linear tetrad. Formation of megaspores from megaspore mother cell is called megasporogenesis. Usually, one megaspore of the tetrad becomes functional and remaining three megaspores degenerate (Fig. 10D).

The functional megaspore is the first cell of the female gametophyte. It divides by three successive mitotic divisions to form an eight-nucleate female gametophyte or embryo sac (Fig. 10 E-G). Out of the eight nuclei, three get organised at the micropylar end as egg apparatus (one egg and two synergids), three at the chalazal end as antipodals, and two at the centre as polar nuclei (Fig. 10H). The polar nuclei fuse to form a single diploid nucleus, called secondary nucleus. The egg apparatus consists of two synergids and an egg cell. This type of embryo sac development is called Monosporic type of embryo sac development (Fig. 10 A-H), generally referred to as the Polygonum type. The female gametophyte is classified into monosporic, bisporic and tetrasporic embryo sac, depending upon the number of meiotic products taking part in development.
At the organized female gametophyte stage, the embryo sac consists of one egg, two synergid cells, two polar nuclei and three antipodals (Fig. 11). The synergid cells show filiform apparatus.
POLLINATION

The word pollination refers to the process of transfer of pollen grains from anther and their deposition on to the stigmatic surface of the flower.
Types of Pollination

If the pollen is transferred from anther to stigma of the same flower, it is called self-pollination or autogamy. Autogamous flowers are always bisexual. Autogamy occurs naturally in almost all legumes (e.g. pea, beans) and many cereals (e.g. wheat, rice, maize). In cases where pollen is transferred from anther of flower to stigma of another flower of the same plant, it is referred to as geitonogamy.

In plants, where the pollen grains move from the anther of one flower to the stigma of another flower of a different plant, it is termed cross-pollination or xenogamy or allogamy (Fig. 12).

Fig. 12. Patterns of pollen transfer within and between flowers and plants

Most of the flowering plants bear chasmogamous flowers (the flowers which open normally) but in some plants flowers do not open at all and pollination, fertilization takes place in an unopened flower. Such flowers are called cleistogamous flowers (e.g. Viola, Oxalis).

Agencies of cross-pollination

The process of transfer of pollen grains from anther to stigma can occur by a number of agencies like air, water and animals (Table 1).
Table 1. Agencies and types of cross pollination

<table>
<thead>
<tr>
<th>Agencies</th>
<th>Types of pollination</th>
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<tr>
<td><strong>Abiotic agencies</strong></td>
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<td>Wind</td>
<td>Anemophily</td>
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<td>Water</td>
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<td><strong>Biotic agencies</strong></td>
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<td>Bats</td>
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<td>Ants</td>
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<td>Snails</td>
<td>Malacophily</td>
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**Anemophily**

Pollination by wind is called anemophily and the flowers which practice this type of pollination are called anemophilous flowers. The wind-pollinated flowers are generally unisexual as in coconut palm, date palm, maize (Fig.13), many grasses, *Cannabis*, etc. They possess following characteristics which help to increase the chances of pollen reaching the stigma:

1. The pollen grains are produced in large quantities. They are so small, smooth and light that they can be carried to considerable distances on air currents.
2. The flowers are small, inconspicuous and produce no nectar.
3. They occur in a position where they are easily blown.
4. They have stamens with large anthers borne on long filaments.
5. The stigmas are large and feathery which have more chances of receiving the blown pollen.

The wind pollination (anemophily) is not precise, as it involves the movement of pollen grains over long distances with respect to the direction of wind. The winged pollen grains of pines are found hundreds of kilometres away from the parent plants. As there is much wastage, pollen are produced in enormous quantities. For example, a single flower of *Cannabis* produces 5,00,000 pollen grains.
Hydrophily

Water also acts as an agent of pollination. The transfer of pollen grains from anther to stigma through the agency of water is called hydrophily. It is categorized into two groups:

1. Ephydrophyli: In this category the pollination takes place on the surface of water e.g. Vallisneria, (Fig. 14), Hydrilla, Lemna. The male flowers are released to the surface of water...
where they get themselves attached to the stigma of the floating female flowers held afloat by long stalks. After pollination the female flower is withdrawn inside the water by coiling of the stalk (Fig. 12).

2. Hyphrophily: Pollination takes place under the water e.g. *Ceratophyllum, Zostera*. At maturity stamens abscise and rise to the surface of water. Pollen grains germinate while still in the anthers. After dehiscence of anthers pollen grains gradually sink and come in contact with the stigma of submerged female flowers.

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**Fig. 14.** *Vallisneria* showing water pollination
Zoophily

Animals are also responsible for pollination and this phenomenon is called zoophily. Insects, birds, bats, ants, snails, etc. play an important role in pollination.

**Entomophily:** Insects are the most common pollinators and this process is referred to as entomophily. Flowers pollinated by insects have certain characteristics which make the process effective:

1. The individual flowers are large and brightly coloured.
2. The flowers are usually scented (fragrant) and produce nectar to attract insects.
3. The surface of the stigma is coated with a sticky secretion which taps pollen grains. Pollen grains are large, sticky and spiny.

The flowers producing nectar and fragrance, with bright colours, attract the insects. The flowers of sunflower family are generally pollinated by the bees and butterflies (Fig.15).

![Fig. 15. Diagram showing how pollination is effected by insects](image)

Ornithophily

A large number of tropical plants are pollinated by birds like humming birds, sunbirds etc. The pollination by birds is called ornithophily. Bird pollinated flowers develop certain adaptations to facilitate the process
of pollination (Fig. 16). They possess both tubular and disc type of flowers that are highly coloured and scented. The flowers secrete large quantities of nectar. Bird pollinated flowers include coral tree, bottle-brush, *Butea monosperma*, *Erythrina variegata* and silk cotton tree.

**Chiropterophily**

The pollination carried out by bats is called chiropterophily. Some of the plant species which are pollinated by bats are: *Adansonia, Bombax, Ceiba* and *Kigelia*.

**Need and Significance of Pollination**

1. The process of pollination leads to fertilization resulting in the formation of seeds and fruits. It ensures continuity of plant life.
2. The seeds and fruits are also a source of nutrition for animals, including human beings.
3. The pollination, especially cross-pollination, results in the production of plants with a combination of characters from two plants. The role of pollination in the production of hybrid seeds (vigorous seeds) is of great significance in crop production.

**POLLEN-PISTIL INTERACTION**

Pollen grains are transported to the stigma by wind, water, animals or directly by the contact between open anther and stigma. The first interaction between pollen and stigma is attachment or capture of the pollen grains. This is accomplished by the sticky nature of the pollen surface, the stigmatic exudates, or the pellicle covering the stigmatic papillae. One of the prerequisite for sexual reproduction in any organism is the ability of the gametes to establish recognition so as to facilitate fusion of only the right type of gametes. After pollination, incompatibility reactions occur either in stigma, style or ovule. Pollen exine and intine contain mobile proteins. These wall proteins are readily released into the medium on moistening. If compatible, pollen grains germinate and the tube enters the stigma, and grow through the style. If incompatible, the pistil will initiate rejection reaction and pollen tube growth is blocked on the stigma, in the style, or in the ovary. Pollen-pistil interactions in angiosperms can be divided into a number of phases, namely capture, adhesion, rehydration, germination, tube penetration, and tube growth. Major events involved during pollen-pistil interaction are given in figure 17.
**Pollen Adhesion and Hydration**

Pollen adhesion mainly depends on the nature and extent of the components present on the surface of the stigma and of pollen. In wet stigma, the exudate holds any pollen that lands on the stigma because of the stickiness and surface tension of the exudates. In dry type of stigma, pollen adhesion depends on the nature and extent of pollen coat substances and of the pellicle. Recent studies have shown that pollen adhesion and hydration are more complex and both lipid and protein components present on pollen coat substances and/or stigma surface play a crucial role in these processes. The long chain lipids act as signals to stimulate pollen hydration.

**Pollen Germination and Pollen Tube Entry into Stigma**

The stigma provides all the requirements, particularly inorganic minerals, boron and calcium, needed for pollen grains to germinate. In dry-type of stigma, pellicle components seem to be involved in pollen germination. For example, in *Gladiolus*, washing of stigma with a detergent, sodium deoxychlorate, removed the ability of the stigma to support pollen germination. In *Raphanus*, enzymatic digestion of the pellicle reduced pollen germination and totally inhibited entry of the pollen tubes into the stigma.

In wet type of stigma, in which the cuticle of the stigmatic surface/papillae is disrupted during secretion of the exudates, there is no physical barrier to pollen tube entry into the intercellular spaces of the transmitting tissue of the stigma. In dry stigma, the cuticle provides a physical barrier to pollen tube entry. The pollen tube has to erode the cuticle at the region of contact by activation of cutinases.

**Pollen Tube Growth Through Style**

The style may be solid (*Nicotiana*) or hollow (*Lilium*). In solid styled pistils, pollen tubes enter the cuticle of the papillae, grow down the papillae between the cuticle, and pectocellulosic wall and enter the extracellular matrix (ECM) of the stigma. Further growth takes place through the ECM of the stigma and
style. In hollow styled plants, the stylar canal is filled with a secretion product. The pollen tubes enter the stylar canal and grow down the surface of the canal cells.

The amount of nutrients present in the pollen is limited and not sufficient to support pollen tube growth until the pollen reaches the ovule. Pollen tubes have to take up nutrients from the pistil during their growth. Pollen tubes follow a predetermined path in the pistil. The distance between the stigma surface and the embryo sac varies from a few millimeters to more than 10 cm. Irrespective of this distance, pollen tubes follow a precise pathway. Pollen tubes enter the stigma, grow through the transmitting tissue or canal of the style and enter the ovary.

Pollen Tube Growth in Ovary

After growing through style, the pollen tubes enter the ovary through the transmitting tract. The pollen tube has to change direction by 90° to enter the micropyle. This activity takes place due to response to a chemotropic stimulus localized at the micropyle. The synergids also secrete some chemotropic substances to attract pollen tubes (Fig. 18).

![Pollen Tube Growth in Ovary](image)

**Fig. 18. Diagram of the pistil of Arabidopsis thaliana showing entry of pollen tubes**

SELF-INCOMPATIBILITY

After pollination, pollen grains germinate producing a pollen tube which grow through the tissues of the pistil and discharge the sperms in the vicinity of the egg for fertilization, an event leading to the development of seeds and fruits. In many species, however, pollen grains may fail to bring about fertilization of ovules in the same plant resulting in the failure of embryo and seed development. This phenomenon is called self-incompatibility (SI) or self sterility. In other words, SI is defined as the inability of a hermaphrodite plant producing functional gametes to effect fertilization upon self-pollination. SI is therefore a prefertilization barrier.

The incompatibility is the inability of certain gametes, even from genetically similar plant species, to fuse with each other. This is also called intraspecific incompatibility, self sterility or self–incompatibility. This may be due to the prevention of some physiological or morphological mechanisms. It involves many complex mechanisms associated with interaction of pollen and stigmatic tissues. Incompatibility occurs
between species (interspecific incompatibility) as well as within the species (intraspecific incompatibility) or self incompatibility.

On the basis of floral morphology, SI has been divided into two broad categories- homomorphic and heteromorphic. In former category, all individuals of a species produce only one type of flower, e.g. *Petunia, Nicotiana*. In heteromorphic category, different individuals of a species produce either two or three types of flowers differing in length of stamens and style (heterostyly). Occurrence of two types of styles is called heterostyly (e.g. Primula, Fig. 19).

![Diagram of heteromorphic incompatibility](image)

**Fig. 19.** Diagram of heteromorphic incompatibility. A. Dimorphic system. B. Trimorphic system
Self-incompatibility may be categorized into two groups: gametophytic self-incompatibility and sporophytic self-incompatibility.

1. Gametophytic self-incompatibility (GSI): The incompatibility is determined by pollen.
2. Sporophytic self-incompatibility (SSI): The incompatibility reaction is controlled by the genotype of the sporophytic tissue of the plant from which the pollen is derived.

This may be due to prevention of pollen germination, retardation of growth, deorientation of pollen tube, or even failure of nuclear fusion.

**Genetics of Self-incompatibility:** It is controlled by a single gene, called S-gene, which has several alleles (s-allele). In compatible matings of the same species, the pollen tube grows at a normal rate and fertilization is complete after the entry of the pollen tube into the ovule. The rate of pollen tube growth is governed by a series of alleles ($S_1$, $S_2$, $S_3$ etc.) for incompatibility. If a plant with the genotype, $S_1S_2$ is pollinated with its own pollen, or with pollen from another plant with $S_1S_2$ genotype, the pollen tube rarely penetrates the style far enough to reach the ovule. If a plant having $S_1S_2$ genotype is pollinated with pollen from a plant with genotype $S_1S_3$, usually only the pollen with $S_3$ allele penetrates the style and fertilizes the ovule. If $S_1S_2$ genotype is pollinated with the pollen from an $S_1S_4$ plant, either the $S_1$ pollen or the $S_4$ pollen may enter the style and effects fertilization (Fig. 20).

**Fig. 20. Pollen tube growth in compatible and incompatible pollinations**

Self incompatibility is a hindrance in crop improvement programme. There are several methods employed for overcoming both intra- and interspecific incompatibility. Some of the techniques are: use of mentor pollen, intraovarian pollination, test tube fertilization, bud pollination, pistil grafting and application of growth substances, etc.

1. Mentor Pollen: If the incompatible pollen is mixed with compatible, the pollen type of the former would be encouraged to grow. The pollen-wall proteins of killed mentor pollen contribute the proteins necessary for and mobilizing the incompatibility component in incompatible pollen.
2. Intra-ovarian Pollination and Test tube Fertilization: The technique of intra-ovarian pollination involves injecting pollen grain (suspended in a suitable medium) directly into the ovary, achieving pollen germination, pollen tube entry into ovule, and fertilization.
3. Bud Pollination: The incompatibility barrier can be overcome by pollinating immature flower buds.

4. Pistil Grafting: In cases where incompatibility reaction is confined to the stigma or the length of the style of the female parent is more than the maximum length attained by the pollen tube of the male parent, pistil grafting has been helpful in overcoming incompatibility.

5. Irradiation: Sexual incompatibility can be overcome by exposing the pistils to different doses of gamma or X-rays.

6. Application of Growth Substances: One of the factors responsible for failure of fertilization in incompatible forms is the premature shedding of the flower. Use of growth hormones like IAA, 2,4-D in overcoming incompatibility has been made.

**DOUBLE FERTILIZATION**

Fertilization in angiosperms involves interactions of the male gametophyte (the pollen tube) with the female sporophyte (pistil) and the female gametophyte (embryo sac) (Fig. 21). The pollen tube enters the ovule through the micropyle and discharges its contents in the embryo sac. One sperm fuses with the egg (syngamy) and other with secondary nucleus (triple fusion).

A short cytoplasmic outgrowth, called germ tube, emerges from the pollen and continues to grow as pollen tube. It produces enzymes which digest the tissues of the stigma and the style. The pollen tube grows chemotropically and intercellularly into the style due to a concentration gradient of calcium-boron-inositol sugar complex. The nucleus of the generative cell forms two male gametes by mitotic division. The pollen tube finally enters the ovule through its micropyle.

![Fig. 21. Pollen production, its transfer on stigma and fertilization](image)
After reaching the ovule, the pollen tube normally reaches the embryo sac by entering the micropyle (porogamy). The pollen tube may also enter the ovule through chalaza (chalazogamy) or integuments (mesogamy). Electron microscopic studies have shown that the pollen tube enters in the embryo sac through filiform apparatus (FA) of synergids (Fig.22). After growing through the filiform apparatus for sometime, the pollen tube enters the cytoplasm of synergid. Both the sperms and vegetative nucleus are released in the synergids.

The sperm released into the synergid cytoplasm are not nuclei but definite cells. One of the male gametes fuses with the egg, resulting in the production of zygote. This is called syngamy. The second male gamete fuses with the secondary nucleus (formed by the fusion of two haploid polar nuclei) forming a triploid primary endosperm nucleus. This is called triple fusion. Thus, in an embryo sac there occurs two sexual fusions: one is syngamy, and the other is triple fusion. This phenomenon is called double fertilization. The phenomenon of double fertilization is unique only to angiosperms which was first reported by Navaschin (1898).

![Fig. 22. Pollen tube entry, discharge and fusion of gametes](image)

In some taxa (e.g. Gossypium, Petunia, Hordeum, Plumbago) the two male gametes formed by the generative cell are not identical and they are attached with each other forming a male germ unit (MGU). They show distinct differences in morphology and contents. One sperm cell consistently is attached to the vegetative cell by a projection while the other is linked to the first by plasmodesmatal connections. One sperm has majority of mitochondria with very few plastids while other contains plastids with a very few mitochondria. Sperm dimorphism suggest a preferential fertilization.

**FORMATION OF SEED**

Following fertilization, the ovule develops into a seed that consists of the embryo, endosperm, and a seed-coat. In some plants, the endosperm surrounds the embryo and is the part of seed; in others, the endosperm is stored in the cotyledons and is the part of embryo.

**Endosperm**

The endosperm develops from the primary endosperm nucleus in angiosperms, and is produced by repeated divisions of primary endosperm nucleus. In most angiosperms, the endosperm is triploid.
The chief function of endosperm is to provide nourishment to the developing embryo and later during germination. In many taxa, the endosperm is utilized during the development of the seed. Such seeds are called non-endospermic e.g. pea, beans. In endospermic seeds, the endosperm serves as an organ of storage and persists in the mature seed e.g. castor, coconut.

**Development**

The development of endosperm begins just before the embryo development and is of three types: (i) Nuclear, (ii) Cellular and (iii) Helobial (Fig. 23).

1. **Nuclear Endosperm**: The primary endosperm nucleus undergoes repeated divisions without any cell wall formation. When many nuclei have been formed, they arrange themselves in the periphery, leaving a large central vacuole. Cytokinesis begins from the periphery towards the centre, making it cellular at maturity. This is the most common type and found in maize, wheat, rice, sunflower, coconut, (Fig. 23A) etc.

2. **Cellular Endosperm**: In Cellular type, every nuclear division is followed by cytokinesis (cell wall formation). This type of endosperm is cellular from the beginning. Many plants exhibiting cellular endosperm show formation of haustoria e.g. *Thunbergia, Linaria* (Fig. 23B).

3. **Helobial Endosperm**: This type of endosperm is mostly found in monocotyledons. In Helobial type, the primary endosperm nucleus moves to the chalazal end of the embryo sac where it divides forming a large micropylar chamber and a small chalazal chamber (Fig. 23C). In chalazal chamber the nucleus either remains undivided or divides only a few times. In large micropylar chamber, free nuclear division takes place. Cell wall formation, if any, begins at a much later stage.

![Fig. 23. Types of endosperm development: (a) Nuclear, (b) Cellular, (c) Helobial](image)
**Ruminate Endosperm**

The endosperm which exhibits any degree of irregularity and unevenness in its surface contour within the mature seed is called ruminate endosperm. Ruminate endosperm occurs in *Passiflora, Annona, Myristica*.

**Embryo**

The zygote (Fig. 24A) starts dividing together with development of endosperm. The first division of the zygote produces two cells: an apical cell (ca) and a basal cell (cb) (Fig. 24B). The basal cell lies towards the micropyle, and apical cell towards the chalaza. The next division may be transverse in both the terminal cell and basal cell thus forming a linear proembryonal tetrad (Fig. 24C). The daughter cells are designated / and /'. The derivatives of cb are designated as m and ci. The term proembryo is applied from the two-celled condition till the initiation of organs in the embryonal mass. Different developmental stages in dicot embryo development is given in figure 24 A-J.

In majority of angiosperms early proembryo is differentiated into two distinct parts: the embryo proper and suspensor. The suspensor is an ephemeral organ which neither forms a part of embryo nor involved in the formation of seedling. It is organized from the derivatives of ci. The suspensor pushes the proembryo into the endosperm to enable the developing embryo to receive nutrition. Long filamentous suspensor is characteristic of Brassicaceae.

The development of embryo up to the octant stage is almost similar in monocotyledons and dicotyledons. But in later stages, in dicots, two cotyledons are produced in the embryo whereas in monocot plants, one of the two cotyledons gets suppressed at an early stage, leaving only one in the mature embryo (Figs. 24J, 25A,B).

![Fig. 24 A-J. Embryogeny in niger (*Guizotia abyssinica*)](image-url)
Polyembryony: Occurrence of more than one embryo in the seed is called polyembryony. It may be due to the presence of more than one egg cell in the embryo sac, or more than one embryo sac in the ovule, and all the egg-cells may get fertilized. In some cases, a number of embryos may develop simultaneously from different parts of ovule, like synergids, antipodal cells, fertilized or unfertilized egg-cell, the tissues of nucellus or from integuments. Onion, groundnut, mango, lemon and orange are some of the examples for this phenomenon.

SEED
The seed develops from an ovule. During development of seed, the integuments mature into seed-coat. In bitegmic ovules, the seed-coat may be formed by both integuments (e.g. *Gossypium*) or inner integument may degenerate and seed-coat is formed by the outer integument alone (*Pisum* and other legumes). In Cucurbitaceae, the seed-coat develops from outer integument alone whereas inner integument degenerates. The seed-coat formed by outer integument is called testa and those formed by inner ones is called tegmen. They together constitute the seed-coat. Depending upon the presence or absence of endosperm, seeds are called albuminous or exalbuminous.

A true seed is fertilized mature ovule that possesses an embryonic plant, stored food material and a protective coat or coats. As the seed gets detached from the funicle, a scar is left on its surface, known as hilum. During development of seed, in some taxa special structures arise from various parts of the ovule. They are aril, caruncle, operculum, elaiosome etc.
Special Structures and Adaptations

Aril

Arils are fleshy seed appendages, often with vivid colours to attract animals, e.g. *Myristica, Litchi* (Fig. 26A, B). The aril usually arises from the funicle, outer integument, or both. In *Myristica* (nutmeg) seed, aril differentiates as an annular protuberance from the funicle and envelops the seed as an orange coloured membrane known as the mace of commerce.

![Aril Diagram](image)

**Fig. 26.** A. *Myristica* seed with aril. B. L. S. mature seed of *Litchi chinensis* showing aril

Sarcotesta

The term sarcotesta is applied to the pulpy and edible part of the seed-coat. Sarcotestal seeds are often attractively coloured (e.g. *Magnolia*) and is adapted for zoochory.

Elaiosome

The term elaiosome was introduced by Sernander (1906) for all fleshy and edible parts of seeds dispersed by ants. The elaiosome arises as an outgrowth of raphe or hilum (e.g. *Trillium*) (Fig. 27). It contains food material, and attracts ants which help in seed dispersal.
Caruncle
The tip of the outer integument forms a reflexed outgrowth leading to the formation of a massive or small structure known as caruncle, e.g. seeds of castor (Ricinus communis). Being sugary it is eaten by ants which help in dispersal of seeds. Being hygroscopic in nature, it absorbs water from the soil and passes it on to the embryo at the time of germination.

Operculum
Operculum (pl. opercula) are formed by the micropyar and hilar region, exo- and endostome, endostome alone or by the endosperm haustorium. The operculum is generally present in monocotyledons, e.g. Lemna. The opercula facilitate germination and also provide extra protection to the micropylar region of the seed.

Jaculator
It occurs in the members of family Acanthaceae. It is hook-like outgrowth of the funcile which remains attached to the fruit after seed expulsion.

Winged seeds
Winged seeds are meant for anemochory. The wing of the seed is a local outgrowth of the seed-coat. Spinning seeds, with three equidistant wings occur in Moringa oleifera (shahjan).

FRUIT DEVELOPMENT AND MATURATION
With sexual reproduction completed, the flower parts that were needed for pollination (sepals, petals and stamens) wither away. As embryos and seeds develop, the ovary of the flower matures into a fruit. Like many animals, humans rely on fruits as a primary source of nutrition. Whether a fruit is green or brightly coloured, juicy or dry, soft or hard, all or part of it is formed from a ripened ovary. Grains and nuts are dry fruits; the fruit wall of a walnut is dry and intact at maturity. Apples and tomatoes are fleshy fruits. A raspberry is an aggregate of many fruits from one flower. Multiple ovaries remain clustered together in a pineapple.

The fruits may be simple, aggregate or multiple. It depends upon whether fruit develops from the ovary of one pistil (simple fruit), from many pistils in a single flower (aggregate fruits), or from the pistils of separate flowers (multiple fruits).

Normally fertilization triggers fruit development. In a few cases, however, fruit develops through a process called parthenocarpy. The term was first introduced by Noll (1902) who defined parthenocarpy as the “development of fruits without pollination”. According to Nitsch (1965) parthenocarpy refers to the formation of fruits without fertilization. The fruit development without pollination is termed as vegetative parthenocarpy and with pollination as stimulative parthenocarpy.

In other words, parthenocarpy is the development of fruit in an unfertilised flower, resulting in a seedless fruit. It may occur naturally as in certain varieties of pineapple, grapes, apple, pear and banana. This may be induced by the application of hormones as in tomato. Seeds may be formed either by the formation of a diploid embryo, embryo sac by a somatic cell, or by the suppression of modification of the process to produce an unreduced megaspore. Parthenocarpy may be genetical, environmental or chemically induced.

**SIGNIFICANCE OF SEED**

Seeds, the great staple food of the world, feed more people than does any other type of food. The economic importance of seeds depends largely on the presence of reserve nutritive materials such as lipids, carbohydrates and proteins. The endosperm or cotyledons with their rich food reserves for the developing embryo and seedling offer man and other animals a highly nutritious food that can be easily stored. The Poaceae (grass family) contributes more food seeds than any other plant family, viz. rice, wheat, maize etc. The Fabaceae (legume family) provides us with peas, gram peanuts, soybeans, beans, lentils, chick-peas and other edible seeds. Besides human diet, seeds constitute feed for livestock and poultry birds.

Man uses other seeds, such as spices, condiments and nuts, in his diet. Some of the popular beverages are derived from seeds: coffee and chocolate (cocoa) made from coffee and cocoa seeds, beers from barley, whisky and gins fermented from mashes of cereal grains. Seed and seed extracts are also used as medicines. Cotton, a major fibre, is spun from the hairs from cotton seed.

Another major contribution from seeds is the edible and industrial oils expressed from peanut, coconut, cotton, palm, mustard, sunflower, safflower, rape, flax, sesame, tung, castorbean and numerous seeds. The oil content varies from about 30% in sunflower to 50% in castor bean, maize and peanuts, and even more in copra (*Cocos nucifera*).

**DISPERSAL STRATEGIES**

It is advantageous for any plant to be able to disperse its seeds- first, so as not to compete with its own seedlings, and second, in order to be able to invade new habitats. The function of any fruit is to ensure dispersal of the seeds from the parent plant. In one flowering season, a single plant can produce hundreds, thousands, and even millions of seeds, each of which contains an embryo capable of growing into a new plant. If all the seeds grow just below the parent plant, there will be intense competition for resources among the developing plants. Dispersal is necessary to reduce competition between the members of the same species. There are many different agents for the dispersal of fruits and seeds (Table 2).
### Table 2. Agents of dispersal

<table>
<thead>
<tr>
<th>Agent</th>
<th>Descriptive term</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dispersal by the plant itself</td>
<td>Autochory</td>
<td><em>Echallium, Impatiens</em></td>
</tr>
<tr>
<td>Wind</td>
<td>Anemochory</td>
<td><em>Papaver, Orchids</em></td>
</tr>
<tr>
<td>Water</td>
<td>Hydrochory</td>
<td><em>Cocos</em></td>
</tr>
<tr>
<td>Animals</td>
<td>Zoochory</td>
<td><em>Martynia, Tibulus</em></td>
</tr>
</tbody>
</table>

The seeds of some plants are expelled explosively from the fruit. Many leguminous fruits like pea, beans burst along with sutures to disperse seeds. The ripe fruits of balsam when touched, burst immediately (Fig. 28A). The light weight, tiny seeds of the orchid fruit can be widely distributed on air currents when the ovarian walls rupture. The poppy (*Papaver*) produces spore like seeds which are so light that they may be carried to long distances along with air current. The fruits and seeds of plants growing in or near water sources are adapted for floating. The fruits of coconut (Fig. 28B) are specially adapted for dispersal by ocean currents. Many fruits have hooks, spines, hairs, or sticky surfaces (Fig. 28C). Some fruits like Sycamore develop wings which help in dispersal by wind (Fig. 28D). These fruits are dispersed by animals. Fleshy fruits such as those of strawberries and cherries are tasty to many animals and are well adapted for moving through the animal gut which contains powerful digestive enzymes. The enzyme removes just enough of the hard seed-coats to enhance the likelihood of successful germination when the indigestible seeds are expelled from the body.
VEGETATIVE REPRODUCTION

Vegetative reproduction occurs naturally among wounded plants. For example, when a leaf falls or is torn away from an African violet plant, a new plant can develop from meristematic tissue adjacent to vascular bundles just inside the wound (meristematic cells are cells that retain the potential for continued division). The regeneration of plants from a portion of the vegetative part is quite common and diverse. The organs like root, stem, leaf and even buds are variously modified to help plant in vegetative propagation (Table 3). For the propagation of economically useful plants, several techniques have been developed by humans. These are cutting, grafting and layering, and are generally referred to as artificial methods of vegetative propagation. The resulting offspring are normally identical, and resemble the parent forms in almost all respects. Therefore, gardeners often prefer these methods for multiplying the number of individuals for their gardens. The methods of vegetative propagation are categorized into two groups: (i) natural and (ii) artificial.

Table 3. Vegetative reproductive methods in angiosperms

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Reproductive structures</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modified stems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Runner</td>
<td>Strawberry</td>
<td>New plants develop at nodes on an above ground horizontal stem</td>
</tr>
<tr>
<td>2. Rhizome</td>
<td>Ginger</td>
<td>New plants develop at nodes on an above ground horizontal stem</td>
</tr>
<tr>
<td>3. Bulb</td>
<td>Onion</td>
<td>New plants arise from axillary bud on short underground stem</td>
</tr>
<tr>
<td>4. Tuber</td>
<td>Potato</td>
<td>New shoots arise from axillary buds on tubers</td>
</tr>
<tr>
<td>5. Corm</td>
<td><em>Gladiolus</em></td>
<td>New shoots arise from axillary bud on short, thick, vertical underground stem</td>
</tr>
<tr>
<td>Parthenogenesis</td>
<td>Orange</td>
<td>Embryo arises without nuclear or cellular fusion (formation of embryo from an unfertilized egg)</td>
</tr>
<tr>
<td>Vegetative</td>
<td><em>African violet, Bryophyllum</em></td>
<td>New plants develop from tissues or organs (e.g. leaf) that drops or is separated from plant</td>
</tr>
<tr>
<td>Propagation</td>
<td><em>Wheat, rice, Chrysanthemum</em></td>
<td>New plant develops from cell in parent plant which has not irreversibly differentiated; laboratory technique</td>
</tr>
</tbody>
</table>
Natural Methods

In natural methods of propagation, a portion of the plant gets detached from the body of the mother plant. This detached portion may be a part of stem, leaf, root or even flower which develops into a new independent plant under suitable environmental conditions.

1. Underground stems: The modifications in stems are meant to perform some special functions and to overcome unfavourable conditions. The underground modification of stem-like rhizome (e.g. ginger), tuber (e.g. potato), bulb (e.g. onion) and corm (e.g. gladiolus) are organs for vegetative propagation of plants in nature (Fig.24). New buds are produced on these modified stems which gradually grow up to new plants.

2. Subaerial stems: The stem of plants with subaerial modifications, like runner (Centella), stolon (Colocasia), offset (Pistia, Eichhornia) and suckers (Chrysanthemum), are also used for propagating plants.

3. Modified roots: The plants of sweet potato, asparagus, tapioca, and dahlia (Fig. 29A, B) are propagated through modified roots.
1. Adventitious buds: *Bryophyllum* and *Kalanchoe* are commonly propagated through leaves. The adventitious buds are produced in the notches along the leaf margin. These buds when drop on the ground, develop into new plants.

2. Bulbils: In garlic (*Allium sativum*) some of the lower flowers of the inflorescence become modified into small multicellular bodies called bulbils. In plants like American aloe (*Agave*) reproductive buds or bulbils often take the place of many flowers of the inflorescence. In wild yam (*Dioscorea*) bulbils are produced in the leaf axil. In wood-sorrel (*Oxalis*) a cluster of small buds (bulbils) arise on the top of the swollen tuberous root.

**Artificial Methods**

Some flowering plants have a capacity to develop a part of their somatic body into a new independent plant. This is done by applying special techniques.
1. **Cuttings:**

   (a) **Stem cuttings** - Many plants like rose, sugarcane, garden croton, tapioca, china-rose, drum-stick (*Moringa*), coleus can easily be grown from stem cuttings. When cuttings are placed in the moist soil, they develop roots and adventitious buds which form the shoot.

   (b) **Root cuttings** - Sometimes, as in lemon, tamarind, etc. root cuttings when placed in soil produce roots and shoots.

2. **Layering:**

   It is one of the most common methods used for propagating plants like rose, jasmine, grape-vine, *Ixora* and lemon. Layering can be done by bending down the lower branch of a plant close to the ground. A ring of bark to the length of 2.5 to 5 cm is removed and portion is pushed into the soft ground, covered with soil and a stone or brick is placed on it. The covered portion of the branch produces roots after 2-4 months. These branches can be cut and grown independently.

3. **Grafting:**

   It is practiced in plants which do not root easily, or have a weak root system. It is an art of joining parts of two plants of the same or allied species in such a way as to bring about an organic union (fusion of the tissues). It is successful in plants which have cambium for secondary growth. The basic or main part of the plant (root to the soil) is called stock, and the portion to be grafted on to the stock is called a scion. The scion is generally taken from the plant having superior characters. The scion grows retaining all its qualities, while the stock which may be of inferior quality but physically sturdy supports it by providing water and other nutrients from soil. It is practiced in mango, apple, pear, citrus, guava and rubber plant. Grafting may be of different types, namely bud grafting, approach grafting, tongue grafting, wedge grafting and crown grafting, depending on the methods of uniting the two parts maintained, are propagated vegetatively. Grafting is of the following types:

   (a) **Bud grafting** - A T-shaped incision is made in the bark of the stock and a bud cut out from a selected plant is inserted into the T-shaped slit and bandaged (Fig. 30A).

   (b) **Approach grafting** - A scion of a plant is made to unite with a small plant in a pot firmly tying them together. It is commonly practiced in rose.

   (c) **Tongue grafting** - The stock is cut above the ground. The sloping cuts are made as shown in figure 30B. The scion of same thickness is cut in the same manner and is fit into the stock.

   (d) **Wedge grafting** - The stock is cut above the ground and a V-shaped incision is made with the help of a sharp knife. A scion is cut obliquely downward into a solid V. The scion is closely fit in the incision made in the stock.

   (e) **Crown grafting** - The stem is cut above the ground. The bark of the stock is cut lengthwise (12-15 cm) and bark is partially opened on either side. A small branch from another plant of the same species is cut and inserted into the opened bark and fixed firmly.
4. Gootee

It is a method commonly used for propagating lemon, orange, guave and litchi during the early monsoon rains. In this case, a healthy and woody branch is selected and the bark is sliced off in a ring form of about 2.5 to 5 cm in length. A thick plaster of grafting clay (clay, cow-dung, finely cut hay, and water) is wrapped up with straw or rag and tied onto the debarked portion. A suitable arrangement is made for keeping the clay moist. In about 1-3 months, the roots arise and the gootee is ready to be cut below the bandage for propagation.

**Significance of Vegetative Reproduction**

1. Vegetative propagation is used for maintaining characters of the parents.
2. Plants with reduced power of sexual reproduction, long dormant period of seed or poor viability, are also multiplied easily through this method.
3. Vegetative reproduction also helps in removing common infections from the parent plant.
4. Grafting helps in getting an economically important plant having useful characters of two different individuals in a short time.

**SPECIAL MODES OF REPRODUCTION**

Both vegetative and sexual modes of reproduction are generally normal and occur in nature. There are cases where propagation takes place even without the act of fertilization. It may be by processes like apomixis and polyembryony. Plant tissue culture techniques are also being used extensively for propagation.
Apomixis

Apomixis may be defined as the phenomenon in which normal sexual reproduction is completely replaced by asexual reproduction. The plants exhibiting such a phenomenon are called apomicts. When embryos are produced without fertilization, the apomictic process is referred to as agamospermy. It includes two different modes of reproduction: adventive embryony and gametophytic apomixis.

(i) **Adventive embryony**: In this type of agamospermy, the new sporophyte develops from a somatic cell of ovule (nucellus or integument). Adventive embryony leads to development of more than one embryos in a seed, e.g. citrus, mango.

(ii) **Gametophytic apomixis**: In this type the female gametophyte develops from an unreduced generative cell (sporogenous or megaspore mother cell). Gametophytic apomixis is classified into two categories: diplospory and apospory.

1. **Diplospory (Generative apospory)**: The unreduced embryo sac develops from a generative cell i.e. either from female gametophyte or megaspore mother cell.

2. **Apospory (Somatic apospory)**: The unreduced eggs are formed from the somatic cells of nucellus.

Apomixis is widespread in the plant kingdom. It is often associated with polyploidy. Apomixis is of great practical application in breeding in maintaining varieties. Apomictic reproduction allows one to fix any desirable homozygous gene combination and to maintain new heterozygous varieties with valuable agronomical properties such as disease resistance.

Parthenogenesis

When embryo develops directly from an unfertilized egg, the phenomenon is known as parthenogenesis. Depending upon whether the embryo sac is haploid or diploid, seeds produced in this way may be haploid or diploid.

Parthenogenesis can be introduced by: (i) exposing the ovary to very high or very low temperature soon after pollination, (ii) use of x-rayed pollen on stigma, (iii) use of foreign pollen or of delayed pollination and (iv) chemical treatment.

Parthenogenetic development of haploid plants in the cultures of unfertilized ovaries has been reported in barley (*Hordeum vulgare*), tobacco (*Nicotiana tabacum*) and wheat (*Triticum aestivum*).

Micropropagation

The plant tissue culture also helps in propagating plants to a great extent. In micropropagation, the cells, tissues or organs are detached from the plant to be propagated. These are called explant. They are grown in a suitable artificial medium. **In vitro** (in test tube), these explants develop to form callus (an undifferentiated mass of cells). This callus can be differentiated to produce plantlets by supplementing the medium with hormones like auxin and cytokinins. This technique has been commercially used for the propagation of orchids, carnation, gladiolus, gerbera and chrysanthemum. By this method, one can get unlimited number of plants in a limited space and short time, besides getting pathogen-free plants.

Artificial seeds are also being used for large scale propagation of desired plants. Artificial or synthetic seeds contain a multicellular “somatic embryo”. This is not a sexually produced embryo but an embryo-like product of mitotic divisions in tissue culture. Individual cells or small cluster of cells isolated from the body of a suitable parent plant may develop in liquid culture into a suitable structure similar to normal embryos derived from zygotes. These embryos are encapsulated in alginate matrix because of this reason, somatic embryos does not dry out and it may be stored and transported before planting.

**Comparison of Vegetative and Sexual Reproduction in Flowering Plants**
We have seen that how flowering plants may use two very different methods of reproduction, an asexual or vegetative method involving a process of budding and a sexual method resulting in the formation of seeds. Advantages of vegetative reproduction are that it is a relatively safe method because food is available from the parent plant for early development hence the progeny can be quite large before becoming independent. They can compete better with other plants. In vegetatively propagated plants if upper parts are destroyed they can form new aerial shoots from their underground buds. The main disadvantage is that dispersal is limited to the immediate vicinity of the plant.

The sexual method is more hazardous as majority of pollen does not reach a suitable stigma and majority of seeds never reach a suitable habitat. A great advantage of sexual reproduction is that seeds can be taken to long distances. Sexual reproduction allows variation in the progeny. The seeds can survive over long periods of unfavourable conditions in a state of dormancy. Thus both methods have their advantages and disadvantages.

**Suggested Readings:**