Sexual reproduction is the process of fusion of haploid gametes, resulting in the production of a diploid zygote, which ultimately develops into a new organism. All flowering plants show sexual reproduction.

[TOPIC 1] Flower and Its Parts

1.1 Flowers

Flowers are the site of sexual reproduction in flowering plants.

(*i*) A flower has parts namely sepals, petals, stamens and pistils arranged in four whorls, i.e. calyx (sepals), corolla (petals), androecium (stamens) and gynoecium (pistils). These whorls are attached on central axis called **thalamus**.

(*ii*) Flowers may contain both male (stamens) and female (carpels or pistils) reproductive parts or organs in it such flowers are called **bisexual**.

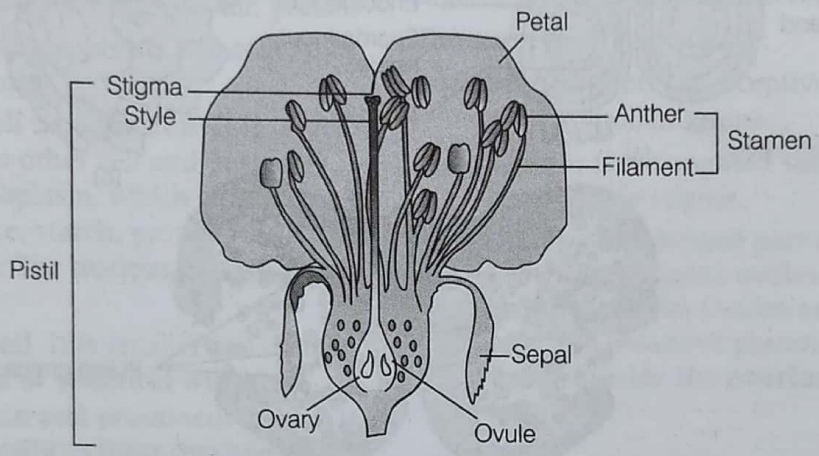


Figure 2.1 Diagrammatic representation of LS of a flower

(*iii*) In **unisexual flowers**, only either of the reproductive parts are present, e.g. corn, the tassels represent the male flowers (stamens) and the ears or silk represent the female flower (styles and stigma).

Male Gametophyte

Stamen

Stamen is the male reproductive unit of angiosperm. It consists of following two parts:

(*i*) The long and slender stalk called the **filament.**

(*ii*) The terminal generally bilobed structure called the **anther**.

Anther

Anther is a bilobed structure with each lobe having two **theca**, therefore, it is called **dithecous**. In a cross-section, it appears four sided, i.e. tetragonal. It consist of four microsporangia, located at four corners, (two in each lobe). **Microsporangia** after development become pollen sacs by producing pollen grains.

Microsporangium

Structure of microsporangium contains following features in a transverse section:

(*i*) Appears nearly circular in outline.

(*ii*) It is surrounded by four wall layers. The outer three layers are **epidermis**, **endothecium** and **middle layers**. These three wall layers are protective in function and they also help in dehiscence of anther to release the pollen. The fourth and innermost layer called the **tapetum** nourishes developing pollen grains. It contains cells with dense cytoplasm and more than one nuclei.

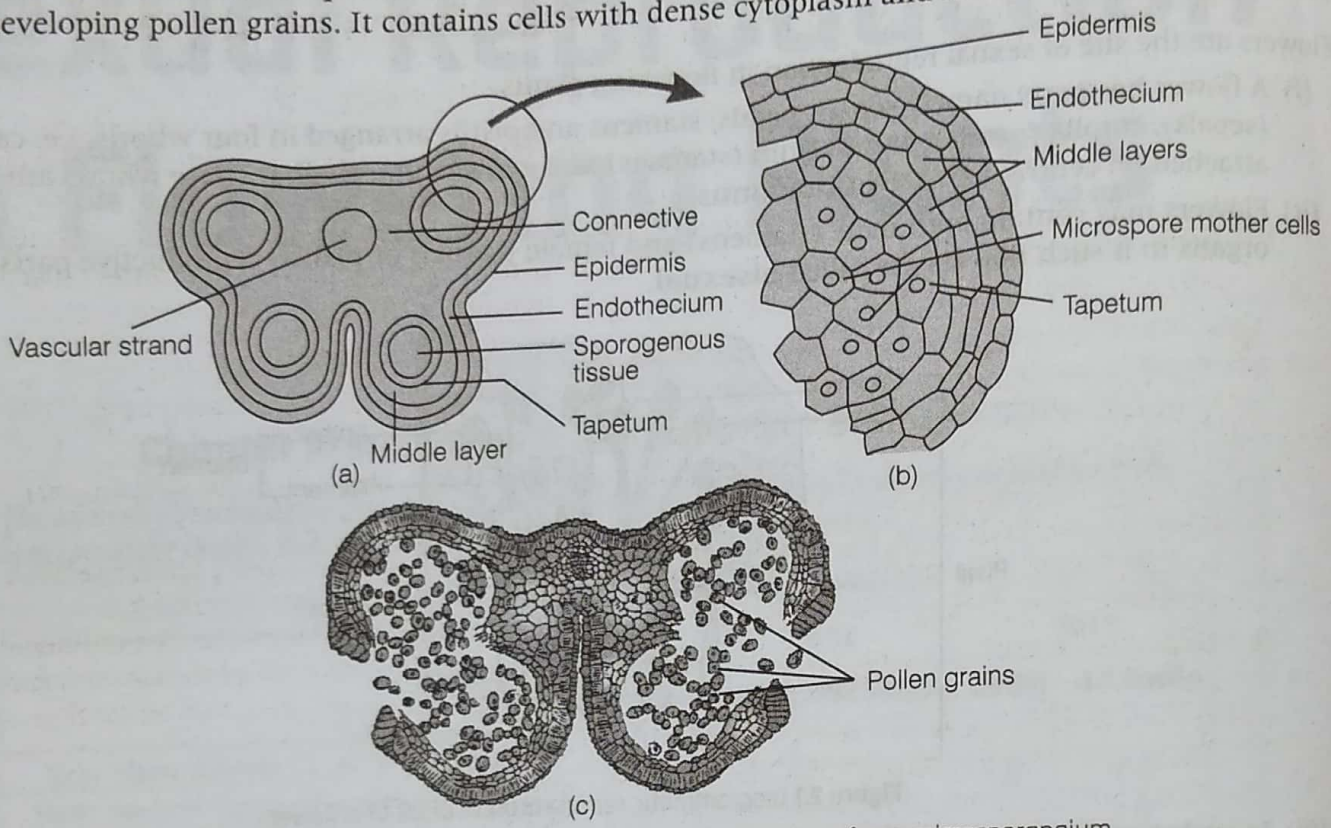


Figure 2.2 (a) TS of a young anther (b) Enlarged view of one microsporangium showing four wall layers (c) A mature dehisced anther

(*iii*) The microsporangial wall layers enclose a mass of sporogenous tissue.

(*iv*) Each cell of sporogenous tissue undergoes meiosis to form four cells, which remain associated in microspore tetrad. Each cell of this tetrad after separation develop into pollen grains that represent male gametophyte.

Microsporogenesis

The process of formation of microspores from a pollen mother cell (each cell of sporogenous tissue) through meiosis is called **microsporogenesis**.

(*i*) **Microspores** are arranged as tetrad. As the anther mature and dehydrate they dissociate from each other and develop into pollen grains. Pollen grains or the male gametophytes are later released during dehiscence of anther.

(*ii*) Pollen grains have the following characteristic features:

- Generally **spherical**, about 25-50 micrometers in diameter.
- Mature pollen grain consists of an outer covering called sporoderm.

It is differentiated into two layers:

(a) **Outer hard layer** or **Exine** is made up of one of the most resistant organic material **sporopollenin**, that enables them to resist high temperatures and action of strong acids and alkali. Further no enzyme is yet known to degrade sporopollenin, because of which pollen grains are well-preserved as fossils.

The regions on exine, where sporopollenin is absent are called **germ pores**. These help in the formation of pollen tube, while the pollen grain germinates on stigma.

(b) **Inner thin, continuous layer**, i.e. **intine** is made up of cellulose and pectin.

A mature pollen grain contains two cells, that are formed *via* mitosis.

(a) **Vegetative cell or tube cell** It is larger as compared to other cell and possesses vacuolated cytoplasm, which is rich in reserve food, i.e. starch, protein, fat and cell organelles. The nucleus is large and irregular.

(b) **Generative cell** It is smaller cell usually spindle-shaped or spherical with thin dense cytoplasm and prominent nuclei. It divides mitotically to form two non-motile male gametes, prior to release of pollen grain. The process of formation of male gametes from generative cell is called **microgametogenesis**.

(*iii*) In about 60% of angiosperms, pollen grains shed at 2-celled stage (1 vegetative cell +2 male gametes) .

(*iv*) In about 40% flowering plants, the generative cell divides mitotically to give rise to the two male gametes before pollen grains are shed at 3-celled stage (1 vegetative cell +2 male gametes).

(*v*) Pollen grains of many species (e.g. *Parthenium* or carrot grass) causes severe allergic, chronic respiratory disorders like asthma, bronchitis, etc.

(*vi*) Viability of pollen grains depends on temperature and humidity.

(*vii*) Pollen grains are rich in nutrients and are used as food supplements in the form of pollen tablets and syrups. Its consumption has been claimed to increase the performance of athletes and race horses.

Female Gametophyte

Pistil/Gynoecium

It is the female unit of flower. A flower may be **monocarpellary** (having one pistil) or **multicarpellary** (having more than one pistils). Pistils may be **syncarpous** (fused together) or **apocarpous** (free).

The main parts of pistil are:

(*i*) **Stigma** topmost receptive part that receives pollen grains.

(*ii*) **Style** is the elongated slender part beneath the stigma.

(*iii*) **Ovary** is the bulged part at the base of style that contains ovules or megasporangia. Ovules are connected to ovary by means of placenta which is located inside the **ovarian cavity** or **locule.**

Megasporangium

It arises from the placenta. Ovule is attached to the placenta by a stalk called **funicle**. The number of ovules in an ovary may be one (wheat, paddy and mango) to many (papaya, watermelon and orchids).

The main parts of megasporangium (ovule) are:

(*i*) **Hilum** is a junction between ovule and funicle.

(*ii*) Each ovule has one or two protective envelopes called **integuments.**

(*iii*) **Micropyle** is an opening present at the tip where integument is absent.

(*iv*) **Chalaza** is opposite to the micropylar end representing the basal part of the ovule.

(*v*) The integuments encloses a mass of cells called the **nucellus**, which have food reserves.

(*vi*) **Embryo sac** or **female gametophyte** is located in the nucellus (generally one formed from a megaspore through reductional division).

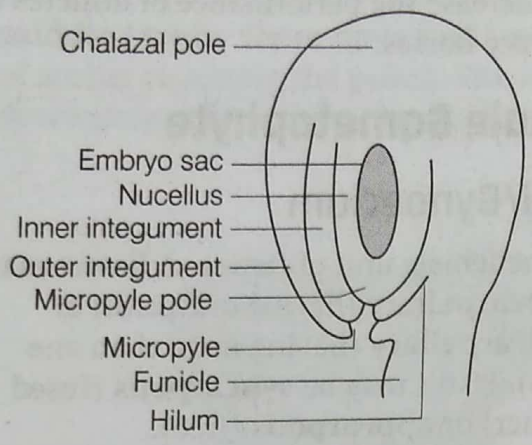


Figure 2.3 Diagrammatic view of a typical anatropous ovule

Megasporogenesis

It is the process of formation of **megaspores** from the **Megaspore Mother Cell** (MMC). The MMC is a large cell with dense cytoplasm and prominent nucleus. It undergoes meiosis resulting in the production of four megaspores.

Development of Female Gametophyte

Different stages of development of female gametophyte are given below:

(*i*) Out of the four magaspores, only one is functional, while the other three degenerate in majority of angiosperms.

(*ii*) Only the functional megaspore develops into the **female gametophyte** or **embryo sac**. This is called **monosporic development.**

(*iii*) Nucleus of the functional megaspore divides mitotically to form two nuclei, which move to the opposite poles forming the **2-nucleate** embryo sac.

(*iv*) Nuclear divisions result into the formation of **4-nucleate** and later **8-nucleate** stages of the embryo sac.

(*v*) Six of the eight nuclei are surrounded by cell walls and organised into cells. The remaining two nuclei called **polar nuclei**, are situated below the egg apparatus in the large central cell.

(*vi*) Three cells group together at the micropylar end and constitute the **egg apparatus.**

(*vii*) The egg apparatus consists of two **synergids** and one **egg cell**.

(*viii*) A **filiform apparatus** made of cellular thickenings of synergids at the micropylar end, plays an important role in guiding the pollen tubes into the **synergid**.

(*ix*) At the chalazal end, three cells are present called **antipodals**.

(*x*) Thus, a typical angiosperm embryo sac, at maturity is **8-nucleate** and **7-celled**.

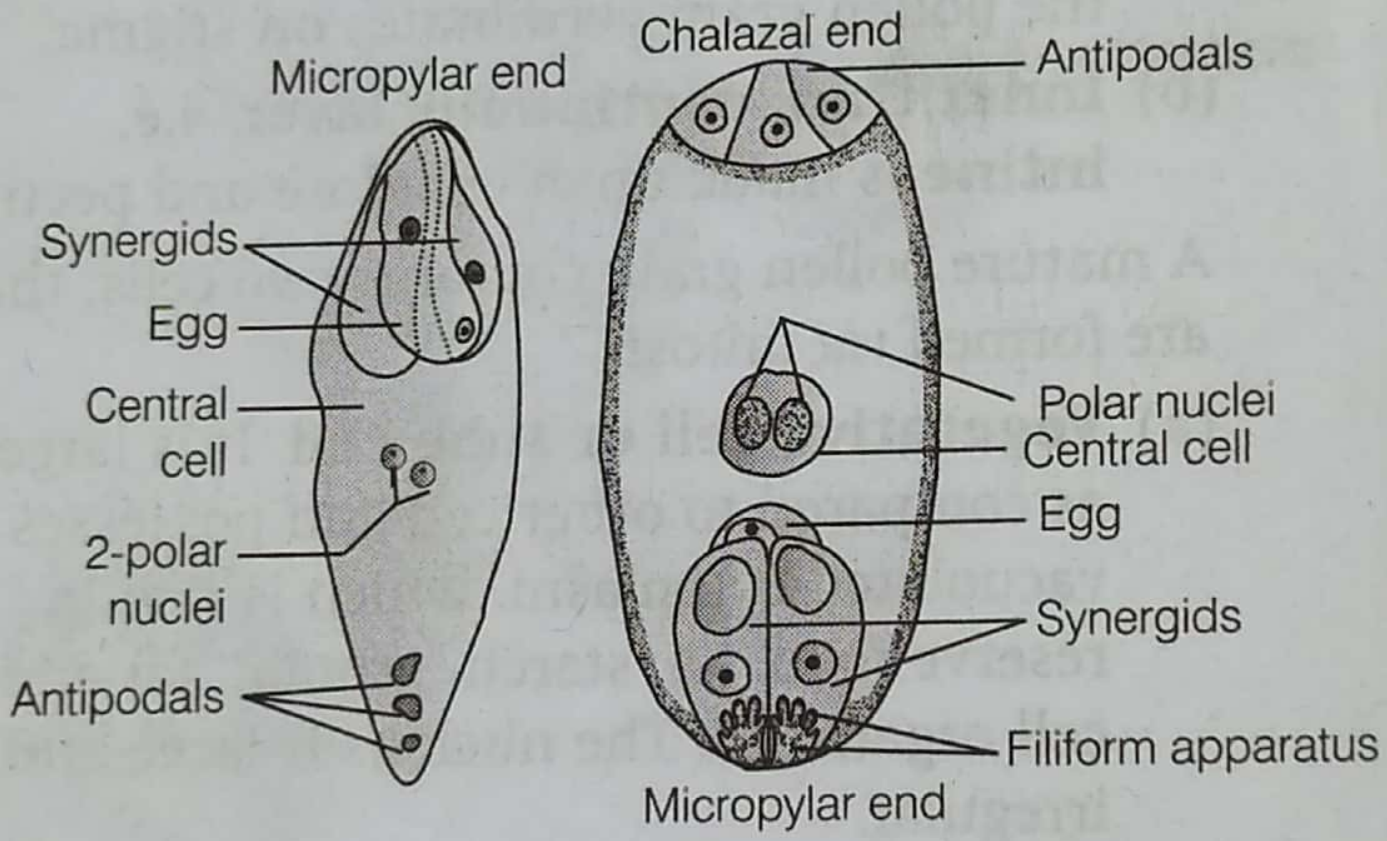
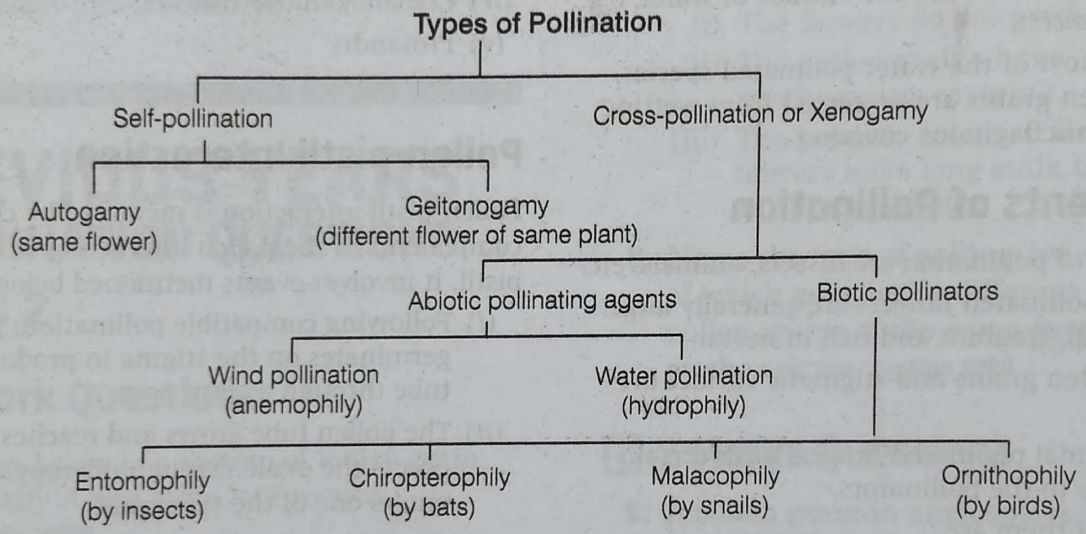


Figure 2.4 A Diagrammatic representation of the mature embryo sac

[TOPIC 2] Pollination

2.1 Types of Pollination

Pollination is the transfer of pollen grains from anther to the stigma of a pistil.



(*i*) **Autogamy** is the transfer of pollen grains from anther to the stigma of the same flower. Anthers and the stigma lie close to each other in a way that self-pollination occurs, i.e. cleistogamous flowers and assure seed-set even in the absence of pollinators.

(*ii*) **Geitonogamy** is the transfer of pollen grains from anther to the stigma of another flower of same plant. Continuous geitonogamy leads to inbreeding depression. It is genetically similar to autogamy, but functionally related to cross-pollination.

(*iii*) **Xenogamy** is the transfer of pollen grains from anther to the stigma of a different plant's flower.

Abiotic Agents of Pollination

1. **Wind pollinated** flowers have:
   (*i*) Light and non-sticky pollen grains.
   (*ii*) Generally a single ovule in each ovary and numerous flowers packed into an inflorescence, e.g. corn cob.
   (*iii*) Well-exposed stamens and large feathery stigma to trap air-borne pollen grains.
   (*iv*) Common in grass, maize, date palm, etc.
2. **Water pollination** occurs in mostly monocotyledons (in about 30 genera). Some examples of water pollinated plants are *Hydrilla*, *Vallisneria* and *Zostera*.
   (*i*) In majority of aquatic plants, the flowers emerge above the level of water and are pollinated by insects or wind, e.g. water hyacinth and water lily.
   (*ii*) The female flower reaches the surface of water by the long stalk and pollen grains are released onto the surface of water, e.g. *Vallisneria*.
   (*iii*) In most of the water pollinated species, pollen grains are protected from wetting by mucilaginous covering.

Biotic Agents of Pollination

Biotic agents of pollination are insects, animals, etc.

(*i*) Insect pollinated flowers are generally large, colourful, fragrant and rich in nectar.

(*ii*) The pollen grains and stigmatic surface are sticky.

(*iii*) The animal pollinated flowers offer certain rewards to the pollinators.

Some of them are :

(a) They offer nectar and (edible) pollen grains.

(b) Some species provide safe place for laying eggs, e.g. *Amorphophallus* and *Yucca*. A relationship exists between a species of moth and the plant *Yucca*, where both species–moth and the plant cannot complete their life cycles without each other. The moth deposits its eggs in the locule of the ovary and the flower, in turn, gets pollinated by the moth. The larvae of the moth come out of the eggs as the seeds start developing.

NOTE Plants like *Viola*, *Oxalis* and *Commelina* produce two types of flowers:

(i) **Chasmogamous** Similar to flowers of other species with exposed anther and stigma.

(ii) **Cleistogamous** Flowers do not open at all. Anthers and stigma lie close to each other to effect self-pollination. There is no chance of cross-pollination.

Outbreeding Devices

Outbreeding devices developed by the bisexual flowers to avoid self-pollination and promote cross-pollination because continuous self-pollination results in poor yield and poor quality of seeds or **inbreeding depression**. These devices are:

(*i*) Dichogamy
(*ii*) Self-sterility
(*iii*) Unisexuality
(*iv*) Chasmogamous flowers
(*v*) Protandry
(*vi*) Protogyny

Pollen-pistil Interaction

Pollen-pistil interaction is mediated by chemical components of the pollen interacting with those of pistil. It involves events mentioned below:

(*i*) Following compatible pollination, pollen grain germinates on the stigma to produce a pollen tube through a germ pore.

(*ii*) The pollen tube grows and reaches the ovary, enters the ovule through micropyle and then enters one of the synergids.

In **artificial hybridisation**, desired pollen grains are used for pollination and the stigma is protected from contamination (from unwanted pollen). This is done by emasculation and bagging. Artificial hybridisation creates new genetic recombination with better qualities.

(*i*) In **emasculation**, anthers are removed from the flower bud before they dehisce with the help of a pair of forceps.

(*ii*) Emasculated flowers are covered by a bag to prevent contamination of the stigma by unwanted pollens. This process is called **bagging**.

Double Fertilisation

Double fertilisation occurs after the pollen tube reaches the ovary. It is the characteristic of angiosperms.

(*i*) The pollen tube releases two male gametes into the cytoplasm of a synergid.

(*ii*) One of the male gamete fuses with egg cell (syngamy) which results in the formation of zygote.

(*iii*) The second male gamete fuses with the two polar nuclei to form a triploid **Primary Endosperm Nucleus** (PEN). This is called **triple fusion**.

(*iv*) Since, two fusion, i.e. syngamy and triple fusion occur in an embryo sac, this is called double fertilisation.

(*v*) Central cell and primary endosperm nucleus called as Primary Endosperm Cell (PEC) develops into the **endosperm** and zygote develops into an **embryo**.

[TOPIC 3] Post-Fertilisation : Structures and Events

After double fertilisation, the following changes occur:

(*i*) Endosperm and embryo development.

(*ii*) Maturation of ovule(s) into seed(s).

(*iii*) Maturation of ovary into fruit.

These events are collectively termed as **post-fertilisation events**.

Post-fertilisation changes in floral parts:

(*i*) Sepals fall down or persist in few.

(*ii*) Petals, stamen, stigma and style fall down.

(*iii*) Ovary changes into fruit.

(*iv*) Ovules become seeds.

(*v*) Synergids and antipodal cells degenerate.

(*vi*) Central cell become endosperm. It may persist or get consumed.

3.1 Endosperm and Embryo Development

Endosperm development takes place by three methods:

(*i*) **In nuclear type**, which is a common method, the Primary Endosperm Nucleus (PEN) undergoes repeated mitotic division without cytokinesis. At this stage, the endosperm is called **free nuclear endosperm.**

(*ii*) **In cellular type**, cell wall formation occurs and the endosperm becomes cellular. The number of free nuclei formed before cellularisation varies greatly, e.g. in coconut the water is free nuclear endosperm and surrounding white kernel is cellular endosperm.

(*iii*) **In helobial type** endosperm formation, one half of endosperm is nuclear type and other half is cellular type.

Some Important Terms

1. **Embryo formation** occurs when certain amount of endosperm is formed, because endosperm provides nutrition for embryo development.
   (*i*) Zygote divides by mitosis and forms **proembryo**.
   (*ii*) This results in the formation of globular and heart-shaped embryo that finally becomes horse shoe-shaped (mature embryo) having cotyledon.
2. Dicot embryo consists of two cotyledons and an embryonal axis between them:
   (*i*) The part of embryonal axis above the level of cotyledons is the **epicotyl** which becomes **plumule** (shoot).
   (*ii*) The part of embryonal axis below the level of cotyledons is the **hypocotyl** which becomes **radicle** (root).
3. Monocot embryo consists of only one cotyledon (called scutellum in grass family), e.g. rice, maize plants, etc.
   (*i*) Embryonal axis has the radicle on its lower end (hypocotyl), the radicle is covered by an undifferentiated sheath called **coleorhiza.**
   (*ii*) At the upper end (epicotyl), the embryonal axis has plumule. It is covered by a hollow foliar sheath called **coleoptile.**

3.2 Maturation of Ovule into Seed

Seed or fertilised ovule is the final product of sexual reproduction:

(*i*) It consists of seed coat, cotyledons and an embryo axis.

(*ii*) ***Non-albuminous*** seeds have no residual endosperm as it is completely consumed in embryo development, e.g. pea, groundnut.

(*iii*) ***Albuminous*** seeds retain a part of endosperm as it is not completely used up during embryo development, e.g. wheat, maize, castor, sunflower, etc.

(*iv*) In some seeds such as black pepper and beet, remnants of nucellus are also persistent (perisperm). Integuments of ovules harden as tough protective seed coat.

(*v*) Micropyle remains as a small pore in the seed coat to allow the entry of oxygen and water.

(*vi*) On the availability of favourable conditions, seeds germinate and later dispersed by abiotic and biotic agents.

Seeds have following advantages:

(*i*) Seeds help the species to spread in other areas by dispersal.

(*ii*) They generate new combinations leading to variations.

(*iii*) Seeds are stored and used as food throughout the year.

(*iv*) They can be used in favourable seasons depending on their viability.

3.3 Mutation of Ovule into Seed

Ovary develops into a fruit. The wall of the ovary develops into the fruit wall called **pericarp**. Types of fruits:

(*i*) **True fruits** These fruits develop from ovary, e.g. grapes, cucumber, etc.

(*ii*) **False fruits** Thalamus also contributes in fruit formation, e.g. apple, strawberry, cashewnuts, etc.

(*iii*) **Parthenocarpic fruits** These fruits develop without fertilisation, e.g. banana. Parthenocarpy can be induced through growth hormones and such fruits are seedless.

Special Cases

(*i*) **Apomixis** is the special mechanism to produce seeds without fertilisation, e.g. grass. It is a form of asexual reproduction that mimics sexual reproduction. It is useful for the hybrid industry.

The modes by which apomictic seeds can be produced are agamospermy, adventive embryony, etc.

(*ii*) **Polyembryony** is the presence of more than one embryo in a seed. In many *Citrus* and mango varieties, some of the nucellar cells surrounding the embryo sac start dividing, protrude into the embryo sac and develop into embryos.