MOHAMED KHIDER UNIVERSITY – BISKRA
FACULTY OF NATURAL AND LIFE SCIENCES
DEPARTMENT OF BIOLOGY

PLANT BIOLOGY COURSE HANDOUT

INTENDED FOR 1ST-YEAR LMD BIOLOGY STUDENTS



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Description of the course

This plant biology course provides a comprehensive introduction to the structure, organization, morphology, and reproduction of flowering plants. It begins with the fundamentals of plant classification and plant cell organization, then progressively explores plant tissues, anatomy, morphology, reproduction, and life cycle.

The course first introduces plant diversity and basic cellular organization, presenting major plant groups and the structural features of plant cells. This foundation helps students understand how plant structure relates to function.

Chapter 1 focuses on plant tissues. It describes meristemtic tissues responsible for plant growth and their classification based on origin and position. The chapter examines permanent tissues including dermal tissues, ground tissues, and vascular tissues involved in transport. Secretory tissues are also discussed, highlighting their role in production and storage of specialized substances.

Chapter 2 describes plant anatomy, emphazing the internal structure roots, stems, and leaves in both dicotylenous and monocotyledonous plants. It also explains secondary growth in dicot stems and roots, allowing students to understand how plants increase in thickness and develop woody structures.

Chapter 3 presents the morphology of flowering plants. It examines the external features of roots, stems, leaves, and flowers, including types, modifications, and functions. Topics such as root systems, stem modifications, leaf arrangement, venation, and floral organization are discussed. The chapter also introduces floral characteristics such as symmetry, placentation, cohesion of stamens, and reproductive structures.

Chapter 4 addresses reproduction in flowering plants. It describes male and female gametogenesis, pollen grain structure, ovule development, and embryo sac formation. The chapter continues with pollination, pollen-pistil interaction, fertilization, and double fertilization. Post-fertilization events including endosperm formation, embryogenesis, seed development, and fruit types are also covered.

Finally, chapter 5 explains the plant life cycle and alternation of generations, distinguishing between the diploid sporophytic phase and the haploid gametophytic phase.

Overall, this course provides students with essential knowledge of plant structure, development, and reproduction, forming a strong foundation for further studies in botany, plant physiology, plant taxonomy, and biotechnology.

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Introduction

Plants are eukaryotic, multicellular organisms, primarily immotile, and autotrophs. They are unique among life forms in their ability to produce their own food using energy from sunlight, water and carbon dioxide in a process called photosynthesis.

A. Classification of plants

In 1735, Carl Linnaeus created a hierarchical classification system that places all organisms into successively smaller groups, comprising seven levels. They are, from largest to smallest, kingdom, phylum, class, order, family, genus, and species. In this system of classification the various groups are called taxa (singular: taxon).

Living things are classified into three different domains Archaea, Bacteria and Eukarya. Within each of these domain systems, there are kingdoms: The domain Archaea comprises Archaebacteria, the domain Bacteria comprises all organisms in the kingdom Eubacteria, and the domain Eukarya includes the kingdoms Animalia, Plantae, Fungi, and Protista.

Table 01. Classification of living things.

Domain	Kingdom	Caracteristis
Archea	Archaebacteria	Prokaryotic, single celled organisms, extremophiles (live in extreme environments), cell wall without peptidoglycan, autotrophic or heterotrophic.
Bacteria	Eubacteria	Prokaryotic, single celled organisms, cell wall contain peptidoglycan, autotrophic or heterotrophic.
Eukarya	Protista	Eukaryotic, mostly unicellular organisms.
	Fungi	Eukaryotic, mostly multicellular, heterotrophic organisms, cell wall with

		chitin.
	Plantae	Eukaryotic, multicellular with the cell wall made of cellulose photosynthetic autotrophs organisms.
	Animalia	Eukaryotic, multicellular, and heterotrophic organisms.

Plant kingdom

The plant kingdom is the second largest kingdom and contains an estimated 300,000 plant species.

The four divisions of the plant kingdom are:

Algae: they are chlorophyll-bearing, simple, thalloid, autotrophic and largely aquatic (both fresh water and marine) organisms.

Bryophytes: include the various mosses and liverworts. They can live in soil but are dependent on water for sexual reproduction.

Pteridophytes: include horsetails and ferns.

Spermatophytes: include seed-bearing plants. There are two classes of living seed plants: gymnosperms and angiosperms (flowering plants).

Gymnosperms are non-flowering plants that produce naked seeds. Conifers are examples of gymnosperms.

Angiosperms also called flowering plants constitute the majority of seed plants. Unlike the gymnosperms where the ovules are naked, in the angiosperms, the pollen grains and ovules are developed in specialised structures called flowers.

Angiosperms are divided into two classes: the dicotyledons and the monocotyledons.

Monocots typically have only one cotyledon (seed leaf) and have floral parts (e.g., petals) in multiples of three.

True dicots; usually have two cotyledons and floral parts in multiples of four or five.

- Based on the presence or absence of vascular system, plants are further categorized into non-vascular and vascular plants.

Non-vascular plants lack the specialized fluid conducting tissues and do not possess true roots, leaves, or stems. They include algae and bryophytes.

Vascular plants contain water and nutrient-conducting tissues called xylem and phloem. They have true roots, stems and leaves. This group include pteridophytes and spermaphytes.

- Based on their mode of reproduction, plants are classified into cryptogams and phanerogams:

Cryptogams are non-flowering plants, seedless plants, which produce hidden reproductive organs. They do not produce flowers, seeds and fruits. This group include algae, bryophytes and pteridophytes.

Phanerogams are seed-bearing plants that reproduce by the production of seeds. They include spermaphytes, which are divided into gymnosperms (plants with naked-seeds) and angiosperms (flowering plants that produce seeds enclosed within a fruit).

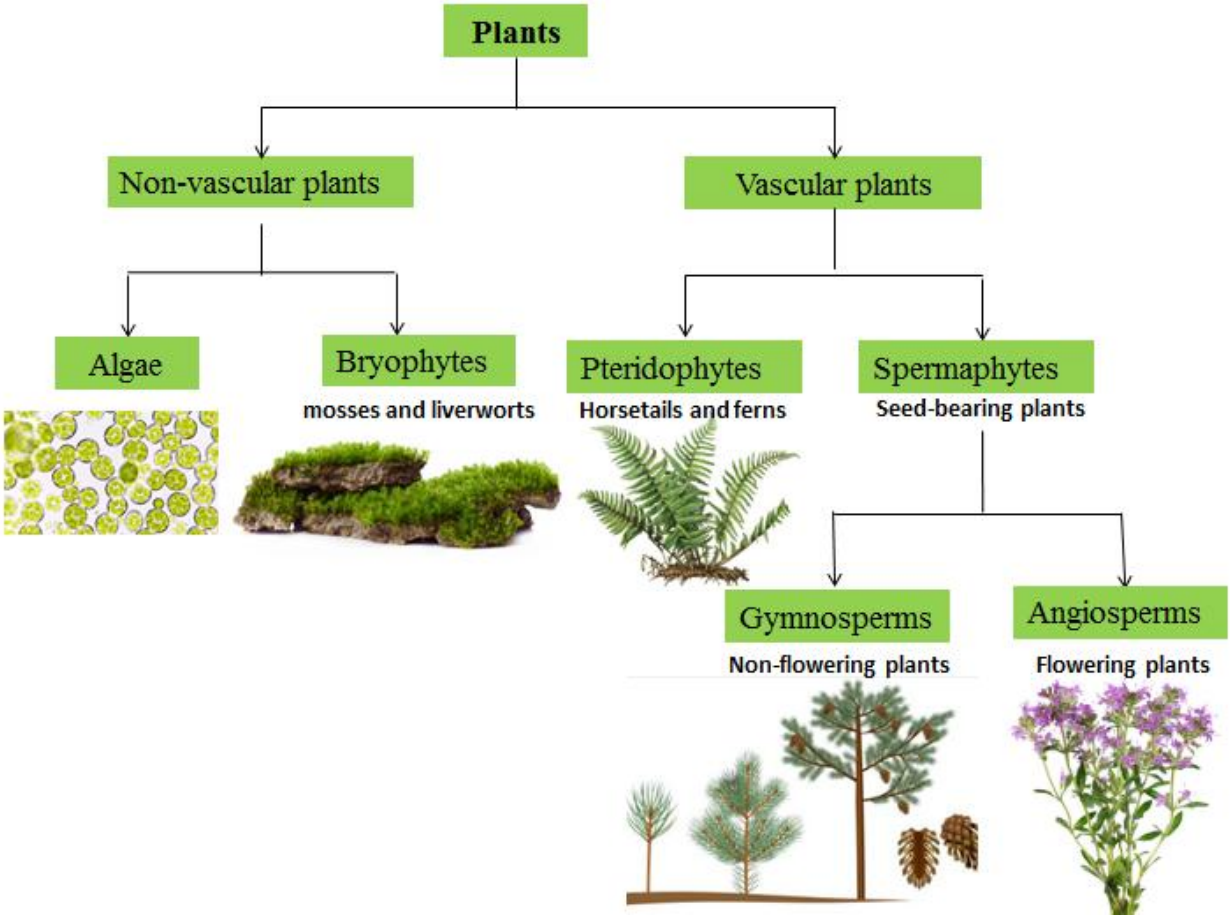


Figure 01. Classification of plants.

B. Plant cell

Plant cell is the basic unit of plant organism. It has eukaryotic organisation with well-organised nucleus, cell membrane and particular structures called organelles that perform various functions such as endoplasmic reticulum, Golgi apparatus, mitochondria and many more.

Some structures distinguish plant cells from other types of cells:

- The plant cell is surrounded by a rigid cell wall besides the plasma membrane. The cell wall provides shape, support, and protection to the cell and its organelles.
- A large permanent vacuole is present in plant cell cytoplasm. Its main functions include storage, structural support and recycling.
- Plastids are usually present in the cytoplasm of plant cells. They bear some specific pigments. Based on their pigments or colouration, three types of plastids are recognised:

a/chromoplasts (coloured plastids) containing variously coloured pigments such as yellow, red, pink and violet responsible for the coloration of flowers, fruits, leaves, etc.

b/ Leucoplasts (colourless plastids) involved in the storage of various kinds of reserve food materials.

c/ Chloroplasts: green plastids present in the green parts of the plant, mainly the green leaves. They contain a green pigment called chlorophyll which allows to plant to perform photosynthesis.

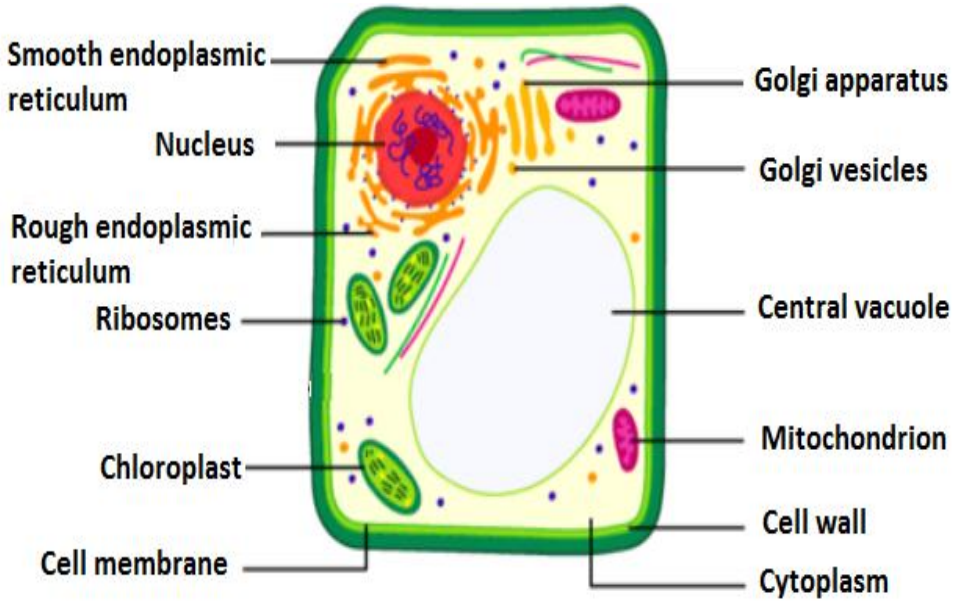
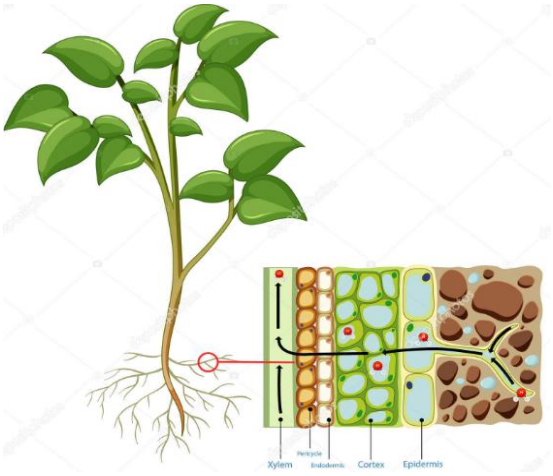


Figure 02. Plant cell structure.

CHAPTER 1:
PLANT TISSUES



Learning Objectives

By the end of this chapter, students will be able to:

•Describe the different types of plant tissues and their functions.

•Differentiate between meristematic and permanent tissues.

•Identify and describe the regions where plant growth occurs.

•Summarize the roles of dermal tissue, vascular tissue, and ground tissue

Introduction

In unicellular organisms all the life processes such as digestion, respiration, excretion, and reproduction are performed by the single cell. In multicellular organisms, different groups of cells perform different functions.

In plants, as in animals, a group of cells that are similar in structure and work together to achieve a particular function forms a tissue. When different types of tissues combine to perform a specific function, they create an organ; organs working together form organ systems.

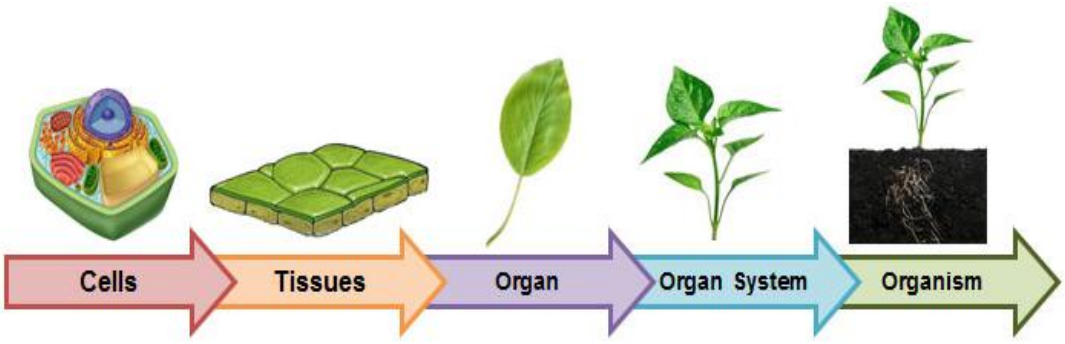


Figure 03. Organization levels of the plant body.

An organ is a structure that is composed of multiple tissues. The organs of the plant, leaves, stems, roots, and flower parts are composed of tissues arranged in different patterns. Some of the tissues are composed mostly of a single cell type; these are called simple tissues. Tissues made from aggregates of different cell types are called complex tissues.

1.1. Meristematic tissues

The growth of plants occurs only in certain specific regions. This is because the dividing tissue, known as meristematic tissue, is located only at these points.

Meristematic tissue is a group of cells which divide constantly and produce new cells indefinitely throughout the plant life. The new cells are formed by division giving rise to permanent tissue by growth and differentiation.

Characteristics of meristematic cells

Cells of meristems divide continuously and help in increasing the length of the plant. These cells show the following characteristics:

- The cells of meristematic tissue are similar in structure and have thin cellulose cell walls.
- The cells are in active stage of cell division.
- Each meristematic cell contains dense or abundant cytoplasm and a single large nucleus.
- The meristematic cells may be spherical, oval, polygonal or rectangular in shape.
- The meristematic cells contain few vacuoles or no vacuoles at all.

1.1.1 Classification of meristematic tissues based on origin

A. Promeristem or primordial meristem: It consists of a group of meristematic cells representing the earliest of youngest stage of a growing organ. Through successive cell divisions, the promeristem gives rise to the primary meristem.

B. Primary meristem: The primary meristems are responsible for both the elongation of the plant and the formation of the tissues that make up the organs. They retain their ability to divide during the life of the plant and are composed of the cells, which are direct descendants of the embryonic cells.

C. Secondary meristem: It is formed when some of the permanent tissues regain the power of division by the effect of environmental factors or hormones. The cork cambium or phellogen is an example of secondary meristem.

1.1.2 Classification of meristematic tissue based on position in plant body

Depending on the region where they are present, meristematic tissues are classified as apical, lateral and intercalary.

A. Apical meristem

It is situated at the growing tip of the stems and roots, i.e., present at the apex of root or stem. Apical meristem is responsible for increase in length of the axis, leading to the elongation of both the root and the stem. This results in an increase in the height of the plant, which is called primary growth.

B. Lateral meristem

It lies on the lateral sides of stem and root and helps in increasing their thickness (girth). It causes these organs (stem or root) to enlarge in diameter and girth. This is called secondary growth.

The two main types of lateral meristem are: vascular cambium and cork cambium.

C. Intercalary meristem

These are located at the base of leaves or internodes on twigs. They help in longitudinal growth of plants i.e. responsible for increase in length of intermodal region.

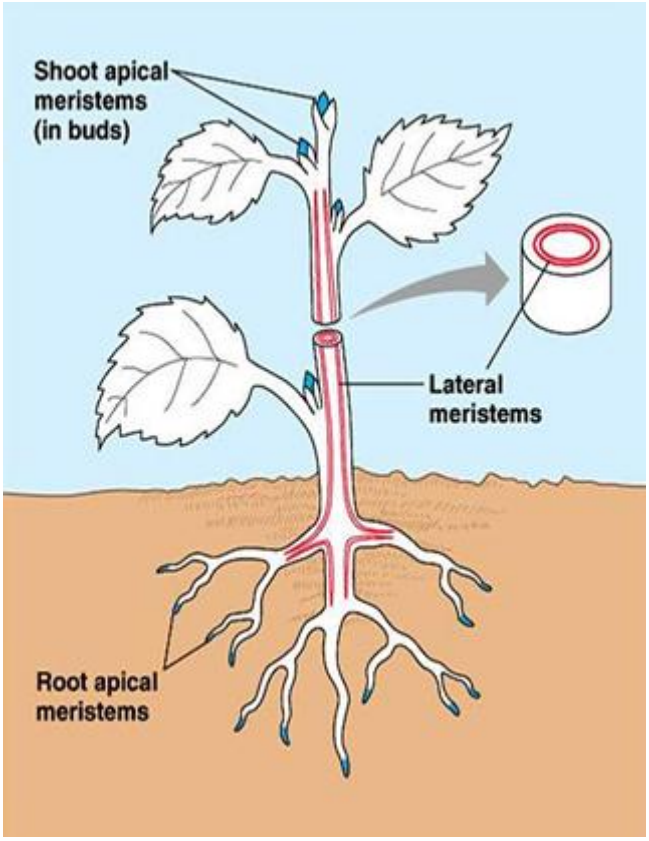


Figure 04. Classification of meristematic tissue based on position in plant body.

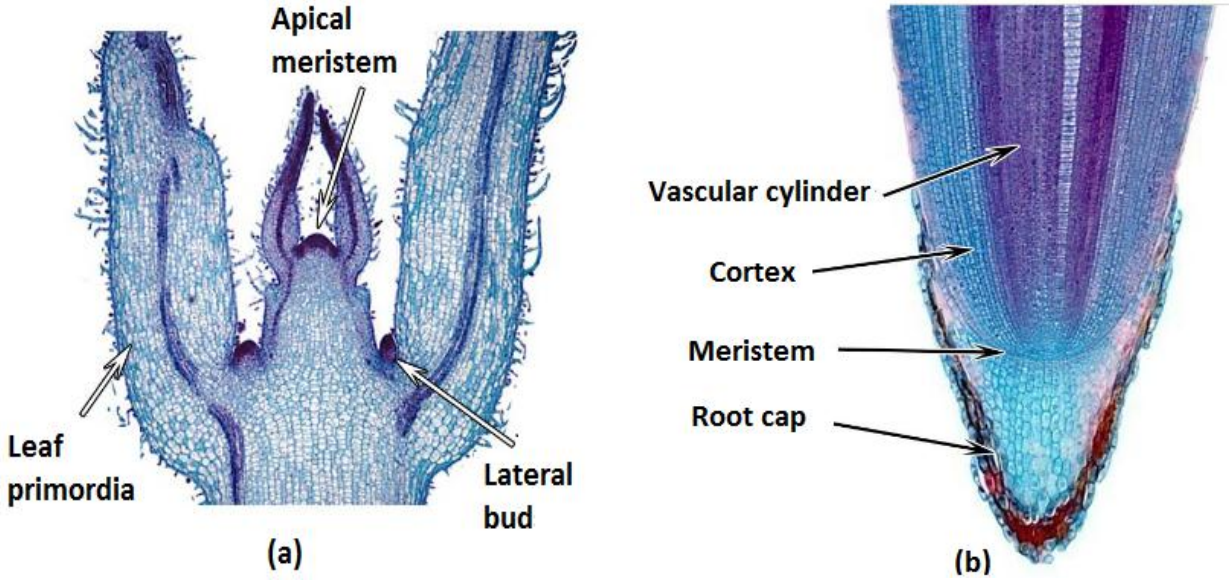


Figure 05. Apical meristem (a) Shoot apical meristem (b) Root apical meristem.

1.2. Permanent tissues

New cells produced by meristem are initially like those of meristem itself, but as they grow and mature, their characteristics slowly change and they and lose the ability to divide. As a result, they form a permanent tissue.

Cell differentiation: the process of taking up a permanent shape, size and function is called differentiation. Differentiation leads to the development of various types of permanent tissues.

Permanent tissues having all cells similar in structure and function are called simple tissues. Permanent tissues having many different types of cells are called complex tissues.

1.2.1. Dermal tissue (protective tissue)

Dermal tissues are the outermost layers that cover the entire surface of a plant. They protect the plant organs against water loss, various physical and chemical effects, and disease-causing organisms.

During primary growth the covering of plant body is known as epidermis (in root it is known as epiblema) but in secondary growth the epidermis may be replaced by periderm.

2.1.1 Epidermis

Epidermis is usually a single layer of flattened cells. Epidermal cells in leaves and stems secrete cutin, a wax-like substance that makes up the cuticle on the external surface. The cuticle prevents evaporative water loss from the plant by acting as a waterproof barrier.

- Since it has a protective role to play, cells of epidermal tissue form a continuous layer without intercellular spaces.

- Most epidermal cells are relatively flat. Often their outer and side walls are thicker than the inner wall.

- Small pores in the epidermis of the leaf are called stomata (singular: stoma). Stomata are enclosed by a pair of kidney-shaped cells called guard cells which occur on either side of the pore and regulate the opening and closing of each stoma.

-Stomata are necessary for exchanging gases with the atmosphere (Gases such as carbon dioxide, oxygen, and water vapor are exchanged through these stomata).

- The guard cells are the only epidermal cells with chloroplasts.

- Transpiration (loss of water in the form of water vapour) also takes place through stomata.

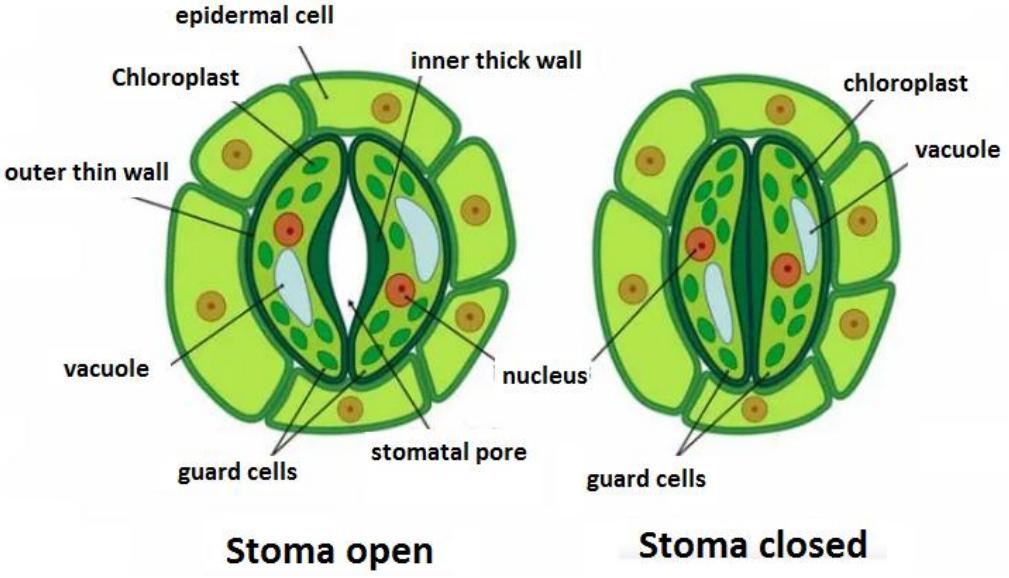


Figure 06. Diagrammatic representation of stoma.

In some plants, hairs (trichomes) may be present on the epidermis. Although usually microscopic, they may be abundant enough to give a fuzzy appearance and texture to leaves or stems. Trichomes may also be glandular, often imparting an aroma when they are brushed, as you can experience by rubbing a geranium or tomato leaf.

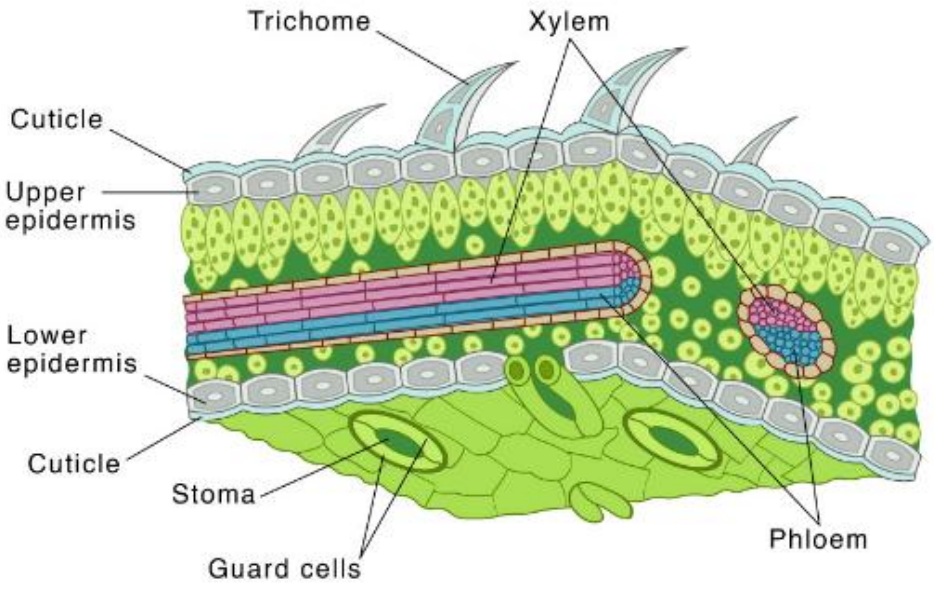


Figure 07. Cross-section of a leaf.

Epidermal cells of the roots, whose function is water absorption, commonly bear long hair-like parts that greatly increase the total absorptive surface area.

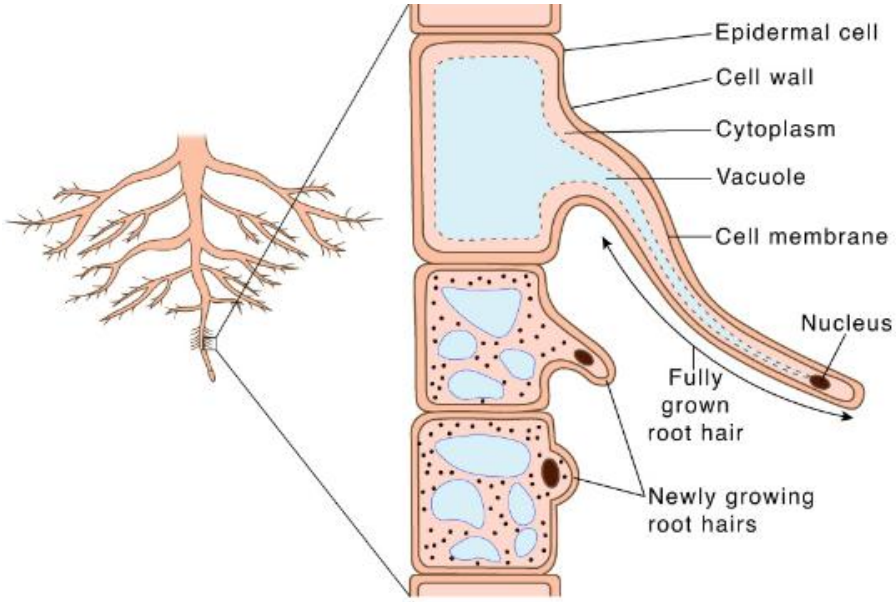


Figure 08. Root epidermis.

1.2.1.2 Periderm

In woody plants, as the stem continues to increase in girth, the epidermis gets broken and is replaced by a new protective surface layer due to the activity of a lateral meristematic tissue called cork cambium or phellogen.

Phellogen produces cells on both sides. The outer cells differentiate into cork or phellem which is impervious to water due to suberin deposition in the cell wall. The inner cells differentiate into secondary cortex or phelloderm. Together, the phellogen (cork cambium), phellem (cork), and phelloderm constitute the periderm.

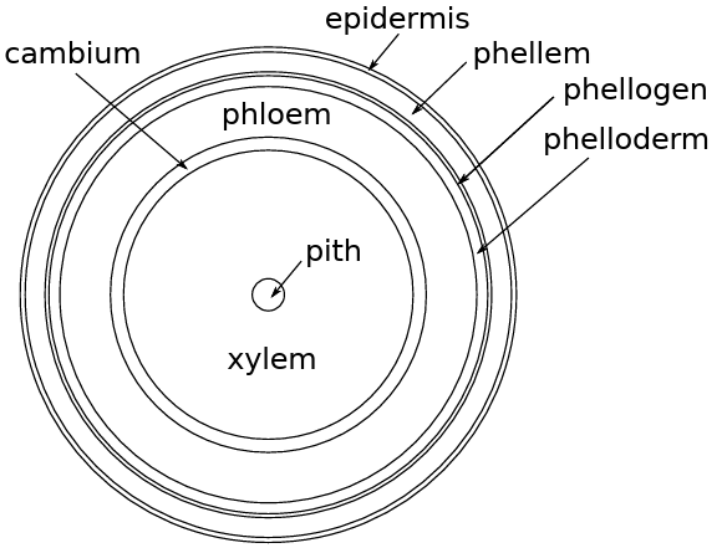


Figure 09. Principal location of stem tissues.

1.2.2 Ground tissue

All tissues except epidermis and vascular tissues constitute the ground tissue. It makes up the bulk of the plant body. The ground tissue is composed of three types of simple tissues: parenchyma, collenchyma and sclerenchyma.

1.2.2.1 Parenchyma

Parenchyma forms the bulk of the plant body. It is widely distributed in plant body such as stem, roots, leaves, flowers and fruits.

-Parenchyma cells are living. They are usually somewhat spherical or elongated, but they may have diverse shapes.

-The cell wall is thin, made up of pectocellulose (primary cell wall) and encloses a dense cytoplasm which contains a small nucleus and surrounds a large central vacuole.

-Usually parenchyma tissue is loosely arranged, with many intercellular spaces which allow gaseous exchange.

-Furthermore, they retain the meristematic ability to differentiate, making them important cells for wound healing and regeneration.

A. Functions

Parenchyma cells are capable of performing many different functions:

- Photosynthesis: in the mesophyll of leaves and green stems.
- Storage: in all plant organs. The starch in potato tubers, the water in cactus stems, and the sugar in sugar beet roots are all stored in parenchyma cells.

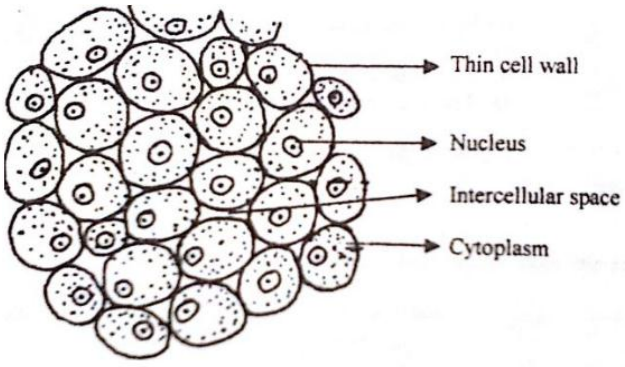


Figure 10. A typical parenchyma tissue.

B. Types of parenchyma tissue

There are four types of parenchyma according to their function.

1.2.2.1.1 Photosynthetic parenchyma: This type of parenchyma, also known as chlorenchyma, is specialized in photosynthesis thanks to the many chloroplasts present in the cells. It is commonly found under the epidermis, where light is more intense, and it is abundant in leaves, but also in the cortex of green shoots.

The photosynthetic parenchyma of the leaves is known as mesophyll, which is usually divided in two types: palisade and spongy mesophyll.

Palisade mesophyll is close to the upper epidermis of the leaves, where it gets more light, whereas the spongy mesophyll is in the lower and darker side of the leaves. Parenchymatic cells of the palisade mesophyll are more tightly packaged and contain more chloroplasts, so that the photoshyntetic activity is higher.

The **spongy mesophyll** cells occur below the palisade layer and are loosely packed together. This creates air chambers (intercelular spaces). These spaces allow carbon dioxide to diffuse from the stomata located on the underside of the leaf to reach the chloroplasts within the cells.

1.2.2.1.2 Storage parenchyma

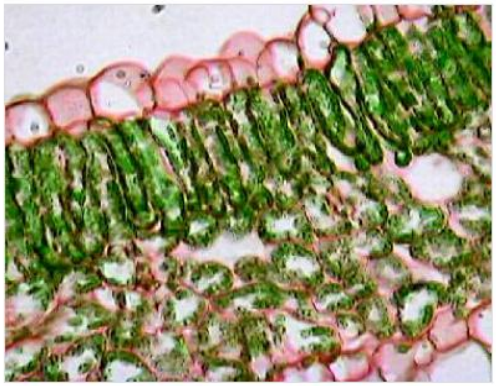
The cells in this tissue synthesize and store a number of substances. Although these substances can be solid, like starch grains and crystallized proteins, they are mostly found in solution, such as lipids, proteins, and others. Usually they are stored in vacuoles.

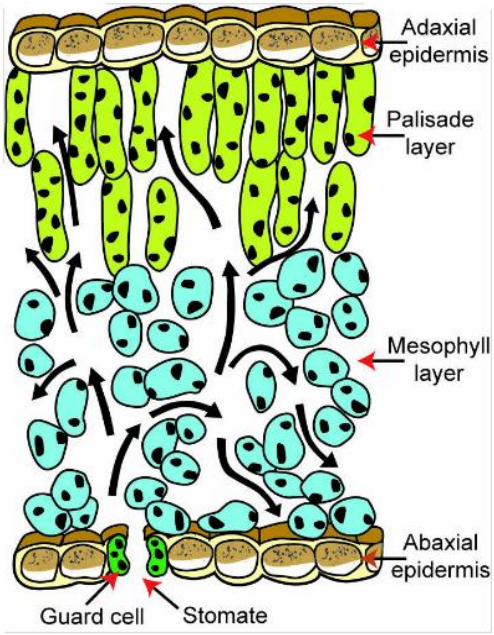
1.2.2.1.3 Aquiferous parenchyma

Aquiferous parenchyma cells are specialized in water storage. They are large cells, with a thin cell wall and a very large vacuole where water is stored. This type is present in plants that live in dry environments, known as xerophyte plants.

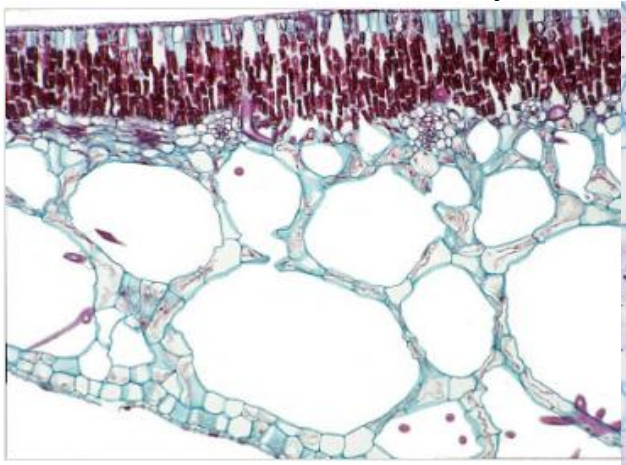
1.2.2.1.4 Aeriferous parenchyma (aerenchyma)

It contains large intercellular empty spaces, larger than in other plant tissues. This tissue is well-developed in plants living in wet or aquatic environments (these plants are known as hydrophytes).

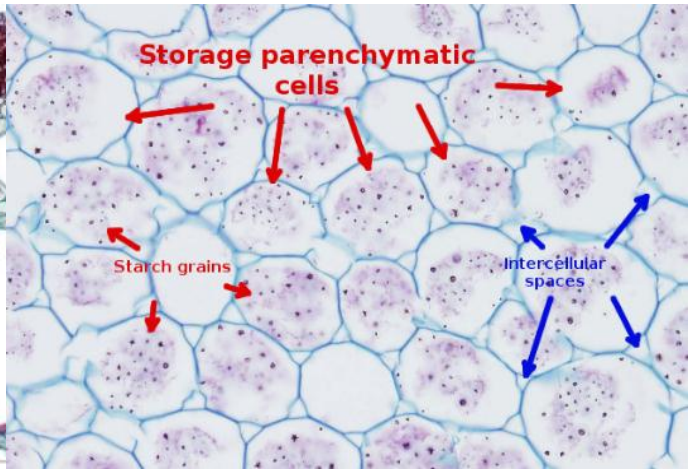




Chlorenchyma in a leaf cross-section



Aerenchyma in a leaf cross-section in Nymphaea (Water lily)



Storage parenchyma

Figure 11. Different types of parenchyma tissue.

1.2.2.2 Collenchyma

Collenchyma tissue consists of living cells. Its cells are surrounded by thick, primary and usually non-lignified cell walls, which are characterized by the deposition of extra cellulose at the corners of the cells.

These features make collenchyma well-suited for providing structure and support in regions of a plant that are still elongating, such as young stems and petioles. It allows easy bending in various parts of a plant (leaf, stem) without breaking. In collenchyma, intercellular spaces are generally absent.

The cells of collenchyma are located below the epidermis of dicotyledon stem and petiole. Collenchyma is absent in monocot stems, roots and leaves.

Types of collenchyma tissue

A. Lacunar Collenchyma: contains intercellular spaces, and thickening is more around these spaces.

B. Angular collenchyma: In this type, the thickening occurs at the corners of the cells, giving them a distinct angular appearance. It is the most common collenchyma tissue.

C. Annular collenchyma: the cell wall is uniformly thickened.

D. Lamellar collenchyma: Lamellar Collenchyma cells have continuous layers of thickening in their cell walls. The cell walls are unevenly thickened, with the thickest regions forming these layers.

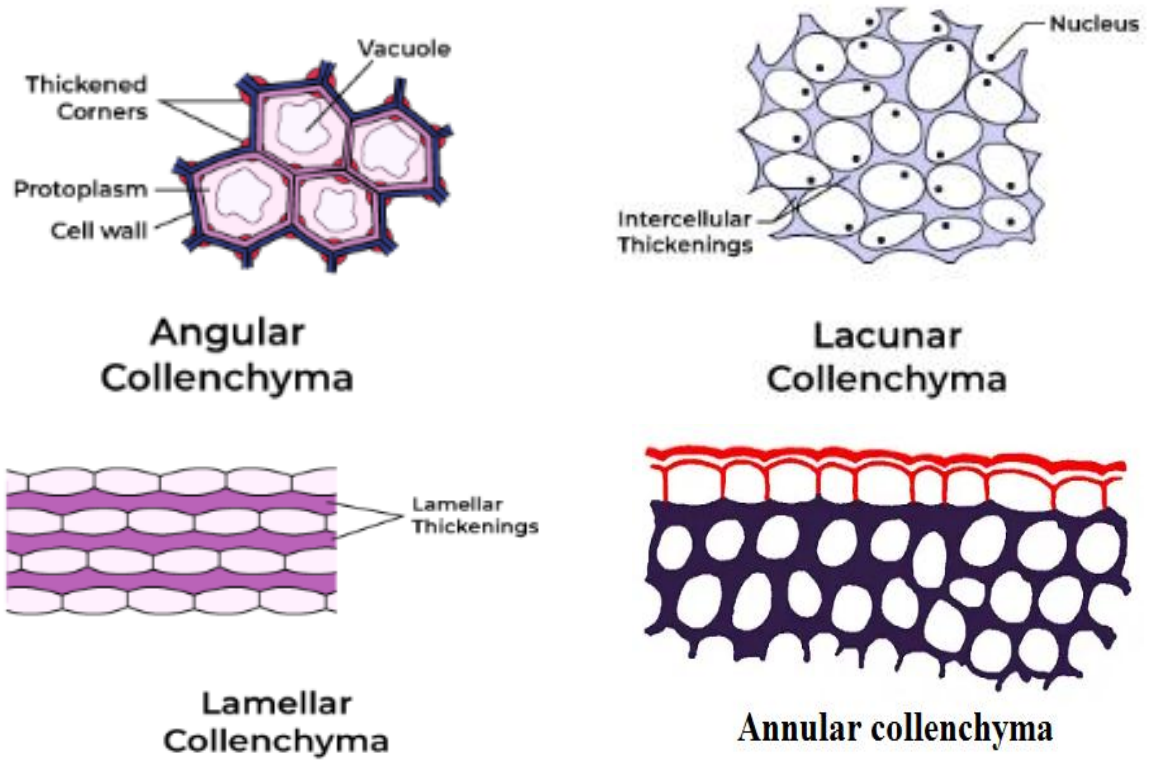


Figure 13. Types of collenchyma tissue.

1.2.2.3 Sclerenchyma

The cells making sclerenchyma tissue are rigid and add strength to plant parts that are no longer elongating. Unlike collenchyma cells that need to be flexible, sclerenchyma cells are non-living at maturity and have thick secondary cell walls due to deposition of lignin (a chemical substance that makes wood hard and supportive).

Secondary cell walls are deposited inside the primary cell walls by the plasma membrane once the cell is finished elongating.

Sclerenchyma tissue has two cell types: **fibers** and **sclereids**:

Fibers are very long, narrow cells with thick secondary walls. They usually occur in bundles.

Sclereids are a diverse type of sclerenchyma cells found in many plants. These cells are variable in shape and often branched. They may be either scattered throughout a tissue, or clustered together. The major function of these cells is to provide mechanical support and protection.

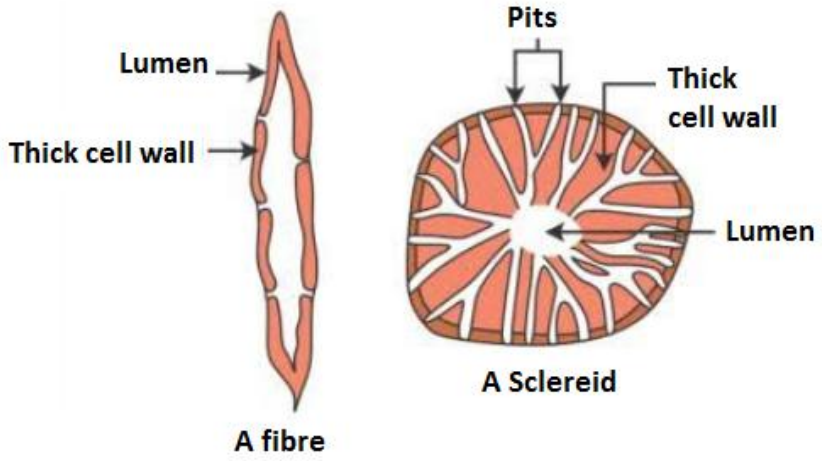


Figure 14. Sclenrenchyma cells.

1.2.3 Vascular tissues (conducting tissues)

Vascular tissues are the conducting tissues in plants. They consist of an interconnected network of cells that traverse the entire body of the plant. There are two types: xylem, which conducts water and minerals from the roots upward, and phloem, which transports organic materials synthesized by the plant. Both xylem and phloem are complex tissues composed of several cell types.

1.2.3.1 Xylem

Two principal types of water-conducting cells exist in the xylem: Tracheids and vessel elements. Both cell types have secondary walls, and at maturity, these cells are dead and consist only of cell walls. Before the cells die their cell wall becomes thickened with cellulose and lignin, and then the protoplast degenerates.

Vessel members and tracheids have many structural and functional characteristics in common, so the term tracheary elementis used to refer to them generally.

- **Tracheids** are long, thin cells with tapering ends and numerous pits in the walls. Water must pass through pairs of bordered pits (interruptions of the secondary cell wall) in order to cross from one cell to another. Gymnosperms (such as conifer trees) and some flowering plants contain only tracheids,
- **Vessel elements** are usually shorter and wider and often have horizontal end walls with large openings. Like the tracheids, the side walls have numerous pits. Vessel elements are attached end to end to form a long, pipelike vessel.

Vessel elements are the dominant tracheary element of angiosperms. They allow for more rapid translocation of water than tracheids: there are fewer pits to slow water flow and wider passages.

Fibers are present in the xylem, where they provide additional support. Parenchyma cells, which also occur in the xylem are the only living cells found in this tissue.

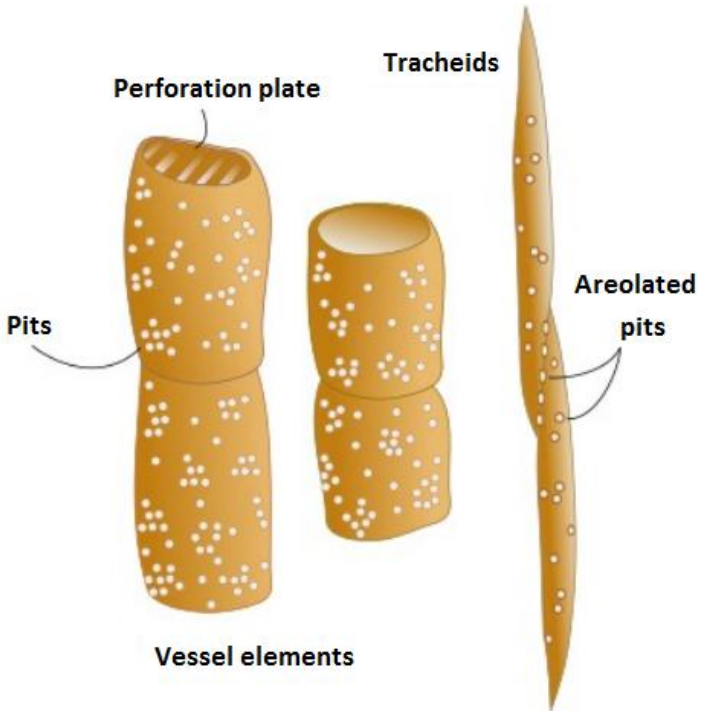


Figure 15. (a) Vessel formed by vessel members joined end-to-end at perforation plates. **(b)** Tracheids connected by bordered pits.

- Two categories of xylem are found within a plant: protoxylem and metaxylem.

Protoxylem is formed in the root and shoot apex very early (during elongation), while metaxylem is xylem that differentiates after elongation has finished.

-The secondary cell wall, deposited after the cell stops enlarging, forms in one of several patterns: annular (ring shaped), spiral, scalariform (ladder like), reticulate (forming a network), or pitted. These patterns relate to the timing of their formation.

- Cells in an elongating organ must be able to stretch. For this reason, the lignified walls of protoxylem vessel elements are either helical (like a spring) or annular (a series of rings): this way the vessels may elongate without breaking.

- Metaxylem cells tend to have "pitted" cell walls. The entire cell wall is highly lignified and perforated.

- Spiral", scalariform, and reticulate are intermediate forms.

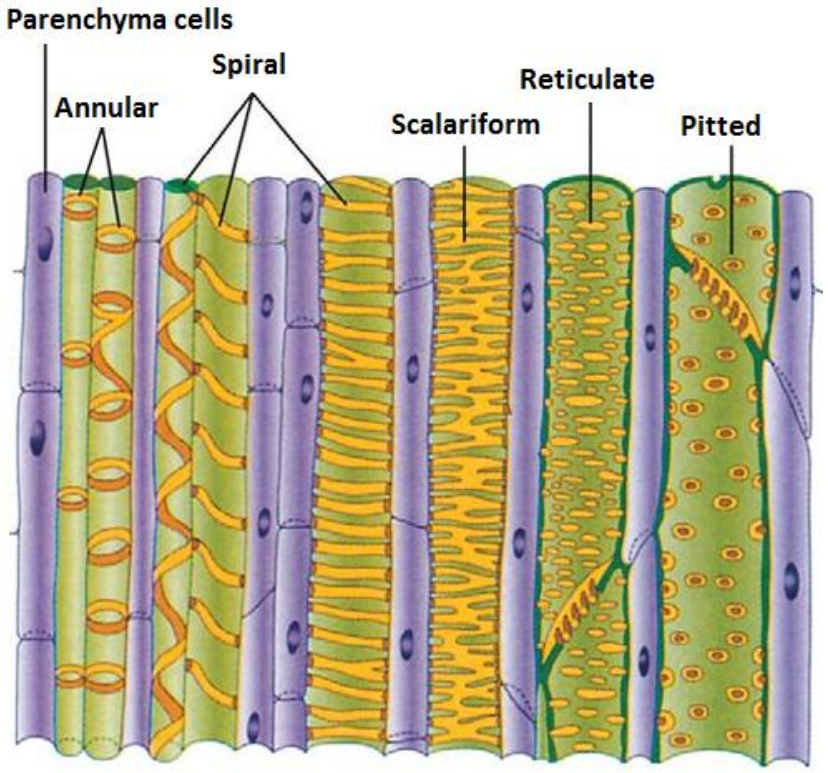


Figure 16. Different patterns of secondary cells walls in tracheary elements.

1.2.3.2 Phloem

In flowering plants (angiosperms) the phloem is made up of several different types of cells: sieve-tube members, companion cells, parenchyma and sometimes fibers and/or sclereids.

The cells involved in the transport of organic materials in the phloem are the sieve tube members. Unlike the conducting cells in the xylem, the sieve tube members are living cells with only primary walls which join at their ends, to form long sieve tubes.

-They are unusual living cells because the nucleus and some organelles degenerate as the sieve tube member matures. The end walls of these cells have several to many large pores called sieve plates.

-When the sieve-tube member is mature, one or more companion cells lie connected to it by plasmodesmata. The smaller companion cell has a large nucleus that controls the adjacent sieve tube member through the numerous plasmodesmata that connect the two cells. Companion cells are also known to play an important role in the mechanism of loading and unloading the phloem.

As in the xylem, both fibers and parenchyma cells are found in the phloem.

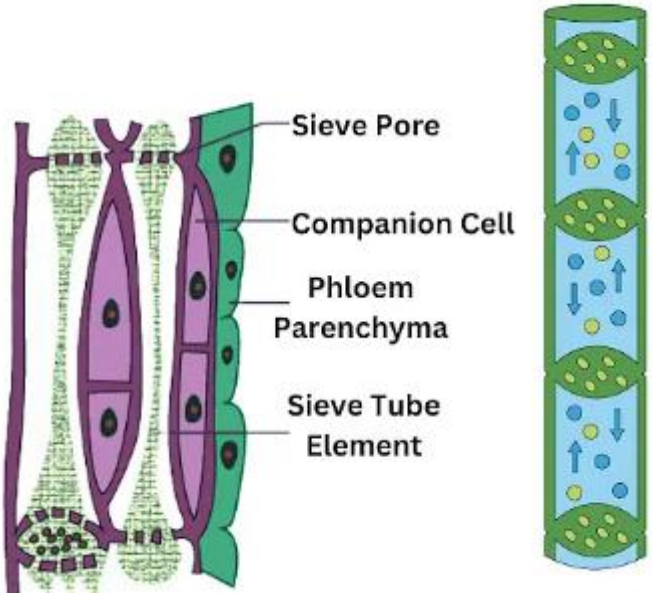


Figure 17. Cells of xylem.

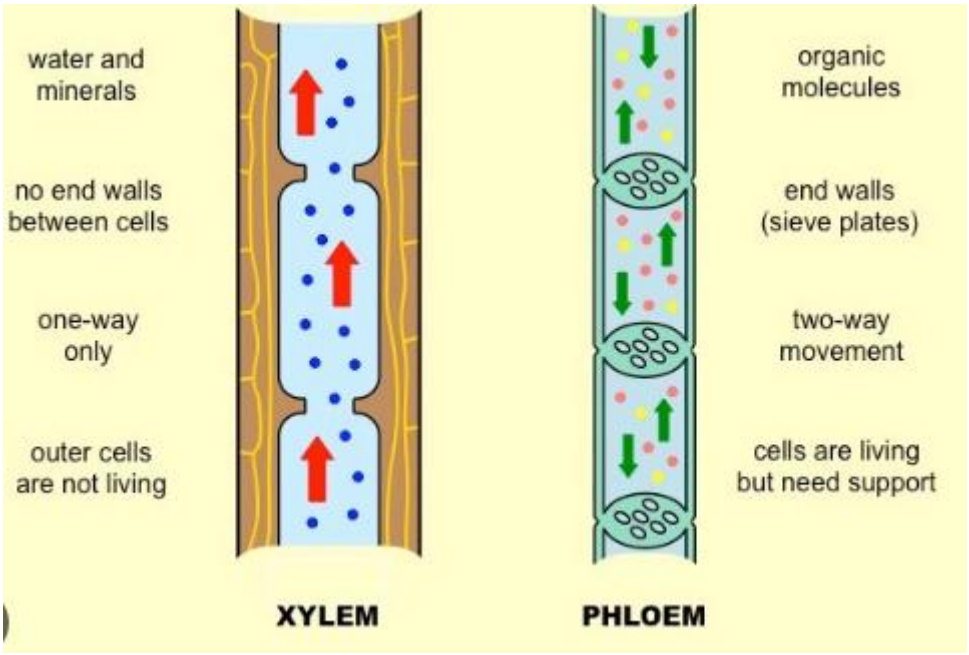


Figure 18. Difference between xylem and phloem.

1.2.4 Secretory tissue

It consists of living cells that secrete solid or liquid substances such as water, alkaloid, glycoside, nectar, mucilage, latex, resin, ethereal oil and tannin.

Secretory cells are structures that either accumulate their secretions within the cell or release them outside the cell.

In cells that release the secretory substance out of the cell, the secretion is either stored in the secretory pockets (intercellular spaces) within the plant or excreted from the plant.

Secretory tissues are further classified into two main types: laticiferous tissues and glandular tissues.

1.2.4.1 Laticiferous tissue

Laticifers are specialized cells or files of cells that contain a viscous, colloidal fluid called latex. Although most often milky in color, this fluid may also be yellow, orange, red, brown, or even colorless. Its chemical composition is highly variable and may include substances like sugars, proteins, alkaloids, enzymes, rubber etc.

Latex is present in laticiferous ducts, which are of two types that differ in structure and morphology: latex cells and latex vessels.

- **Latex cells** (Non articulate latex ducts): They are independent unit that originate as minute structures. They elongate and ramify by repeated branching in all directions, extending for long distance in the plant body without fusing together.
- **Latex Vessels** (Articulate latex ducts): They are made up of many elongated cells. The cell walls between these cells dissolve, forming continuous tube so they are called articulated laticifers.

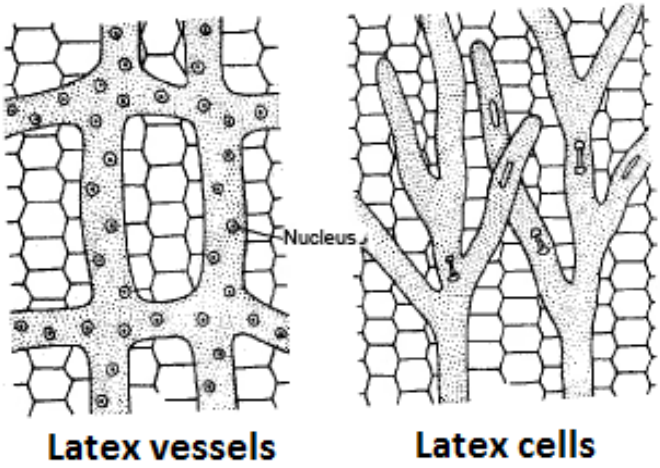


Figure 19. Latex cells and latex vessels.

1.2.4.2 Glandular tissue

Glandular tissue consists of specialized structures called glands which contain secretory or excretory products. The glands may be composed of isolated cells or small group of cells with or without a central cavity. They are of two types: external glands and internal glands.

1.2.4.2.1 External glands

They are present on the epidermis, usually in the form of outgrowths. These are of several types:

A. Hydathodes (water stomata): These are stomata like pores located at the tips or margins of the leaves of many herbaceous angiosperms, such as some grasses and tomato plants. Through these structures, water is exuded as droplets from the tip or margins of the leaves. The exudation of water is called guttation. Pores are present over a mass of loosely arranged cells with large intercellular spaces, known as the epithem.

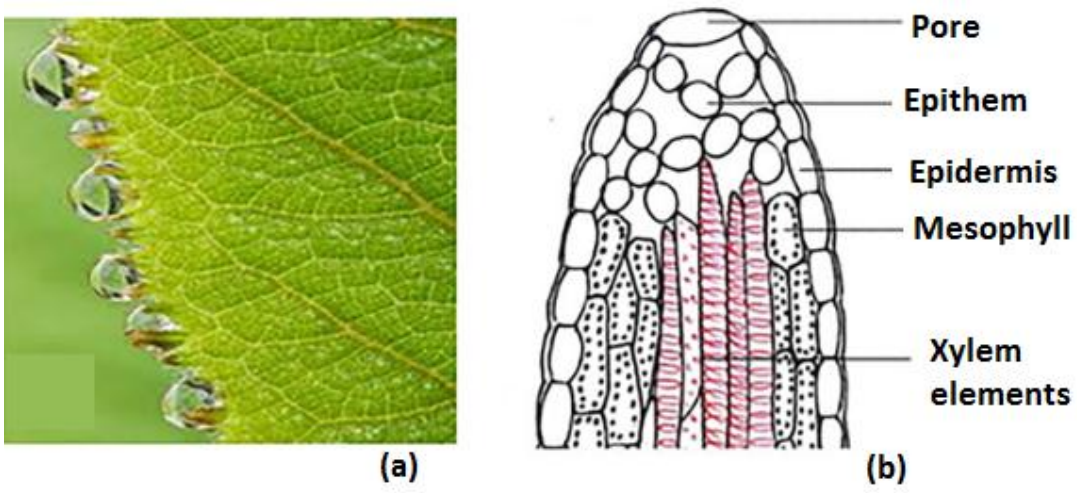


Figure 20: (a) Guttation droplets on leaf margin (b) Structure of hydathode.

B. Glandular hair: They are small hair found on epidermis, having unicellular or multicellular stalk and a single head possessing one or more secretory cells which secrete a various substances such as slime or mucilage.

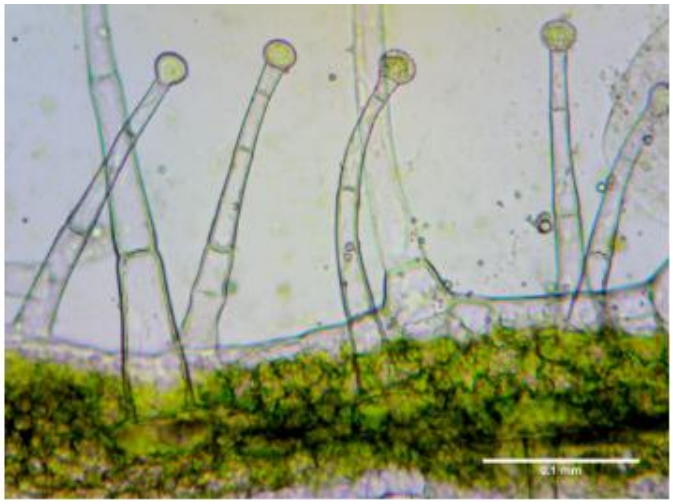


Figure 21. Tobacco glandular hair.

C. Stinging hair: Some plants, such as *Urtica*, protect themselves from gazing animals by secreting a poison through hairs located on the lower surface of their leaves. The poison cause irritation and blisters on the skin.

D. Nectaries: These are specialized glands usually located on the floral parts. They secrete a sugary substance called nectar, which accumulate on the surface of the gland in form of droplets, and thus attract the pollinating insects.



Figure 22. Floral and extra-floral nectaries.

E. Digestive glands: They are located at the base of the pitcher insectivorous plants such as Drosera. These structures secrete proteolytic enzymes that digest captured insects.

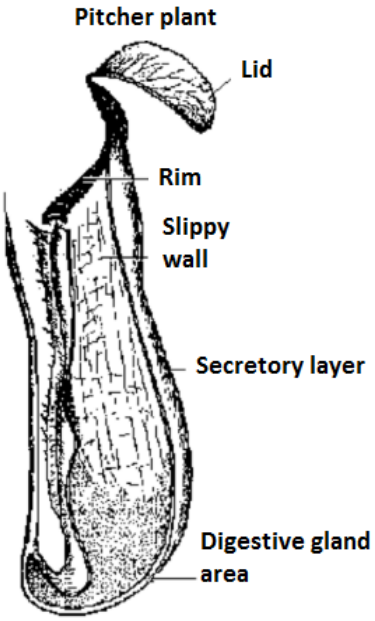


Figure 23. Digestive gland.

1.2.4.2.2 Internal glands

Internal glands are located within the plant body embedded in various tissues of roots, stems, leaves, flowers and fruits. They may consist of a single cell, a group of cells or an entire tissue. These are of the following types:

A. Schizogenous cavities or Ducts: These cavities are formed by the separation of cell walls in the center of a group of glandular cells creating an intercellular space that enlarges greatly

during development. The cavity is surrounded by epithelial cells which secrete their products such as resins and tannins into it.

B. Lysigenous cavities: These are intercellular spaces that arise due to the dissolution of entire secretory cells. The secretory products released from these cells accumulate in the large cavities that serve as reservoirs. The lysogenous cavities in the rind of *Citrus* fruits and leaves of *Eucalyptus* store essential oils.

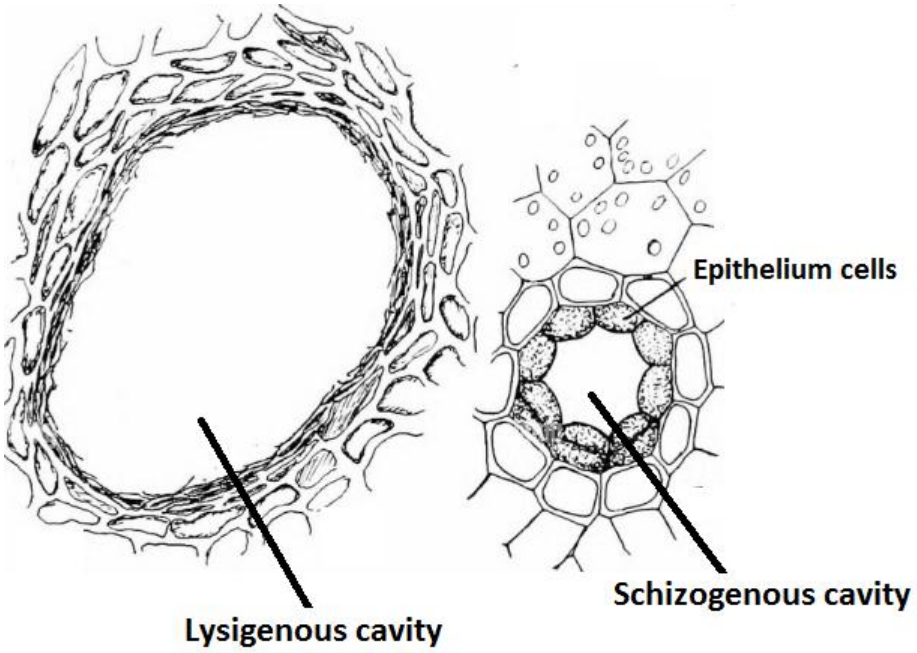
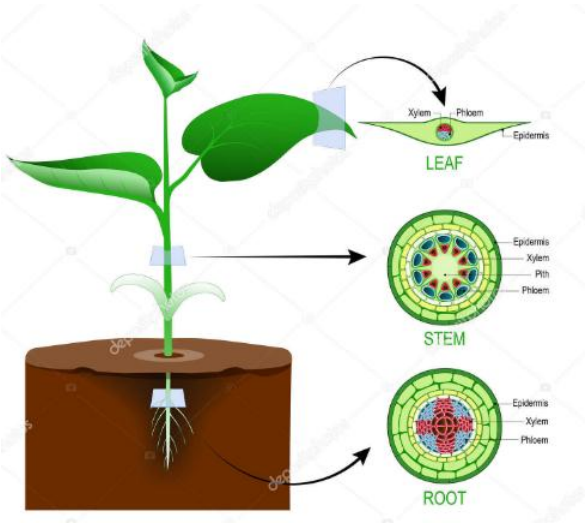


Figure 24. Lysigenous and schizogenous cavities.

CHAPTER 2:
PLANT ANATOMY



Learning Objectives

By the end of this chapter, students will be able to:

• Describe the internal organization of plant organs.

• Interpret transverse sections of plant organs.

• Compare the anatomical features of monocot and dicot plant organs.

•Explain how tissue organization contributes to plant growth, support, and transport of water and nutrients.

• Distinguish between primary growth and secondary growth.

Introduction

Plant anatomy describes the structure and organisation of the cells, tissues and organs of plants. For a better understanding of tissue organisation of roots, stems and leaves, it is convenient to study the transverse of these organs.

Within Angiospermic plants, monocot and dicot plants have different anatomical features:

2.1 Anatomy of root

2.1.1 Anatomy of dicot root

The internal tissue organisation shown in the transverse section of the dicot root is as follows:

1. Epiblema (Epidermis): It is the outermost layer, also called rhizodermis. Some of epidermal cells form root hairs which are unicellular, long and tubular. They help in both absorption and anchorage.

2. Cortex: It is quite large and extensive in roots. The cortex consists of several layers of thin-walled parenchyma cells with intercellular spaces.

Endodermis is the innermost layer of cortex. It is exclusive to roots, and serves as a checkpoint for materials entering the root's vascular system. A waxy substance called suberin is present on the walls of the endodermal cells. This waxy region, known as the Casparian strip, forces water and solutes to cross the plasma membranes of endodermal cells instead of slipping between the cells.

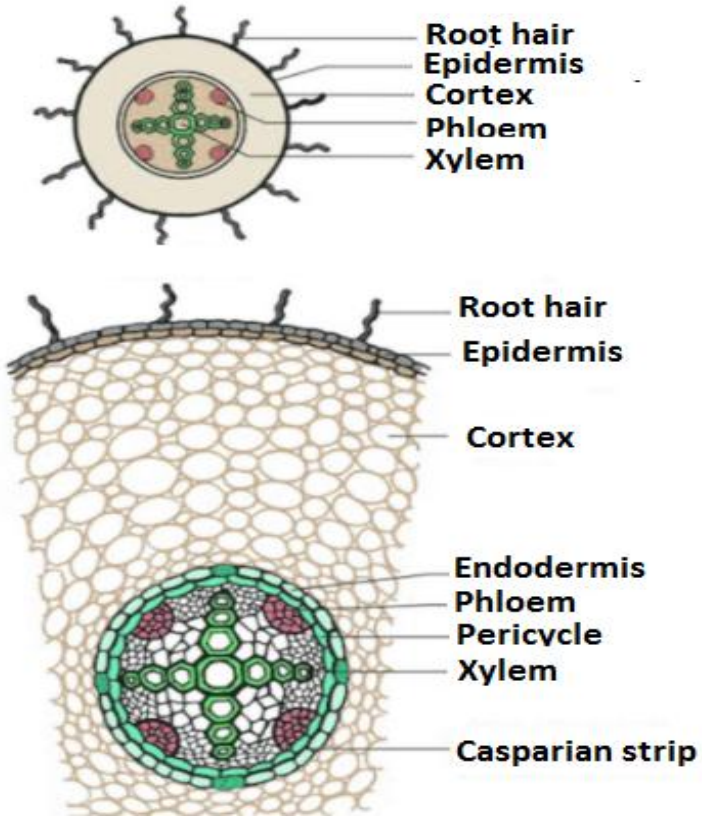


Figure 25. Transverse section in dicot root.

3. Stele or central cylinder: The outermost cell layer of the root's stele is the **pericycle**, made up of thick-walled parenchyomatous cells. This region is responsible for giving rise to lateral roots.

Vascular bundles: Vascular bundles are composed of phloem and xylem. Within a vascular bundle xylem and phloem are arranged in an alternate manner, this arrangement is called **radial**. In dicotyledonous roots the number of bundles is limited. There are two to six bundles occurring alternately. The parenchymatous cells which lie between the xylem and the phloem are called **conjuctive tissue**.

The xylem is arranged in a way that the metaxylem is towards the centre, and the protoxylem lines are at the periphery. This is called **exarch xylem** (centripetal development).

Pith: At the centre there is small parenchymatous pith. It may be even absent.

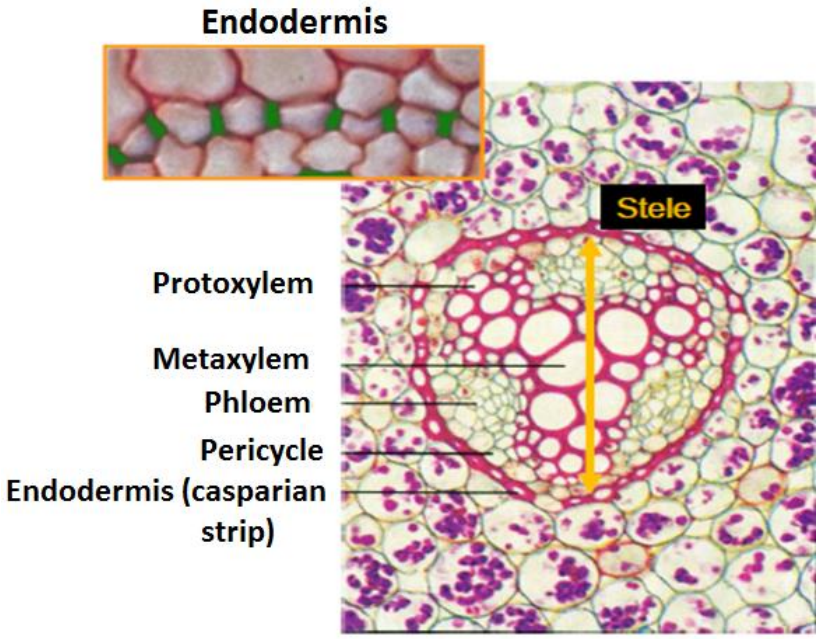


Figure 26. Structure of the endodermis and the central cylinder in dicot root.

2.1.2 Anatomy of monocot root

The monocot root and dicot root have many similar characteristics in terms of anatomy. But they also tend to have a few differences.

The epidermis is the uppermost layer, like in dicots, followed by the cortex, pericycle, endodermis, vascular bundles (xylem and phloem), and pith.

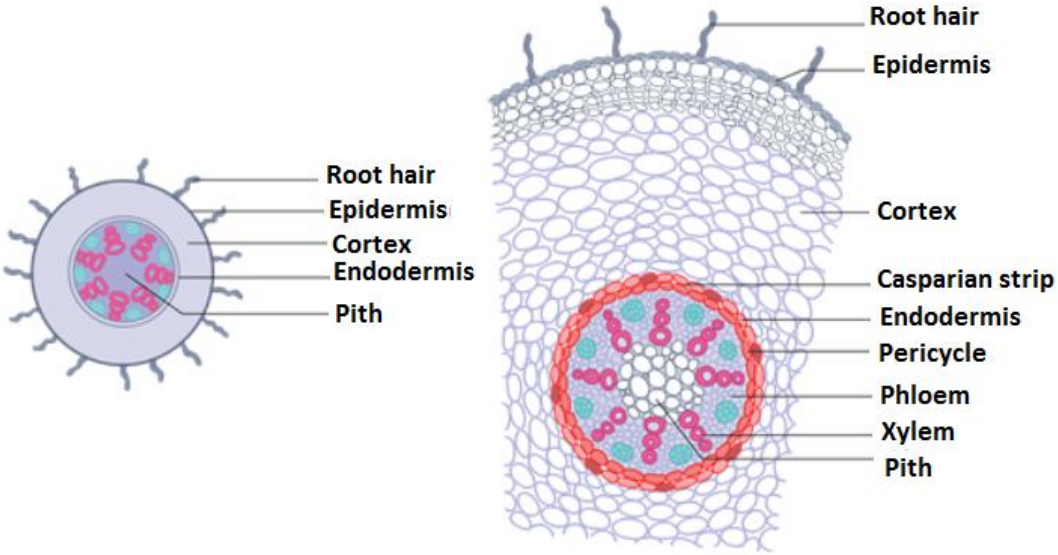


Figure 27. Structure of monocot root.

Some of the cells in the endodermis are **thin-walled** and are known as **passage cells**. The passage cells allow water to pass into the xylem vessels.

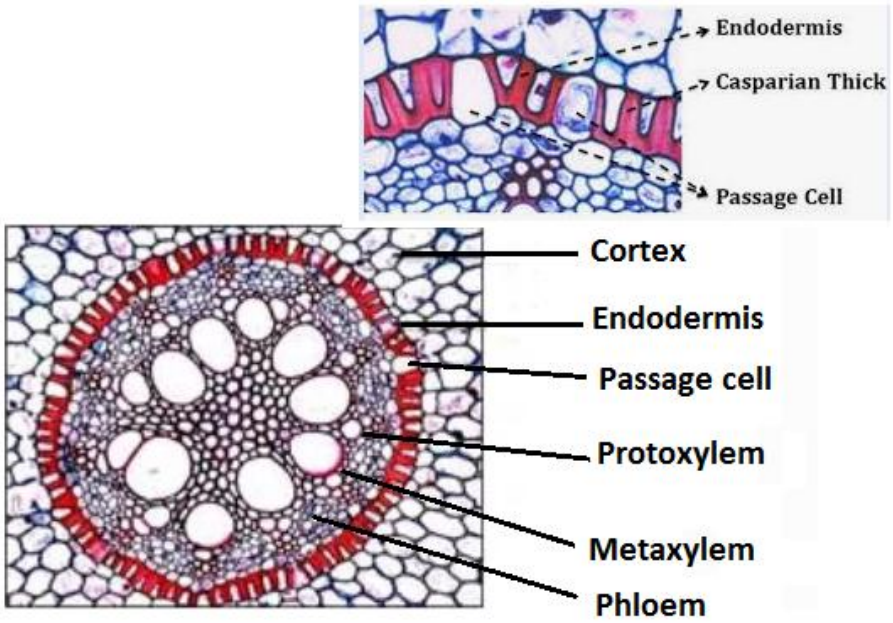


Figure 28. Structure of the endodermis and the central cylinder in monocot root.

- The number of xylem and phloem in the monocot root is more compared to that of the dicot roots. There are more than six xylem bundles hence called as **polyarch**.
- The center is occupied by large parenchymatous pith. Pith cells serve to store food.
- The monocot plants do not exhibit secondary growth.

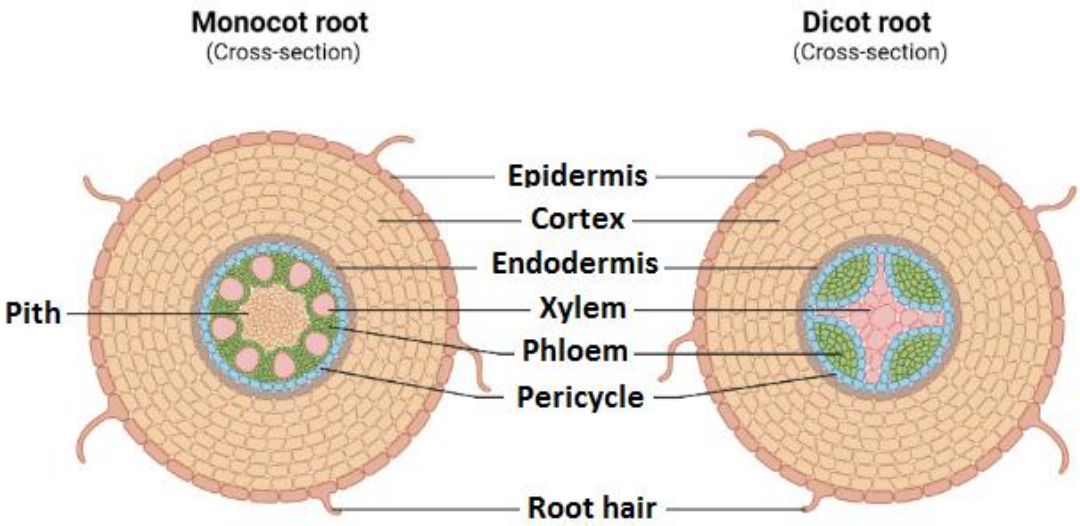


Figure 29. Difference between monocot and dicot root structure.

2.2 Anatomy of stem

2.2.1 Anatomy of dicot stem

The study of the transverse section of the dicotyledonous stem shows the following regions of tissues:

1. Epidermis: The epidermis consists of a single layer of living cells which are closely packed. It is covered with a thin layer of cuticle. The epidermis also may contain stomata for gas exchange and multicellular stem hairs called trichomes.

2. Cortex: It consists of three regions:

The **hypodermis** comprises a few layers of **collenchyma cells** located just below the epidermis, which provide mechanical strength to the young stem.

Beneath the collenchyma cells are a few **cortical layer**s composed of parenchyma cells, with intercellular spaces.

The innermost layer is the **endodermis.** This layer is also known as **starch sheath** because its cells are rich in starch grains.

3. Stele: This region comprises the pericycle, vascular bundles and pith (medulla).

Pericycle: It consists of a few layers of sclerenchyma cells located between the endodermis and vascular bundles. These cells provide protection for the vascular bundles.

Vascular bundles are arranged in a ring around the pith. The 'ring' arrangement of vascular bundles is a characteristic of dicot stem.

The phloem and xylem are situated at the same radius. The arrangement is called **conjoint**. The phloem is located towards the outside of the bundle and the xylem towards the center. Within the xylem, the protoxylem lies towards the centre (pith) and the metaxylem lies towards the periphery. This is called **endarch xylem**.

Each vascular bundle contains a cambium layer between phloem and xylem; such vascular bundles are called **open vascular bundles**.

A few layers of radially arranged parenchymatous cells located between the vascular bundles constitute the medullary **rays**.

Pith: It occupies the large central part of the stem. It consists of parenchyma cells with intercellular air spaces. The main function of the pith is food storage.

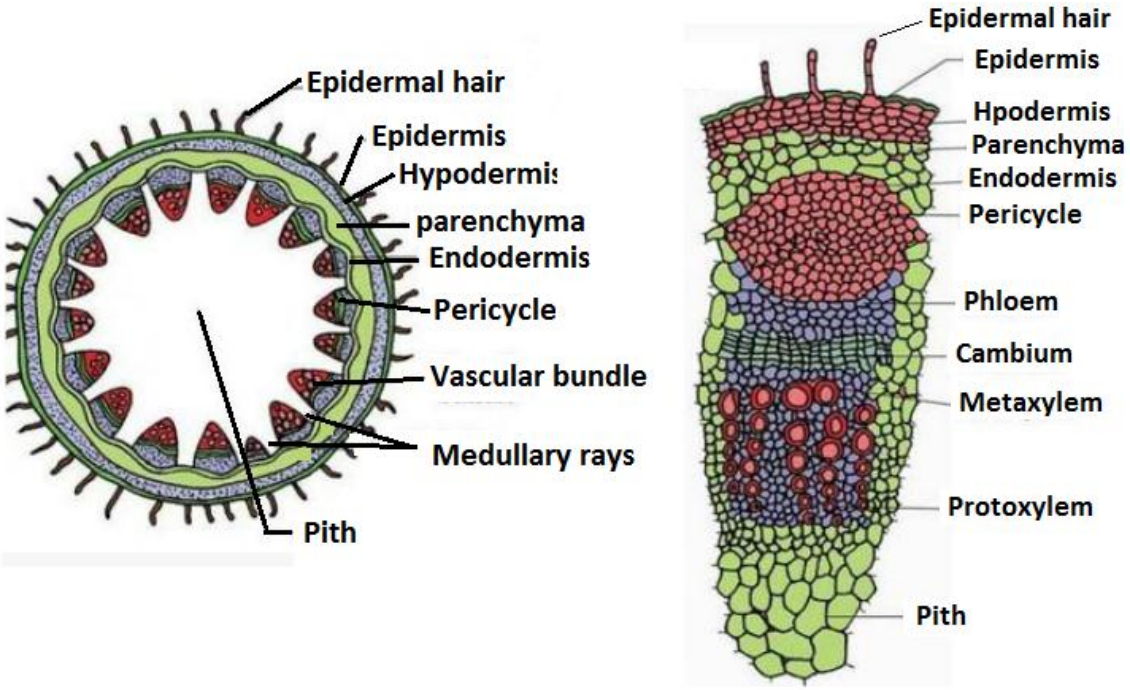


Figure 30. Primary structure of dicot stem.

2.2.2 Anatomy of monocot stem

In the monocot stem, the hypodermis consists of a few layers of **sclerenchymatous cells** lying below the epidermis. It has numerous vascular bundles scattered within the parenchymatous tissue, each surrounded by a sheath of sclerenchymatous fibres called **bundle**

sheath which protect the vascular bundles and give strength to the stem. Peripheral vascular bundles are generally smaller than the centrally located ones.

Vascular bundles are **conjoint**, **closed** (without cambium) and possess **endarch xylem**. The two metaxylem vessels are located at the upper two arms and one or two protoxylem vessels at the base. (Y shaped).

In a mature bundle, the lowest protoxylem disintegrates and forms a cavity known as **protoxylem lacuna**.

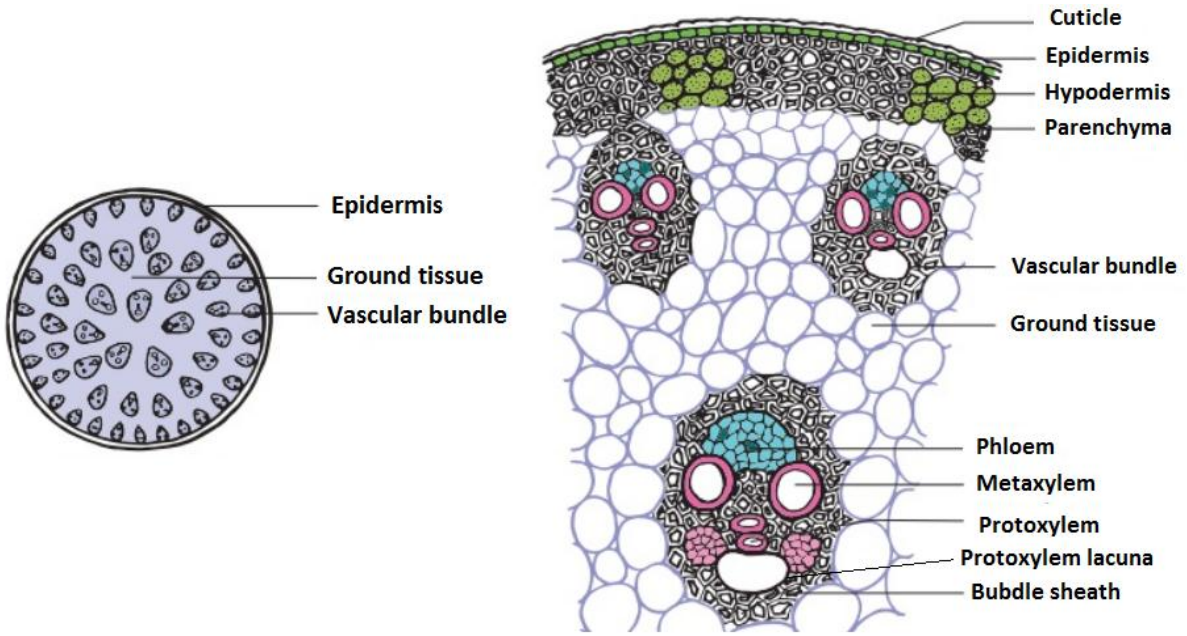


Figure 31. Structure of monocot stem.

2.3 Anatomy of leaf

2.3.1 Anatomy of dicot leaf

Three parts can be seen in the vertical section of dicot leaf: The epidermis, mesophyll, and vascular system.

Epidermis: covers both the upper surface (adaxial epidermis) and lower surface (abaxial epidermis) of the leaf. It has a noticeable cuticle.

The lower epidermis generally contains more stomata than the upper epidermis.

Mesophyll: The term "mesophyll" refers to the tissue that lies between the top and lower epidermis.

The mesophyll is made up of two types of parenchyma cells: the **palisade parenchyma** and the **spongy parenchyma**.

Palisade lies just below the upper epidermis. It is composed of elongated cells which are arranged vertically and parallel to each other. The oval or round and loosely arranged spongy parenchyma is situated below the palisade cells and extends to the lower epidermis. There are big intercellular spaces between these cells.

Vascular system: Many large and small vascular bundles can be seen. Their size is dependent on the size of the veins. Vascular bundles are conjoint, with the xylem oriented towards the upper epidermis and the phloem towards the lower epidermis. Each vascular bundle is surrounded by a layer of thick walled bundle sheath cells.

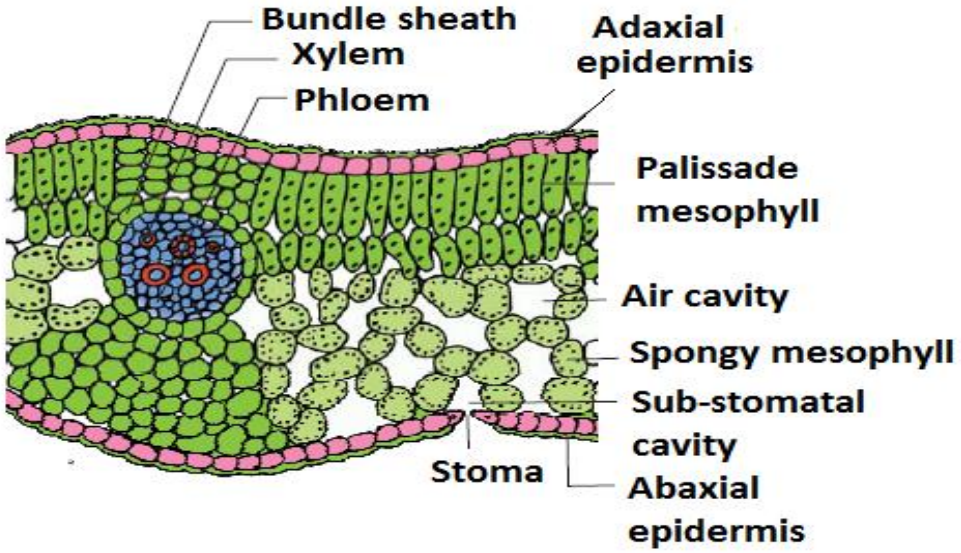


Figure 32. Transverse section of dicot leaf.

2.3.2 Anatomy of monocot leaf

The anatomy of a monocot leaf is similar to that of the dicot leaf with only slight differences.

Epidermis with cuticle and stomata are present on both the surfaces of the epidermis.

Mesophyll: It is not clearly differentiated into palisade and spongy parenchyma but the cells just next to the epidermal layers are a bit longer while the cells of the central mesophyll region are oval and irregularly arranged.

Vascular bundles:

Many vascular bundles are present. They are conjoint and each vascular bundle is surrounded by a bundle sheath. Monocotyledonous leaves are characterized by parallel venation, which is reflected in the nearly similar size of the vascular bundles, except in the main veins.

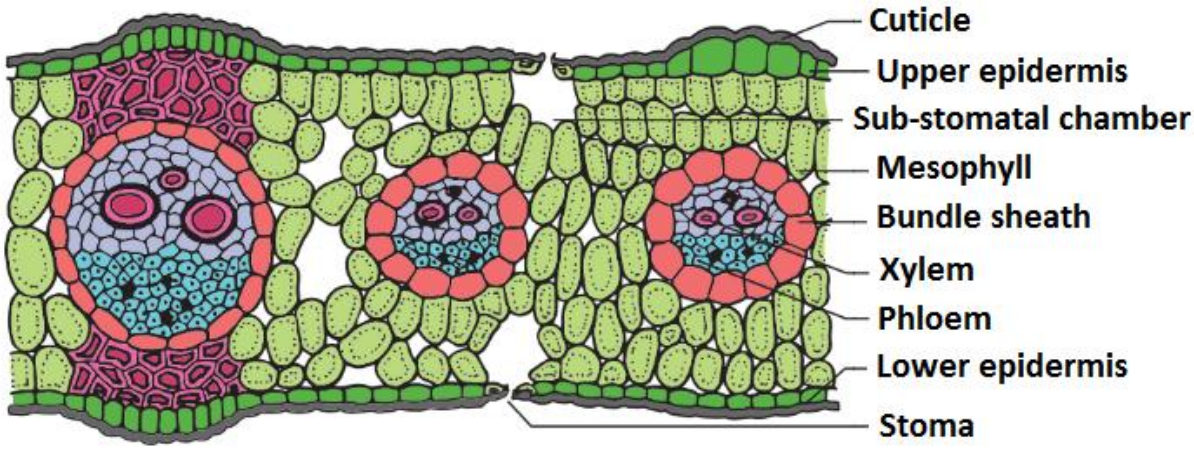


Figure 33: Transverse section of monocot leaf.

2.4 Secondary growth

Dicotyledonous plants exhibit an increase in girth called the **secondary growth**. **Secondary tissues** are formed by two types of lateral meristems, **vascular cambium** and **cork cambium** or **phellogen**.

2.4.1 Secondary growth in dicot stems

A.Vascular cambium

In dicot stems, the cells of cambium present between primary xylem and primary phloem is the **intra-fascicular cambium**. The cells of medullary rays which occur at the level of intra-fascicular strips become meristematic and form the **inter-fascicular cambium**. Thus, these two types of meristematic tissues get connected to form a **ring of continuous vascular cambium**.

The cambial ring becomes active and begins produce new cells. It gives **secondary phloem** toward the outer part and **secondary xylem** toward the inner part. The new layers of secondary xylem push the vascular cambium toward the surface of the root. In this way the perimeter of vascular cambium increases in length and xylem progressively accumulates so that the root increases in thickness. The cambium forms a narrow band of parenchymatous cells that extends radially through the secondary xylem and the secondary phloem, forming **the secondary medullary rays.**

B. Cork cambium

Secondary growth takes place in cortical region due to the activity of **cork cambium** also known as **phellogen.** This lateral meristematic tissue originates from the hypodermis or from the outer layer of cortex, which become meristematic. Through repeated divisions, the phellogen gives rise to new cells. It produces **phellem** or **cork cells** on the outer side, and

phelloderm on the inner side. The cork is impervious to water due to suberin deposition in the cell wall. Phellogen, phellem, and phelloderm are collectively known as periderm.

Phellem or cork is produced in greater quantity than phelloderm or secondary cortex, since the activity of the cork cambium is more towards the outer side. Consequently, the bulk of the periderm is usually composed of cork.

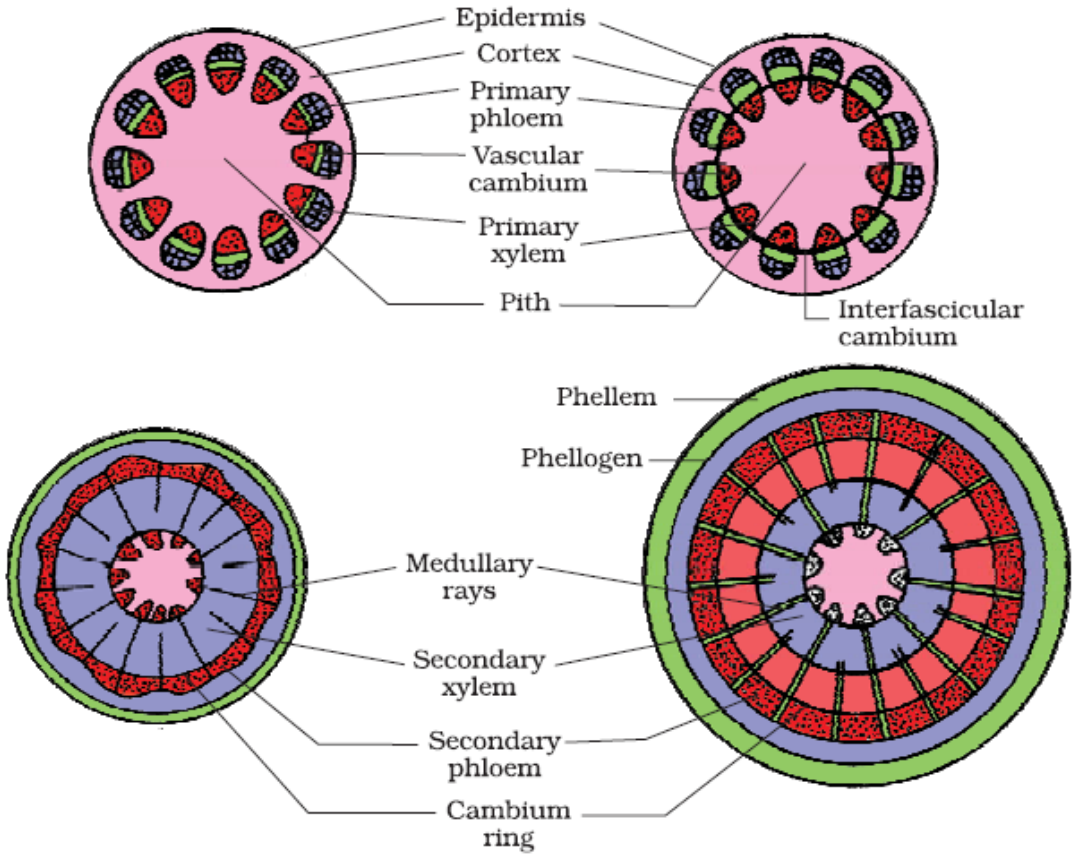


Figure 34. Secondary growth in a dicot stem.

2.4.2 Secondary growth in dicot roots

In dicot roots, a few parenchyma cells below each phloem group become meristematic and thus form strips of cambium, the number of strips being equal to the number of phloem groups present. At the same time, the cells of the pericycle against the protoxylem group divide and form a few layers.

Later, the vascular cambium originated from the cells below the phloem and that originated from the pericycle are connected to form the **continuous vascular cambium**. Further events are similar to those described above for a dicot stem.

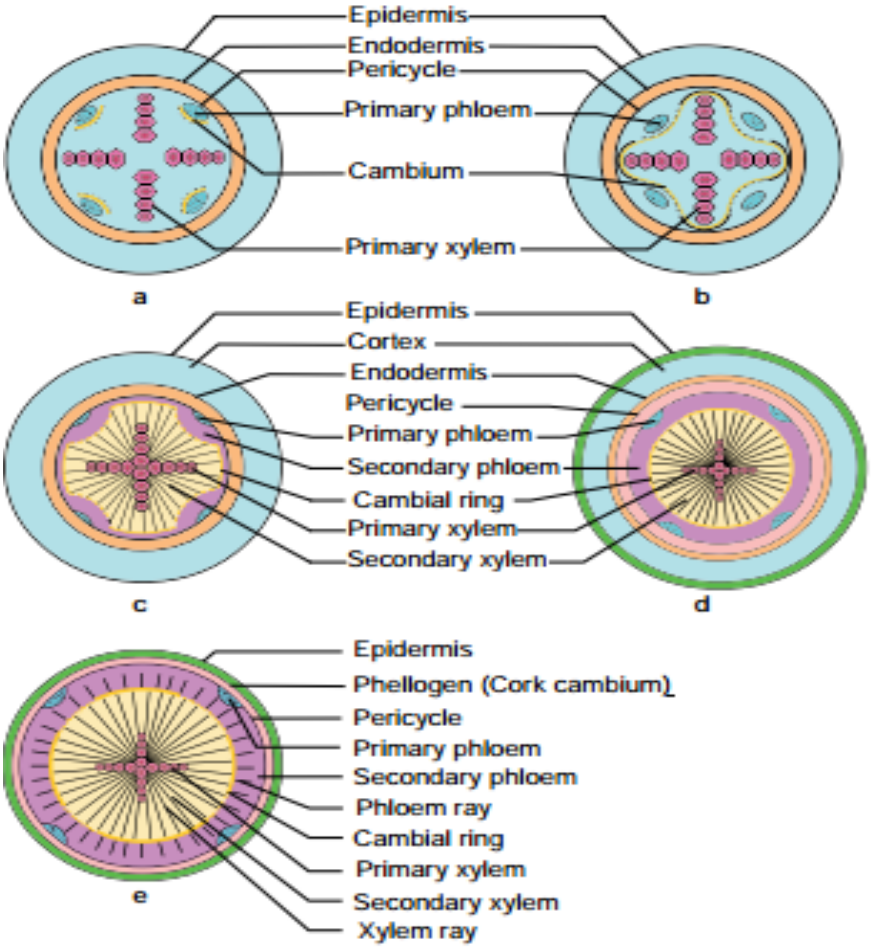
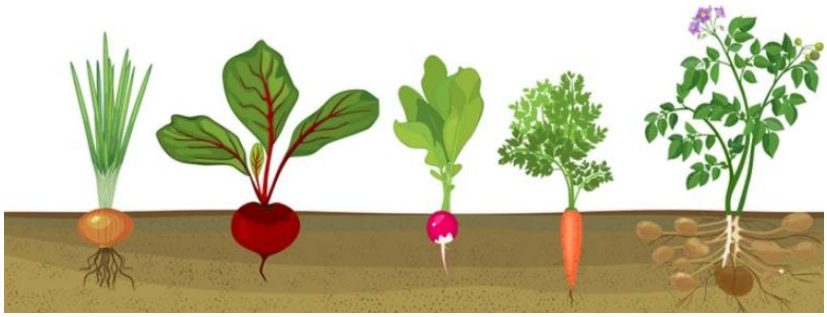


Figure 35. Different stages of the secondary growth in a typical dicot root.

CHAPTER 3: MORPHOLOGY OF FLOWERING PLANTS



Learning Objectives

By the end of this chapter, students will be able to:

• Describe the shoot system and the root system.

• Recognize, describe, and compare the various types of stems, roots, leaves, and flowers based on their morphological characteristics and functions.

•Identify and explain the anatomical adaptations of roots, stem, and leave to different environmental conditions.

Introduction

Morphology – (Morphe = form + logos = study) is the branch of biology that deals with the study of external features of an organism. Plant morphology focuses on examining the shapes and characteristics of various plant organs, such as roots, stems, leaves, flowers, seeds, and fruits. It plays crucial role in the recognition and identification of plants.

A typical plant consists of two parts: the root system and the shoot system.

- **The shoot system** comprises the aboveground vegetative parts, such as stems and leaves, as well as the reproductive structures, including flowers and fruits.

- **The root system** supports the plant and absorbs water and minerals. It is usually underground. The Figure below shows the organ systems of a typical plant.

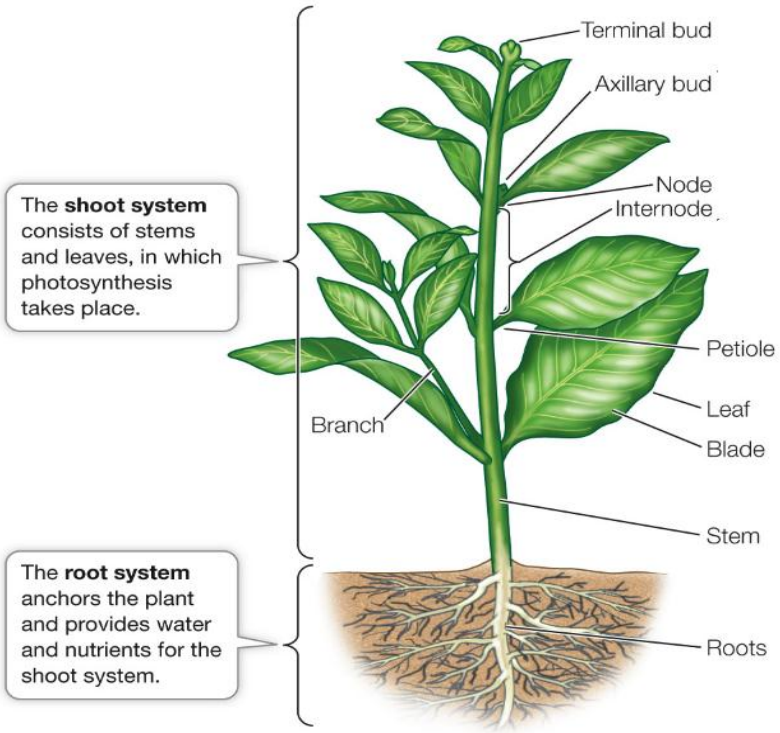


Figure 36. Parts of a flowering plant body.

3.1 Morphology of the root

Root is the cylindrical descending part of the plant axis. It is generally non-green and non-photosynthetic. Root develops from the radicle of the embryo during seed germination. It is positively geotropic and negatively phototropic.

Unlike stems, roots do not have nodes and internodes.

The roots of seed plants have three major functions:

-Anchoring the plant to the soil,

-Absorbing water and minerals

-Storing the products of photosynthesis.

3.1.1 Regions of the root

When a plant seed germinates, the embryo emerges from the seed and the radicle of the embryo forms the root system. Four distinct regions are present in roots.

A. Root cap: Protective cells covering the tender apex of the growing root. It protects the apical meristem from damage as the root grows through the soil.

B. Region of cell division or meristematic region: Is a small area of just a few millimeters above the root cap. It consists of thin walled, compactly arranged meristematic cells which divide repeatedly.

C. Region of elongation: In this region, newly formed cells originating from the apical meristem of the root elongate rapidly. This increases the length of the root.

D. Region of maturation: Where the root cells begin to differentiate into special cell types and also where root hairs are formed.

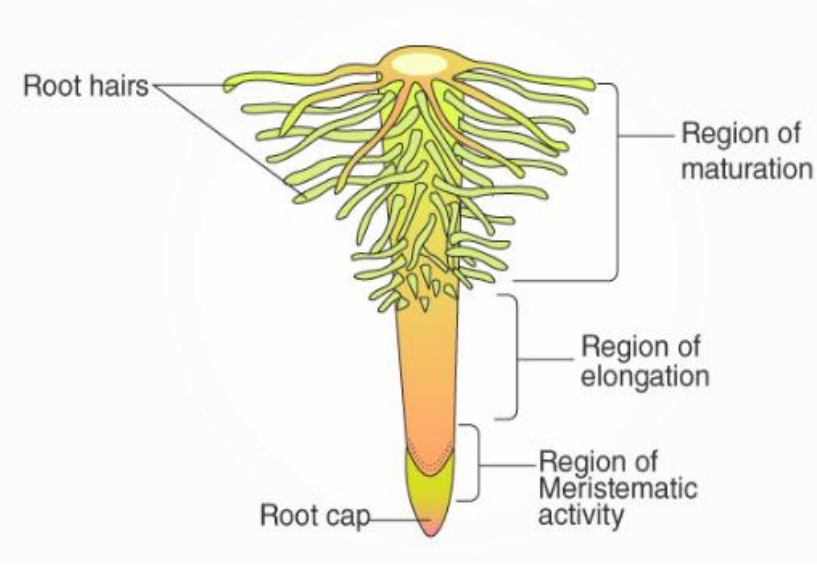


Figure 37. Regions of roots.

3.1.2 Types of root systems

A. Tap root system: It has a main root that grows down vertically, from which many smaller lateral roots emerge. This type characterizes dicotyledonous plants. Tap root system extends deep into the soil.

B. Fibrous root system: it consists of many small roots. This root system is located closer to the soil surface; therefore it does not provide strong anchorage. The fibrous root system is the main root system of monocots.

C. Adventitious root system: A root formed from any other part other than the radicle is known as adventitious root.

-It may develop from the nodes or internodes of the stems, or from leaves.

- Adventitious root system can be both underground and above ground.

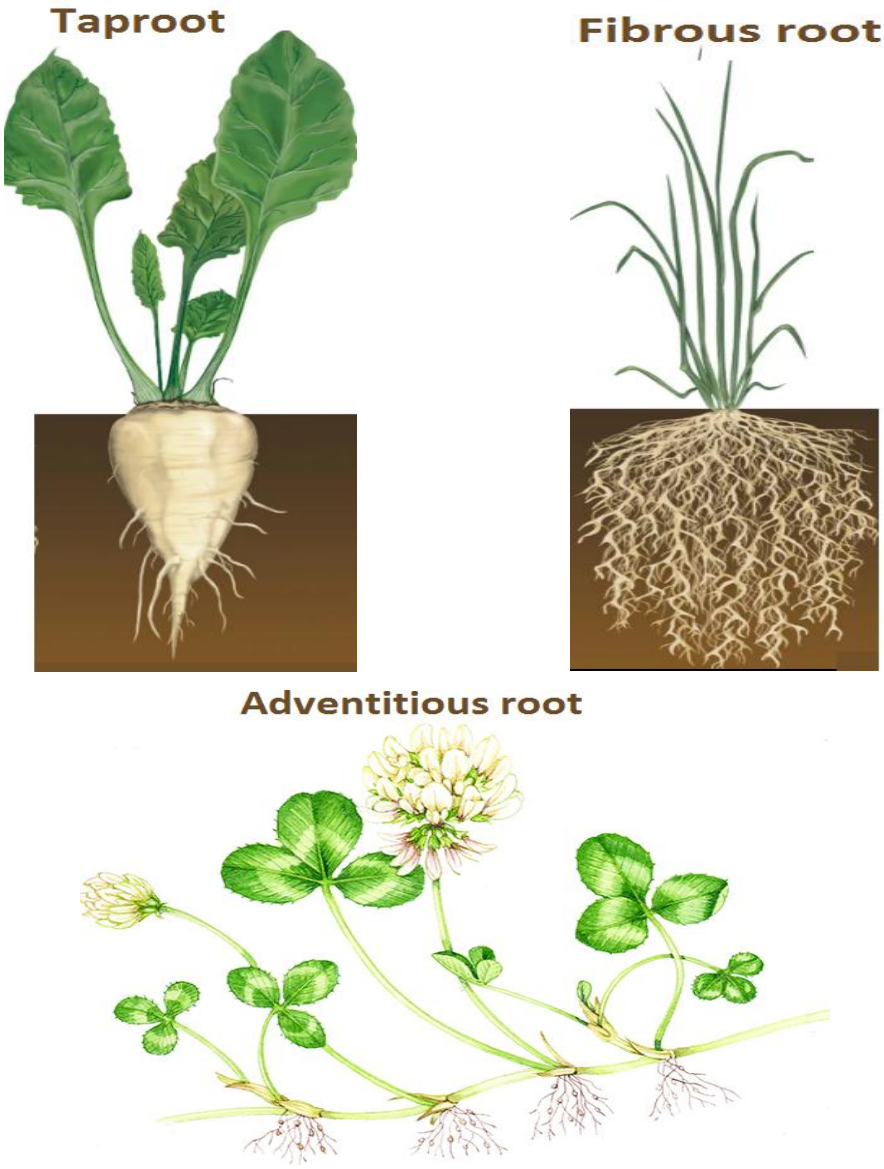


Figure38. Types of root system.

3.1.3 Root modifications

In some plants, the roots change their shape and get modified to perform specialized functions.

3.1.3.1 Modifications of taproot

A. Fleshy taproot

The tap root becomes fleshy due to the storage of food while the secondary roots remain thin. Stem is reduced and discoid in the beginning and bears radical leaves.

Based on their shapes, fleshy taproots are of the following types:

Conical: the primary root is cone-shaped, that is, the thickest towards base and gradually tapering towards the apex. Many thread-like secondary roots arise all along the conical root, e.g., Carrot (Daucus carota).

Fusiform: the fleshy root is like a spindle. The root also bears a reduced discoid stem and radicle leaves e.g., Radish (Raphanus sativus).

Napiform: The storage root is very thick at the base and is almost spherical. It suddenly thins out towards the apex (top-like), e.g., Beet (Beta vulgaris), Turnip (Brassica rapa).

Tuberous roots: are thickened, irregularly shaped taproots, such as in Mirabilis jalapa (Four O'Clock).

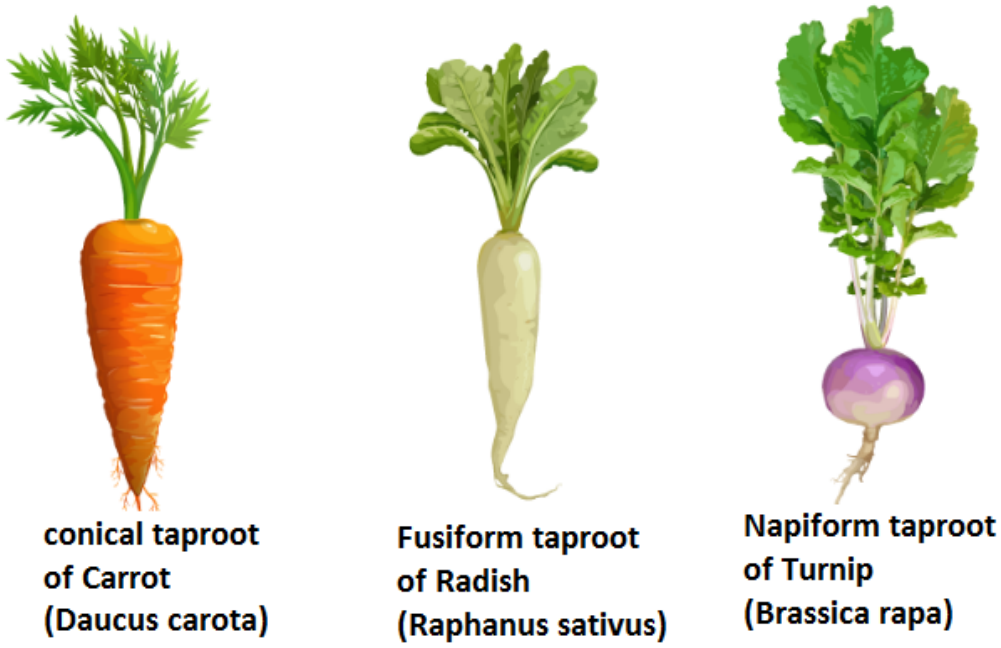


Figure 39. Fleshy taproot.

B. Pneumatophores or respiratory roots: This type of root is found in halophytes and mangrove plants (plants growing in swamps near the seashores). The roots of these plants do not get air for respiration, so some branches of the tap root grow vertically and emerge from the soil for gas exchange. These are called respiratory roots or pneumatophores. They bear small pores called lenticels or pneumatothodes near their tips. eg. *Rhizophora, Heritiera*.

C. Nodulated taproot: Many small irregular swellings, called root nodules, are formed on the branches of roots by nitrogen-fixing bacteria (Rhizobium), such as in plants of the Leguminosae family (Papilionaceae).

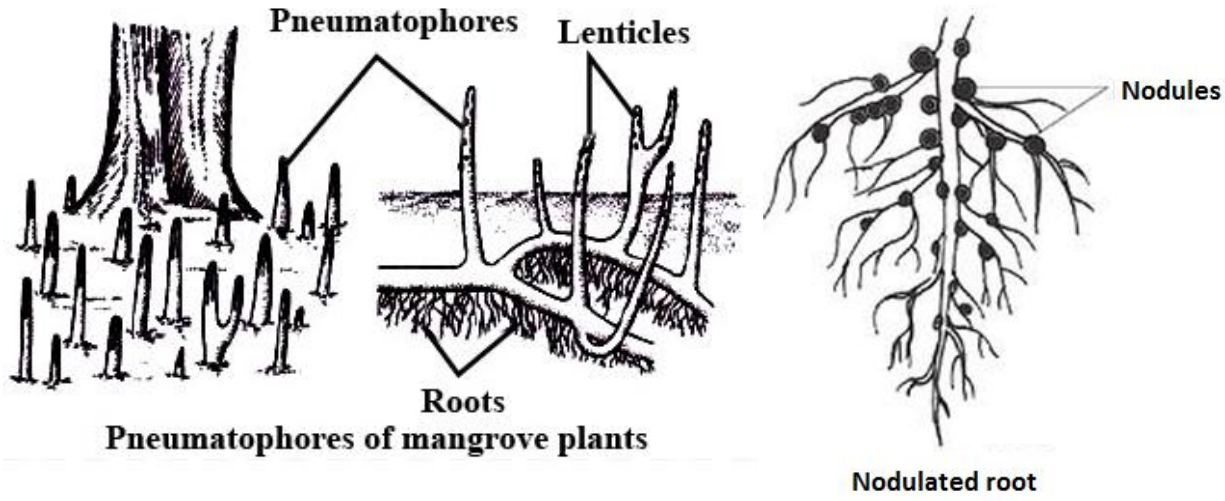


Figure 40. Modification of taproot: respiratory root and nodulated root.

3.1.3.2 Modification of adventitious roots

3.1.3.2.1 Storage adventitious roots: Adventitious roots become thick and fleshy due to the storage of food. They are of following types:

A. Tuberous Root or Root Tubers: Such roots always borne singly at the nodes of prostrate stem. They become swollen and do not assume a definite shape. e.g., Sweet potato.

B. Fasciculated Roots: A cluster of thick and fleshy adventitious roots arises at the base of the stem. e.g., Asparagus, Dahlia.

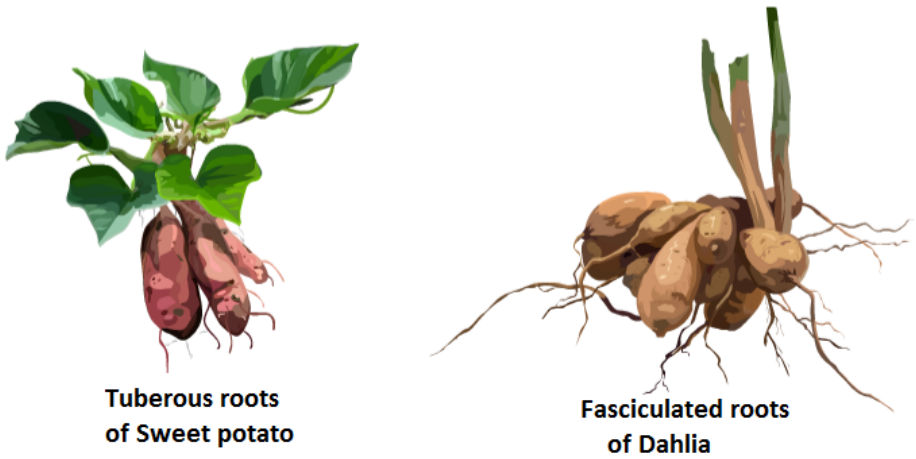


Figure 41. Storage adventitious roots.

3.1.3.2.2 Adventitious roots modified for additional support

A. Prop root or pillar roots: Pillar-like adventitious roots arise from branches of plant and grow downward towards soil. They provide mechanical support to the heavy branches. eg. Banyan.

B. Climbing roots: Some plants produce roots from their nodes which help plant in climbing. e. g., Pothos (Money plant).

C. Stilt root or brace roots: These roots develop obliquely from the basal nodes of the stem and penetrate down into the soil. They give support to the plant, e.g., maize (*Zea mays*).

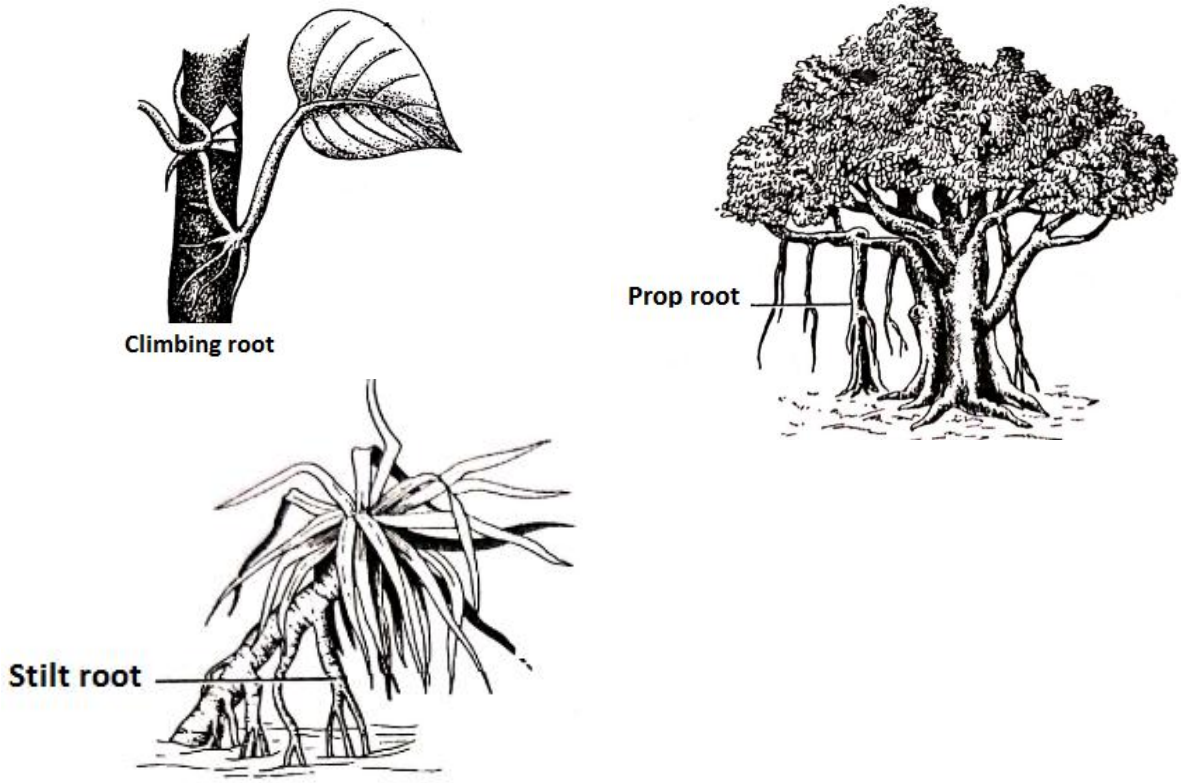


Figure 42. Adventitious roots modified for additional support.

3.1.3.2.3 Roots modified for vital functions

A. Hygroscopic or epiphytic roots: These aerial, hanging roots are developed by epiphytes. They are spongy due to presence of a special tissue called velamen, which helps the roots in absorbing atmospheric moisture. e.g. Venda.

B. Assimilatory or photosynthetic roots: These green roots develop from the stem nodes; they are capable of photosynthesis, e.g., Trapa (Water Chestnut).

C. Haustorial or parasitic roots: Parasitic plants develop microscopic parasitic roots, also called sucking roots or suckers, which help absorb food directly by establishing contact with the vascular tissue of the host plant. e.g., Cuscuta (Dodder Plant).

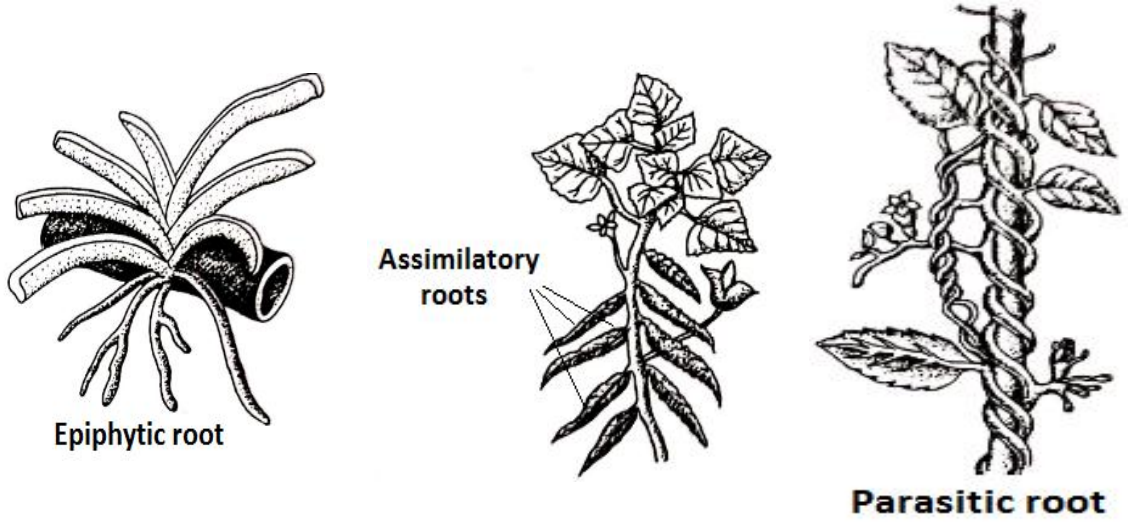


Figure 43. Roots modified for vital functions.

D. Floating roots or root floats: These roots develop at the nodes of some aquatic plants. They store air, become inflated, and help the plant float on the surface of the water. They also assist in in gaseous exchange for respiration.

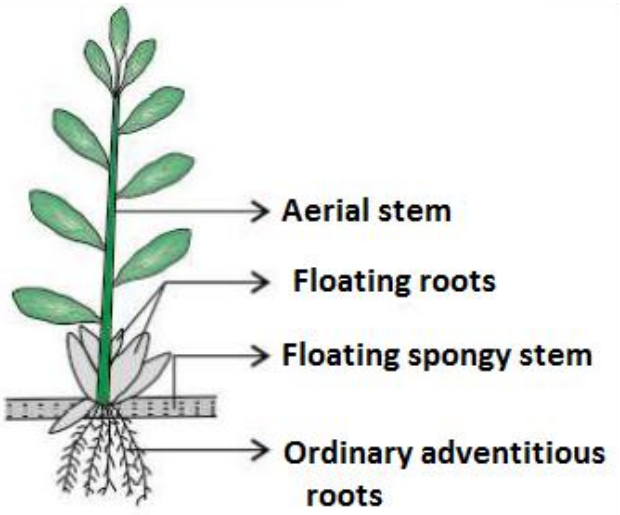


Figure 45. Floating roots.

E. Reproductive roots: These are adventitious fleshy roots that develop adventitious buds. The adventitious buds are used for vegetative reproduction, as they can produce new plants under favorable conditions, e.g., sweet potato.

3.4 Morphology of the stem

The stem is the ascending part of the axis bearing branches, leaves, flowers and fruits. It develops from the plumule of the embryo of a germinating seed. Functionally, the stem exhibits positive phototropisme and negative geotropisme.

-Plant stems may range in length from a few millimeters to hundreds of meters, and also vary in diameter, depending on the plant type.

-The stem is characterized by the presence of nodes and internodes. The regions of the stem where leaves are born are called nodes **Nodes**, while part of the stem between two adjacent nodes is called **internode.**

-The stem bears **buds**, which are the stem's primary growing points. They may be **terminal** (located at the tip of a stem), lateral (borne on the sides of the stem) or **adventitious buds** when they arise at sites other than in the terminal or lateral position.

-Buds can be either **leaf buds** (vegetative) or **floral** (reproductive) buds.

-The apex (tip) of the shoot contains the apical meristem within the apical bud.-Stems are usually above ground, although the stems of some plants, such as the potato, also grow underground.

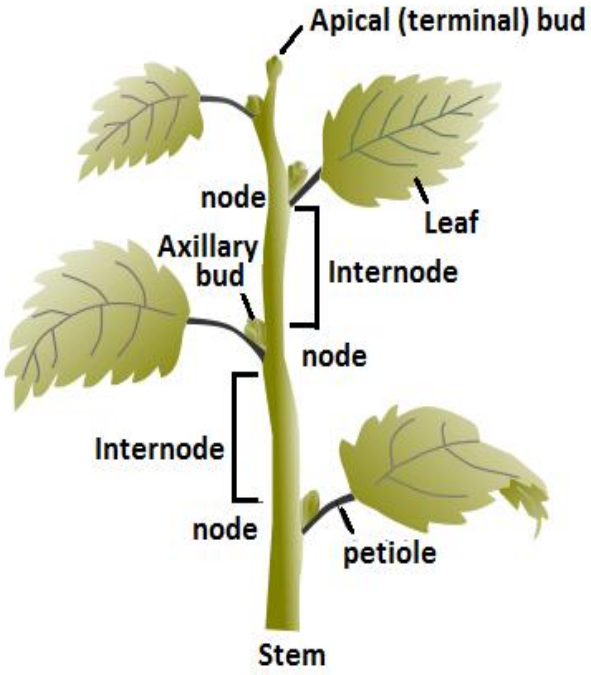


Figure 46. Parts of a stem.

The mains functions of stem:

-To bear branches, leaves, flowers and fruits.

- To conduct water, minerals and photosynthates.

-Some stems perform the function of storage of food, support, protection and of vegetative propagation.

3.2.1 Different forms of stem

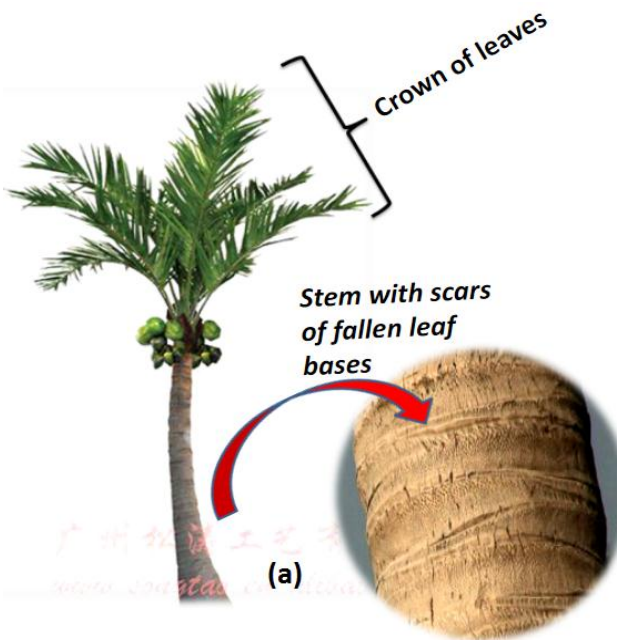
A. Erect stems: Most angiosperms have upright, ascending, and vertically growing stems which are anchored in the soil with the support of roots. Erect stems belong to four categories:

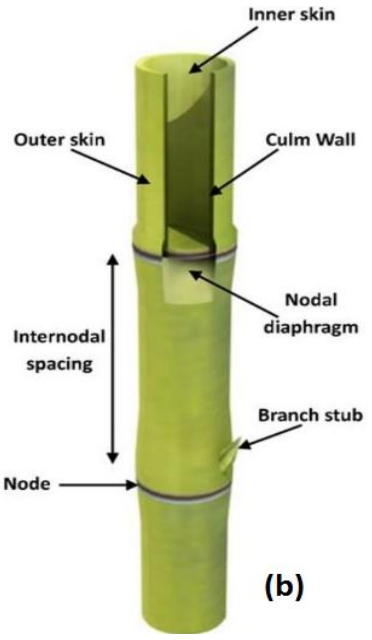
Caudex : The main stem is unbranched, erect, cylindrical and bears a crown of leaves at its top. e.g., Palm.

Culm: Stem is jointed with solid nodes and hollow internodes. eg. Bamboo (Graminae)

Excurrent: The branches develop from the main stem in acropetal succession giving the tree a conical shape. e.g. *Pinus*, *Eucalyptus*, etc.

Decurrent (Deliquescent): The lateral branches grow more vigorously than the main trunk, eventually dominating and giving the tree a dome-shaped appearance, e.g., mango (*Mangifera indica*), and banyan (*Ficus bengalensis*).





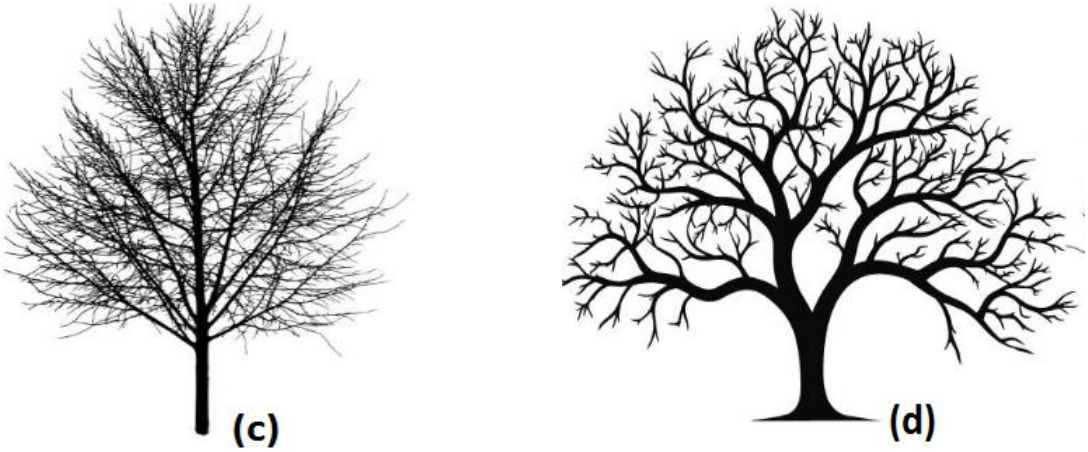


Figure 47. Types of erect stems (a) Caudex (b) Culm (c) Excurrent (d) Decurrent.

B. Reduced stems: In some plants, the stem is reduced to a small disc which is not differentiated into nodes and internodes. e.g. radish, turnip.

-In some aquatic plants, the reduced discoid stem is green and flattened to float on the surface of water. e.g. Lemna.

C. Weak stems: In this type, stem is thin, soft and weak and needs a support for spreading. It can be upright or prostrate.

a. Upright weak stems: it is of two types:

Twiners: The long and flexible stem twines around the support without any special organ of attachment. e.g., Cuscuta.

Climbers: Plants have long weak stem which bears organs of attachment for climbing like adventitious roots, tendrils. e.g. Smilax.

b. Prostrate or Sub areal weak stems:

Creepers – The stem creeps on earth and the roots arise at the nodes, e.g., Grasses, Oxalis.

Traliers: The stem creeps on the ground without developing roots at the nodes.

3.2.2 Stem modification

Some plant species have modified stems that are especially suited to a particular habitat and environment.

3.2.2.1 Underground modification

A. Rhizome is a modified stem that grows horizontally underground and has nodes and internodes**.** It acts as storage organ. eg. Ginger.

B. Tuber: is an underground stem that may store starch, as seen in the potato (*Solanum* sp.).

C. Bulb: is a modified underground stem surrounded by enlarged fleshy scales (leaves) that attach at the base of the stem, as seen in onion and iris.

D. Corm: it is a compressed stem with reduced scaly leaves (such as in gladiolus). It grows vertically and stores food materials.

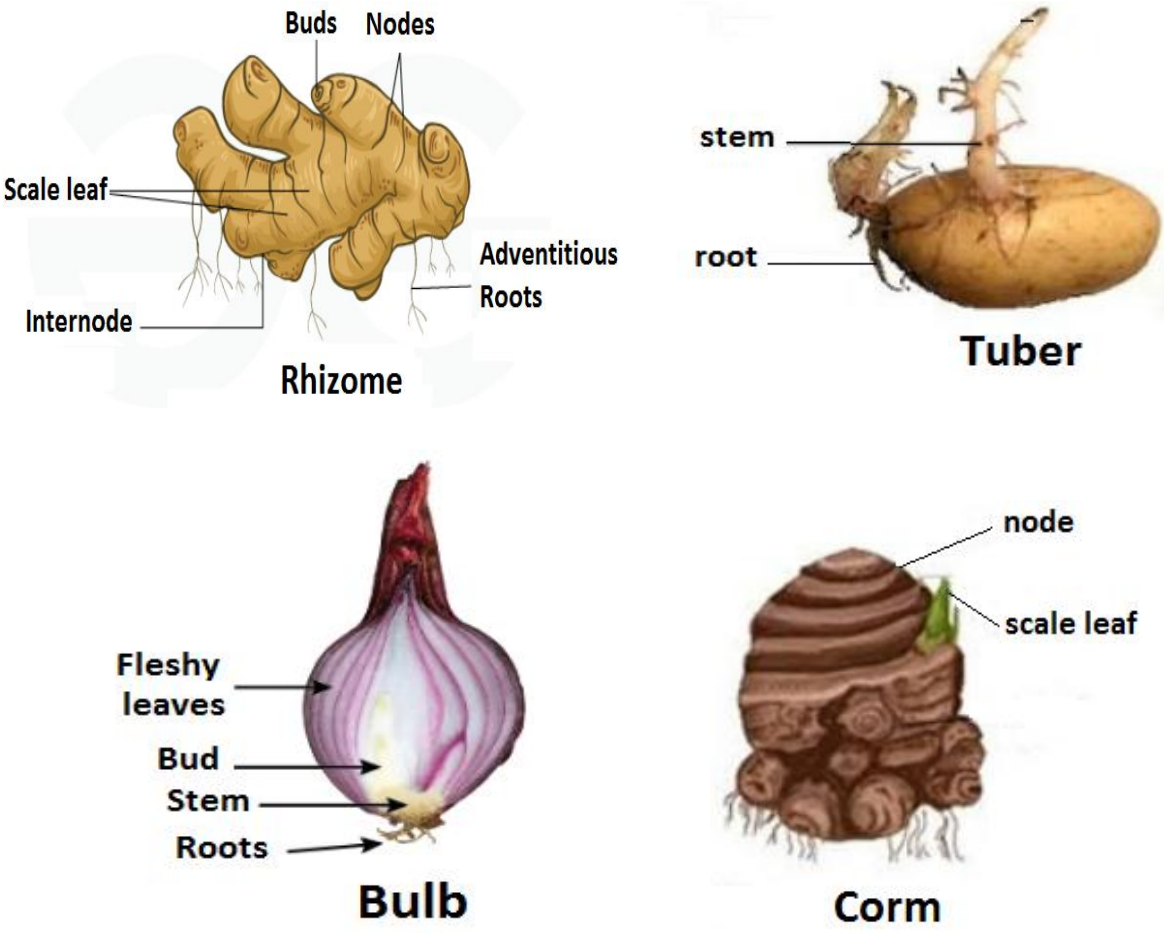


Figure 48. Underground modified stems.

3.2.2.2 Sub-aerial modification

A. Stolon: is a specialized stem that grow horizontally above the soil surface, and can give rise to new plants at the nodes. e.g. Strawberry

B. Runner: It is a type of stolon that grows and spread on the surface of soil. Roots are developed at lower side and leaves from upper side from node e.g.Oxalis.

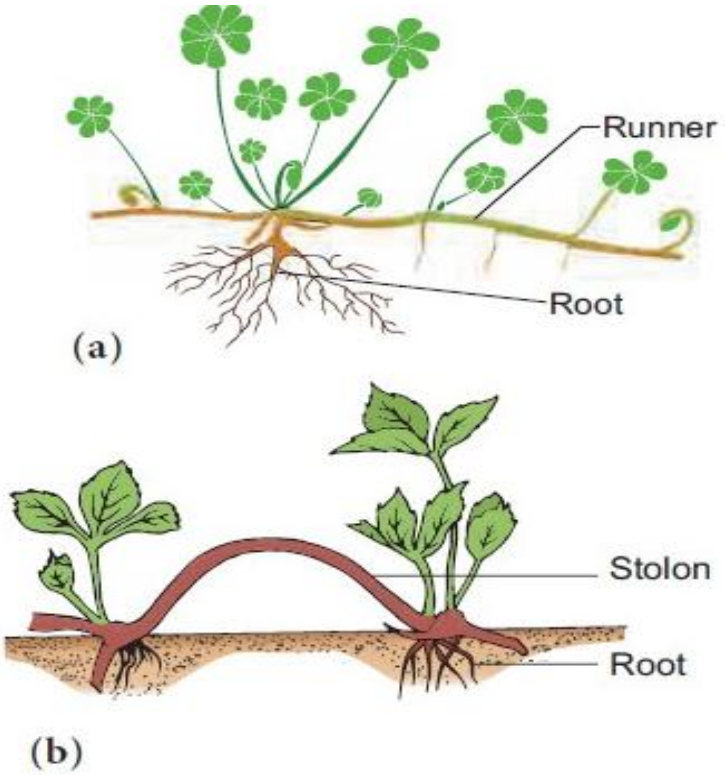


Figure 49. (a) Runner **(b)** Stolon

C. Offset: It is similar to runner but found in aquatic plants especially in rosette leaved forms. e.g. *Eichhornia* (water hyacinth)

D. Sucker: It emerges from an underground stem and grows obliquely upward and gives rise to new plantlet. e.g. *Chrysanthemum*.

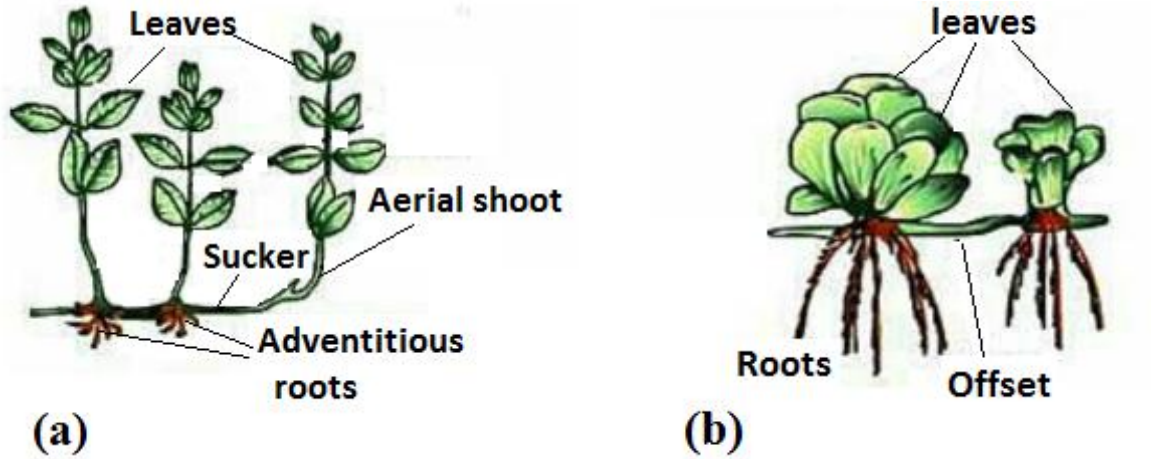


Figure 50: (a) Sucker (b) Offset

3.2.2.3 Areal modification

A. Phylloclades (Cladophyll): Stem is modified into a fleshy flat or a fleshy cylindrical and green leaf like structure with leaves either feebly developed or reduced to spines. It performs photosynthesis and mostly found in xerophytic plants. e.g. Euphorbia, Cactus.

B. Cladode: It is a phylloclade having one or two internode long and succulent as seen in Asparagus.

C. Thorn: It is hard woody, pointed modified stem which may either develop from axillary bud or terminal bud.

D. Bulbils: They are condensed, fleshy axillary buds. Bulbils participate in vegetative propagation by developing into new plants once they become detached from the parent plant.

E. Stem tendrils: They are wiry, coiled sensitive and delicate structures that result from the modification of axillary bud in the weak stems of some plants. Tendrils help in climbing.

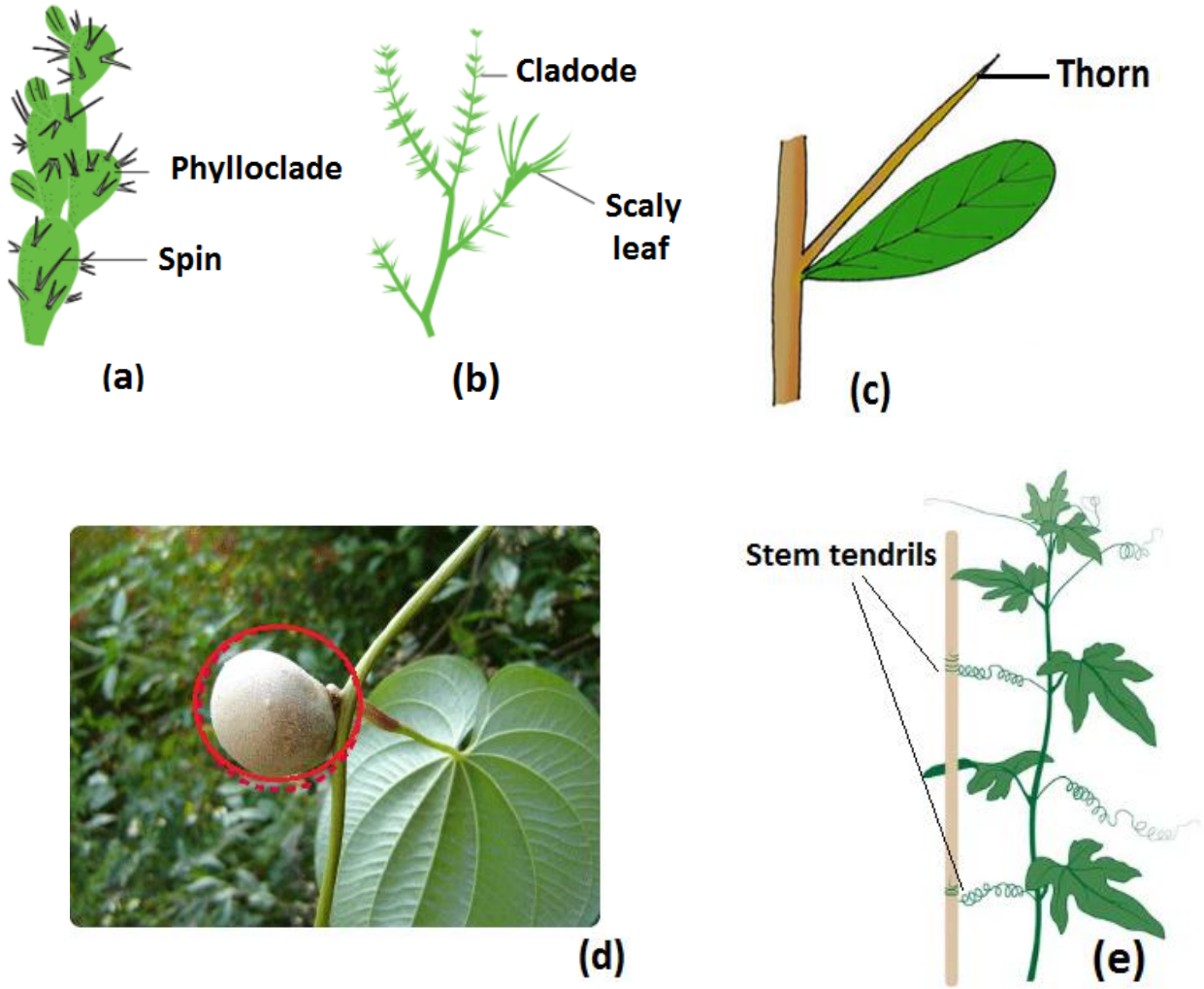


Figure 51. Ariel stem modification (a) phylloclade (b) cladode (c) Thorn (d) Bulbils (e) Stem tendrils.

3.3 Morphology of the leaf

The leaf is a lateral, generally flattened structure borne on the stem. It develops at the node of the stem or its branches and bears a bud in its axil. It is originate from shoot apical meristems.

- Leaves are the main sites for photosynthesis: the process by which plants produce their food.
- Most leaves are typically green because of the presence of the photosynthetic pigment called chlorophyll in their cells. However, some leaves may have other colors.
- All the green leaves of a plant together are referred to as **the foliage**.

3.3.1 Parts of a typical leaf

The main parts of the leaf include:

A. Leaf Base (Hypopodium): is the lowermost part of the leaf, by which the leaf is attached to the stem. In many plants, the leaf base possesses two small green leaves known as **stipules.**

B. Petiole or mesopodium: It is a cylindrical or sub-cylindrical, thin flexible stalk.

The petiole holds the blade help hold the blade to light and supports it. Long thin flexible petioles allow leaf blades to flutter in wind.

The leaves with petioles are called **petiolate leaves**.

In some plants, leaves do not have a petiole and are directly attached to the plant stem, they are called **sessile leaves**.

C. The lamina or the leaf blade is the green largest part of the leaf. It is supported by a system of veins acting as channels of transport for water, minerals and food materials. Veins contain both xylem and phloem. There is, usually, a middle prominent vein, which is known as the midrib. The edge of the leaf is called the margin. The veins, petiole, and midrib all work together to position the blade to face the light source.

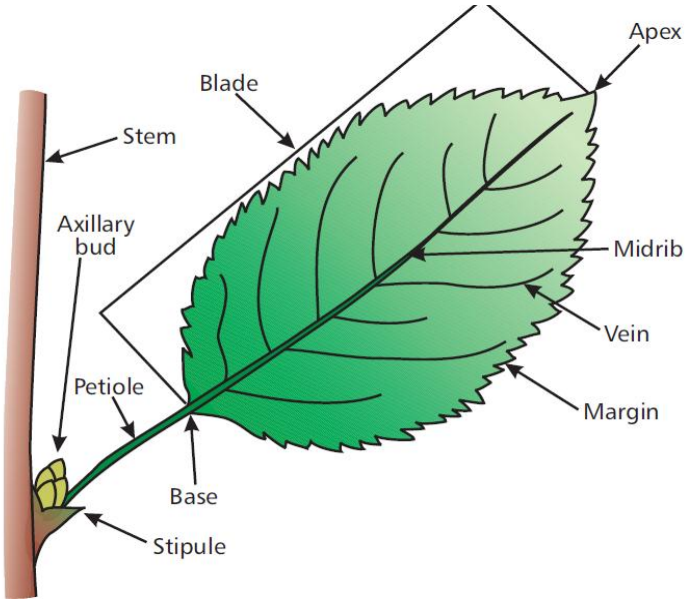


Figure 52. Parts of a leaf.

3.3.2 Venation

The arrangement of veins and veinlets in a leaf is called **venation**.

Types of venation

A. Reticulate venation: veins connect and branch from each other to form a network. This type of venation is the characteristic of leaves of dicot plants.

Reticulate venation is classified into two subtypes based on the number of main veins or midribs in the lamina:

B. Pinnate or Unicostate reticulate venation: The lamina has a single main vein or midrib extending from the base to the apex, from which lateral veins arise. These lateral veins branch and re-branch into veinlets, forming a network.

C. Palmate or multicostate reticulate venation: The lamina has more than one prominent or principal vein, each giving rise to lateral veins, which further branch into veinlets.

D. Parallel venation: the veins run parallel to each other within a lamina. Leaves of monocotyledonous plants generally possess parallel venation.

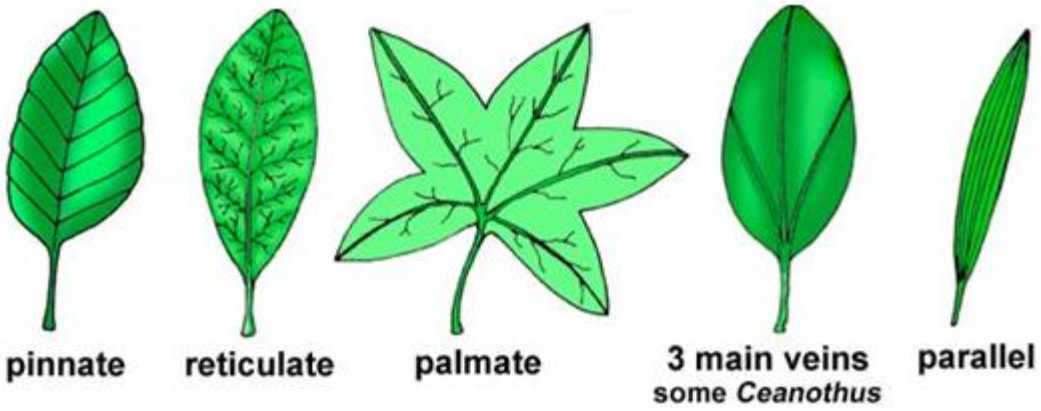


Figure 53: Types of leaf venation

3.3.3 Types of leaves

There are two broad categories of leaves **simple** and **compound.**

A. **Simple leaf:** when its lamina is entire or when incised, the incisions do not touch the midrib.
B. **Compound Leaf:** the lamina is divided into several small parts called leaflets or pinnae, the leaflets are distinct, free from one another and joined to **the rachis** or the tip of the petiole.

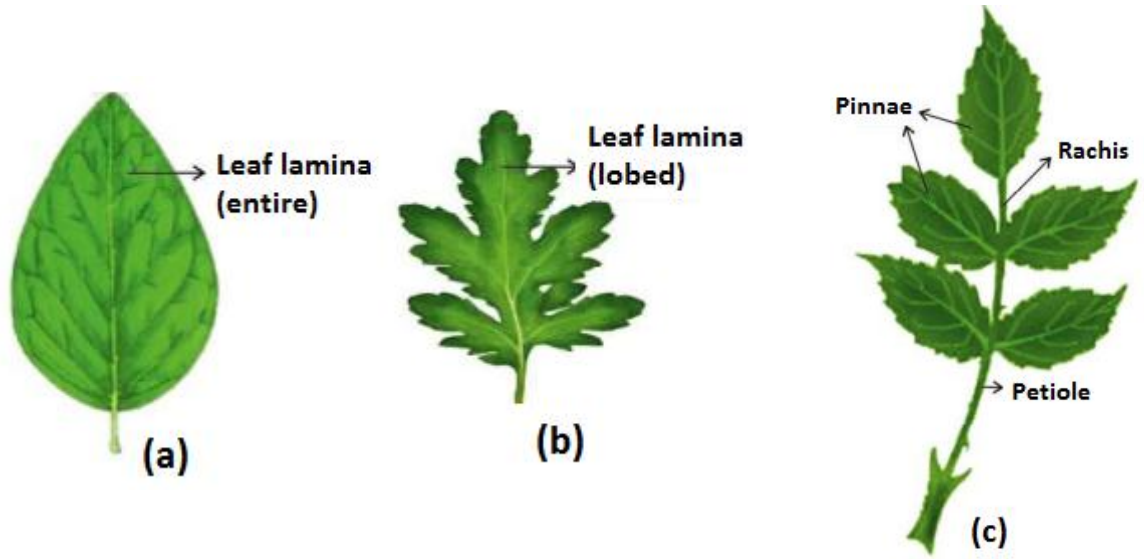


Figure 54: types of leaves (a); (b) simple leaves, (c) compound leaf.

The compound leaves may be of two types:

- **Palmately compound leaf**: The leaflets are attached at a common point.
- **Pinnately compound leaf:** When multiple leaflets are attached along a **rachis**, or axis.

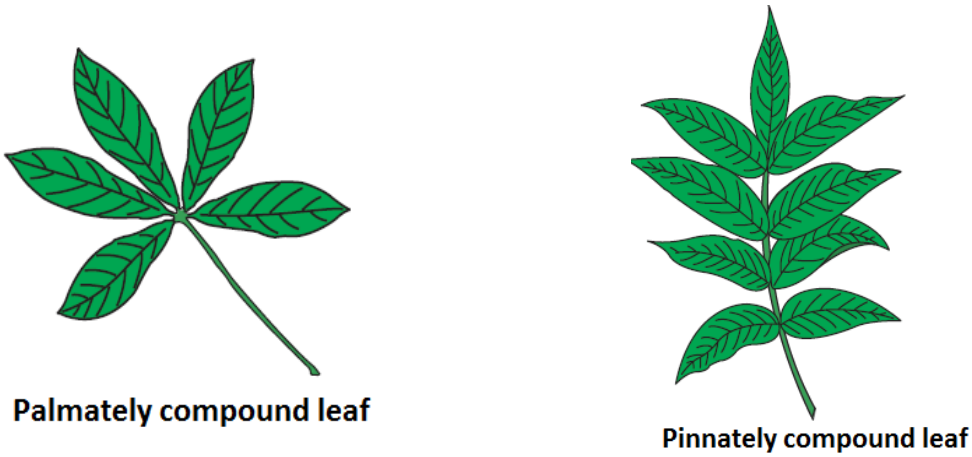


Figure 55. Types of compound leaves.

3.3.4 Phyllotaxy

Phyllotaxy is the pattern of arrangement of leaves on the stem or branch.

Plants with a single leaf per node have leaves arranged in either an **alternate** pattern, where they alternate on each side of the stem in a flat plane, or a **spiral** pattern, where they are arranged in a spiral along the stem.

In an **opposite** leaf arrangement, a pair of leaves arises at each node and lies opposite to each other along the branch.

If three or more leaves are connected at a node, forming a whorl, the leaf arrangement is called **whorled**.

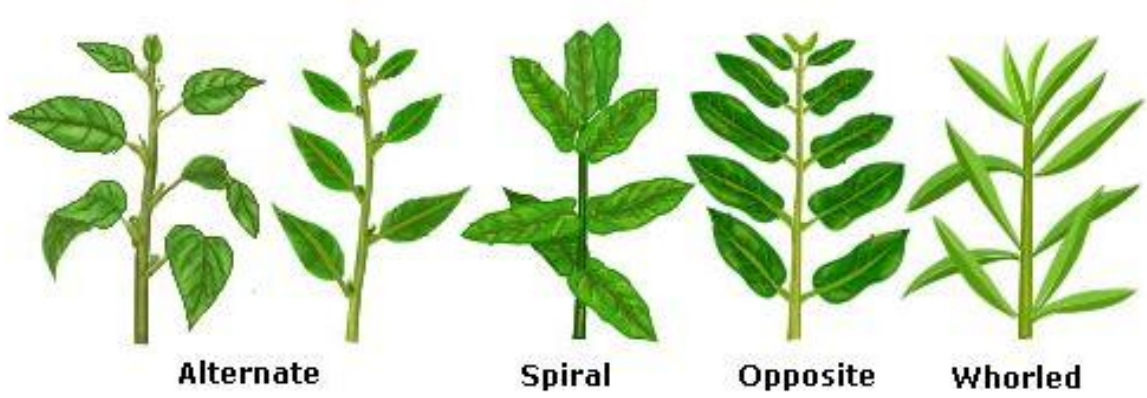


Figure 56. Different types of phyllotaxy.

3.3.5 Modification of leaves

The modifications of leaves help to perform special functions.

A. Leaf tendrils

In some plants with weak stem, the leaves or their parts are modified into thin thread like structure known as tendrils. These structures help the plant to climb up a support to expose its foliage to sunlight.

B. Leaf spines

Certain plants have their leaves modified into sharp pointed structures called spines. These spines protect the plant from grazing animals and also reduce water loss due to transpiration.

C. Phyllodes or Phyllodia

In a few plants, the petiole becomes flattened, taking the shape and functions of the leaf and turns green in colour. This is known as **phyllode**.

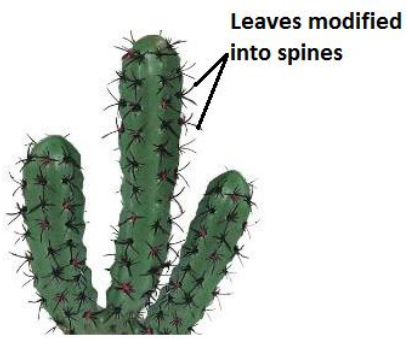
D. Leaf pitchers

In some insectivorous plants, the leaf-lamina is modified into a pitcher-like structure. These leaf pitchers are specialized for capturing and digesting insects.
In pitcher plants, the leaf apex gives rise to a coloured lid for attracting the insects.

E. Storage or Fleshy leaves

They are fleshy and thick which store food materials and water e.g., Onion.





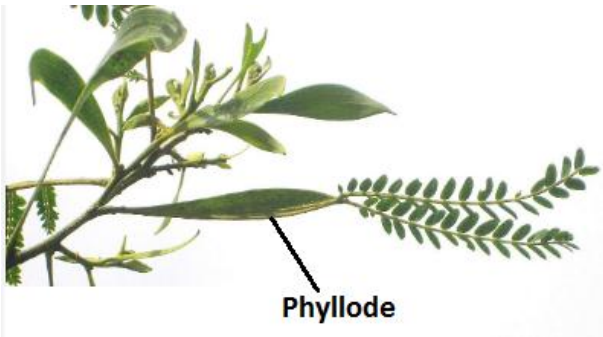




Figure 57. Leaf modifications.

3.4 Morphology of the flower

Flowers are the reproductive structures produced by plants which belong to the group known as Angiosperms, or 'Flowering plants'.

The flower is a highly condensed and specialized **reproductive shoot.**

It typically arises from a structure called **the bract.**

The flower is attached to the plant by a stalk known as **the pedicel**, which may be short or long.

The upper end of the pedicel is often swollen and spherical or conical in shape; this part is called **the thalamus** or **receptacle**, and it serves as the base on which the floral organs are arranged.

Modified leaves known as **floral organs** or **floral leaves** are attached to the thalamus**.**

In a typical flower there are four types of floral leaves arranged in four whorls. These are **sepal**, **petal**, **stamen** and **carpel**.

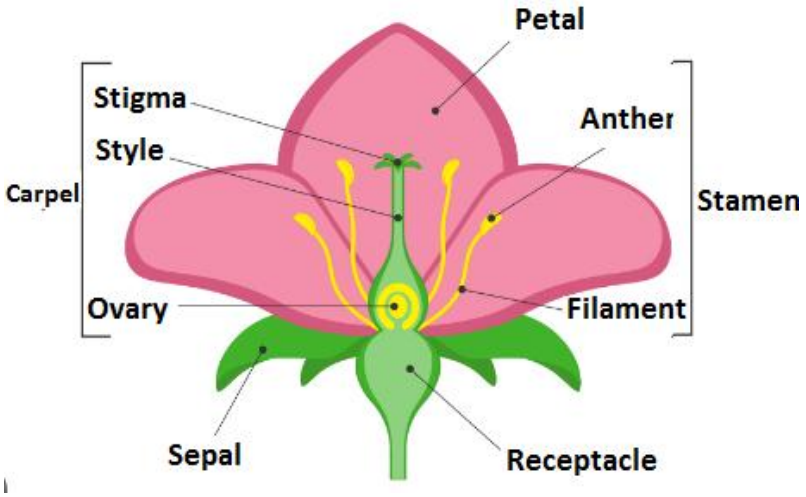


Figure 58. Parts of a flower.

3.4.1 Parts of flower

3.4.1.1 Calyx

It is the outermost whorl. Floral leaves of this whorl are called **sepals** which are usually green. Their function is that of protection of the unopened bud.

When all the sepals of a flower are **free** from one another, then the flower is called **polysepalous**, as seen in plants like mustard and radish. In contrast, when the sepals are **fused together**, the flower is known as **gamosepalous**.

3.4.1.2 Corolla

It is the second whorl of floral leaves which are called petals. They are usually, brightly colored. When all the petals are free, then it is called **polypetalous** while when petals are fused, then it is called **gamopetalous**.

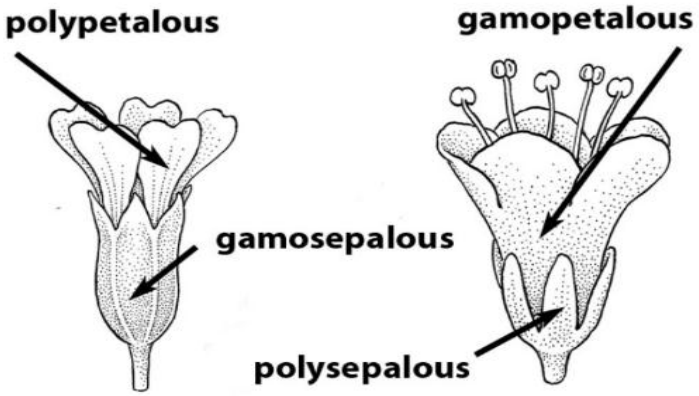


Figure 59. Petal and sepal fusion.

3.4.1.2.1 Aestivation

The mode of arrangement of sepals or petals in floral bud with respect to the other members of the same whorl is known as **aestivation**.

There are four main types of aestivation: They are as follows:

A. Valvate aestivation: Sepals or petals in a whorl just touch one another at the margin, without overlapping. It is observed in Calotropis.

B. Twisted aestivation: If one margin of the appendage overlaps that of the next appendage, such in China rose and cotton.

C. Imbricate aestivation: When the margins of sepals or petals overlap one another but not in any particular direction As in Cassia.

D. Vexillary (papilionaceous) aestivation: In pea and bean flowers, there are five petals; the largest (called standard) overlaps the two lateral petals (wings) which further overlap the two smallest anterior petals (called keel).

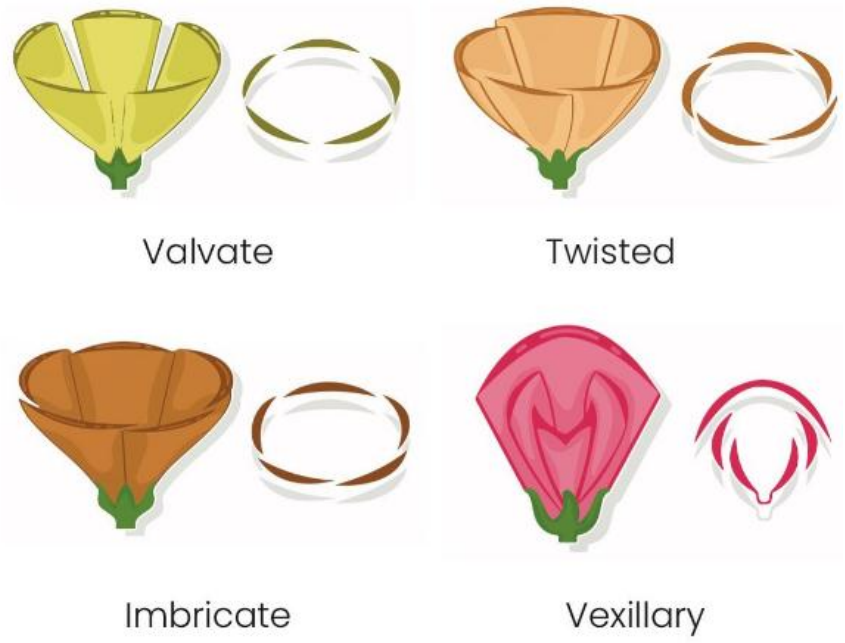


Figure 60. Types of aestivation in corolla.

The number of sepals and petals varies depending on whether the plant is a monocot or dicot. In monocots, petals usually number three or multiples of three; in dicots, the number of petals is four or five, or multiples of four and five. Together, the calyx and corolla are known as the perianth.

3.4.1.3 Androecium

The third whorl contains the male reproductive structures called **stamen**. It is made up of one or more stamens. Each stamen has following parts:

• **Filament:** Lower thread like part of stamen is called filament.
• **Anther:** This is the upper swollen part of stamen. Each anther is typically **bilobed**, and each lobe contains two chambers known as **pollen sacs**. The pollen grains are formed and stored within these pollen sacs.

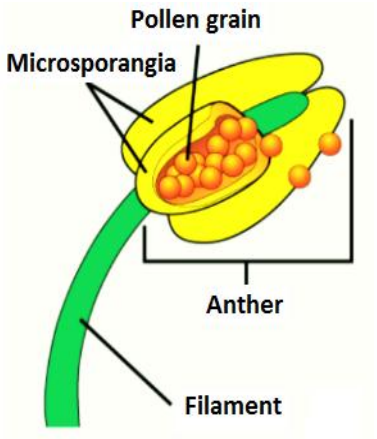


Figure 61: Structure of the stamen

3.4.1.3.1 Types of stamen cohesion

- When the stamens of an androecium are free from one another, it is called **polyandrous**.
- When only anthers are united in bundle but filaments remain free, it is called **Syngenesious**.
- When anthers as well as filaments of stamens are united through their whole length, it is called **Synandrous**.
- When stamens are united by their filament only, it is called **adelphous**. It is of following types:

A. Monadelphous: All the filaments are fused together into a single bundle, while the anthers remain free. This arrangement often forms a tube around the gynoecium, known as the staminal tube. Example: Cotton.

B. Diadelphous: The filaments are grouped into two bundles, but the anthers remain separate. Example: Pea, Bean.

C. Polyadelphous: The filaments are united into more than two bundles, with free anthers. Example: Citrus, Castor.

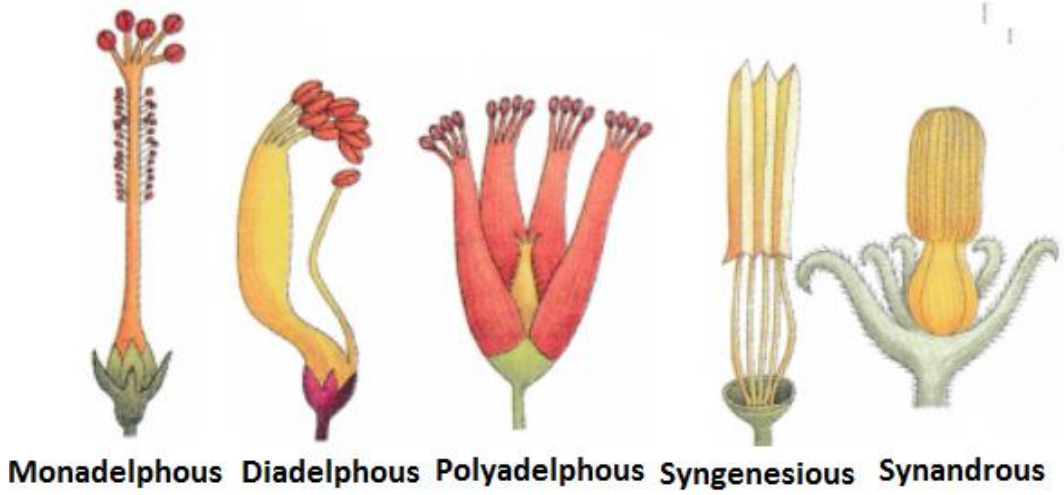


Figure 62. Types of stamen cohesion.

3.4.1.4 Gynoecium (=Pistil)

This is the last (fourth) central whorl in the flower and is the female reproductive organ of the flower. Each carpel is differentiated into three parts:

(a) Uppermost part, **the stigma.** It serves as a landing platform for pollen grains.

(b) **The style** is the elongated slender part beneath the stigma

(c) The lower swollen part containing ovules; **the ovary**, it contain one or more ovules.

The gynoecium may be **monocarpellary** (made up of one carpel only) or **multicarpellary** (made up of many carpels).

When the number of carpels in a gynoecium is two or more, they may be free or united. If they are free it is called **apocarpous gynoecium**, if they are fused it is called **syncarpous gynoecium.**

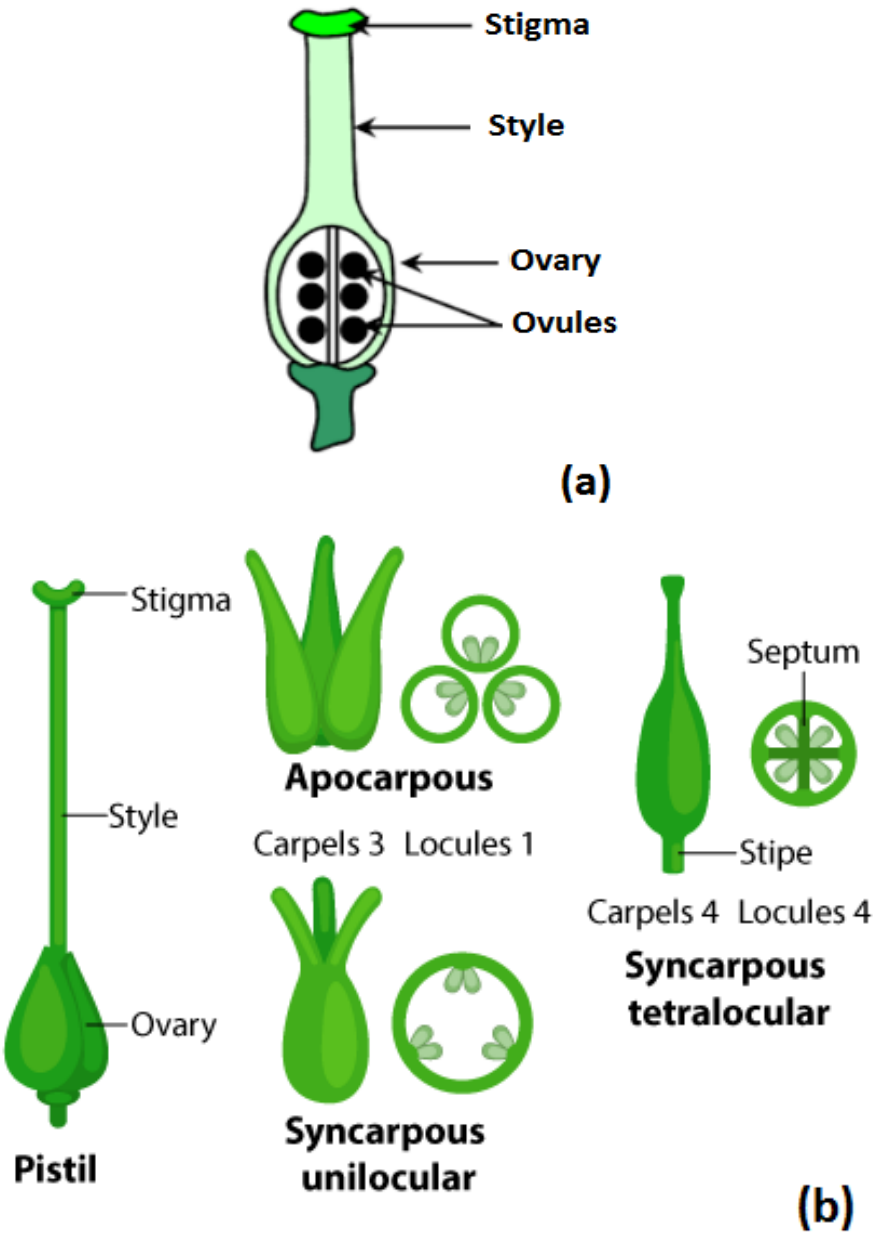


Figure 63. (a) structure of carpel**, (b)** types of gynoecium.

3.4.1.4.1 Placentation

The arrangement of ovules within the ovary is known as **placentation**. They are attached to the ovary wall via a structure called the **placenta**—a cushion-like region on the inner surface of the ovary.

There are several types of placentation, depending on the number of carpels, their fusion, and the position of the placenta:

A. Marginal placentation: Found in monocarpellary gynoecium, where the ovules are attached along the junction of the fused margins of a single carpel. Example: Pea, and other leguminous plants.

B. Parietal placentation: Occurs in a unilocular syncarpous ovary formed by the fusion of two or more carpels along their adjacent margins. The ovules are attached directly to the inner walls (periphery) of the ovary. The number of placentas corresponds to the number of carpels. Example: Cucurbita.

C. Axile placentation: Found in multicarpellary syncarpous gynoecium, where the fused carpels grow inward and meet at the center, forming a central axis. The ovules are attached to this axis, and the ovary becomes multilocular (many-chambered). The number of chambers equals the number of carpels. Example: Tomato, Lemon, Orange, China rose, Potato, Onion.

D. Free central placentation: Present in syncarpous gynoecium with a unilocular ovary, where the ovules are borne on a free-standing central column, not connected to the ovary walls. Example: Primrose and some other herbaceous plants.

E. Basal placentation: In this type, the ovary is unilocular, and a single ovule is attached at the base of the ovary. The placenta develops at the bottom, and there is no central or marginal axis. Examples: Marigold, Sunflower (family Asteraceae).

F. Superficial placentation: This type of placentation is found in multicarpellary syncarpous gynoecium. The ovules are borne on placentae which develop all around the inner surface of the ovary.

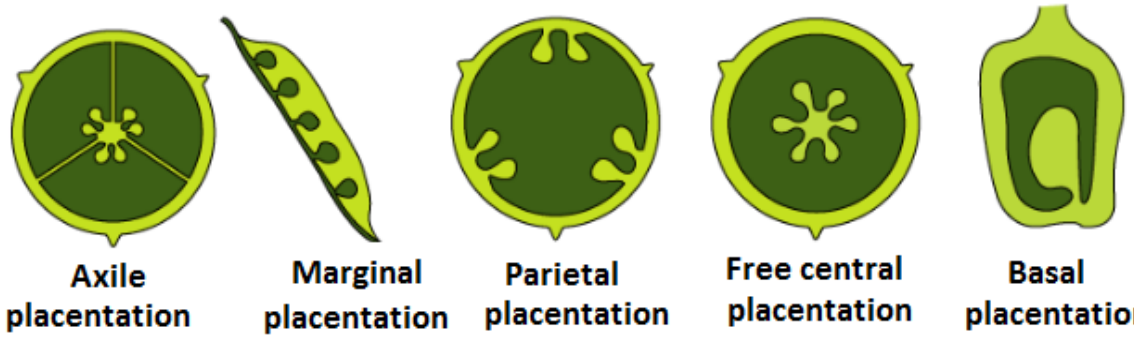


Figure 64. Types of placentation.

3.4.2 Insertion of floral parts

The flower is **hypogynous** when the sepals, petals, and stamens are inserted under the carpel. The ovary is said to be **superior**.

A flower is described as **perigynous** when the thalamus grows upward, forming a shallow, cup-shaped structure known as **the hypanthium.** The ovary is positioned at the center of this concave thalamus. In this condition, the ovary is said to be **half-superior**.

In an **epigynous** flower, the sepals, petals, and stamens arise from a point above the ovary. Such an ovary is described as **inferior**.

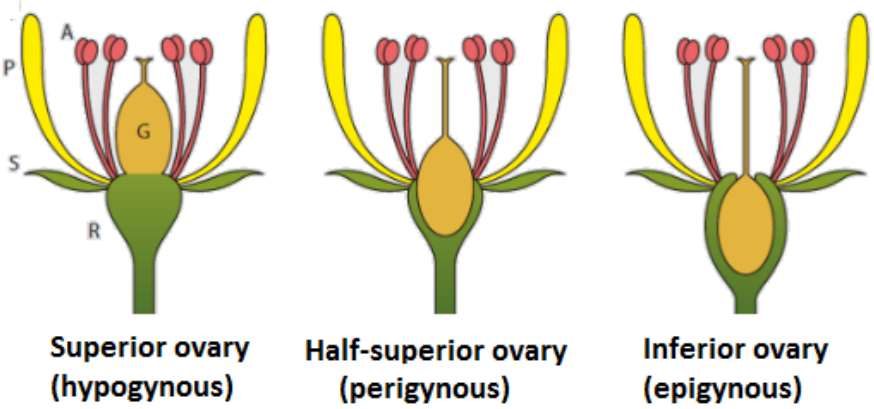


Figure 65. Insertion of floral parts.

3.4.3 Complete and incomplete flower

A flower is **complete** when it possesses all four floral whorls: the calyx, corolla, androecium, and gynoecium. If any of these components are absent, the flower is termed **incomplete.**

- ✓ Flowers that have both male (androecium) and female (gynoecium) reproductive organs are referred to as **perfect, bisexual, or hermaphroditic.**
- ✓ There are two types of incomplete flowers: **staminate flowers,** which contain only the androecium, and **carpellate flowers**, which contain only the gynoecium.
- ✓ A **unisexual flower** would be male or staminate (if only stamens are present) and female or pistillate (if only carpels are present).

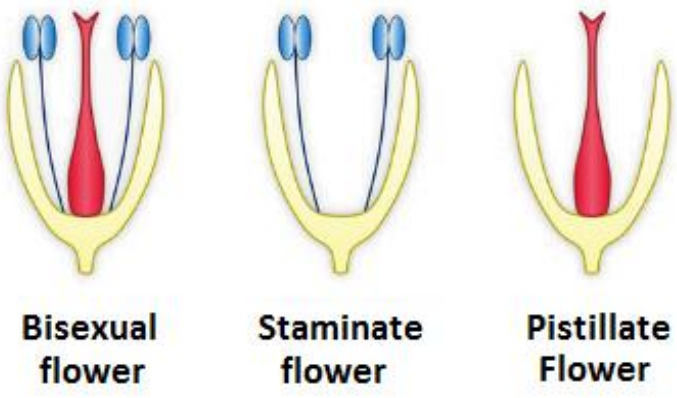


Figure 66. Bisexual and unisexual flowers.

3.4.4 Monoecious and dioecious plants

A. Monoecious plants: These plants bear both types of unisexual flowers—staminate (male) and pistillate (female)—on the same individual. Examples: Cucurbits, Maize.

B. Dioecious plants: In dioecious species, individual plants produce only one type of unisexual flower—either staminate or pistillate meaning male and female flowers occur on separate plants. Examples: Date palm, Mulberry.

C. Polygamous plants: These plants produce more than one type of flower on the same individual, such as bisexual (intersexual), male (staminate), and neuter flowers. Examples: Mango, Cashew nut.

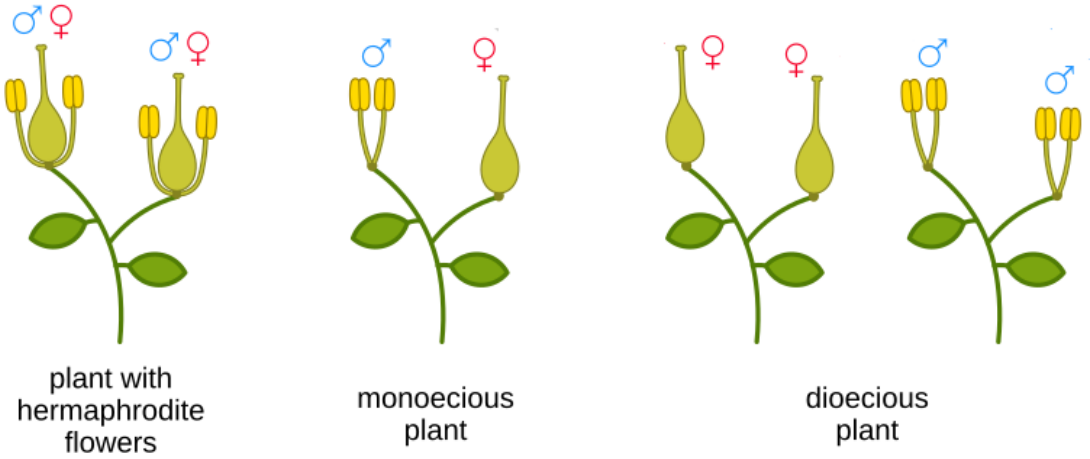


Figure 67. Monoecious, dioecious and hermaphroditic plants.

3.4.5 Regular and irregular flowers

A flower is said to be **regular** when all floral parts in each whorl (such as petals or sepals) are similar in size, shape, colour, and origin.

A flower is **irregular** if any of the floral organs differ in shape, size, colour, or origin within the same whorl.

3.4.6 Floral symmetry

The arrangement of the floral organs around the thalamus of the flower is known as **floral symmetry**. Based on this, flowers can be classified into three types:

A. Actinomorphic: Flowers that can be divided into two or more identical halves by multiple longitudinal planes passing through the center. Actinomorphic flower has **radial symmetry**. Example: Mustard.

B. Zygomorphic: Flowers that can be divided into two equal halves in only one plane. zygomorphic flower has **bilateral symmetry**. Example: Pea.

C. Asymmetric (Acyclic): Flowers that cannot be divided into two equal halves by any vertical plane. Example: Canna.

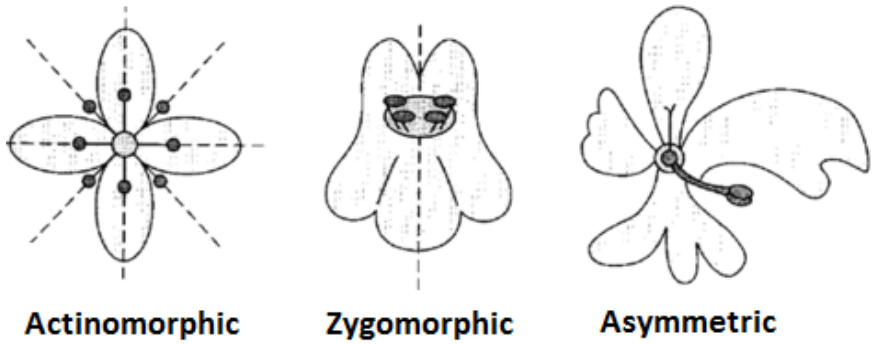


Figure 68. Types of floral symmetry.

3.4.6 The inflorescence

An inflorescence is a group or cluster of flowers arranged on the axis of the plant. It consists of the main axis called peduncle while the stalks of individual flowers are called pedicel.

Types of inflorescence

Depending upon the mode of branching of peduncle, two major types of inflorescences are defined: racemose and cymose.

3.4.6.1 Racemose inflorescence

The main axis continues to grow and the flowers are in acropetal succession i.e. youngest flowers at apex and oldest at the base. If the peduncle is reduced, the flowers are borne in the centripetal manner (i.e., older towards the periphery and younger towards centre).

Racemose inflorescence is of two types:

A. Simple racemose inflorescence: The flowers are borne directly on an unbranched peduncle. The main types are as follows:

•**Typical raceme:** Pedicellate (Stalked) flowers are attached along an unbranched and elongated peduncle in an acropetal order.

•**Umbel:** A cluster of pedicellate flowers of equal length arising from the same point at the tip of a short peduncle, arranged in a centripetal manner.

•**Capitulum or racemose head:** Sessile flowers, called florets, are arranged in a centripetal manner (younger towards the centre and older towards the periphery) on the expanded tip of the peduncle.

•**Spike:** The flowers, which are sessile or have very short pedicels, are attached along an elongated and unbranched peduncle.

•**Corymb:** Pedicellate flowers of unequal length are attached along an unbranched and elongated peduncle, forming a flattopped inflorescence.

B. Compound racemose inflorescence: The peduncle is branched in racemose manner and ultimate branches bear flowers in acropetal or centripetal succession.

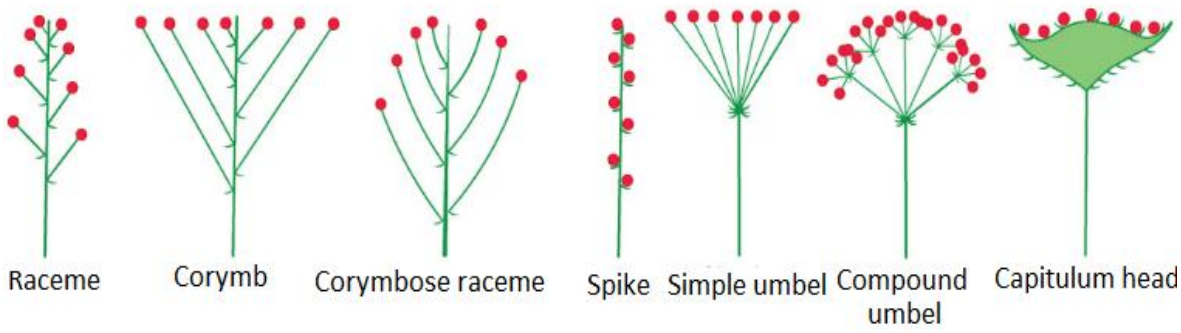


Figure 69. Types of racemose inflorescence.

3.4.6.2 Cymose inflorescence

In this type of inflorescence, the growth of the peduncle is **definite** and the main axis terminates in a flower. Growth of the axis continues by the formation of one or more lateral branches, which also terminate in flowers. The arrangement of flowers is either **basipetal** or **centrifugal**.

Depending on the number of lateral branches formed, a cymose inflorescence is classified as uniparous, biparous, or multiparous.

- **Uniparous cyme:** The main axis terminates in a flower below which a single lateral axis is produced, ending in a flower. This pattern is repeated a number of times.
- **Biparous cyme:** The peduncle terminates in flower and gives rise to two daughter axes that end in flowers. The process gets repeated.
- **Multiparous cyme:** The main axis or peduncle ends in a flower which produces three or more daughter axes, and each continues to branch in the same manner.

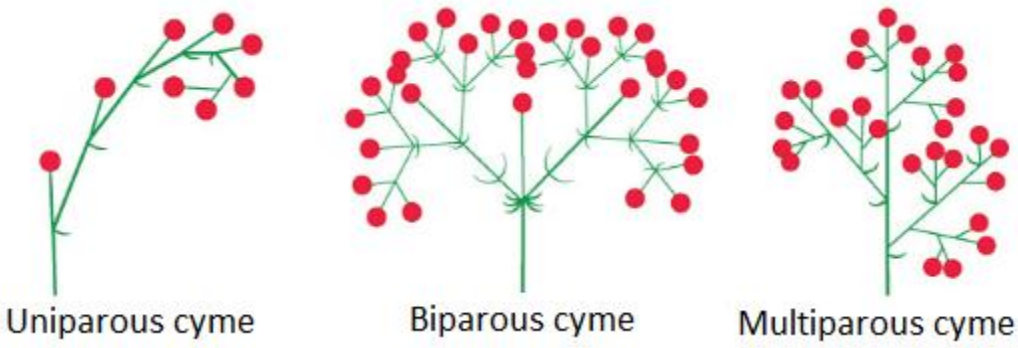


Figure 70. Types of cymose inflorescence.

3.4.7 Floral formula

A floral formula is symbolic (numeric) representation of different parts of a flower. It provides information on the kinds and number of floral parts.

Floral formula consists of five symbols indicating from left to right:

•**Symbol 1:** Floral symmetry

(*) Radial symmetry: Divisible into equal halves by two or more planes of symmetry.

(x) Bilateral symmetry: Divisible into equal halves by only one plane.

($) Asymmetrical flower: lacking a plane of symmetry.

•**Symbol 2:** Number of sepals **"K"**

•**Symbol 3:** Number of petals, with **"C"** representing "corolla"

•**Symbol 4:** Number of stamens, with **"A"** representing "androecium".

A∞ indicates numerous stamens and is used when stamens number more than twelve.

•**Symbol 5**: Number of carpels, with **"G"** representing "gynoecium".

- **Other symbols used in floral formulas.**

Br	Bracteate
P	Perianth
∞	Indefinite number of floral parts in a whorl.
⊕	Actinomorphic condition.
%	Zygomorphic condition.
$\mathbf{K_5}$	Calyx with five free sepals (polysepalous).
K(5)	Calyx with five sepals fused (gamosepalous).
⚥	Bisexual flower.
♂	Unisexual, staminate flower.
♀	Unisexual, pistillate flower.
$\mathbf{A_{5+5}}$	Androecium with 10 Stamens, two whorls, each whorl 5 stamens (free).
G–	Semi inferior ovary.
$\overline{\text{G}}$	Inferior ovary.
$\underline{\text{G}}$	Superior ovary.

3.4.8 Floral diagram

A floral diagram is a schematic cross-section of a young flower in which all the individual organs or elements of the flower are projected into one plane. It represents the floral whorls as viewed from above.

Different parts of the flower are represented by clear symbols. Fusions between different parts are shown by connecting lines and the orientation of the flower by placing reference points in relation to the axis of the inflorescence and the subtending bracts.

The branch that bears the flower is called **mother axis**.

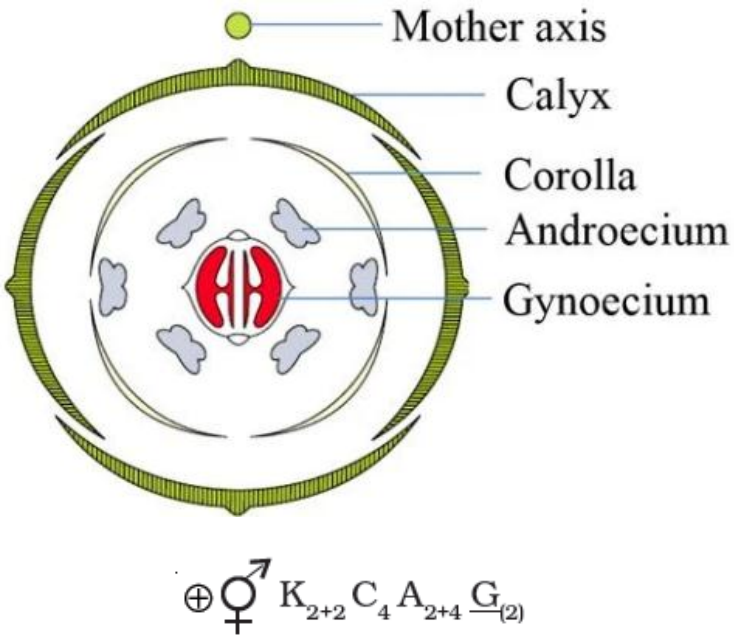


Figure 71. Floral diagram with floral formula.

CHAPTER 4: SEXUAL REPRODUCTION IN FLOWERING PLANTS



Learning Objectives

By the end of this chapter, students will be able to:

- Explain the processes and stages of male and female gametogenesis.
- Describe the different types and mechanisms of pollination.
- Define and explain double fertilization.
- Describe the stages of embryogenesis.
- Describe the formation, structure and different types of fruits and seeds.

Introduction

In angiosperms there are several modes of reproduction. Generally, there are asexual or vegetative and sexual types. In sexual reproduction there is fusion of male and female gametes.

4.1 Male gametogenesis

4. 1. 1 Development of male gametophyte (pollen grain)

The male gametophyte develops in the anther. It consists of two anther lobes connected by a tissue known as connective. Each anther lobe contains two pollen sacs or microsporangia.

Mature anther contains four pollen sacs (microsporangia) having many pollen grains.

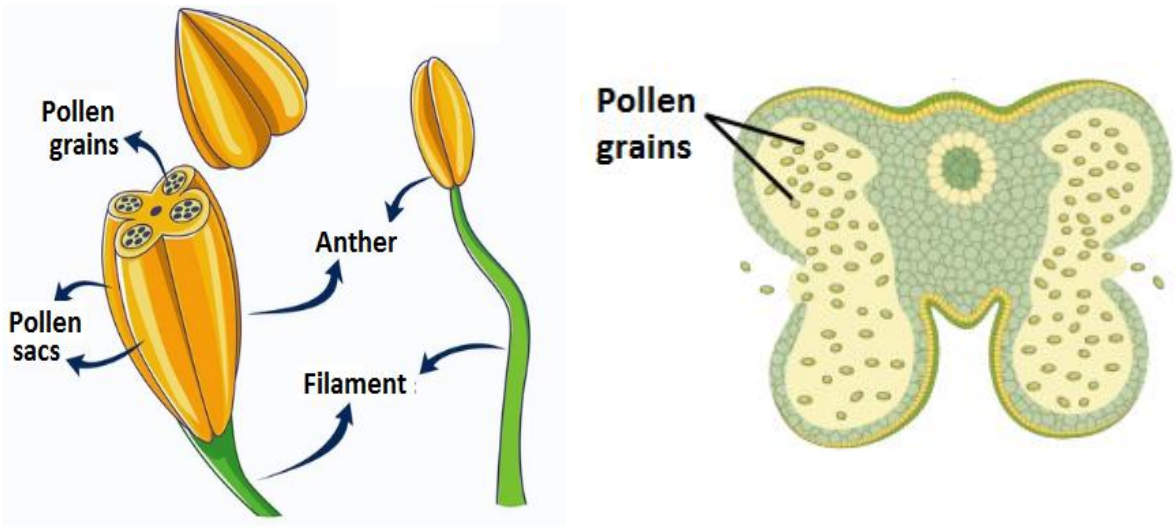


Figure 72. Structure of anther.

Within the microsporangium (pollen sac), the microspore mother cell which is diploid cell divides by meiosis to give rise to **four haploid microspores** or **pollen grains**.

Microspore mother cells → **Meiosis I** **→** **Meiosis II (pollen grain)**

Diploid **2 haploid cell** **4 Microspore**

The single nucleus of the pollen grain divides by mitosis to form two nuclei: tube nucleus and generative nucleus. The cell wall is developed between the two to form unequal cells, a smaller generative cell and larger tube or vegetative cell.

Upon germination, the tube cell forms the pollen tube through which the generative cell migrates to enter the ovary. During its transit inside the pollen tube, the generative cell divides to form two male gametes (sperm cells). Upon maturity, the microsporangia burst, releasing the pollen grains from the anther.

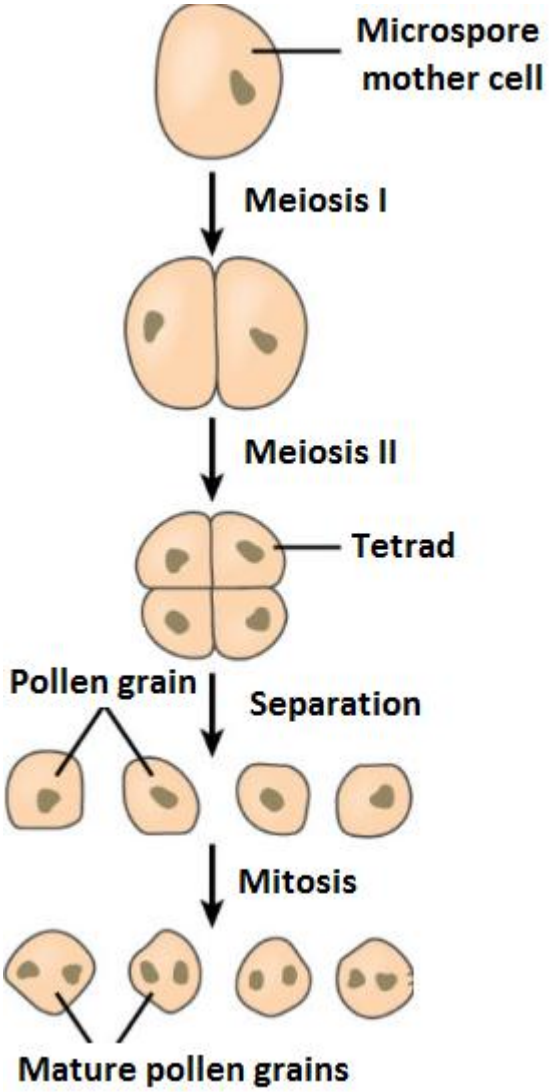


Figure 73. Development of pollen grain.

4.2.2 Structure of pollen grain

Each pollen grain has two coverings: **the exine** (thicker, outer layer) and **the intine**.

The exine contains **sporopollenin**, a complex waterproofing substance. Sporopollenin allows the pollen to survive under unfavorable conditions and to be carried by wind, water, or biological agents without undergoing damage.

Pollen grain exine has prominent apertures called **germ pores**. When the pollen grain is mature it contains two cells, **the vegetative cell** and **generative cell**.

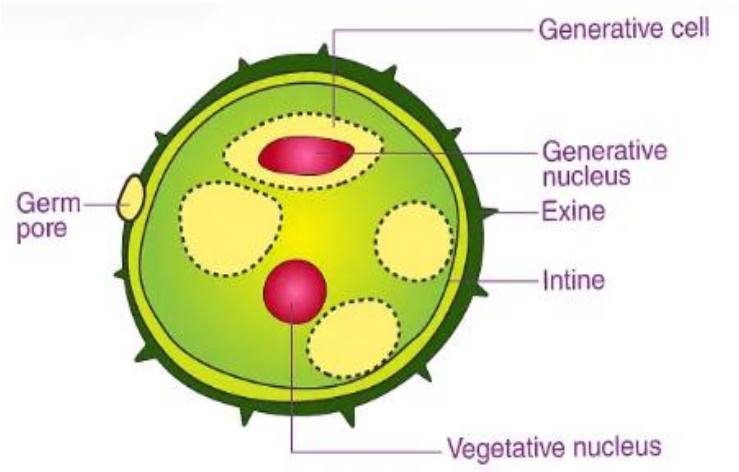


Figure 74. Pollen grain structure.

4.2 Female gametogenesis

4.2.1 Ovule structure

The ovule is a small structure attached to the placenta by means of a stalk called **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**. Opposite the micropylar end, is the **chalaza**, representing the basal part of the ovule. In the nucellus, female gametophyte is present, also known as **embryo sac**.

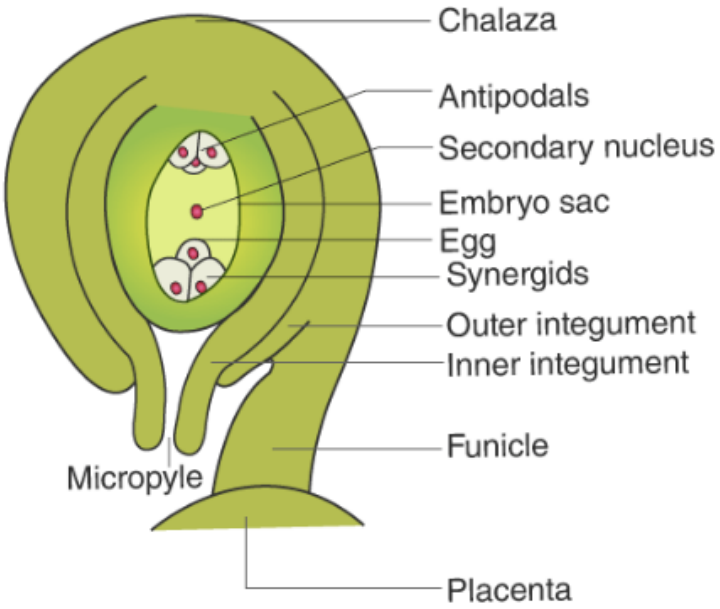


Figure 75. Structure of ovule.

4.2.1.1 Types of ovules

Mature ovules can also be classified based on their orientation and curvature as follows:

A. Atropous or Orthotropous ovule: The micropyle, nucellus, and funicle are aligned in a straight line.

B. Anatropous ovule: The ovule is entirely inverted by 180 degrees. As a consequence, the micropyle points downward, and both the micropyle and chalaza are positioned close to each other. It is the most common type of ovule type in angiosperms.

C. Amphitropous ovule: Due to uneven (unilateral) growth, the micropyle bends closer to the nucellus, resulting in a curved structure.

D. Hemitropous or Hemianatropous ovule: The funicle is positioned at a right angle to the nucellus and integuments.

E. Campylotropous: The embryo sac becomes curved into a horseshoe shape, and the ovule appears bent.

F. Circinotropous ovule: The funicle elongates and coils around the ovule, eventually encircling it completely.

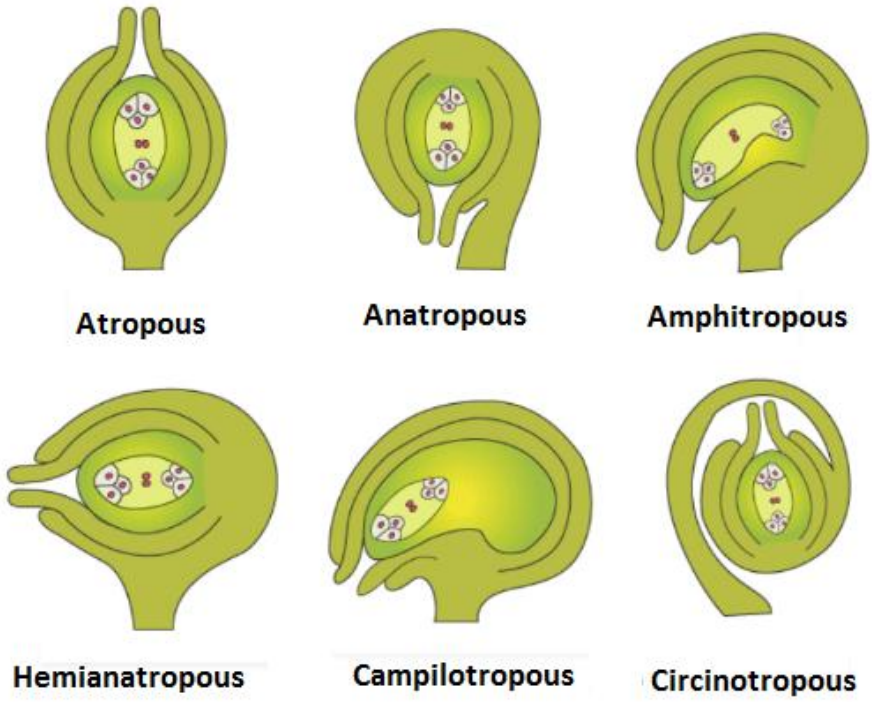


Figure 76. Types of ovules.

4.2.3 Development of the female gametophyte (Embryo sac)

Female gametophyte development occurs within the ovule. **Megaspore mother cell (MMC)**, also known as **megasporocyte** is diploid. The MMC undergoes **meiotic division**. Meiosis results in the production of four megaspores. One of the megaspores is **functional**

while the other three degenerate. The functional megaspore now forms **the female gametophyte (embryo sac)**.

The nucleus of the functional megaspore divides **mitotically** to form two nuclei which move to the opposite poles. Two more sequential mitotic nuclear divisions result in the formation of the **4-nucleate** and later the **8-nucleate** stages of the embryo sac.

Three cells are grouped together at the micropylar end and consist of **two synergids and one egg cell.** Three cells are at the chalazal end and are called the **antipodals**. The large central cell, has two **polar nuclei**.

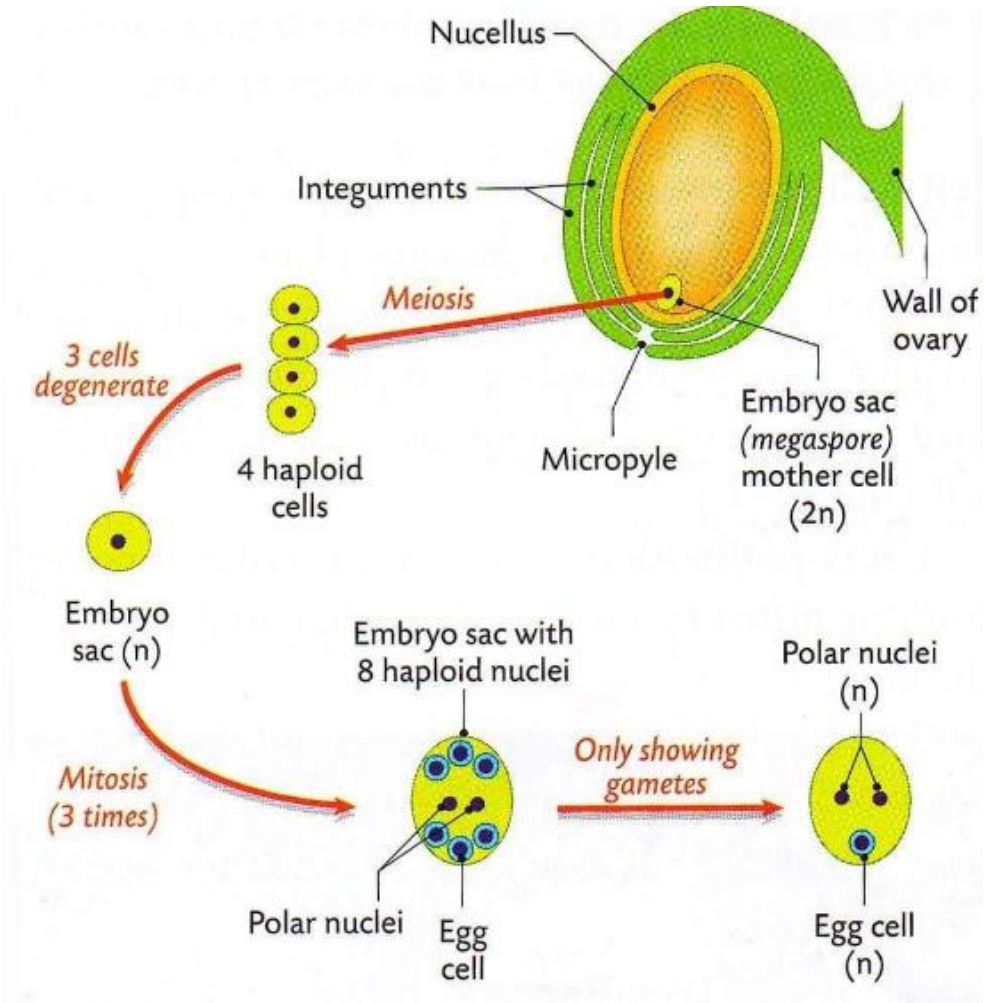


Figure 77. Development of embryo sac.

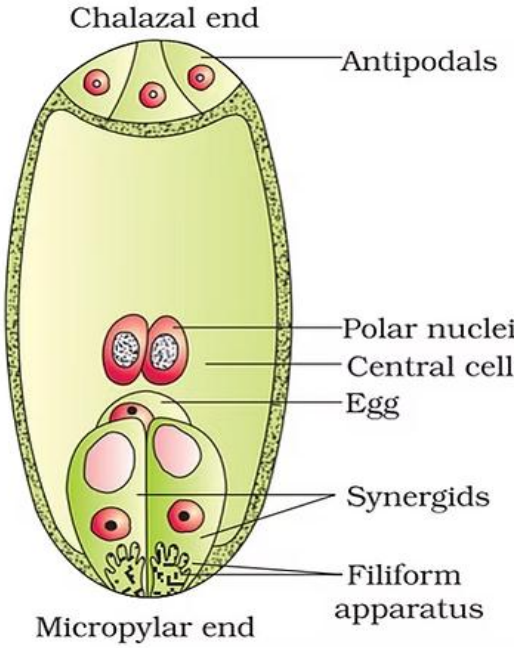


Figure 78. Structure of mature embryo sac.

4.3 Pollination

In flowering plants, male and female gametes are formed within the pollen grain and the embryo sac, respectively. Since both gametes are non-motile, they must be brought together for fertilisation to take place.

Pollination refers to the transfer of pollen grains, released from the anther, to the stigma of a pistil.

4.3.1 Types of Pollination

Based on the origin of the pollen, pollination can be classified into different types.

A. Self-Pollination: Transfer of pollen grains from the anther to the stigma of the same flower or flower on the same plant. Self-pollination is further divided into two types

- **Autogamy:** This form of pollination occurs within the same flower, where pollen is transferred from the anther to the stigma of the same flower.
- **Geitonogamy:** The transfer of pollen grains from the anther to the stigma of a different flower on the same plant. Although this involves two different flowers, it is genetically similar to autogamy, as the pollen originates from the same individual plant.

B. Cross-pollination or Xenogamy: It is the transfer of pollen grains from the anther to the stigma of another flower on another plant.

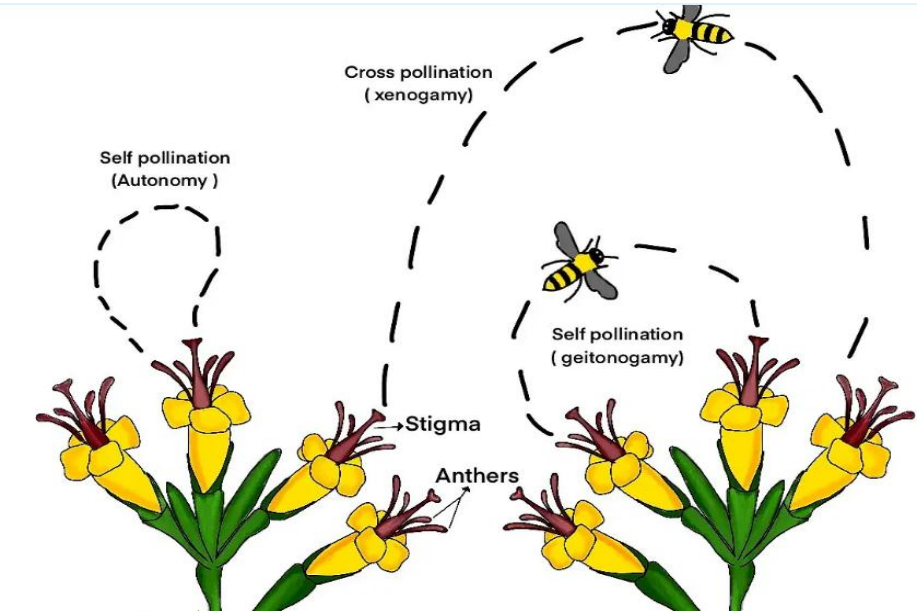


Figure 79. Types of pollination.

4.3.2 Agents of pollination

To achieve pollination, plants use two main types of agents: **abiotic** and **biotic**.

A. Abiotic agents: there are two abiotic agents that help in pollination: wind and water.

Anemophily: It is the pollination of plants by wind. This type of pollination is more common in grasses. Anemophilous flowers are generally small and their pollen grains are small, light, smooth and dry so that can be easily carried by the wind.

Hydrophily: It refers to the pollination of flowers with the help of water. It is common in aquatic plants. The pollens of these plants are elongated, needle-like and are protected from wetting by a mucilaginous covering. The stigma of the flowers is very long to facilitate pollination.

B. Biotic agents: the majority of flowering plants use a range of animals for pollination. The most common pollinating agents include bees, butterflies, flies, beetles, wasps, ants, moths, as well as birds and even bats.

- **Entomophily** refers to pollination of the flowers by insects.
- **Ornithophily** is the pollination that occurs with the help of birds.
- **Chiropterophily** is the pollination of flowers by bats.

Generally, flowers of animal pollinated plants are specifically adapted for a particular species of animal. These flowers are brightly coloured and produce nectar or sweet fragrance to attract these animals.

4.4 Pollen-pistil interaction

The pistil can recognize whether the pollen is compatible or incompatible. When the pollen is compatible, the pistil accepts it and facilitates post-pollination processes that lead to fertilization.

If the pollen is incompatible, the pistil rejects it by inhibiting pollen germination on the stigma or preventing the growth of the pollen tube within the style. This recognition and response are mediated by chemical interactions between the components of the pollen and those of the pistil.

4.5 Germination of pollen grain

After pollen deposition on the stigma, the pollen grain germinates to produce a pollen tube through one of the germ pores. The contents of the pollen grain move into the pollen tube. The generative cell divides by mitosis and forms the two male gametes. Pollen tube grows through the tissues of the stigma and style and reaches the ovary.

Upon reaching the ovary, the pollen tube enters the ovule through the micropyle and penetrates one of the synergids through the filiform apparatus which is present at the micropylar part of the synergids. Filiform apparatus guides the entry of pollen tube.

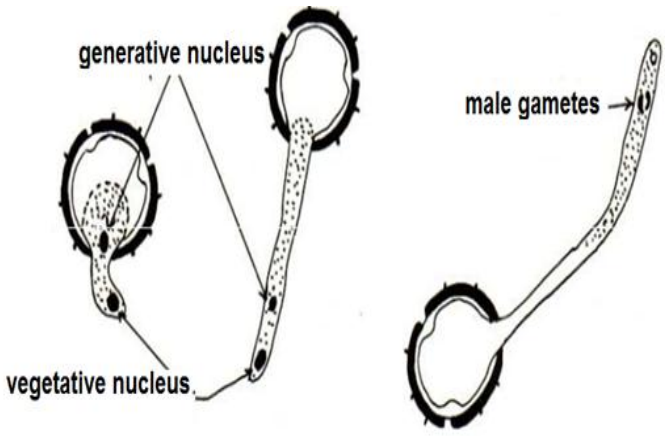


Figure 80. Pollen germination.

4.6 Double fertilisation

Once the pollen tube enters into the embryo sac, fertilisation occurs. The pollen tube releases the two male gametes. Two types of fusions take place:

- **Syngamy:** One of the male gametes fuses with the egg cell nucleus. This results in the formation of a diploid cell, **the zygote**.
- **Triple fusion:** The second male gamete fuses with the two haploid polar nuclei to produce **triploid primary endosperm nucleus (PEN).**

Since two types of fusions, syngamy and triple fusion occur in an embryo sac the phenomenon is termed double fertilisation. This process is unique to **angiosperms**.

The **primary endosperm cell (PEC)** develops into **the endosperm** while the zygote develops into **an embryo**.

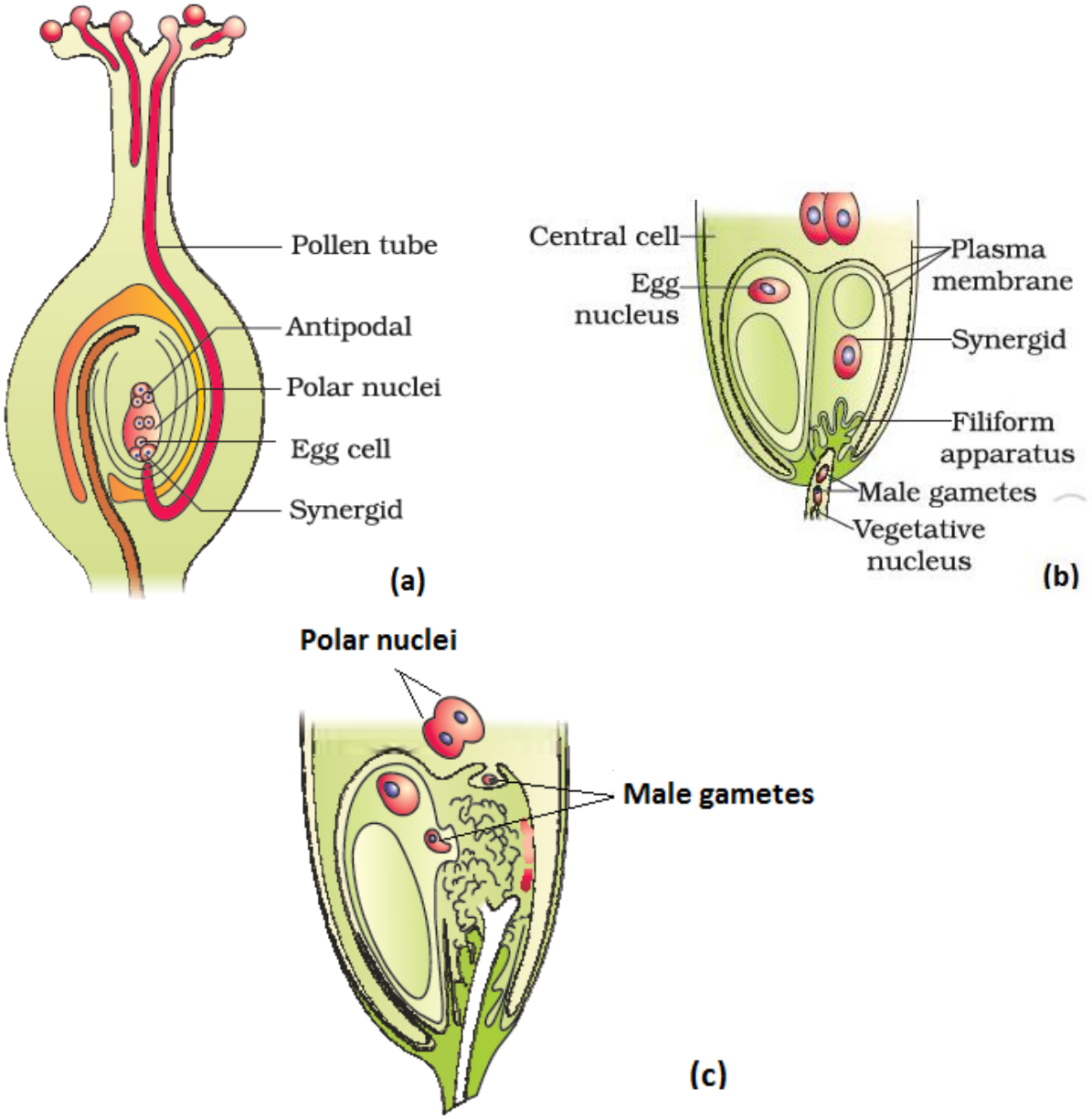


Figure 81. (a) Longitudinal section of pistil showing path of pollen tube growth.
(b) Entry of pollen tube into a synergid.

(c) Discharge of male gametes and the movements of the sperms, one into the egg cell and the other into the central cell.

4.7 Post -Fertilization: Structure and events

After double fertilisation, a series of processes occur, including:

–The development of the endosperm,

–The development of the embryo,

–The transformation of ovules into seeds, and

–The transformation of the ovary into a fruit.

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

4.7.1 Endosperm

Following fertilization, the first tissue to develop in the embryo sac is the endosperm. The primary endosperm cell undergoes **repeated divisions** to form a **triploid endosperm tissue.**

The cells of this tissue are filled with **reserve food materials**, which serve as a source of **nutrition for the developing embryo**. For this reason, endosperm development occurs before embryo development.

Based on its mode of development, endosperm can be classified into the following types:

a. Nuclear Endosperm: The primary endosperm nucleus undergoes repeated nuclear divisions without the formation of cell walls, resulting in a multinucleate structure with free nuclei suspended in cytoplasmic sap.

b. Cellular Endosperm: In this type, each nuclear division is followed by cell wall formation, leading to a multicellular structure from the beginning.

c. Helobial Endosperm: It is found mostly in the **monocotyledons**. Half the endosperm is cellular and half is free nuclear.

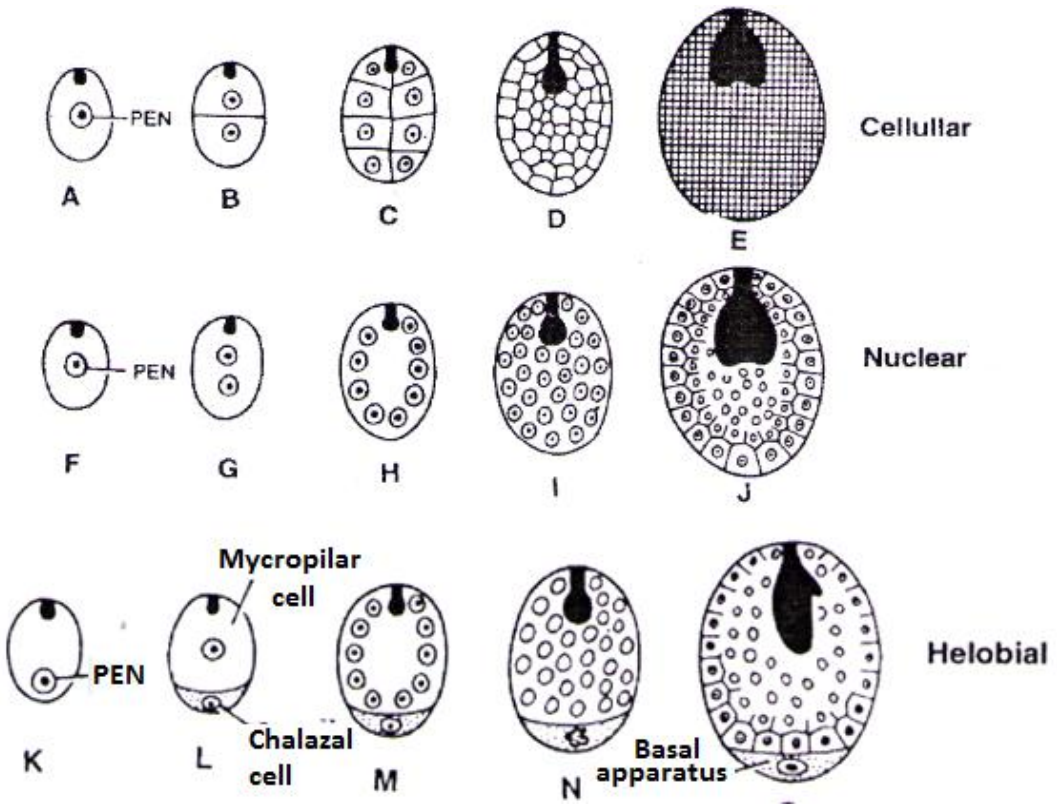


Figure 82. Types of endosperm.

4.7.2 Embryogenesis

The zygote develops to form the **embryo** at the micropylar end of the embryo sac. The process of development of mature embryo from diploid zygote is called embryogenesis. Most zygotes divide only after certain amount of endosperm is formed.

4.7.2.1 Dicotyledonous Embryo

The zygote divides transversely to produce two cells:

– **the basal cell**, located toward the micropyle, and

– **the apical or embryonal cell**, positioned toward the chalazal end.

- The basal cell undergoes transverse division, while the apical (terminal) cell divides longitudinally, resulting in a T-shaped, four-celled proembryo.
- The two basal cells continue to divide transversely to form a long, filament-like structure known as the **suspensor**, which pushes the developing embryo deeper into the endosperm to facilitate nutrition.

- The uppermost cell of the suspensor is called the **haustorial cell**, while the lowermost cell is called the **hypophysis**.
- The four cells derived from the quadrant (formed by the apical cell) divide again to form an eight-celled embryo.
- The four cells closer to the hypophysis are known as **hypobasal cells** and will give rise to **the radicle** and **hypocotyl.**
- The four cells located toward the chalazal end are called **epibasal cells** and will develop into the **two cotyledons** and the **plumule**.
- The eight cells continue to divide and develop into a **globular embryo**.
- The globular embryo then transforms into **a heart-shaped embryo**, marking the initiation of cotyledon formation. This stage is followed by the **torpedo-shaped embryo stage**.
- In dicots, the **mature embryo** consists of an **embryonal axis** and **two cotyledons**.
- The **epicotyl** is the part of the embryonal axis above the cotyledons, which ends in the **plumule**.
- The **hypocotyl** is the portion below the cotyledons, which ends in **the radicle**.
- **The plumule is the future shoot while radicle is the future root.**

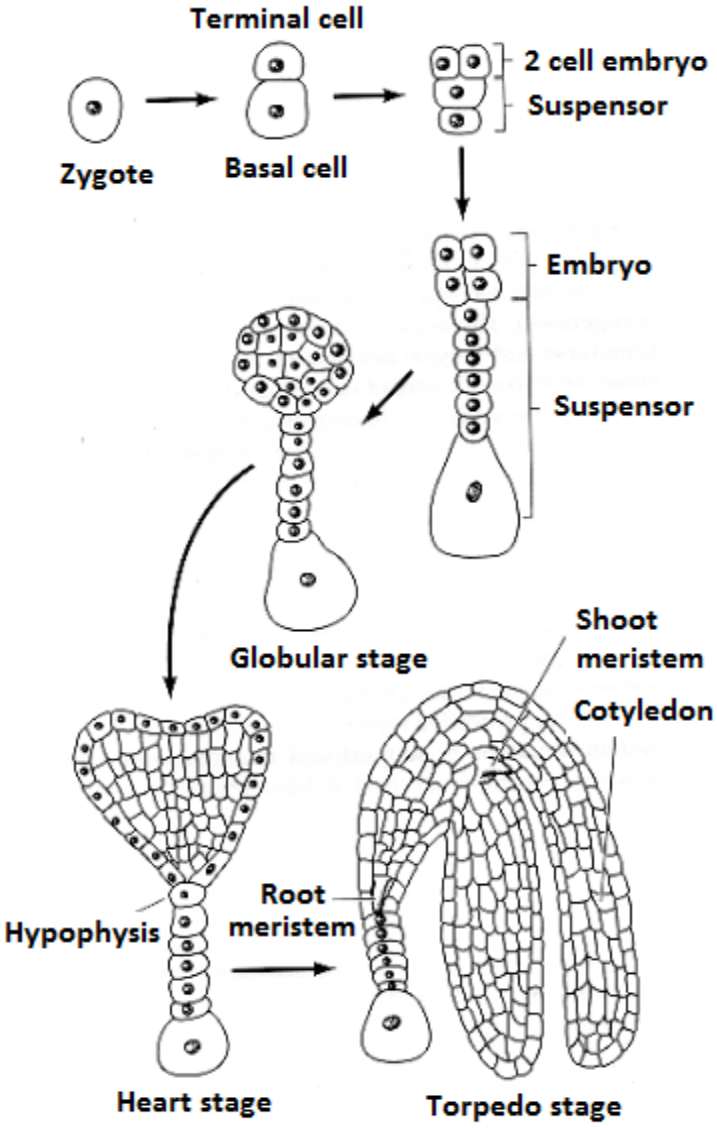


Figure 83. Stages in embryo development in a dicot.

4.7.2.2 Monocotyledonous embryo

The zygote undergoes a transverse division, forming two cells. The upper cell, located toward the chalazal end, is called the **embryonal cell**, while the lower cell, situated toward the micropylar end, is known as **the basal cell**.

The basal cell increases in size and develops into a **vesicular suspensor** that helps in pushing the embryo into the endosperm.

The embryonal cell then divides to produce two cells: a **terminal cell**, which will eventually give rise to **the cotyledons,** and a **lower embryonal cell**.

A transverse division in this lower embryonal cell forms two new cells. One of them gives rise to **the plumule initial**, and the other to **the radicle initial**.

The plumule initial continues to divide and develops into **the plumule (future shoot)**, while the radicle initial divides to form **the radicle (future root)**.

The **embryo of monocotyledons** possesses **only one cotyledon**. In members of the **Gramineae (grass) family**, this cotyledon is called the **scutellum**, and it is located on the lateral side of the embryo.

The embryonal axis includes **the radicle and the root cap**, both of which are enclosed within a protective sheath called the **coleorhiza**.

The **epicotyl** bears **the plumule**, which is protected by another sheath known as the **coleoptile**.

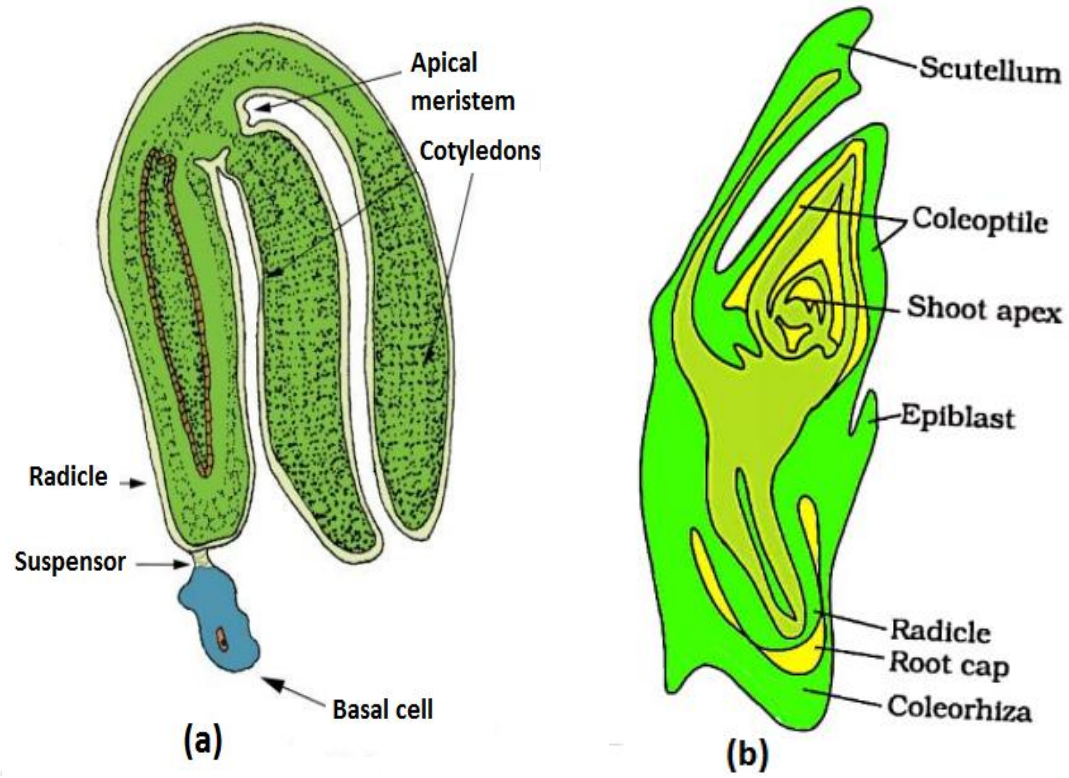


Figure 84. (a) A typical dicot embryo (b) L.S. of an embryo of grass (monocot embryo).

4.8 Seed

4.8.1 Types of seeds

Based on the location of food storage tissue, mature seeds can be classified into the following types:

A. Non-Endospermic Seeds (or **Non-albuminous seeds**)**:** These seeds lack residual endosperm because it is completely consumed during embryo development, as seen in pea and groundnut.

B. Endospermic Seeds (or **Albuminous seeds**)**:** These retain a portion of the endosperm, which is not entirely used up during embryo development. Examples include wheat, maize, barley, and castor.

C. Perispermic Seeds: In some seeds, such as black pepper and beet, remnants of the nucellus persist. This remaining tissue is known as the **perisperm** and serves as a food storage tissue.

4.8.2 Seed structure

Seeds develop within fruits and typically consist of **one or two seed coats**, **cotyledon(s)**, and an **embryo axis**.

A. The seed coat: As ovules mature, their integuments harden to form a tough and **protective seed coat**. It is the outermost layer of the seed that provides protection and plays a key role in regulating dormancy and germination processes.

In most seeds, the seed coat consists of a thick outer layer called **the testa**, and a thin, membranous inner layer known as **the tegmen. The micropyle** is a small pore in the seed coat that facilitates the entry of water and oxygen and water during germination.

During seed maturation, the water content decreases, making the seeds relatively dry, with only 10–15% moisture by mass. As a result, the metabolic activity of the embryo slows down, and the embryo may enter a period of dormancy. However, if favourable environmental conditions—such as sufficient moisture, oxygen, and temperature—are present, the seed may germinate.

B. The cotyledons of the embryo are usually simple and thickened structures, often swollen due to the accumulation of stored food reserves, as seen in legumes. As we have seen, dicots, such as beans and tomatoes, have two cotyledons, whereas monocots, like grasses, possess only one.

C. Embryonal axis: It includes **the plumule** and **the radicle**, which later develop into the shoot and root, respectively. The region between the cotyledons and the radicle is known as the **hypocotyl**, while the part between the cotyledons and the plumule is called the **epicotyl**.

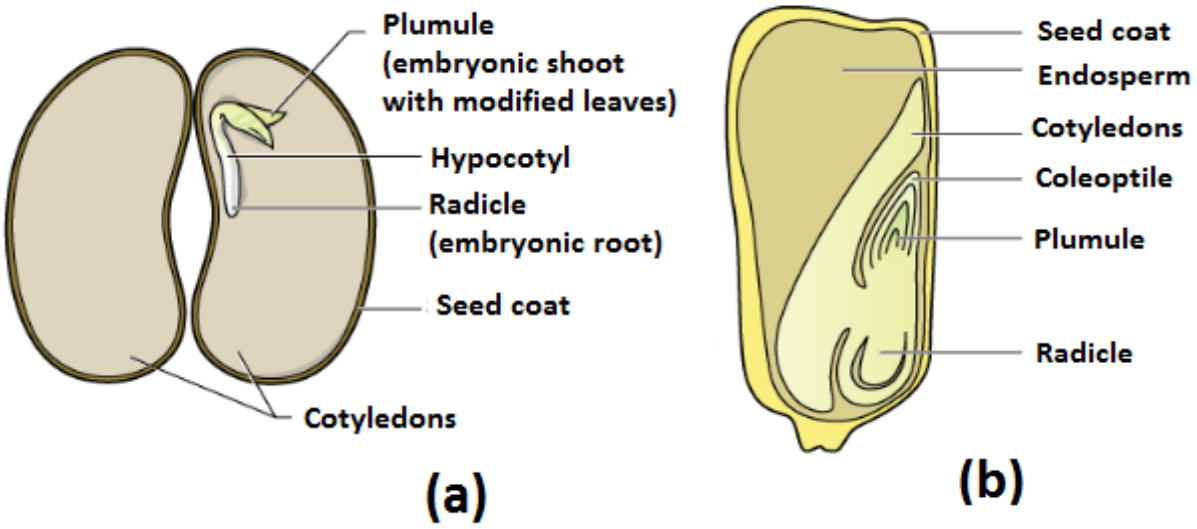


Figure 85. (a) Structure of bean seed (dicot)
(b) Structure of corn seed (monocot).

4.9 Fruit

After fertilisation, as the ovules mature into seeds, the ovary simultaneously develops into a fruit. During this process, the **ovary wall** transforms into the fruit wall, known as **the pericarp**. **Pericarp** is divided into layers: **endocarp, mesocarp** and **exocarp.**

There are two main types of fruits that can be formed:

A. True fruit: This type of fruit develops only from the ovary, with no contribution of other floral parts in its formation.

Examples: Mango, Tomato.

B. False fruit (also called accessory fruit): In this case, parts of the flower other than the ovary also contribute to fruit formation. Examples: Strawberry, Apple, Cashew.

- Although in most species fruits develop after fertilisation, there are some species in which fruits form without fertilisation. These are known as **parthenocarpic fruits**. These fruits do not produce seeds. Example: Banana, Citrus.

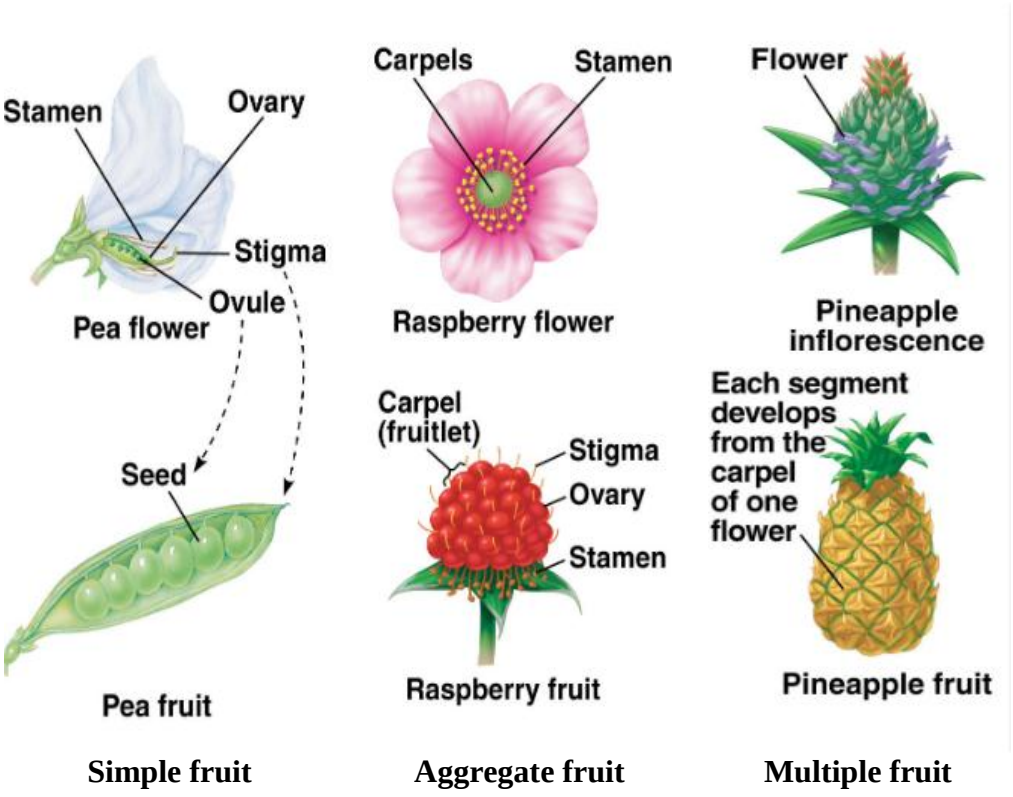


Figure 86. Types of fruits.

4.9.1 Types of fruits

The three main types of fruits are: **Simple fruits**, **Aggregate fruits** and **Multiple fruits**.

4.9.1.1 Simple fruits

Simple fruits are formed from the ovary of a single pistil within a single flower. Example: Pea (Pisum sativum).

A. Dry simple fruits: In this category, the pericarp (fruit wall) is dry and may be thin, leathery, or woody. It is not clearly divided into three layers (epicarp, mesocarp, and endocarp).

a) Dry and dehiscent fruits: These fruits split open at maturity to release their seeds.

Follicle: Develops from a monocarpellary, superior ovary and opens along one suture only. Example: Delphinium.

Legume: Arises from a monocarpellary, superior ovary with marginal placentation; it splits along both the dorsal and ventral sutures. Examples: Pisum, Lathyrus.

Silique: Formed from a bicarpellary, syncarpous ovary with parietal placentation and a false septum. It is long, narrow, and contains multiple seeds. It dehisces from the base upward along both sutures. Example: Members of the Cruciferae family, such as Brassica.

Capsule: Originates from a bi-, tri-, or multicarpellary ovary, which may be superior or inferior. It dehisces in various ways—longitudinally, transversely, or through pores.

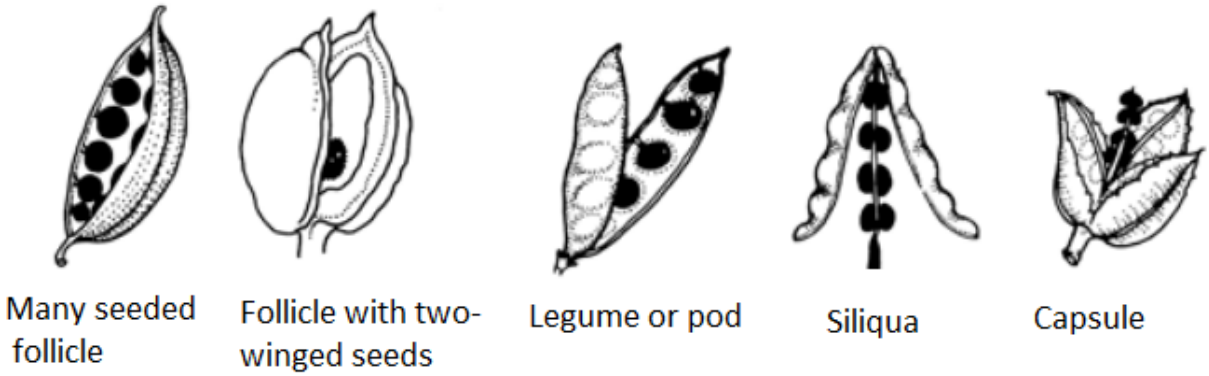


Figure 87. Types of dry and dehiscent fruits.

b) Dry and indehiscent fruits: These fruits do not open at maturity; the seeds remain enclosed within the fruit.

Achene: Derived from a monocarpellary, superior ovary. The seed coat is free from the hard pericarp. Examples: Clematis, Boerhaavia, Mirabilis.

Caryopsis: Also develops from a monocarpellary ovary. In this case, the pericarp is fused inseparably with the seed coat (testa). Examples: Triticum (wheat), Zea (corn).

Cypsella: A dry, one-chambered, one-seeded fruit formed from a bicarpellary or polycarpellary, syncarpous, inferior ovary with basal placentation. The pericarp and seed coat are separate. Examples: Launaea, Helianthus.

Nut: A hard, one-chambered, one-seeded fruit with a woody wall, derived from a bicarpellary to polycarpellary, superior ovary. Examples: Trapa, Anacardium.

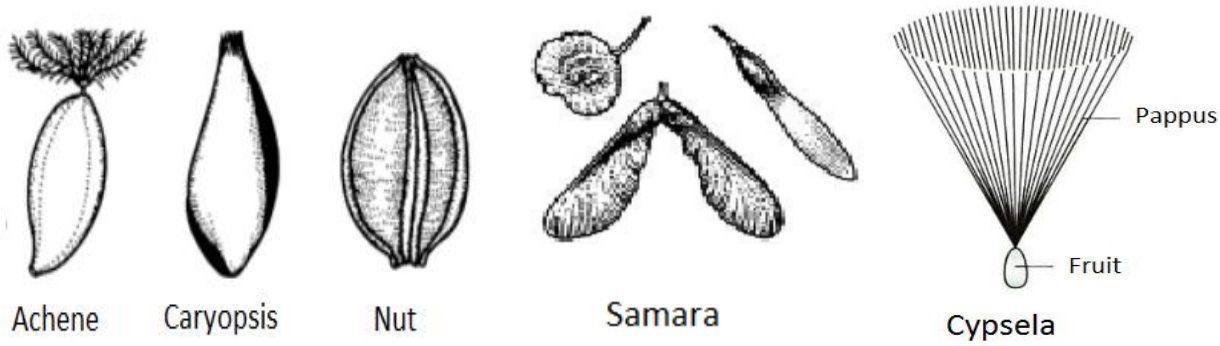


Figure 88. Types of dry and indehiscent fruits.

c) Dry and schizocarpic fruits

These fruits break into one-seeded units called mericarps at maturity, but the mericarps themselves do not split open.

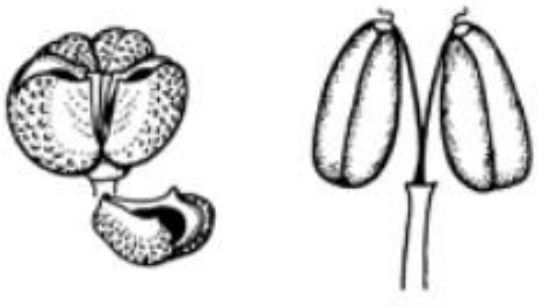


Figure 89. Schizocarpic fruits.

B. Fleshy simple fruits

These fruits also develop from a single pistil in a flower, but the pericarp becomes thick and fleshy.

Drupe: A fleshy fruit with a single seed enclosed in a hard, stony endocarp (pit).

Berry: Typically develops from a compound ovary and contains multiple seeds. A true berry has a thin skin and a soft, fleshy pericarp.

Pepos: Characterized by a thick rind; common in pumpkins and squashes.

Hesperidium: Has a leathery rind with oil glands; found in citrus fruits.

Pome: Most of the edible portion is derived from the enlarged floral tube or receptacle that surrounds the ovary. Example: Apple.

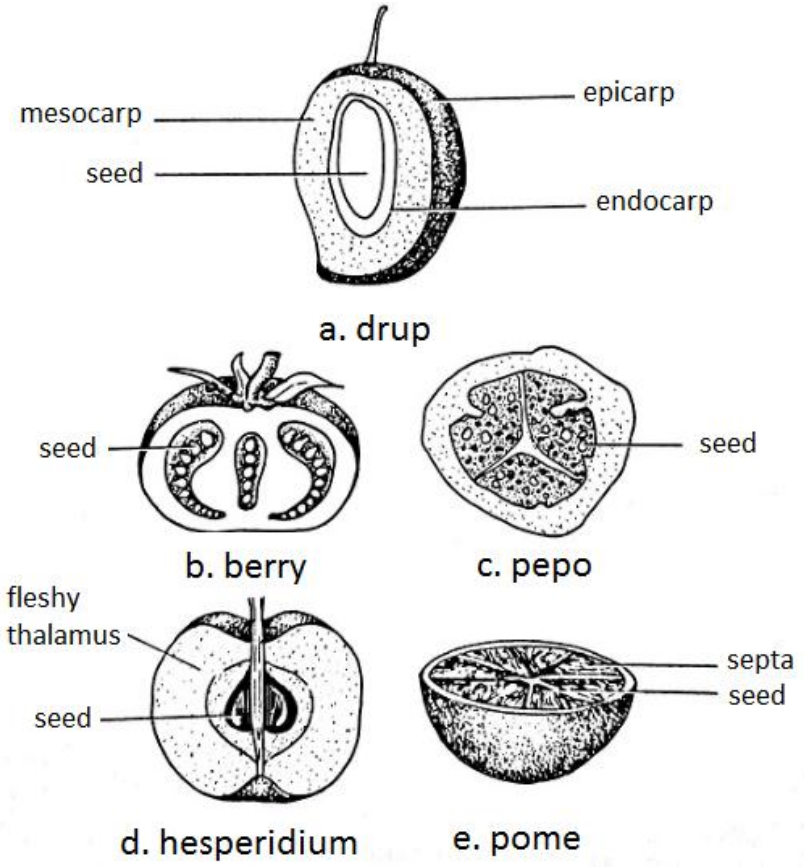


Figure 90. Types of fleshy fruits.

4.9.1.2 Aggregate fruits

These fruits originate from a single flower with multiple, free carpels (pistils). Each carpel forms a small fruit, and all are clustered together on a common receptacle. Example: Strawberry.

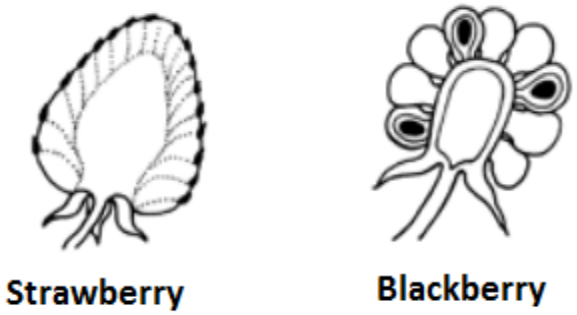


Figure 91. Aggregate fruits.

4.9.1.3 Multiple fruits

These develop from an entire inflorescence consisting of many individual flowers. As each flower produces a fruit, they merge into a single mass. Examples: Pineapple, Fig.

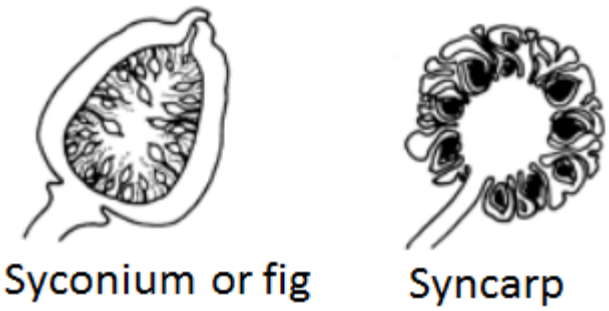
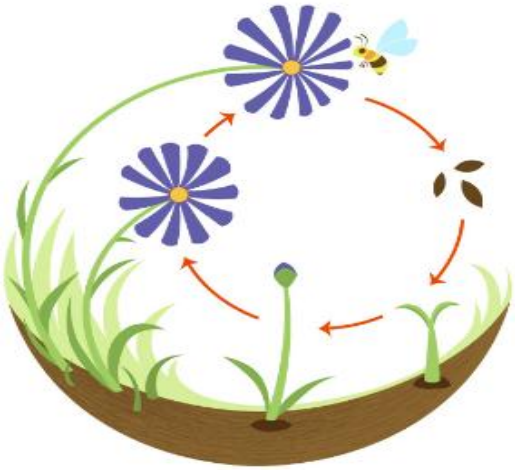


Figure 92. Multiple fruits.

CHAPTER 5: LIFE CYCLE AND THE ALTERNATION OF GENERATION



Learning Objectives

By the end of this chapter, students will be able to:

- Explain the concept of alternation of generations in flowering plants.
- Differentiate between the diploid (sporophytic) and haploid (gametophytic) phases.
- Interpret diagrams or life cycle showing the alternation of generations in angiosperms.

5. Alternation of generation in flowering plants

The concept of **alternation of generations** in plant life cycles means that plants alternate between two different life stages, or generations, in their life cycle; **a haploid stage** called **gametophyte** and a **diploid stage** called **sporophyte.**

In flowering plants (angiosperms), the life cycle alternates between two multicellular stages: the **diploid sporophyte (2n)**, which is the dominant phase, and the **haploid gametophyte (n)**.

5.1 Diploid generation (2n)

The diploid generation begins with the **formation of a zygote (2n)**, resulting from the fusion of two **haploid gametes (n)**. This zygote develops through mitotic divisions into the **sporophyte**, which corresponds to the **main plant body** in flowering plants.

The mature sporophyte produces flowers which contain male (stamens) and female (pistil) reproductive organs.

5. 2 Haploid generation (n)

Anthers contain **microsporangia**. **The microspore mother cells (2n)** divides by meiosis to produce **microspores**. Microspores divide by mitosis to form male **gametophytes (pollen grains)**, which contain sperm cells.

Ovaries contain **megasporangia. The megaspore mother cell (2n)** undergoes meiosis, producing four **haploid megaspores (n)**. One of the 4 megaspores divides by mitosis to form a **multicellular female gametophyte (embryo sac)**, which contains an egg cell **(n)**.

Fertilization takes place when a sperm cell fuses with the egg cell, producing a diploid **zygote**.

This zygote then divides by mitosis, giving rise to a **new sporophyte**, thus continuing the alternation of generations.

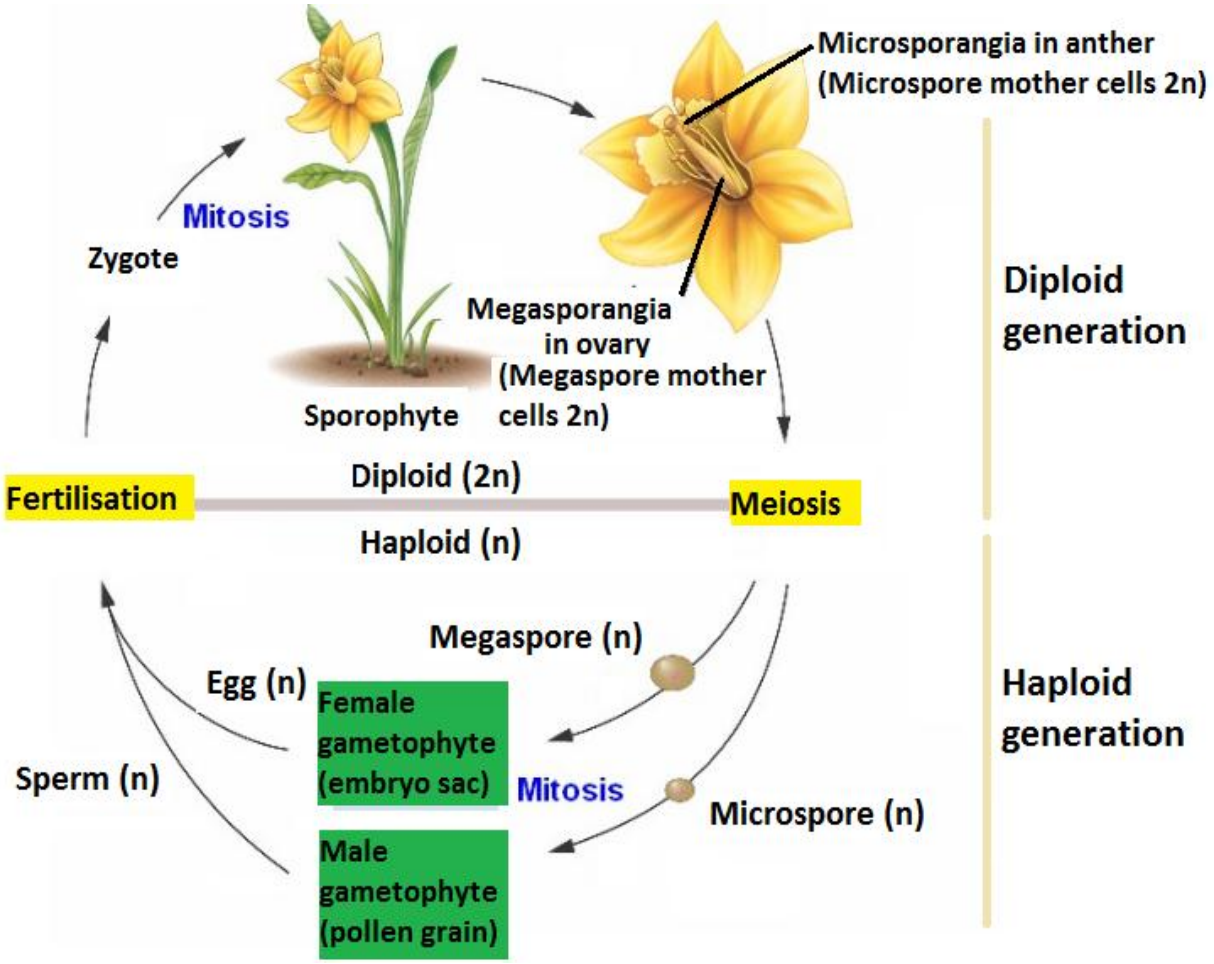


Figure 93. Life cycle of an angiosperm.

BIBLIOGRAPHY

Beck, C. B. (2010). An introduction to plant structure and development: plant anatomy for the twenty-first century. Cambridge University Press.

Bonner, F. T. (2008). Seed biology. Woody plants seed manual. USDA Forest Service, 3-37.

Bowman, J. L., Sakakibara, K., Furumizu, C., & Dierschke, T. (2016). Evolution in the cycles of life. Annual review of genetics, 50(1), 133-154.

Clark, M. A., Douglas, M., & Choi, J. (2018). Biology 2e.

De Craene, L. P. R. (2022). Floral diagrams: an aid to understanding flower morphology and evolution. Cambridge University Press.

Evert, R. F. (2006). Esau's plant anatomy: meristems, cells, and tissues of the plant body: their structure, function, and development. John Wiley & Sons.

Glimn-Lacy, J., & Kaufman, P. B. (2006). Botany illustrated: introduction to plants, major groups, flowering plant families. Springer Science & Business Media.

Guignard, J. L., & Potier, P. (2000). Biochimie végétale. Dunod, 274p.

Gunning, B. E., & Steer, M. W. (1996). Plant cell biology: structure and function. Jones & Bartlett Learning.

Haider, N. (2018). A brief review on plant taxonomy and its components. The Journal of Plant Science Research, 34(2), 277-292.

Hazzoumi, Z., Moustakime, Y., & Joutei, K. A. (2019). Essential oil and glandular hairs: Diversity and roles. In Essential oils-oils of nature. IntechOpen.

Iwamoto, L., Vicentini, T. A., Ramos, F. P., Ribeiro, C. C., & Teixeira, S. P. (2023). Diversity of leaf glands and their putative functions in Rhamnaceae species. Plants, 12(21), 3732.

Krishnamurthy, K. V., Bahadur, B., John Adams, S., & Venkatasubramanian, P. (2015). Meristems and their role in primary and secondary organization of the plant body. In Plant

Biology and Biotechnology: Volume I: Plant Diversity, Organization, Function and Improvement (pp. 113-151). New Delhi: Springer India.

Lucas, W. J., Groover, A., Lichtenberger, R., Furuta, K., Yadav, S. R., Helariutta, Y., ... & Kachroo, P. (2013). The plant vascular system: evolution, development and functions f. Journal of integrative plant biology, 55(4), 294-388.

Mauseth, J. D. (2014). Botany: an introduction to plant biology. Jones & Bartlett Publishers.

McMahon, E. L (2008). Plants and Society. McGraw-Hill Professional Publishing.

Pickard, W. F. (2008). Laticifers and secretory ducts: two other tube systems in plants. New Phytologist, 177(4), 877-888.

Shipunov, A. (2021). Introduction to botany. Minot State University.

Stephens, N. (2006). Plant Cells and Tissues. Infobase Publishing.