SEXUAL REPRODUCTION IN FLOWERING PLANTS

- Sexual reproduction is the formation of new individuals through the meiotic gamete formation and their subsequent fusion during fertilization. It is also called **amphimixis.**
- The flower is the main structure concerned with reproduction. The reproductive organs or the sporophylls are produced within the flowers. The sporophylls are of two types microsporophyll (stamen) and megasporophyll (carpel).
- Flowers are morphological and embryological marvels, which are concerned with sexual reproduction. Flower arises laterally or terminally in the axil of leaf which itself arises from the node. The stalk of flower is called **pedicel** which bears whorls of floral parts. The outermost whorl of floral parts is composed of sepals, collectively called the **calyx.** Petals, together called the **corolla,** form the next inner whorl. Sepals and petals are sterile parts of flowers.

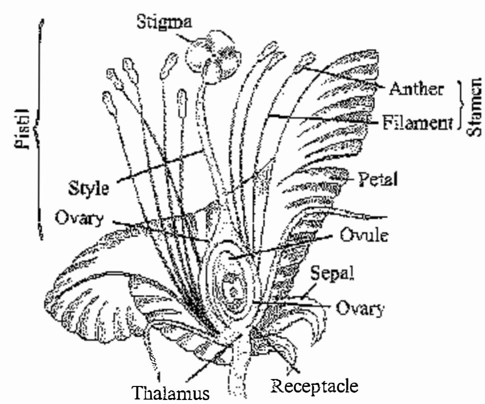

Fig.: Flower in sectional view (L.S.)

- The fertile parts are the **androecium,** arises just inside the corolla and the **pistil** or **gynoecium** in the centre of the flower. The **androecium** and **gynoecium** are the collective terms used for male reproductive and female reproductive organs respectively.

Complete flower

- **Non-essential whorls**
  - Outermost whorl called **Calyx** → units → **Sepals** → functions → To protect inner whorls in bud condition
  - Inner to calyx is **Corolla** → units → **Petals** → functions → To help in pollination and protection of inner whorls
- **Essential whorls**
  - **Androecium** → units → **Stamens** → Anther, Connective, Filament → functions → In reproduction as male reproductive organ
  - **Gynoecium** → units → **Carpels** → Ovary, Style, Stigma → functions → In reproduction as female reproductive organ

Flow chart : Parts of a flower

MALE REPRODUCTIVE UNIT (STAMEN)

- A stamen or microsporophyll is the **male reproductive** unit of angiosperms. It consists of an **anther** and a **filament.**
- The anther is bilobed and each lobe encloses 4 **pollen sacs** or **microsporangia.** Each pollen sac contains a number of pollen grains. The four pollen sacs in a dithecous anther appear to lie in the four corners of an anther, thus a typical anther is **tetrasporangiate.**
- The wall of anther consists of 4-5 layers (wall layers) of cells.
- **Wall layers of anther include :**
  - **Epidermis :** One cell thick and protective in function.
  - **Endothecium :** Second wall layer. Usually single layered. Cells have a cellulose thickening with a little pectin and lignin in some cases. It helps in dehiscence of anther.
  - **Middle layers :** The number of middle layers ranges from 1-6. The middle layers degenerate at the maturity of the anther.
  - **Tapetum :** This is the innermost layer of anther wall which surrounds the sporogenous tissue. Tapetal cells are nutritive. They are multinucleated and polypoid. In these cells the **Ubisch bodies** are present which help in the ornamentation of microspore wall. A compound **sporopollenin** is secreted by Ubisch bodies which is deposited in the exine of microspore wall.
- A mature anther dehisces by slits and pores to liberate the pollen grains.

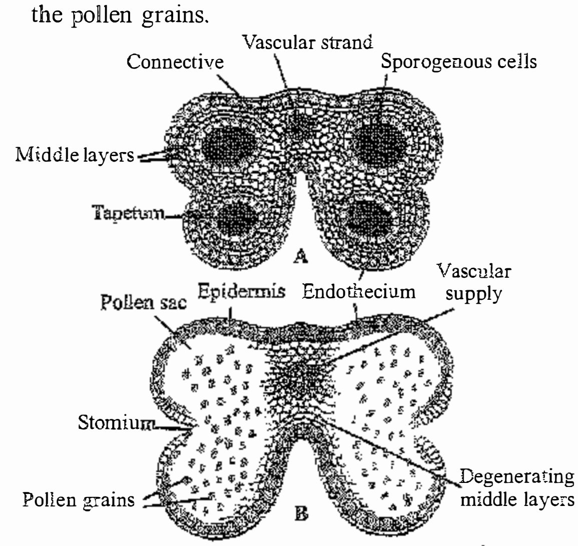

Fig : **A.** T.S. or young anther; **B.** T.S. of mature dehisced anther (common or longitudinal type)

- The **pollen grains** (microspores) develop inside the pollen sacs and while developing they consume the middle layer and tapetum; such that a mature anther has 2 layers-epidermis and endothecium only.

Microsporogenesis

- The formation and differentiation of microspore (pollen grain) is called **microsporogenesis.** The PMCs (pollen mother cells) divide **meiotically** each forming tetrahedral tetrads.
- The microspores separate from the tetrad configuration and get surrounded by a two layered wall, outer **exine**

and inner **intine**. The pollen grains are the first cells of the male gametophyte.

Structure of microspore (Pollen grain)

- Pollen grains may be oval, ellipsoidal, triangular, lobed or even crescent shaped. Typically, pollen grain is a haploid, unicellular body with a single nucleus.
- The outer layer called **exine** is **thick** and **sculptured** or **smooth**. It is cuticularised. The cutin is of special type called **sporopollenin which is resistant to chemical and biological decomposition** so pollen wall is preserved for long periods in fossil deposits.
- At certain places the exine remains thin. The thin areas are known as **germ pores**, when they are circular in outline and **germinal furrows** when they are elongated.
- The intine is thin and elastic. It emerges out as the pollen tube from the germ pores during germination.

Development of male gametophyte

- Pollen grain is the first cell of a male gametophyte. The size of the nucleus increases and it divides mitotically to produce a bigger **vegetative cell** or **tube cell** and a smaller **generative cell**.
- At this stage, the dehiscence of the anther takes place and the two celled pollen grains are released. In large majority of flowering plants, pollen are shed at **two celled stage**.
- The tube nucleus descends to the tip of the pollen tube and finally gets degenerated. The generative cell passes into the pollen tube and divides into 2 male gametes.

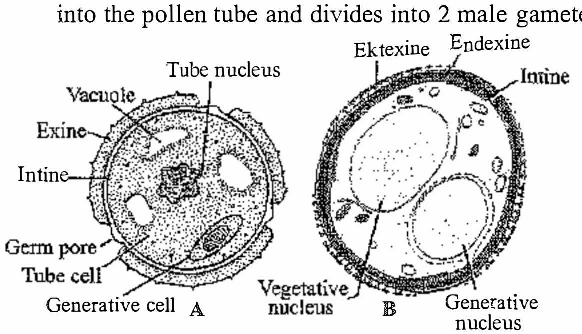

Fig.:A Section of a mature 2 celled pollen grain of an angiosperm.
B. Fine structure of a pollen grain

FEMALE REPRODUCTIVE UNIT (PISTIL)

- The pistil or gynoecium of a flower is the female reproductive unit. A pistil has a **terminal receptive disc-like stigma**, a **stalk-like style** and a **basal swollen ovule bearing part called ovary**. An ovary may have one to several ovules.

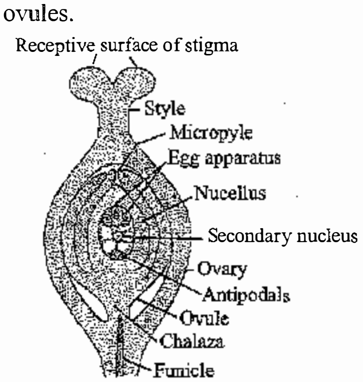

Fig.: Pistil in longitudinal section

Megasporangium (Ovule)

- Ovule is an **integumented megasporangium** found in spermatophytes which develops into seed after fertilization. Each ovule is attached to the placenta by a slender stalk called **funicle**. The point of attachment of the body of the ovule to its stalk of funicle is known as **hilum**.
- In inverted ovule, the part of funicle remain attached beyond the hilum alongside of the body of the ovule forming a sort of ridge called **raphe**.
- The ovule contains a mass of thin walled parenchymatous cells called **nucellus**. The nucellus is protected by one or two multicellular coats called **integuments**. The basal portions of the nucellus from where the integuments appear is called **chalaza**. A small opening is left at the apex of integuments known as **micropyle**.
- A large oval cell lying embedded in the nucellus towards the micropylar end is the **embryo sac** or **female gametophyte.** This makes the most important part of the mature ovule. It is the embryo sac, which bears the embryo later on.

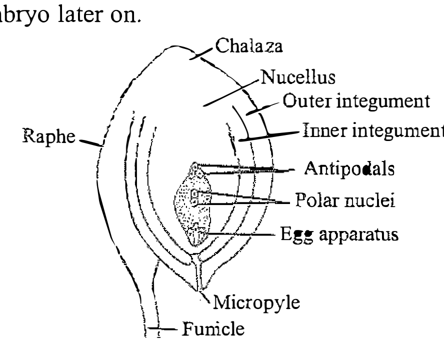

Fig.: Structure of a typical ovule of angiosperms

Types of ovules

- Depending upon position of micropyle in relation to chalaza and funiculus, **ovules are of 6 types** in angiosperms. These are orthotropous, anatropous, hemianatropous, campylotropous, amphitropous and circinotropous.

(i) **Orthotropous (Erect) :** Most primitive and simplest type. Micropyle, chalaza and funiculus are in same line, *e.g.*, *Polygonum.*

(ii) **Anatropous (Inverted) :** Most common type of ovule found in **angiosperms.** Micropyle is on lower side which is close to hilum and lie side by side to funiculus.

(iii) **Hemianatropous:** Nucellus and integuments are at right angles to stalk of funicle, *e.g.*, *Ranunculus*.

(iv) **Campylotropous:** Body of ovule is placed at right angle to the funicle. Here the body of the ovule gets curved and micropyle is directed downwards, *e.g.*, in chenopodiaceae, cruciferae .

(v) **Amphitropous:** Embryo sac becomes horse-shoe-shaped, *e.g.*, alismaceae, papaveraceae.

(vi) **Circinotropous:** Ovule turns at more than 360° angle. Funicle becomes coiled around the ovule, *e.g.*, in cactaceae.

Megasporogenesis

- The megaspore mother cell undergoes meiosis to form **four haploid megaspores**. The process of meiotic formation of haploid megaspores from diploid megaspore mother cell is called **megasporogenesis**.

- Out of four megaspores in a linear tetrad, usually the upper three degenerate and lowermost enlarges to become **functional megaspore**.

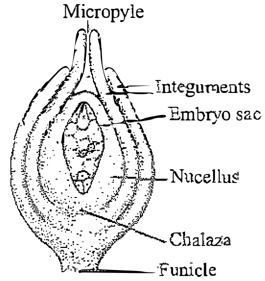

Fig.: Orthotropous ovule

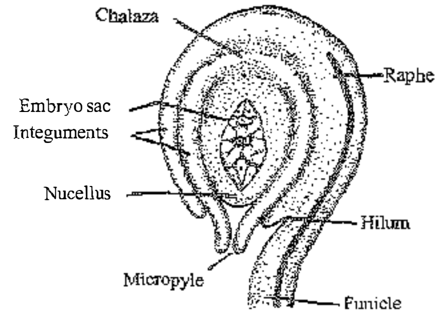

Fig.: Anatropous ovule

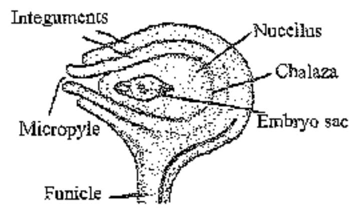

Fig.: Hemianatropous ovule

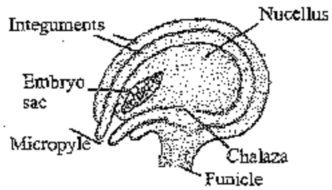

Fig.: Campylotropous ovule

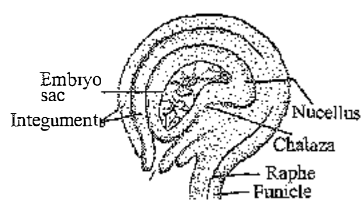

Fig.: Amphitropous ovule

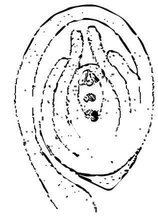
Fig.: Circinotropous ovule

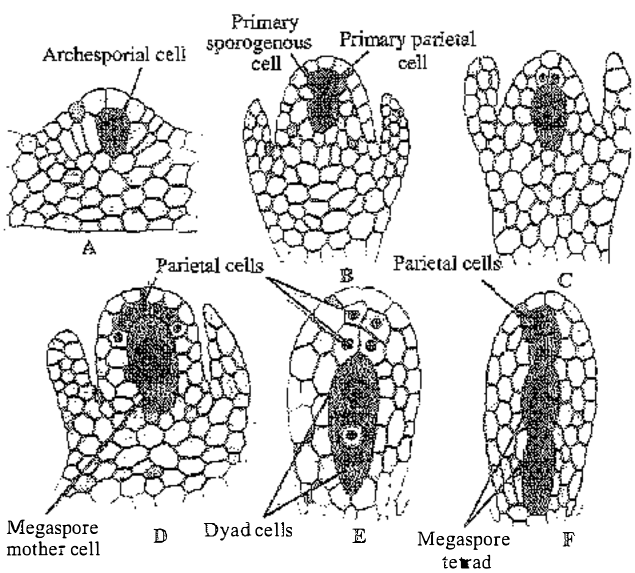

Fig.: Megasporogenesis – different stages in the development of linear tetrad of megaspores. **A**, archesporial cell; **B**, formation of primary parietal cell and primary sporogenous cell; **C-D**, formation of parietal cells and megaspore mother cell; **E-F**, formation of linear tetrad of megaspores from megaspore mother cell

Megagametogenesis (Female gametophyte)

- **The functional megaspore is the first cell of female gametophyte or embryo sac.** The nucleus of megaspore divides (free nuclear division) into two, four and finally eight daughter nuclei. Four of which are located at each pole. One nucleus from each pole migrates to the centre to form **two polar nuclei** which further fuse to form a diploid or **secondary nucleus**.
- Three nuclei at the base of embryo sac form **antipodal cells**. The remaining three nuclei at the micropylar end get surrounded by cytoplasm and constitute **egg apparatus**, which consists of two cells known as **synergids** or **help cells** and an egg or **oosphere** which hang between the two. It has a central or micropylar vacuole and a nucleus towards the chalazal end. The egg cell on fertilization gives rise to **zygote**, while synergids get disorganized soon after fertilization. The antipodal cells sooner or later also get disorganised. They may, however, be **nutritive** in function.
- Thus a typical embryo sac contains **8 nuclei but 7 cells – 3 micropylar, 3 chalazal and one central.**
- **A filiform apparatus** is special cellular thickening at the micropylar tip in the synergids.
- The filiform apparatus is useful for the absorption and transportation of materials from the nucellus to the embryo sac and guide the pollen tube into synergids. Hook like structures help in easy penetration of pollen tube and liberation of male gamete from the pollen tube.

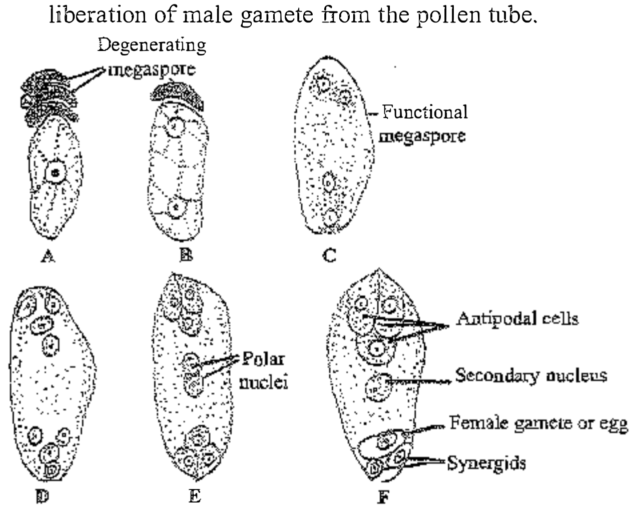

Fig.: Development of embryo sac

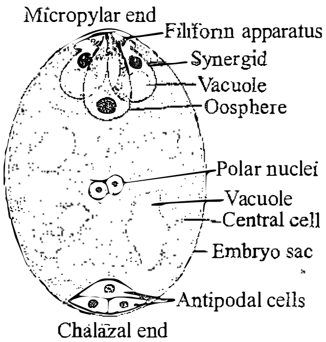

Fig.: Normal or *Polygonum* type of embryo sac

POLLINATION

- The term **pollination** refers to the process of transfer of pollen grains from anther and their deposition on to the stigmatic surface of the flower. **It is pre-requisite for fertilization.**
- Pollination is of two types **self pollination** and **cross pollination**.

Self pollination

- **Self pollination** is the transfer of the pollen grains from the anther of a flower to the stigma of either the same or genetically similar flower. Accordingly, self pollination is of two types, **autogamy** and **geitonogamy**.
- If the pollen grains are transferred from anther to the stigma of the same flower the process is called **autogamy**. **Geitonogamy** is the pollination taking place between the two flowers of the same plant or genetically similar plant. Genetically it is self pollination but as the agency is involved it is ecologically cross pollination.
- **Contrivances (Devices) for self pollination:**
  - **Cleistogamy :** As the flowers never opens so there is no alternative other than self pollination in cleistogamous flower. *e.g., Pisum, Lathyrus, Commelina benghalensis.*
  - **Chasmogamy :** When the flowers expose their mature anther and stigma to the pollinating agents. This may be brought about by opening of the flower, or the organs may protrude from a closed flower in such a manner so as to expose themselves to the same agents.

Advantages of self pollination

- The advantages of self pollination are :
  - It maintains the **parental characters** or **purity of the race** indefinitely.
  - Self pollination is used to **maintain pure lines** for hybridisation experiments.
  - The plant does not need to produce large number of pollen grains.
  - Flowers do not develop devices for attracting insect pollinators.
  - **It ensures seed production.**
  - Self pollination eliminates some bad recessive characters.

Disadvantages of self pollination

- The disadvantages of self pollination are :
  - New useful characters are seldom introduced.
  - **Vigour** and **vitality** of the race decreases with prolonged self pollination (Inbreeding depression).
  - Immunity to diseases decreases.
  - **Variability** and hence **adaptability** to changed environment are reduced.

Cross pollination

- **Cross pollination** is defined as the deposition of pollen grains from anther of a flower to the stigma of a different flower of another plant of same or different species. It is also known as **allogamy** or **xenogamy.**
- **Contrivances for cross pollination :** There are special devices or arrangements which favour cross pollination.
  - **Dicliny or Unisexuality :** There are two types of flowers, male and female. The plants may be monoecious or dioecious. Monoecious plant is that in which male and female organs are found on the same plant but in different flowers (for examples maize). Dioecious plant is that in which male and female organs appear on separate individuals, *e.g., Morus alba* (mulberry), *Piper beetel, Vallisneria.*
  - **Self sterility or self incompatibility :** The pollen of a flower has no fertilizing effect on the stigma of the same flower, *e.g.,* in *Thea chinensis* (tea), *Passiflora* (passion flower).
  - **Dichogamy :** Male and female sex organs mature at different times. There are two different conditions: (i) **Protandry :** Anthers mature earlier than the gynoecium, *e.g., Helianthus annus* (sunflower), *Tagetes* (marigold), cotton, lady's finger, etc. (ii) **Protogyny :** Gynoecium matures earlier than the anthers, *e.g., Michelia champaka* (champaka), *Brassica* (mustard), *Ficus* (fig, banana, peepal), *Mirabilis* (four o'clock plants).
  - **Pollen prepotency :** In some plants when the stigma receives pollen from the same flower as well as from the other flower simultaneously, the **foreign pollen germinates vigorously** and fertilize the ovule, *e.g.*, bean and many members of fabaceae.
  - **Heterostyly :** In some plants flowers have two (dimorphic) or three (trimorphic) forms of anthers and stigmas at different levels.
  - **Herkogamy :** It is the presence of natural and physical barrier between androecium and gynoecium which helps in avoiding self pollination. In *Calotropis stignui*, gynoecium is fused with pollinium (anthers) and form **gynostegium**.

Agents of pollination

- The expression of relationship between the agents and structure of flower is called pollination mechanism. For cross pollination, agent is a must. The spreading of pollen grains from plant to plant in cross pollination takes place through biotic agencies (living agencies) or through abiotic agencies (non living agencies).
- Abiotic agencies for cross pollination includes non-living components for pollination such as wind and water
- Biotic agencies for cross-pollination include living agents for pollination.

Agents of cross-pollination

Abiotic
- **Anemophily** (by wind) *e.g.*, Palm.
- **Hydrophily** (by water) *e.g.*, *Vallisneria*

Biotic
- **Entomophily** (by insects) *e.g.*, *Aristolochia*, *Salvia* (bee).
- **Ornithophily** (by birds) *e.g.*, *Bombax*, *Bauhinia* (by humming birds).
- **Chiropterophily** (by bats)
- **Malacophily** (by snails and slugs) *e.g.*, aroids.
- **Myrmecophily** (by ants) *e.g.*, rubiaceae.

Wind pollination (Anemophily)

- **Anemophily** is an abiotic mean of pollination by **wind** and, being non-directional, a wasteful process.
- Characteristics of anemophilous flowers are:
  - Both the stigmas and anthers are exserted. Anthers are versatile.
  - Pollen grains are light, small and dusty. They can be blown to distances upto 1300 km.
  - Pollen grains are dry, non sticky and unwettable.
  - Stigma is hairy, feathery or branched to catch the wind borne pollen grains.
- Examples of anemophilous plants are maize, grass, jowar, *Amaranthus*, palm, mulberry, *Cannabis*.

Water pollination (Hydrophily)

- The mode of pollination through the agency of water is not very common and occur only in few aquatic plants, especially submerged ones, like *Vallisneria*, *Ceratophyllum* and *Zostera*. It is called **hydrophily**. The pollen grains are carried by water and when they reach the stigma, they coil around it and germinate.
- Characteristics of hydrophilous flowers are:
  - Flowers are small and inconspicuous.
  - Nectar and odour are absent.
  - Stigma is long, unwettable but sticky. Hydrophily occurs only in few aquatic plants, *e.g.*, *Vallisneria*, *Zostera*, *Ceratophyllum*, etc. Pollen grains in many species are long, ribbon like and carried passively inside the water. Some of them reach stigma and achieve pollination. In most water pollinated species, pollen grains are protected from wetting by mucilage coating.
- Hydrophily is of two types – **epihydrophily and hypohydrophily**. Epihydrophily takes place over the surface of water *e.g.*, *Vallisneria*. **Hypohydrophily** includes plants which are pollinated inside the water, *e.g.*, *Ceratophyllum*, *Najas and Zostera*.

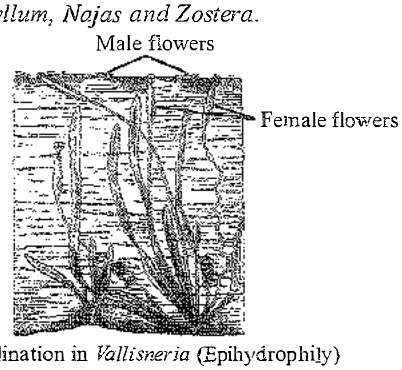

Fig.: Pollination in *Vallisneria* (Epihydrophily)

- Both wind and water pollinated flowers are not colourful and do not produce any nectar.

Insect pollination (Entomophily)

- Insects are the most common pollinators. The flowers producing nectar and fragrance, with bright colour, attract the insects. The mode is called **entomophily**.
- The most common insect pollinators are moths, flies, butterflies, wasps, bees, beetles, etc. The bees and butterflies commonly pollinate the flowers of Asteraceae and Labiatae family.
- The various traits of entomophilous flowers are :
  - They are showy or brightly coloured.
  - The small flowers become conspicuous by their grouping.
  - Where petals are not conspicuous, other parts become showy, *e.g.*, bracts in *Bougainvillea*, leaves in *Euphorbia pulcherrima*.
  - Most insect pollinated flowers have a landing platform. In many cases special markings occur on the petals for guiding the insect to nectar glands. They are called honey or nectar guides (*e.g.*, *Viola*).
  - Edible pollens are produced by *Rosa*, *Clematis*, *Magnolia*, etc.
  - Some plants have special adaptations for the insect visitor to help in cross pollination.

Zoophily

- Pollination that is carried out by the agency of animals is called zoophily. Zoophily is subdivided into many kinds based on the type of animal involved. These are :

(i) **Malacophily** – Agent is snail, *e.g.*, *Lemna*, *Aroids*.

(ii) **Ophiophily** – Agent is snake, *e.g.*, *Arisaema*.

(iii) **Ornithophily** – In some parts of the tropics, birds are more important pollinators than insects. **Humming-birds**, **sun-birds**, and **honey-eaters** are some of the birds which regularly visit flowers.

General characteristics of the ornithophilous flowers are their tubular (*Nicotiana glauca*), cup-shaped (*Callistemon*), or urn-shaped (some members of ericaceae) form, bright colour, large quantities of pollen, and plenty of nectar.

In *Strelitzia reginae* pollination is brought about by sun-birds. The flowers are borne in a boat-shaped bract. Of the three sepals two form a long and stiff spear-head. The stamens and carpel, which are enclosed within the spear-head, get exposed only with the pressure of the visiting birds. A unique feature of this plant is the presence of certain sticky, thread-like structures in the anther cavity, each holding hundreds of pollen grains. When a bird visits these flowers, the pollen-laden threads get attached to its breast or belly and move with it from flower to flower.

(iv) **Chiropterophily** – Pollination by **bats** is called chiropterophily. Chiropterophilous plants have flowers borne singly or in clusters quite away from branches and foliage owing to their long stalk. This facilitates the visit of bats to the flowers. These flowers open only at or after dusk, with the anthers dehiscing almost at the same time.

(v) **Myrmecophily** – **Pollination by ants** is called myrmecophily and such plants pollinated by ants are called myrmecophytes, *e.g.*, some members of family Rubiaceae.

Coevolution of flowers and pollinators

- Coevolution is the evolution of two species that interact extensively with one another so that each acts as a major force of natural selection on the other The coevolution of the flower and its pollinator species are tightly linked with one another. Flower parts are modified, shaped by mutations and natural selection into a form that enhances pollination.
- Majority of insect pollinated flowers are beautifully coloured, fragrant, rich in nectar, large in size or if small, they are grouped into an inflorescence to make them conspicuous. To sustain animal visits, flowers have to provide rewards to the animals. Nectar, pollen grains, shelter and edible floral parts and young seeds are the floral rewards for pollinators and juicy and nutritious fruits for seed dispersers so that insects/animals regularly visit them to feed or take shelter. For harvesting the rewards from the flower, the animal visitor comes in contact with the anthers and the stigmas of the flower The sticky pollens of insect pollinated flowers, get adhered to the body of pollinator. When this pollinator carrying pollen on the body come in contact with the stigma, it brings about pollination.
- Flower pollinated by flies and beetles secrete foul odour to attract these animals.
- Flowers pollinated by animals can be grouped into three categories depending upon the benefits (rewards) which they provide to the pollinators :
  - Food providing flowers (*e.g.*, *Salvia* and bees, Humming-birds and *Bignonia*, Sun-birds and *Streltizia*).
  - Sex providing flowers (*Ophrys* and *Colpa* wasp).
  - Nursery providing flowers (*e.g* , *Yucca* and yucca moth ; fig and wasp).

Advantages of cross pollination

- The advantages of cross pollination are:
  - Cross pollination introduces genetic recombinations and hence **variations in the progeny**.
  - Cross pollination increases the **adaptability of the offspring** towards changes in the environment.
  - It makes the organisms better fitted in the struggle for existence.
  - The plants produced through cross pollination are more **resistant to diseases**.
  - The seeds produced are usually larger and the offsprings have characters better than the parents due to the phenomenon of **hybrid vigour**.
  - New and more useful varieties can be produced through cross pollination.
  - The defective characters of the race are eliminated and replaced by better characters.
  - Yield never falls below an average minimum.

Disadvantages of cross pollination

- The disadvantages of cross pollination are:
  - It is highly wasteful because plants have to produce a large number of pollen grains and other accessory structures in order to suit the various pollinating agencies.
  - A factor of chance is always involved in cross pollination.
  - It is less economical.
  - Some **undesirable characters may creep** in the race.
  - The very good characters of the race are likely to be spoiled.

Significance of pollination

- Pollination is a means of taking the male gametophyte for its growth near the female gametophyte.
- Pollen-pistil interaction determines the suitability of pollen for carrying out the process of sexual reproduction.
- It has freed the seed plants from the dependence on external water during fertilization.
- It can be manipulated to produce pure lines as well as desired varieties.

Pollen-pistil interaction

- Pollen grains of a number of plants may settle over a stigma. Only the right pollen belonging to same species would germinate while others fail to do so. **Compatibility and incompatibility of the pollen-pistil is determined by special proteins.** The compatible pollens are able to absorb water and nutrients from the surface of the stigma. They germinate and produce pollen tubes. Pollen tubes grow into the style. Their growth and path through the style are also determined by specific chemicals.

Artificial hybridisation

- It is one of the major approaches of crop improvement programme. In such crossing experiments it is important to make sure that only the desired pollen grains are used for pollination and the stigma is protected from contamination (from unwanted pollen). This is achieved by **emasculation** and **bagging techniques**.
- If the female parent bears bisexual flowers, removal of anthers from the flower bud before the anther dehisces using a pair of forceps is necessary This step is referred to as **emasculation.** Emasculated flowers have to be covered with a bag of suitable size, generally made up of butter paper, to prevent contamination of its stigma with unwanted pollen. This process is called **bagging.** When the stigma of bagged flower attains maturity, mature pollen grains collected from anthers of the male parent are dusted on the stigma, and the flowers are rebagged, and the fruits allowed to develop.
- If the female parent produces unisexual flower, there is no need for emasculation. In that case the female flower buds are bagged before the flowers open. When the stigma becomes receptive, pollination is carried out using the desired pollen and the flower is rebagged.

FERTILIZATION

- The fusion of two dissimilar sexual reproductive units or gametes (male gamete and female gamete) is called **fertilization**. It results in the formation of **zygote** which is a **diploid structure**. Zygote undergoes division to form an embryo. The phenomenon of fertilization was first reported by **Strasburger** (1884) in *Monotrapa*. The male gametes are brought to the egg containing female gametophyte by a pollen tube. This phenomenon is called **siphonogamy**.

- The different steps of fertilization include :
  - Germination of pollen grain on stigma
  - Path taken by the pollen tube
  - Entry of pollen tube into embryo sac
  - Path of male gametes
  - Fusion of gametes and double fertilization

Germination of pollen grain

- The first requirement for pollen to germinate is their hydration which takes from a few seconds to a few minutes. Pollen absorbs secretion of stigma (sugar, gum, resins and other liquid) and swells up. Exine ruptures and intine comes out in the form of **pollen tube**. Secretion of stigma is sticky and also prevents pollen as well as stigma from desiccation. The stigmas which secrete exudates are called **wet stigmas** (*Petunia*) and those which do not are called **dry stigmas** (cotton). The pollen tubes pierces through stigmatic papilla into tissue of style.

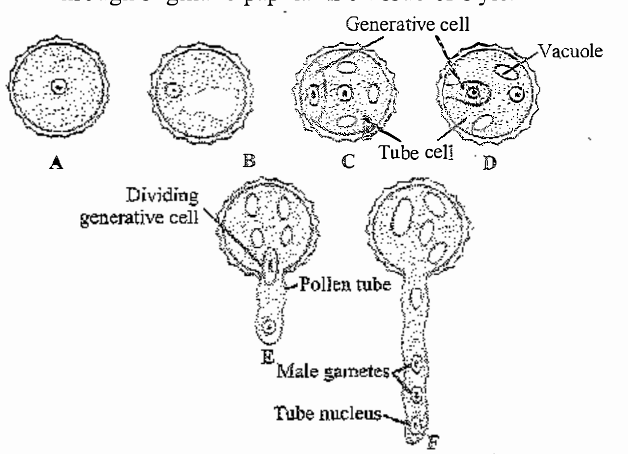

Fig.: Germination of pollen grain, and development of male gametes (A–F)

Path of pollen tube

- After the emergence of the pollen tube from the pollen grain, it makes its way between the stigmatic papillae into the tissues of the style. The style varies in length.
- Histologically the styles have been classified into three main types, *i.e.*, **open**, **half closed** and **closed**.
- In **open type**, the transmitting tissue of the style is **dissolved** by the action of **pectinase enzyme** (found in many monocots like papaveraceae, aristolochiaceae). In **half-closed type** the stylar canal remains surrounded by a rudimentary transmitting tissue of two or three layers (found in several members of cactaceae).In the **closed type** (found in *Datura* and *Gossypium*), there is no open channel but a solid core of tissue, through which the pollen grows downward in order to reach the ovary.
- When the pollen tube reaches in ovary region, it enters into the ovule in either of the 3 ways :
  - **Through micropyle :** This process of entry of pollen tube into ovule through micropyle is called **porogamy** and this is most common in angiosperms.
  - **Through chalaza :** The process of entry of pollen tube into ovule through chalaza is called **chalazogamy**, *e.g.*, in *Betula*, *Casuarina* and *Juglans*.
  - **Through integuments or funiculus :** The process is called **mesogamy**, *e.g.*, in *Cucurbita* (through integuments) and *Pistacia* (through funiculus).
- **Chalazogamy was first reported in** *Casuarina*. The filliform apparatus of synergids secrete some chemotropically active substances which direct the pollen tube towards micropyle of ovule.

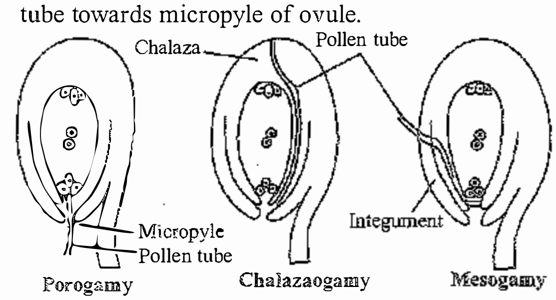

Fig.: Three modes of entry of pollen tube into the ovule.

Entry of pollen tube into the embryo sac

- In normal cases only **one synergid is destroyed** by the impact of the pollen tube and the other remains intact until some time afterwards.

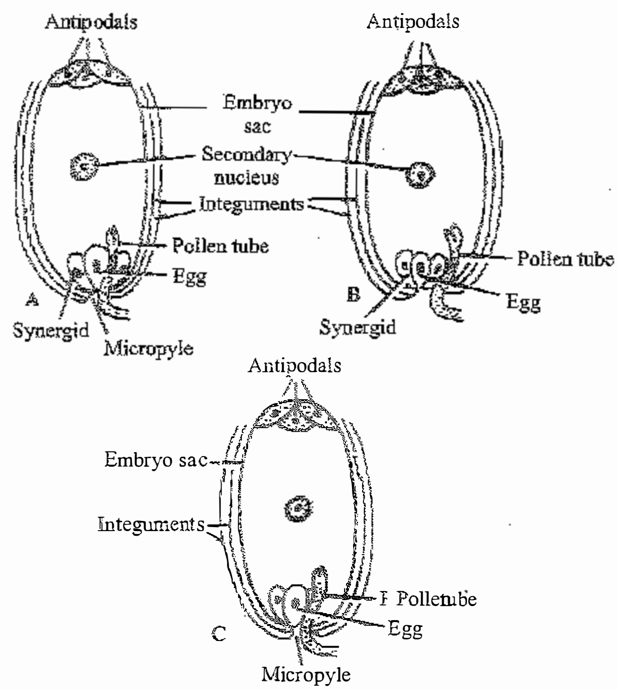

Fig.: **A.** Pollen tube entering between one synergid and egg
B. Pollen tube entering between embryo wall and a synergid
C. Pollen tube entering the embryo sac directly through a synergid.

Path of male gametes

- The pollen tube on reaching the embryo sac discharges the two male gametes through subterminal pore. Usually the pollen tube discharges in the vicinity of the egg and thus the path of the male gametes to the female nuclei varies in its length. The contents of the pollen tube are discharged in the synergid and the **pollen tube does not grow beyond it in the embryo sac.**

Double fertilization

- The pollen tube always enters the embryo sac at the micropylar end. Inside the embryo sac, one male gamete fuses with the egg to form zygote (2n), the process is known as **syngamy** or **generative fertilization**. The second male gamete fuses with 2 polar nuclei or secondary nucleus to form triploid primary endosperm nucleus, the process is known as **triple fusion** or **vegetative fertilization**. The zygote develops into embryo and primary endosperm nucleus develops into endosperm. The occurrence of syngamy and triple fusion simultaneously is called **double fertilization** (specific feature of angiosperm). Double fertilization was first reported by **S.G. Nawaschin (1898)** in *Fritillaria* and *Lilium*.

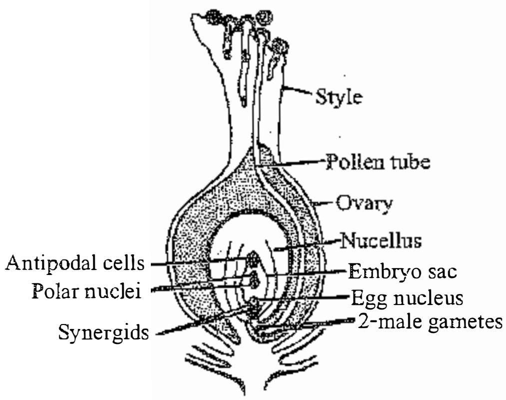

Fig.: Double fertilization.

Significance of double fertilization

- The significance of double fertilization are :

(i) Female gametophyte stops its growth at 8 nucleate stage, further growth continues after double fertilization.

(ii) Syngamy leads a diploid zygote which later on changes into embryo and triple fusion makes endosperm which provides nourshment to developing embryo. Thus, double fertilization is necessary for the formation of viable seeds.

(iii) Secondary nucleus stops its division before fertilization. So, triple fusion induces this dormant nucleus to regain its multiplicative property.

(iv) The formation of endosperm arises after fertilization particularly for developing embryo.

- Thus, we can safely conclude that the formation of endosperm or double fertilization in angiosperms is not a wastage of energy.

Post-fertilization : structure and events

- Soon after fertilization, the flower begins to fade. It is sometimes accompanied by sudden increase in respiration and ethylene production. The petals, stamens and style wither away. The calyx may persist (*e.g.*, tomato, brinjal) and even show growth as in *Physalis* and *Dillenia*. Other changes which take place are **endosperm formation, embryo development, seed formation** and **fruit formation**.

Table : The transformation of part of flower

Before fertilization	After fertilization
Calyx, Corolla, Androecium, Style, Stigma	Wither
Ovary	Fruit
Ovary wall	Pericarp
Ovule	Seed
Integuments	Seed coats
Outer integument	Testa
Inner integument	Tegmen
Micropyle	Micropyle
Funicle	Stalk of seed
Nucellus (persistent)	Perisperm
Egg cell	Zygote (oospore)
Synergids	Disintegrate and disappear

- The events of endosperm and embryo development, maturation of ovule(s) into seeds and ovary into fruit, are collectively termed as **post-fertilization events**.

Endosperm

- As a consequence of triple fusion in which a male gamete fuses with the secondary nucleus, a triploid structure called primary endosperm nucleus (PEN) is formed that divides by mitotic divisions and forms a mass of nutritive cells called the **endosperm**.
- Endosperm development precedes embryo development. Endosperm accumulates food reserves and functions as the nutritive tissue for the developing embryo.
- In gymnosperms, **the endosperm is haploid** and forms as pre-fertilization tissue in continuation of the female gametophyte. On the other hand in **angiosperms**, it is formed by the repeated mitotic divisions of PEN, and is **triploid**. In normal cases, the endosperm is triploid but haploid, tetraploid and polyploid endosperms are also known, *e.g.*, it is 2n in *Oenothera*, 9n in *Pepromea*, 5n in *Fritillaria*. No endosperm is formed in members of families **orchidaceae, podostemonaceae** and **trapaceae**.
- Depending upon the mode of its formation, angiospermic endosperm is of three types – **nuclear, cellular** and **helobial**.
  - **Nuclear endosperm :** It is the most common type of endosperm found in 161 families of angiosperms. The primary endosperm nucleus divides repeatedly without wall formation to produce a large number of **free nuclei.** The multinucleate cytoplasm undergoes cleavage and gives rise to a multicellular tissue, *E.g.*, maize, wheat, rice, sunflower, *Capsella bursa-pastoris*, coconut (*Coccus nucifera*).
  - **Cellular endosperm :** Every division of the primary endosperm nucleus is followed by cytokinesis. Therefore, endosperm becomes cellular from the very beginning, *e.g.*, *Balsam, Datura, Petunia*. It is reported in about 72 families of angiosperms (mostly dicots).

– **Helobial endosperm :** It occurs in order helobiales of monocots. The endosperm is of intermediate type between cellular and nuclear types. The first division of primary endosperm nucleus is followed by transverse cytokinesis to form two unequal cells, larger micropylar and smaller chalazal. *E.g., Asphodelus.*

Embryo

- After fertilization, the **fertilized** egg is called zygote or **oospore** which develops into an embryo. This process of development of embryo is called **embryogenesis**.
- The oospore before it begins to multiply, it undergoes a period of rest which may vary from few hours to few months. Generally the zygote (oospore) divides immediately after the first division of the primary endosperm nucleus.
- Practically there are no fundamental differences in the early stages of the development of the embryos of monocots and dicots. But in later stages there is a marked difference between the embryos of dicotyledonous and monocotyledonous plants.
- Different stages in the development of the embryos of **monocots** and **dicots** is shown in the figure given.

Table : Differences between dicot and monocot embryo

	Dicot embryo	Monocot embryo
1.	Basal cell forms a 6-10 celled suspensor.	Basal cell produces a single celled suspensor.
2.	Terminal cell produces embryo except the radicle.	It forms the whole of the embryo.
3.	The first division of terminal cell is generally longitudinal.	It is transverse.
4.	It has two cotyledons.	There is a single cotyledon.
5.	Plumule is terminal and lies in between the two elongated cotyledons.	Plumule appears lateral due to excessive growth of the single cotyledon.

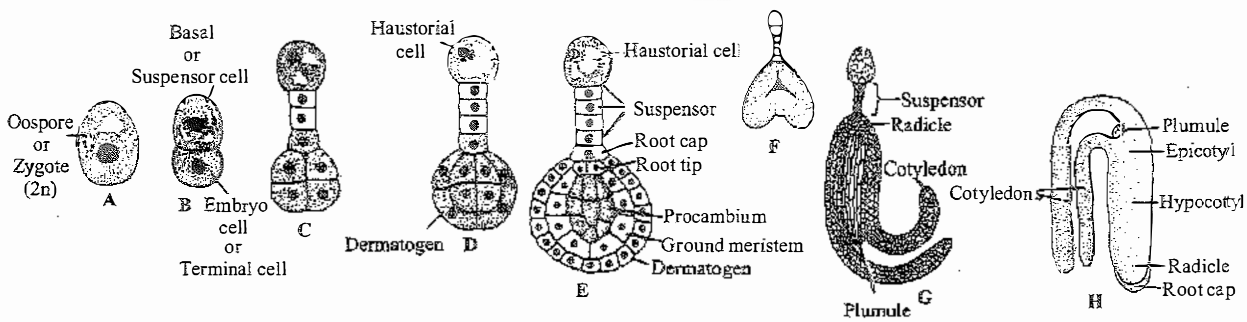

Fig.:(A-H); Stages in the development of a dicot embryo

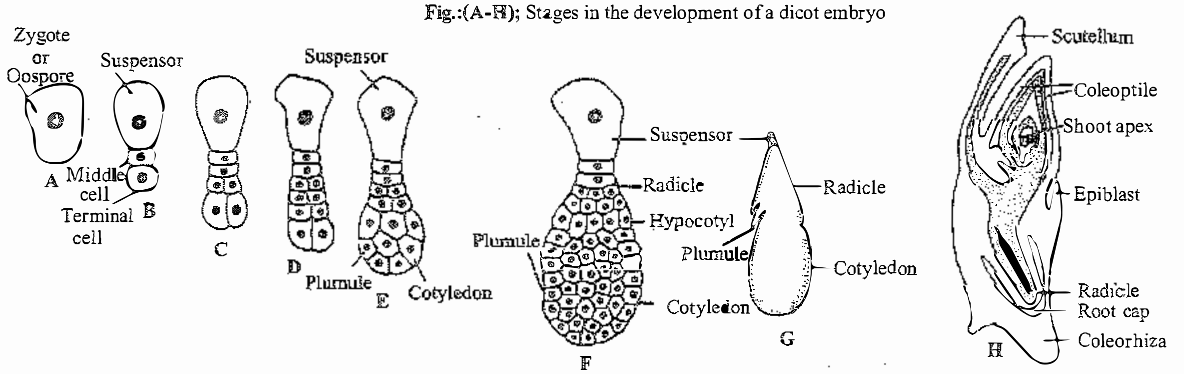

Fig.: A–G; Stages in development of a monocot embryo. H, A monocot embryo of a grass.

Seeds

- Ripened ovules are known as seeds. Integuments of ovule form seed coat. **Outer integument** form testa and tegmen develops **from inner integument.**
- In some cases like litchi (*Pithecolobium*, *Asphodelus*, *Trianthema*, etc) a sort of third integument or **aril** is present, which forms an additional covering of seed.
- **Funiculus** (stalks of ovule) forms **stalk** of the seed. Ultimately, stalk withers and leaves a minute scar called hilum. Antipodals, synergids disorganize and nucellus may disappear or persist as perisperm.
- Depending upon the persistence of endosperm the seeds are classified as
  – **Non-endospermic or ex-albuminous :** Here during the process of development of the embryo, the food stored up in endosperm is completely exhausted by the developing embryo. *E.g.*, seeds of gram, pea, bean, orchid, etc.
  – **Endospermic or albuminous :** Here endosperm grows vigorously and is not exhausted by the developing embryo. Cotyledons are thin here. *E.g.*, seeds of wheat, barley, castor, poppy, etc.

Importance of seeds

(i) **Dependable method :** Unlike bryophytes and pteridophytes, pollination and fertilization of seed plants are free from

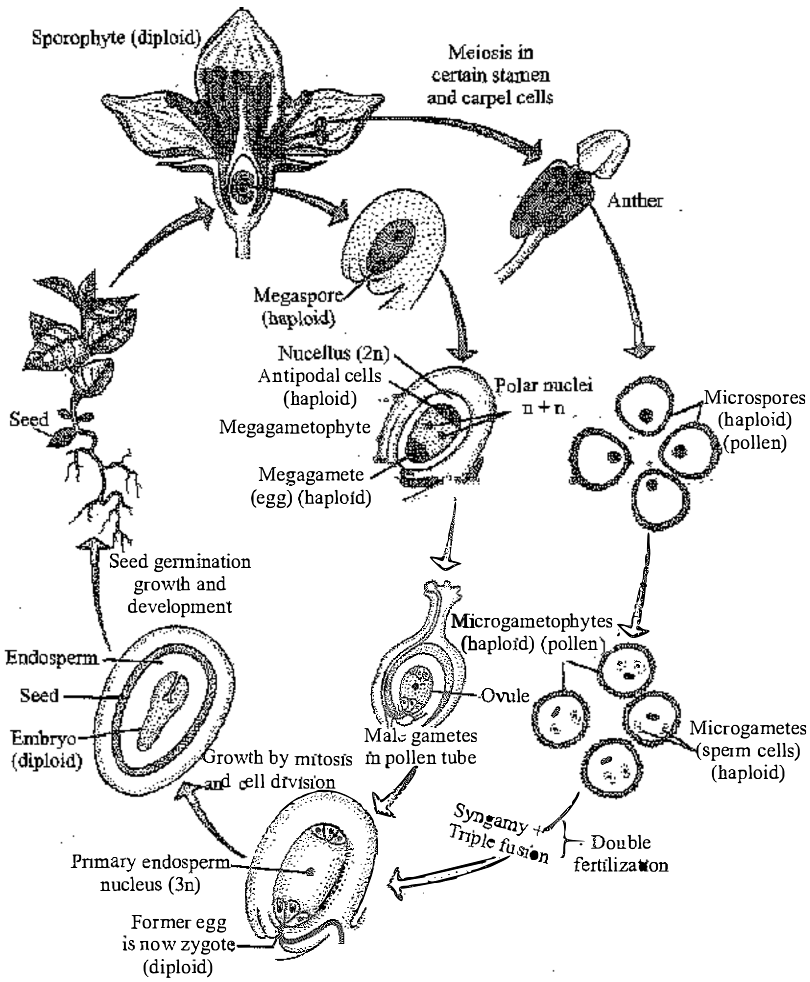

Fig.: Life cycle of an angiospermic plant

requirement of water. Seed formation is, therefore, more dependable.

(ii) **Perennation :** Seed is dry (water content 10-15%) with dormant embryo and thick protective seed coat. It is most suitable for perennation through unfavourable periods.

(iii) **Dispersal :** Seeds have adaptive strategies to get dispersed to new habitats and colonise the same.

(iv) **Reserve food :** Seeds have reserve food for nourishing the young seedlings till they become nutritionally independent.

(v) **Variations :** As seeds are formed through sexual reproduction they carry a number of variations. Variations are essential for adaptability to diverse environmental conditions.

(vi) **Storage :** Seeds can be stored for later use. This is helpful for supply of food throughout the year and to overcome drought and famine conditions.

(vii) **Agriculture :** Seed is the basis of agriculture. Agriculture originated when human learnt to eat, store and sow seeds. Agriculture proved to be turning point for evolution of human civilisation, industrialisation, science and technology.

Fruits

- A fruit is a seed containing part of a plant that develops from a fertilized ovary and often from other tissues that surround it. As fruits are products of flowers and therefore they occur only in flowering plants. The wall covering the fruit is called pericarp. It consists of three parts :

(i) **Epicarp**, called the skin of fruits.

(ii) **Mesocarp**, middle fleshy and pulpy part.

(iii) **Endocarp**, innermost portion that surrounds the seeds.

- Fruits can be classified into three main groups : **simple fruits, aggregate fruits** and **composite (multiple) fruits**.
- A simple fruit develops from **syncarpous (fused) ovary** and aggregate fruit develops from **apocarpous (free) ovary** while a composite fruit develops from a **complete inflorescence**. The fruit may be fleshy as in guava, orange, mango, etc. or may be dry, as in groundnut, mustard, etc.

SPECIAL MODES OF REPRODUCTION

Polyembryony and Apomixis

- The phenomenon of having more than one embryo is called **polyembryony**, *e.g.*, onion, groundnut. It is of 2 types :
  - **Simple polyembryony :** Occurrence of polyembryony due to fertilization of more than one egg.
  - **Adventive polyembryony :** Formation of extra embryos through sporophytic budding.
- Polyembryony was first discovered by **Leeuwenhoek** (1719) and was confirmed later by **Schnarf** (1929). Polyembryony phenomenon is more common in gymnosperms than angiosperms. In angiosperms, it is generally present as unusual feature except few cases like *Citrus*, mango, etc.
- There are two types of polyembryony such as **false** and **true polyembryony**. In false polyembryony more than one embryos arise in different embryo sacs in the ovule. In true polyembryony, more than one embryos are formed in the same embryo sac in the ovule.
- The cause of polyembryony may be :
  - Cleavage of proembryo, *e.g.*, family orchidaceae
  - Development of many embryos from other cells of embryo sac except egg, *e.g.*, *Argemone*
  - Formation of many embryos due to presence of more than one embryo sac in same ovule, *e.g*, *Citrus*
  - Formation of many embryos from the structure outside the embryo sac, (adventitive polyembryony), *e.g.*, mango, *Opuntia*.

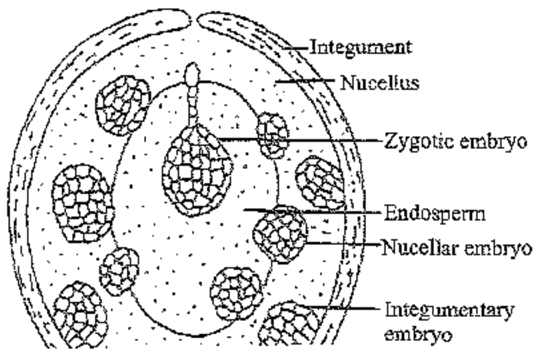

Fig.: Polyembryony in *Citrus*.

- A special and interesting case of polyembryony is found in *Allium odorum*, where **5 embryos develop by different** methods, *e.g.*, 1 --> zygotic, 1 --> synergidal, 2 --> from antipodals, and 1 --> from integuments.
- **Maximum number of embryos**, *i.e.*, **40** are reported inside single seed of *Citrus unshiu.*
- Polyembryony is **practically important because genetically uniform parental type seedlings are obtained from nucellar** embryos.
- Nucellar embryos are superior to those obtained by **vegetative propagation** because nucellar embryo seedlings are disease **free and maintain their superiority for long time.**
- **Most important theory of cause of polyembryony** is **necrohormone theory** given by Haberlandt (1921), *i.e.*, a stimulus for polyembryony is provided by degenerating cells of nucellus.
- The substitution of sexual reproduction by asexual process, a form of reproduction which does not involve syngamy and meiosis is called as **apomixis**. The term apomixis was given by **Winkler (1908)**.
- Apomixis occurs by **vegetative reproduction** and **agamospermy**. Agamospermy is of three types – **recurrent agamospermy**, **adventive embryony** and **non-recurrent agamospermy**.

Types of apomixis

- **Vegetative reproduction**: There is no requirement of seed for production of new plant. New plant is produced from buds, leaves and stem.
- **Agamospermy**: Embryo and seeds are produced without involvement of fertilization and meiosis.
  - **Recurrent agamospermy**: A diploid (2n) embryo sac is formed having diploid egg cell which grows into diploid embryo. *E.g.*, Apple, *Allium*.
    - **Diplospory**: A diploid embryo sac is formed from diploid megaspore mother cell without regular mitotic division.
    - **Apospory**: Embryo developed from diploid nucellar mother cell.
  - **Adventive embryony**: When one or few extra embryos are formed from a diploid cells of nucellus or integument but never from egg. *E.g.*, *Citrus*, *Opuntia*.
  - **Non-recurrent agamospermy**: Embryo developed parthenogenetically from haploid egg, synergid, antipodal cells.

Parthenocarpy

- Development of fruits without fertilization is called **parthenocarpy**. The term parthenocarpy was coined by Noll (1902). The parthenocarpic fruits are seedless, *e.g.*, banana, guava, apple, pineapple, etc.
- Parthenocarpy is of three types- **genetic, environmental** and **chemically induced.**
  - **Genetic parthenocarpy** : Parthenocarpy is due to genetic alteration caused by mutation or hybridisation. It is also called natural parthenocarpy, *e.g.*, navel orange, banana, pineapple, varieties of apple, grape and pear.
  - **Environmental parthenocarpy** : Low temperature, frost and fog have been known to induce parthenocarpy in a number of plants, *e.g.*, pear, olive, *Capsicum*, tomato.
  - **Chemically induced parthenocarpy** : Spray or paste of auxins and gibberellins in low concentration of 10^{-6} – 10^{-7} M has been found to induce parthenocarpy in several plants, *e.g.*, tomato, *Vitis*, cucurbits, *Citrus*, strawberry, blackberry, fig, etc.
- Parthenocarpy **can be induced artificially** by :
  - Spraying auxins (applied after anthesis) and gibberellins (applied at anthesis).
  - Delayed pollination.
  - Use of foreign pollen grains.
  - Use of powdered pollens and pollen extracts.
  - Cutting style from base and applying chemicals like IAA, IBA, etc. in lanolin paste at cut surface.

Importance of parthenocarpic fruits

- They do not contain irritant seeds which have to be removed before eating fruits.
- Fruits can be developed inside the greenhouses where pollinators are not available.
- Quicker food processing.

CONCEPT MAP

Sexual Reproduction in Flowering Plants

It consists of three processes.

Flower

Gynoecium or Carpels

- Style
- Stigma
- Megasporangium/Ovary
  - **Ovule** present inside the ovary serves as **integumented megasporangium.** It develops into seeds after fertilization.
  - **Primary sporogenous cell** of megasporangium functions as **megaspore mother cell** which **meiotically** forms four haploid **megaspores** out of which **one** (usually that on the chalazal side) **remains functional and others degenerate.**

Androecium or Stamens

- Microsporangium / Anther
  - Microsporangium is a **cylindrical sac** consisting of sporogenous tissue.
  - Cells of sporogenous tissue transform into **microspore mother cells** (MMC) or **pollen mother cells** (PMC) which form four haploid **microspores or pollen grains.**
- Filament

Gametogenesis

- Gametogenesis or gamete formation occurs inside the female and male gametophytes.

Female gametophyte

- Megaspore mother cell undergoes meiosis to form four megaspores. Three degenerate and one remains as functional megaspore. It develops into embryo sac, the female gametophyte..
- The nucleus of embryo sac divides mitotically three times and forms 8 nuclei.
- This **7 celled** (three micropylar, 3 chalazal and one central cell), **8 nucleate** embryo is the gametophytic (female) structure in flowering plants.

Male gametophyte

- Inside the microspore (pollen grain), mitosis occurs and a 2-celled male gametophyte is formed. Large one is called **tube cell** or **vegetative cell** and the small one is called **generative cell.**

Pollination

- Pollination is the process in which microspore (with 2-celled male gametophyte) reaches the stigma of a flower through a **pollinating agent.**
- Pollinating agent may be air **(anemophily)**; water **(hydrophily)**; animals **(zoophily)** : insects **(entomophily)**, birds **(ornithophily)**, molluscs **(malacophily)**, bats **(chiropterophily)**.

Types

- Self pollination
- Cross pollination

Fertilization

- After reaching stigma, the microspore (pollen) germinates by forming **pollen tube.**
- Pollen tube is formed by **emergence of tube cell** from germ pore or germinal furrow.
- **Generative cell** of male gametophyte and **tube nucleus** pass into pollen tube. Here generative cell forms two **male gametes.**
- Pollen tube enters the embryo sac through **micropyle** (**porogamy,** most common) chalaza **(chalazogamy)** or sides **(mesogamy).**
- Male gametes are brought to embryo sac through pollen tube **(siphonogamy).** Inside the sac, pollen tube ruptures to release gametes. **Double fertilization** (**Nawaschin**) occurs *i.e.*, one male gamete fuses with egg cell to form **zygote (2n)** and the other fuses with polar nuclei to form **endosperm nucleus (3n).**
- Zygote forms **embryo** and endosperm nucleus forms **endosperm,** the nutritive tissue.