1. Details of Module and its structure

Module Detail	
Subject Name	Biology
Course Name	Biology 03 (Class XII, Semester - 1)
Module Name/Title	Sexual Reproduction in Flowering Plants – Part 2
Module Id	lebo_10202
Pre-requisites	Knowledge about awareness of parts of a plant, process of growth and development, basic information of reproduction in organisms
Objectives	After studying this module the students will be able to: • Discuss the structure and role of Pistil and embryo sac • Explain the structure of embryo sac • Discuss the types of placentations • Discuss the types of embryo sacs
Keywords	Pollen Grains, Pistil, Megasporangium, Embryo Sac, Ovule, Placentation

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Introduction

The essential parts of a flower can be considered in two parts: the vegetative part, consisting of petals and associated structures in the perianth, and the reproductive or sexual parts. A stereotypical flower consists of four kinds of structures attached to the tip of a short stalk. Each of these kinds of parts is arranged in a whorl on the receptacle. The four main whorls (starting from the base of the flower or lowest node and working upwards) are calyx, corolla, androecium and gynoecium.

The Pistil

The ovule bearing or seed bearing female reproductive organ of a flower is called the pistil or gynoecium. The gynoecium represents the female reproductive part of the flower. The gynoecium may consist of a single carpel (monocarpellary, e.g. Pea) or may have more than one carpel (multicarpellary - number of carpels in a gynoecium are 2, 3, 4, 5, they are said to be bi, tri, tetra and penta carpellary, respectively). When there are more than one carpel, the pistils may be fused together (syncarpous) (Figure 9) or may be free (apocarpous) (Figure 10), (Table 1).

What is a carpel?

The pistils of a flower are considered to be composed of **carpels**. A carpel is a theoretical construct interpreted as modified leaves bearing structures called ovules, inside which the egg cells ultimately form. A pistil may consist of one carpel, with its ovary, style and stigma, or several carpels may be joined together with a single ovary, the whole unit called a pistil. The gynoecium may consist of one or more uni-carpellate (with one carpel) pistils, or of one multi-carpellate pistil. Carpels are thought to be phylogenetically derived from ovule-bearing leaves or leaf homologues (megasporophylls), which evolved to form a closed structure containing the ovules. This structure is typically rolled and fused along the margin.

Although many flowers satisfy the above definition of a carpel, there are also flowers that do not have carpels according to this definition because in these flowers the ovule(s), although enclosed, are borne directly on the shoot apex, and only later become enclosed by the carpel. Different remedies have been suggested for this problem. An easy remedy that applies to most cases is to redefine the carpel as an appendage that encloses ovule(s) and may or may not bear them

Table 1: Differences between Apocarpous and Syncarpous Gynoecium

Apocarpous Gynoecium	Syncarpous Gynoecium
1. It is a primitive condition in which carpels are separate from each other.	This is an advanced condition where the carpels are fused.
2. These type of flowers have a unilocular ovary.	These type of flowers have a unilocular to multilocular ovary.
3. In this type a placenta is present in the ovary.	In this type presence of a single placenta in the ovary is rare.
4. When the flowers bear a single carpel, the fruits are simple, but when there are a number of carpels the fruits are aggregate.	Here the fruits are simple.

Each pistil has three parts (Figure 8), the stigma, style and ovary. The stigma is a distal bulbous part which serves as a landing platform for pollen grains. The style is the elongated slender part beneath the stigma. The basal bulged part of the pistil is the ovary. Inside the ovary is the ovarian cavity (locule). The placenta is located inside the ovarian cavity. Various types of placentations are found here.

Placentation

In flowering plants, the ovule is located inside the portion of the flower called the gynoecium. The ovary of the gynoecium produces one or more ovules and ultimately becomes the fruit wall. Ovules are attached to the placenta in the ovary through a stalk-like structure known as a **funiculus** (plural, funiculi). Different patterns of ovule attachment, or placentation, can be found among plant species, these include:

- **Apical placentation**: The placenta is at the apex (top) of the ovary. Simple or compound ovary (Figure 1).

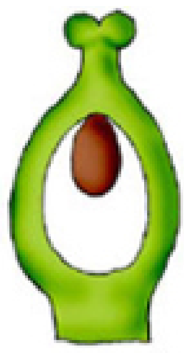

Figure 1: Apical placentation

- **Axile placentation**: The ovary is divided into radial segments, with placentas in separate locules. Ventral sutures of carpels meet at the centre of the ovary. Placentae are along fused margins of carpels. Two or more carpels. (e.g. *Hibiscus*, *Citrus*, *Solanum*) (Figure 2).

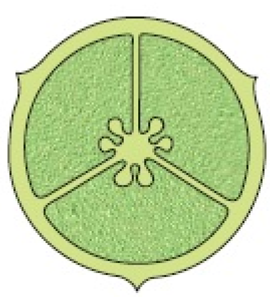

Figure 2: Axile placentation

- **Basal placentation**: The placenta is at the base (bottom) of the ovary on a protrusion of the thalamus (receptacle). Simple or compound carpel, unilocular ovary. (e.g. *Sonchus*, *Helianthus*, Compositae) (Figure 3).

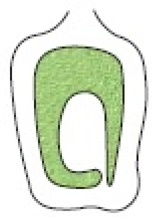

Figure 3: Basal placentation

- **Free-central placentation**: Derived from axile as partitions are absorbed, leaving ovules at the central axis. Compound unilocular ovary. (e.g. *Stellaria*, *Dianthus*) (Figure 4).

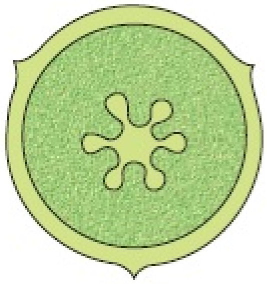

Figure 4: Free-central placentation

- **Marginal placentation**: Simplest type. There is only one elongated placenta on one side of the ovary, as ovules are attached at the fusion line of the carpel's margins. This is conspicuous in legumes. Simple carpel, unilocular ovary (e.g. *Pisum*) (Figure 5).

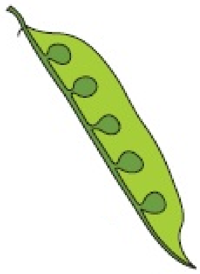

Figure 5: Marginal placentation

- **Parietal placentation**: Placentae on inner ovary wall within a non-sectioned ovary, corresponding to fused carpel margins. Two or more carpels, unilocular ovary. (e.g. *Brassica*) (Figure 6).

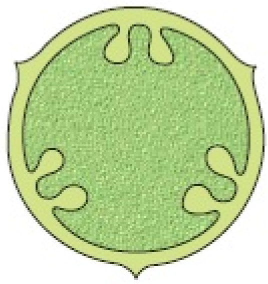

Figure 6: Parietal placentation

- **Superficial**: Similar to axile, but placentae are on inner surfaces of multilocular ovary (e.g. *Nymphaea*) (Figure 7).

Figure 7: Superficial placentation

Arising from the placenta are the megasporangia, commonly called ovules. The number of ovules in an ovary may be one (wheat, paddy, mango) to many (papaya, watermelon, orchids).

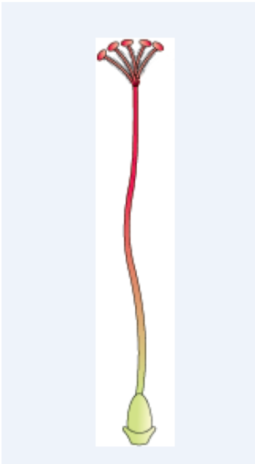

Figure 8: A dissected flower of Hibiscus showing pistil (other floral parts have been removed)

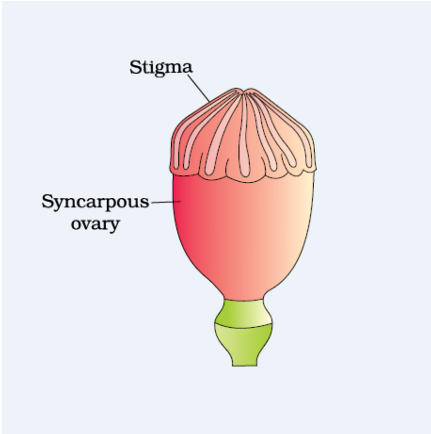

Figure 9: Multicarpellary, syncarpous pistil of Papaver

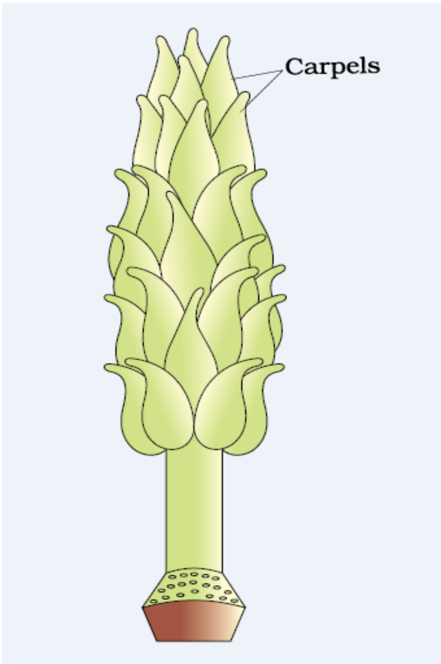

Figure 10: A multicarpellary, apocarpous gynoecium of Michelia

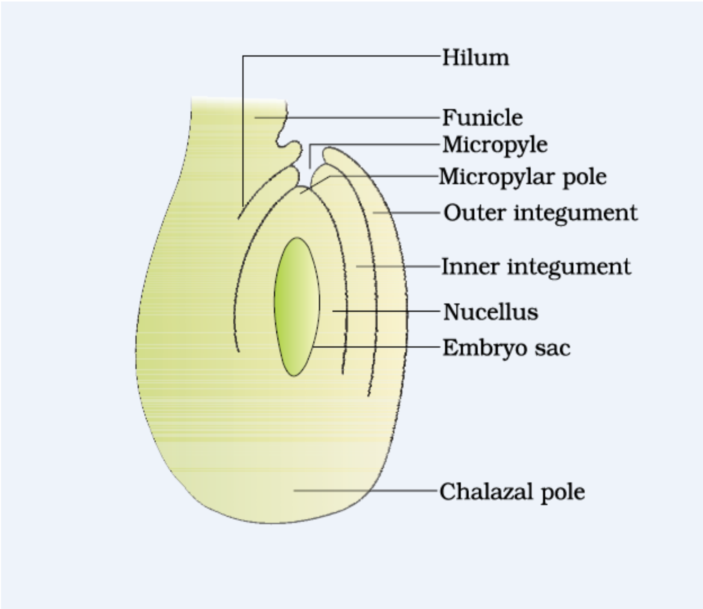

Figure 11: A diagrammatic view of a typical anatropous ovule

The Megasporangium (Ovule)

Ovule is an integumented megasporangium found in spermatophytes which develops into seed after fertilisation. Let us familiarise ourselves with the structure of a typical angiosperm ovule (Figure 11). The ovule is a small structure attached to the placenta by means of a stalk called funicle. The body of the ovule fuses with funicle in the region called hilum. Thus, hilum represents the junction between ovule and funicle. Each ovule has one or two protective envelopes called integuments. Integuments encircle the nucellus except at the tip where a small opening called the micropyle is organised. Opposite the micropylar end, is the chalaza, representing the basal part of the ovule.

Enclosed within the integuments is a mass of cells called the nucellus. Cells of the nucellus have abundant reserve food materials. Located in the nucellus is the embryo sac or female gametophyte. An ovule generally has a single embryo sac formed from a megaspore.

Figure 12: Location of ovules inside a *Helleborus foetidus* flower

Source: https://en.wikipedia.org/wiki/Ovule#/media/File:Ovules_in_flower.png

What is a nucellus?

The nucellus (plural: nucelli) is part of the inner structure of the ovule, forming a layer of diploid (sporophytic) cells immediately inside the integuments. It is structurally and functionally equivalent to the megasporangium. In immature ovules, the nucellus contains a megasporocyte (megaspore mother cell), which undergoes sporogenesis via meiosis. In gymnosperms, three of the four haploid spores produced in meiosis typically degenerate, leaving one surviving megaspore inside the nucellus.

What is a perisperm?

After fertilization, the nucellus may develop into the **perisperm** that feeds the embryo. In some plants, the diploid tissue of the nucellus can give rise to the embryo within the seed through a mechanism of asexual reproduction called nucellar embryony.

What is the role of an integument in the ovule?

An integument is a protective cell layer surrounding the ovule. Gymnosperms typically have one integument (unitegmic) while angiosperms typically have two (bitegmic). The evolutionary origin of the inner integument (which is integral to the formation of ovules from megasporangia) has been proposed to be by enclosure of a megasporangium by sterile branches (telomes). The integuments develop into the seed coat when the ovule matures after fertilization.

What is a micropyle?

The integuments do not enclose the nucellus completely but retain an opening at the apex referred to as the **micropyle**. The micropyle opening allows the pollen (a male gametophyte) to enter the ovule for fertilization. In gymnosperms (e.g. conifers), the pollen is drawn into the ovule on a drop of fluid that exudes out of the micropyle, the so-called pollination drop mechanism. Subsequently, the micropyle closes. In angiosperms, only a pollen tube enters the micropyle. During germination, the seedling's radicle emerges through the micropyle**.**

What is a chalaza?

Located opposite from the micropyle is the chalaza where the nucellus is joined to the integuments. Nutrients from the plant travel through the phloem of the vascular system to the funiculus and outer integument and from there apoplastically and symplastically through the chalaza to the nucellus inside the ovule. In chalazogamous plants, the pollen tubes enter the ovule through the chalaza instead of the micropyle opening.

Types of Ovules

The ovules have been classified into 6 different types depending on the configuration and orientation of the main body of the ovule with respect to the funiculus. The different types are as follows:

(a) **Orthotropous ovule:** This is the most primitive type of ovule. Here the micropyle, chalaza and funicle of the ovule are in a straight line. Examples: *Cycas, Piper, Polygonum*, etc (Figure 13).

Figure 13: Orthotropous ovule

(b) Anatropous ovule: It is an inverted ovule, such that when inverted the micropyle faces the placenta (this is the most common ovule orientation in flowering plants), the ovule turns at the angle of 180 degree. Micropyle lies close to hilum or at the side of hilum (Figure 14).

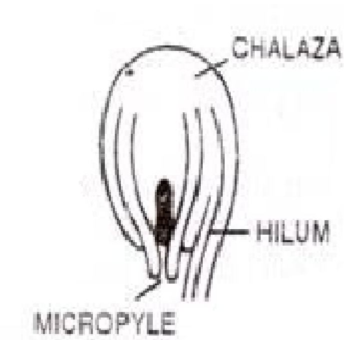

Figure 14: Anatropous ovule

(c) Campylotropous ovule: This type of ovule is curved more or less at right angle to the funicle. The micropylar end is bent down slightly. It is found mostly in the members of Leguminoseae, Cruciferae, etc. (Figure 15).

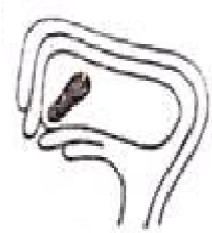

Figure 15: Campylotropous ovule

(d) Hemianatropous ovule: This type of ovule is found half inverted Example: *Ranunculus* (Figure 16).

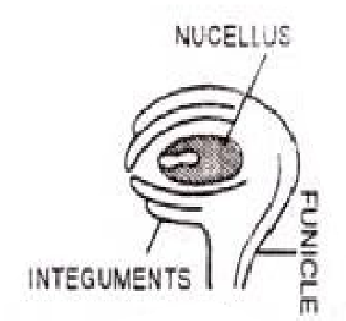

Figure 16: Hemianatropous ovule

(e) Amphitropous ovule: In this type of ovule both body as well as embryo sac are curved like a horse shoe. Example: *Lemna, Poppy, Alisma* (Figure 17).

Figure 17: Amphitropous ovule

(f) Circinotropous ovule: In this type of ovule the funicle is coiled around the ovule. Example: Opuntia (Cactaceae), Plumbaginaceae (Figure 18).

Figure 18: Circinotropous ovule

In gymnosperms such as conifers, ovules are borne on the surface of an ovuliferous (ovule-bearing) scale, usually within an ovulate cone (also called megastrobilus). In some extinct plants (e.g. Pteridosperms), megasporangia and perhaps ovules were borne on the surface of leaves. In other extinct taxa, a cupule (a modified leaf or part of a leaf) surrounds the ovule (e.g. *Caytonia* or *Glossopteris*).

Megasporogenesis: The process of formation of megaspores from the megaspore mother cell is called megasporogenesis. Ovules generally differentiate a single megaspore mother cell (MMC) in the micropylar region of the nucellus. It is a large cell containing dense cytoplasm and a prominent nucleus. The MMC undergoes meiotic division. Meiosis results in the production of four megaspores (Figure 19) (Table 2).

Point to Ponder: What is the importance of the MMC undergoing meiosis?

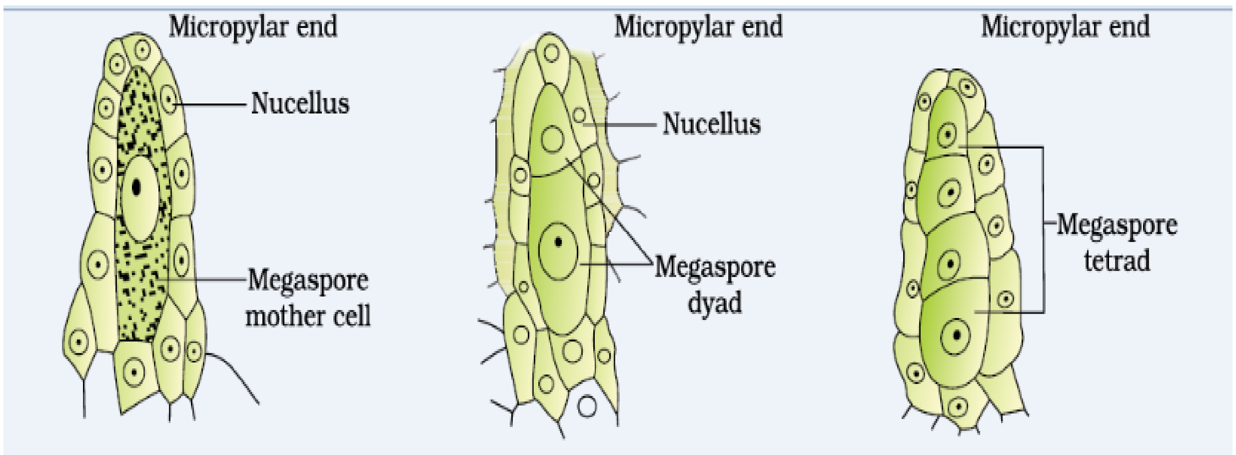

Figure 19: Parts of the ovule showing a large megaspore mother cell, a dyad and a tetrad of megaspores

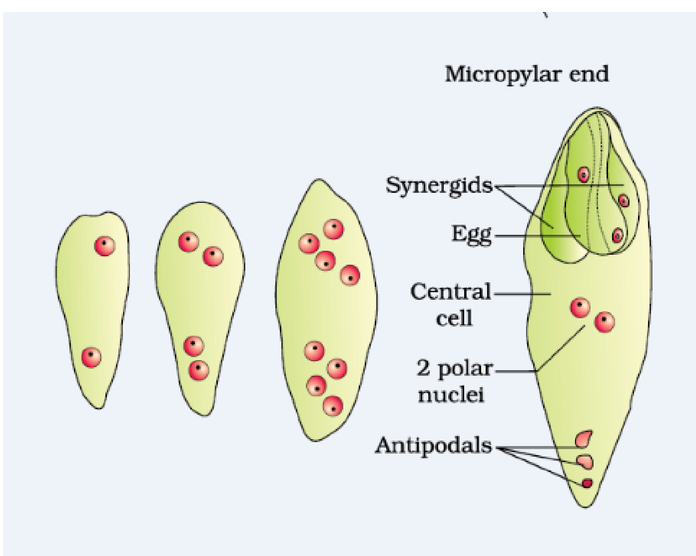

Figure 20: 2, 4, and 8-nucleate stages of embryo sac and a mature embryo sac

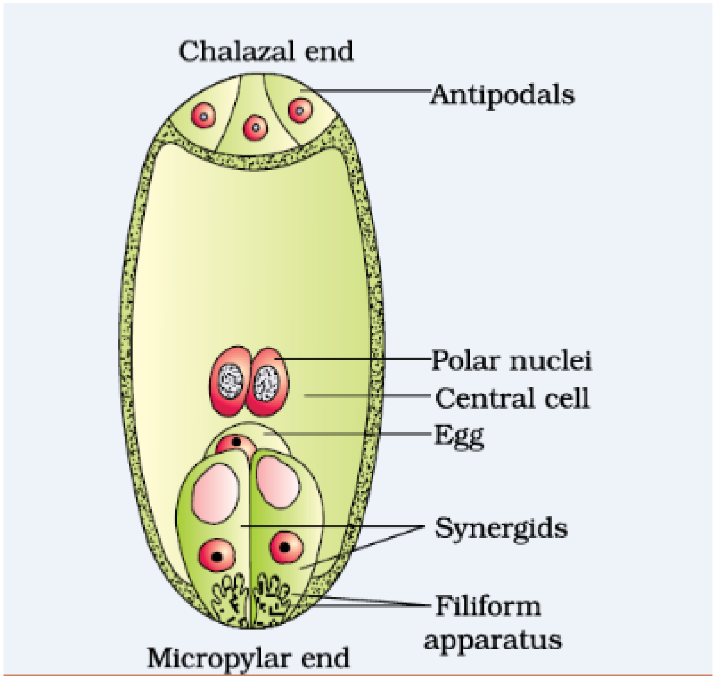

Figure 21: A diagrammatic representation of the mature embryo sac

What is the filiform apparatus?

The synergid cell wall forms a highly thickened structure called the filiform apparatus at the micropylar end, consisting of numerous finger-like projections into the synergid cytoplasm. This structure greatly increases the surface area of the plasma membrane in this region, which is also associated with an elaborated endoplasmic reticulum. It is thought that the filiform apparatus mediates the transport of molecules into and out of the synergid cells.

Table 2: Differences between microsporogenesis and megagametogenesis

Microsporogenesis	**Megasporogenesis**
1. It is meiotic formation of haploid microspores from diploid microspore mother cell.	**1.** It is meiotic formation of haploid megaspores from diploid megaspore mother cell.
2. It shows a tetrahedral arrangement of microspores in a tetrad.	**2.** The megaspores are linearly arranged.
3. All the four microspores of a spore tetrad are functional.	**3.** Only one megaspore of a spore tetrad is functional.

4. This phenomenon is found inside the microsporangium.	**4.** This process takes place inside megasporangium.
5. A large number of microspore mother cells are functional in a microsporangium.	**5.** Generally, a single megaspore mother cell is functional in a megasporangium.

Embryo Sac or Female gametophyte

In a majority of flowering plants, one of the megaspores is functional while the other three degenerate. Only the functional megaspore develops into the female gametophyte (embryo sac) (Table 3). This method of embryo sac formation from a single megaspore is termed monosporic development.

Point to Ponder: What will be the ploidy of the cells of the nucellus, MMC, the functional megaspore and female gametophyte?

Let us study formation of the embryo sac in a little more detail. (Figure 20). The nucleus of the functional megaspore divides mitotically to form two nuclei which move to the opposite poles, forming the 2-nucleate embryo sac. Two more sequential mitotic nuclear divisions result in the formation of the 4-nucleate and later the 8-nucleate stages of the embryo sac. It is of interest to note that these mitotic divisions are strictly free nuclear, that is, nuclear divisions are not followed immediately by cell wall formation. After the 8-nucleate stage, cell walls are laid down leading to the organisation of the typical female gametophyte or embryo sac. Observe the distribution of cells inside the embryo sac (Figure 20, 21). 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.

There is a characteristic distribution of the cells within the embryo sac. Three cells are grouped together at the micropylar end and constitute the egg apparatus. The egg apparatus, in turn, consists of two synergids and one egg cell. The synergids have special cellular thickenings at the micropylar tip called filiform apparatus, which play an important role in guiding the pollen tubes into the synergid. Three cells are at the chalazal end and are called the antipodals. The large central cell (it is the largest cell of the embryo sac) has a highly vacuolate cytoplasm which is rich in reserve food and Golgi bodies, as mentioned earlier, has two polar nuclei which have large nucleoli. Thus, a typical angiosperm embryo sac, at maturity, though 8-nucleate is 7-celled.

What is the function of Synergids and antipodal cells?

The cell closest to the micropyle opening of the integuments differentiates into the egg cell, with two synergid cells by its side that are involved in the production of signals that guide the pollen tube. Three antipodal cells form on the opposite (chalazal) end of the ovule and later degenerate. Antipodal cells are vegetative cells of the embryo sac and are nutritive in nature, they take part in absorbing nourishment from the surrounding nuclear cells.

Table 3: Difference between Male and Female gametophytes of an Angiosperm

Male Gametophyte	**Female Gametophyte**
1. It is derived from a pollen grain or microspore. 2. It does not remain permanently embedded inside the microsporangium. 3. It has two phases of growth - pre-pollination and post-pollination. 4. The male gametophyte comes out of the confines of the pollen grain by formating a pollen tube. 5. The male gametophyte is only 3-celled. 6. All the cells of the male gametophyte are functional. The tube cell is required to carry the two male gametes, both of which take part in fertilization. 7. The remains of male gametophyte	1. It is derived from a megaspore. 2. The female gametophyte remains permanently embedded in the megasporangium or nucellus. 3. All the cells are formed in a single phase of growth. 4. The female gametophyte remains surrounded by the membrane of the megaspore. 5. The female gametophyte is 7-celled. 6. The antipodal cells do not seem to perform any function except absorption of nourishment from nucellus in certain cases. Out of two synergids only one is

disintegrate after fertilization.	required for receiving the pollen tube. 7. After fertilization two new structure are produced both of which show active growth.

Summary

The pistil has three parts – the stigma, style and the ovary. Ovules are present in the ovary. The ovules have a stalk called funicle, protective integument(s), and an opening called micropyle. The ovules have been classified into 6 different types depending on the configuration and orientation of the main body of the ovule with respect to the funiculus. The central tissue is the nucellus in which the archesporium differentiates. A cell of the archesporium, the megaspore mother cell divides meiotically and one of the megaspores forms the embryo sac (the female gametophyte). The mature embryo sac is 7-celled and 8-nucleate. At the micropylar end is the egg apparatus consisting of two synergids and an egg cell. At the chalazal end are three antipodals. At the centre is a large central cell with two polar nuclei.

Exercises

1. Arrange the following terms in the correct developmental sequence:
   Pollen grain, sporogenous tissue, microspore tetrad, pollen mother cell, male gametes.
2. With a neat, labelled diagram, describe the parts of a typical angiosperm ovule.
3. What is meant by monosporic development of female gametophyte?
4. With a neat diagram explain the 7-celled, 8-nucleate nature of the female gametophyte.
5. Describe the difference between microsporogenesis and megagametogenesis.
6. Draw a labelled diagram of L.S. of anatropous ovule.