

# BBYCT-135 PLANT ANATOMY AND EMBRYOLOGY



**VOLUME 1**

**PLANT ANATOMY**  
**Block 1 and 2**

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“शिक्षा मानव को बन्धनों से मुक्त करती है और आज के युग में तो यह लोकतंत्र की भावना का आधार भी है। जन्म तथा अन्य कारणों से उत्पन्न जाति एवं वर्तमान विषमताओं को दूर करते हुए मनुष्य को इन सबसे ऊपर उठाती है।”

— इन्दिरा गांधी

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***“Education is a liberating force, and in our age it is also a democratising force, cutting across the barriers of caste and class, smoothing out inequalities imposed by birth and other circumstances.”***

**— Indira Gandhi**

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Indira Gandhi  
National Open University  
School of Sciences

# BBYCT-135 PLANT ANATOMY AND EMBRYOLOGY

**VOL**

**1**

**PLANT ANATOMY**

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**BLOCK 1**

**TISSUES AND ORGANS**

**5**

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**BLOCK 2**

**SECONDARY GROWTH AND ADAPTIVE FEATURES**

**103**

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# **PLANT ANATOMY AND EMBRYOLOGY**

Anatomy and Embryology is a four credit core theory course that consists of four blocks. Blocks 1, 2 are for Anatomy while 3, 4 are for Embryology. The two subjects have been clubbed together in a single paper because when we study about various types of tissues, structure of plant organs, tissues involved in the secondary growth, However, one will feel interested in knowing about various processes involved in development of organs in plants and origin of a new plantlet. Therefore, embryology is found to be somewhat related to anatomy.

'Anatomy' deals with the study of various types of cells and tissues present in plants. The subject provides information about the internal structure of various plant organs such as stem, root and leaf. It also describes various cells and tissues that play a role in the growth of plants. Various features/anatomical characters involved in the protection and adaptation of plants are also included in the study. The study of the topic becomes important because while studying plant sciences you should have an idea about the structural organization of plants.

Embryology is the branch of science that deals with the study of developmental events in plants. The subject includes study of structure of flower, pollination events, fertilisation, development of embryo, endosperm and formation of fruit and seeds. It forms an important branch in botanical studies because it tells about the structural organization of plants.

The present course contains different blocks having many units. The blocks in 'Anatomy' provide you information about various types of cells, tissues, detailed structure of plant organs i.e. root, stem and leaf, secondary growth processes in plants. The structures involved in the protection of the plants are also included in the study. **Block 1** covers 5 units dealing with the types of cells, tissues found in plants along with detailed note on structure of plant organs. **Block 2** covers 3 units dealing with structure of cambium, the meristematic tissue and secondary growth in stem and root. It also mentions about various protective and adaptive features in plants. **Block 3** contains 3 units that provide information about structure of flower, reproductive parts in flower, process of pollination and fertilization. **Block 4** contains 4 units that provide information about development of embryo and endosperm, development of fruit and seed apomixis and parthenocarpy.

## **Objectives**

After the study of this course you would be able to know :

- basic types of anatomical structures in plants (various cells and tissues);
- structure of plant organs such as root, stem and leaves;
- adaptive and protective features found in plants growing in different environments;
- structural organization of flower, the main reproductive organ in the plant;
- process of pollination and fertilization leading to formation of embryo and endosperm; and
- formation of seeds and development of new plant.



Block

# 1

## **TISSUES AND ORGANS**

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## **BLOCK 1 : TISSUES AND ORGANS**

The entire life span of a plant shows two dominant phases- vegetative and reproductive. Various developmental events take place during these two phases. Before going into the details of these events we need to be aware of the basic anatomy of various structures present in plants. In this first block anatomy of stem, root and leaf is been described .The block contains five units. The first unit discusses about the type of tissues whereas the second unit describes various types of meristematic tissues present in plants. The third, fourth and fifth units describe anatomy of the structure of plant organs i.e., roots, stems and leaves and various modifications.

In unit 1 the detailed information about function of various tissues with emphasis on their role in plant growth is given. Some cells develop specialized structures, some carry out limited functions while the others carry out multiple functions.

The second unit describes various types of meristematic tissues present in the plants along with their functions. We have also discussed about various theories related to organization of root and shoot apex.

Unit 3 gives detail about the organisation, structure, origin and arrangement of various kinds of tissues that makes up a root. You shall also study the functional attributes of various kinds of tissues of both primary and secondary roots and how an organ modifies its structure to carry out specific function and/or to adjust to the environmental needs.

In this unit 4, you will study about the organization and internal structure of the main axis, the stem. You will also study how modified stems perform various functions. It also deals with modified underground stems (rhizome, tuber, bulb and corms) which are for storage and perennation.

Unit 5 deals with leaf which represents a unique organ fulfilling a rather specific function for which it is specialized both structurally and physiologically. We have also discussed the structural aspects of the leaf in this unit. It includes external and internal features, structural adaptations in some common but important kinds of photosynthetic leaves. Some kinds of specialised modifications of leaves with specialized ecological adaptive advantages are also been discussed.

### **Objectives**

After studying this block, you would be able to :

- explain various types of tissues found in the plants; differentiate between simple and complex tissues;
- describe various types of meristematic tissues found in plants;
- describe various components of root and shoot apical meristem; and explain various theories related to root apical organisation and shoot apical organization;
- depict the structure of roots and various modifications in their structure; appreciate the close relationship between structure and function and adaptability especially in reference to specialized roots;

- describe the structure of stems and various modifications in their structure; and appreciate the close relationship between structure, function and adaptability especially in relation to rhizome, tuber, bulbs, corms, suckers and cladophylls; and
- illustrate the structure of leaves and various modifications in their structure and appreciate the close relationship between structure, function and adaptability of some specialized kinds of leaves such as: tendrils; spines; thorns and storage leaves.



# UNIT 1

## TISSUES

### Structure

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|     |                  |     |                         |
|-----|------------------|-----|-------------------------|
| 1.1 | Introduction     | 1.5 | Meristematic Tissues    |
|     | Objectives       |     | Properties of meristems |
| 1.2 | Types of Tissues |     | Types of meristems      |
| 1.3 | Simple Tissues   | 1.6 | Summary                 |
|     | Parenchyma       | 1.7 | Terminal Questions      |
|     | Collenchyma      | 1.8 | Answers                 |
|     | Sclerenchyma     |     |                         |
| 1.4 | Complex Tissues  |     |                         |
|     | Xylem            |     |                         |
|     | Phloem           |     |                         |

### 1.1 INTRODUCTION

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All living organisms are made up of basic units known as cells. The individual cells are grouped to form tissues which perform a specific function. The cells have distinctive shapes, wall characteristics and show specific physiological properties. Depending upon the organization of cells, tissues have been categorized into different types. In this unit you will study about different types of tissues found in plants. Some cells develop specialized structures, some carry out limited functions while the others carry out multiple functions. Cells mainly participate in growth, cell division and differentiation. The detailed information about function of various tissues with emphasis on their role in plant growth will be provided to you in this unit.

### Objectives

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After studying this unit you should be able to :

- ❖ describe different type of tissues;
- ❖ differentiate between simple and complex tissues;
- ❖ define meristematic tissues; and
- ❖ describe the role of different tissues.

## 1.2 TYPES OF TISSUES

Plant body comprises of several types of tissues, now you are going to study about different types of tissues. Fahn defined tissues as 'complex of cells of common origin'. Tissue comprise of group of cells which may possess a common structure or may perform a common function.

Tissues are classified basically into two types :

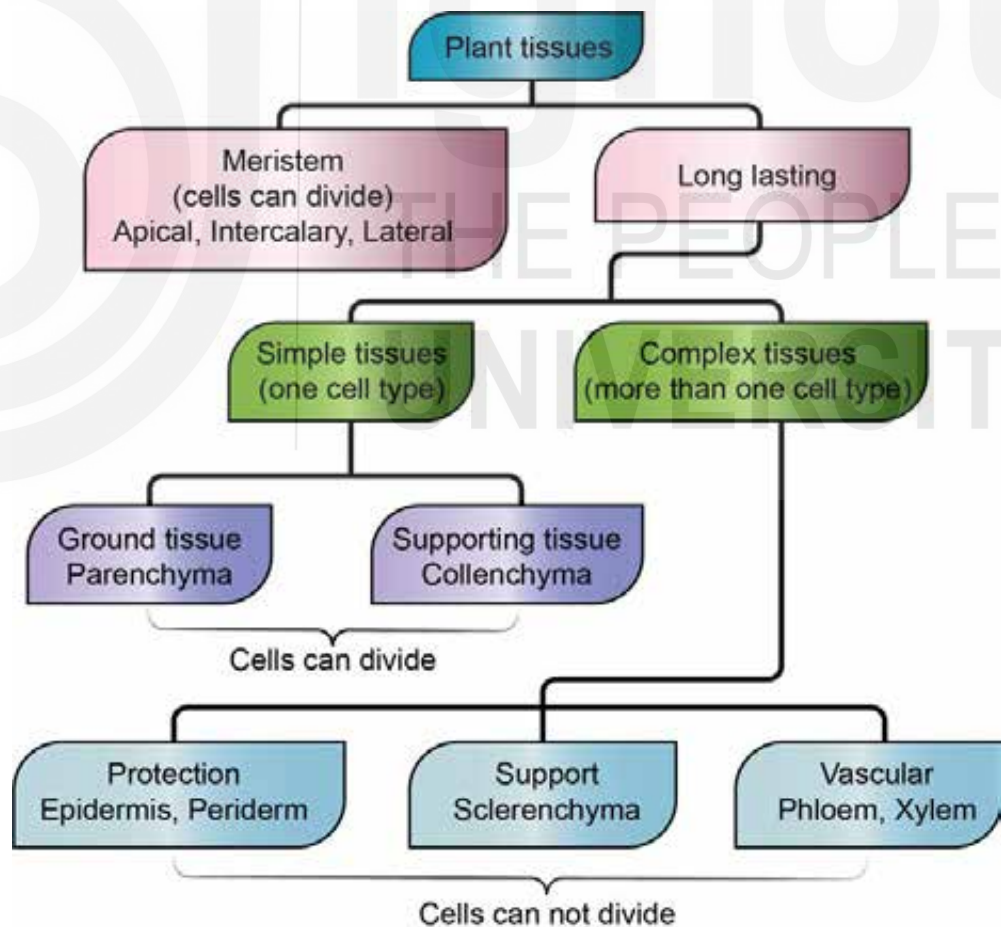
- Simple
- Complex

**Simple tissues**-The tissues which consist of similar type of cells are referred as simple tissues. They appear to be homogeneous. These include parenchyma, collenchyma and sclerenchyma.

**Complex tissues**- The tissues which consist of more than one type of cells are referred as complex tissues. These include xylem and phloem.

Based on the stage of development of the plant body, the tissues are also classified into two types :

- 1) Meristematic tissue; and 2) Permanent tissue



- 1) **Meristematic tissue or meristems** : The cell(s) of this tissue are generally young and immature, and possess the potential to show continuous division. These tissues show the ability to divide and self perpetuate throughout the plant life. A meristem may consist of one or more group of cells and these cells are defined as meristematic cells

(meristem- like). Thus we can say that a cell or group of cells that are meristematic constitute a meristem. You will study about meristems in unit 2 of this course.

- 2) **Permanent tissue** : These cells are derived from a meristem. The cells of this tissue cannot divide as they lose the capacity to divide. The cells of this tissue possess living or dead cells which may be thick or thin walled but have well developed organelles. These cells are also known as mature tissue.

## 1.3 SIMPLE TISSUES

Simple tissues mainly consist of parenchyma, collenchyma and sclerenchyma.

### 1.3.1 Parenchyma

It consists of least specialised and least differentiated cells. They are primarily isodiametric and possess a primary cell wall but may exhibit variety of shapes and forms. They are thin walled living cells and may be capable of regaining the capacity to divide (Fig. 1.1). They are compactly arranged or separated by abundant of intercellular spaces. Parenchyma can have diverse origins. They originate either from an apical meristem or from lateral meristems. They are regarded as the basic ground tissue from which all specialised cells might have developed. The cells occur as scattered diffused elements or homogenous mass. They are generally polyhedral but sometimes morphological variations stellate and armed forms also occur. A typical parenchyma cell is 14 sided. These cells are physiologically very active and participate in various metabolic activities such as synthesis, storage, transport of metabolites, wound healing, repair and regeneration. It is the most common type of tissue and present in all many parts of the plants such as pith and cortex regions of the stems, roots, fleshy tissues of fruits and seeds, photosynthetic leaves and rays of secondary xylem and phloem as well as the axial secondary xylem and secondary phloem. When parenchyma are fully turgid they provide considerable stiffness to stems.

Parenchyma present in different regions arises in different ways. Parenchyma present within the primary plant body differentiates from the ground meristem, procambium and protoderm, while that present in the secondary body, originates from the activity of both vascular and cork cambium.

Parenchyma that contains chloroplast participates actively in the photosynthesis and are known as chlorenchyma. The thin cell wall of these cells allows light and carbon dioxide to pass through to reach chloroplast. Some parenchyma cells can secrete nectar, mucilage resins and oils. These cells contain large amount of dictyosomes and endoplasmic reticulum. They assist in the transfer or transport of large quantities of sugar and minerals.

### 1.3.2 Collenchyma

It is a supporting tissue composed of more or less elongated living cells with unevenly thickened, non-lignified primary walls. It is in regions of primary growth in stems and leaves. The three most characteristic morphological features of collenchyma are axially elongated cells; cell wall thickenings; and living protoplasts.

It consists of elongated cells having a primary cell wall. The cells are axially elongated (up to 2mm long). The cell wall is unevenly/irregularly thickened and rich in pectin. The cell wall is thick at the corners (Fig.1.1). The cell walls of collenchyma are rich in cellulose and pectin. The cell walls possess high tensile strength with high water content. The cells are living at maturity. They give mechanical support principally for the primary organs such as young stems, hypocotyls, pedicels, peduncles etc. The walls of the collenchyma's exhibit plasticity. The cells get deformed under pressure or stress but retain their shape after the stress is relieved.

They are mostly found at the periphery of stem, leaves and floral parts. The collenchyma cells are present as a layer under the epidermis or as bands next to vascular bundles. On the basis of deposition of primary cell wall thickenings, the collenchyma have been categorized as **angular** collenchyma in which the corners are thickened, **tangential** collenchyma in which the inner and outer tangential walls are thickened, **annular** collenchyma in which the walls are uniformly thickened and **lacunar** collenchyma in which the primary cell wall thickenings are present at the places where the cell wall is in direct contact with the intercellular spaces.

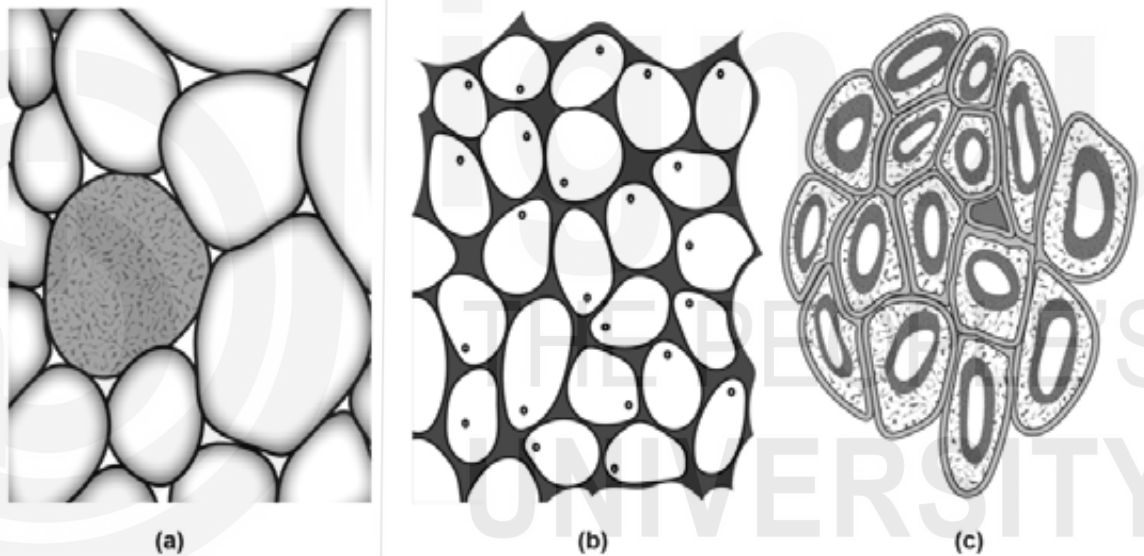


Fig. 1.1: Diagrammatic representations of cells a) Parenchyma; b) Collenchyma; c) Sclerenchyma.

### 1.3.3 Sclerenchyma

It consists of cells having thick, lignified secondary cell walls. They do not retain a living protoplast at maturity. The walls of the cells are elastic i.e. return to their original shape after the pressure or tension is released. The cell wall shows specialized structures called pits. Sclerenchyma prevents the protoplast from expanding. These cells play a protective or supportive function throughout the plant body. Sclerenchyma cells arise within the primary body after differentiation of protoderm, ground meristem, procambium or from fusiform initials of vascular cambium in a secondary plant body.

These cells are classified into two types - **fibers** and **sclereids**.

#### Fibers

Fibers are narrow, elongated sclerenchyma cells with tapering ends. The secondary wall of the fibers is generally thick. They form major component of xylem tissue. They are lignified and non-living, hence incapable of further

growth and division. Most of them are non living but sometimes they can be living particularly those found in the wood of dicotyledons. The mature fiber is thick and almost or entirely occluded. They are also found in various parts of the plant. They are mainly found in primary plant parts such as pericycle, hypodermis, bundle sheaths, pith etc. They function in mechanical support in various organs.

On the basis of their position in plants, fibers are classified as **phloem fibers** (phloem) and **wood fibers** (xylem). The plants also show the occurrence of **xylary and extraxylary** fibers. Extraxylary fibers are those which are positioned in the cortex or phloem and are referred as bast fibers, while **xylary fibers** are those which are occurring in the wood and originating from the vascular cambium (Fig.1.2). In many plants, the extraxylary fibers are very long. The longest fiber has been noted in ramie (*Boehmeria nivea*) which is about 550 mm in length. Bast fibers are economically important because they possess high tensile strength and are used for making ropes and other items. They can be septate (having septum or cross walls) or aseptate (septum is absent). Fibers of some taxa show formation of thick, lignified secondary wall while the others depict the thin partition or septa of secondary wall across the cell lumen. These are referred as **septate** fibers. In some plants, fibers remain active at maturity and carry out metabolism. These living cells store starch or calcium oxalate. Wood fibers show transition during the evolutionary process from tracheid like elements with bordered pits to slender wood fibers without pit borders.

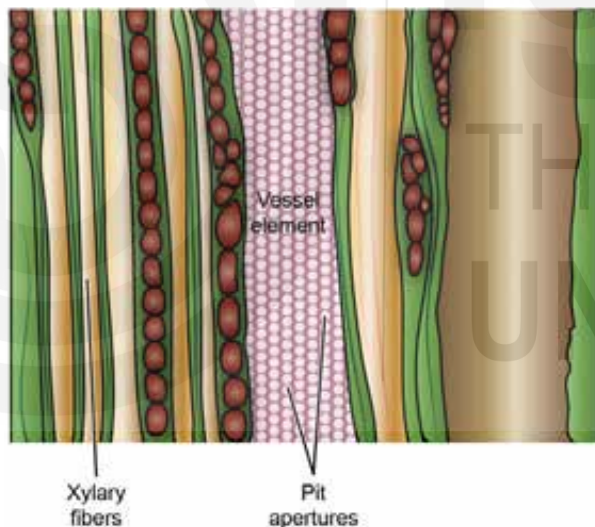


Fig. 1.2: Structure of xylary fibers.

## Sclereids

They are reduced/small, isodiametric (cuboidal) irregular shaped sclerenchyma cells. They have thick lignified cell walls having conspicuous concentric laminations interrupted by pitting. They are non-living at maturity and found to be present in various plant tissues such as the periderm, cortex, pith, xylem, phloem, leaves and fruits. They mainly originate in the vicinity of the midrib or both in the midrib and leaf margins. They can be of different shapes such as spherical, oval or cylindrical. They are known to function in mechanical support and protection such as minimizing or deterring herbivory.

Sclereids can be classified into different types- **astrosclereids**, branched sclereids, **brachysclereids** (stone cells), short roughly isodiametric cells that

resemble parenchyma, **filiform** sclereids, elongated and slender cells resembling fibers, **macrosclereids** elongated cells showing uneven deposition of secondary walls, **osteosclereids** (bone shaped) the cells having columnar middle and enlargement at ends and **trichosclereids**, branched with hair like branches extending into intercellular spaces (Fig.1.3).

On the basis of their occurrence, sclereids have been classified as **diffuse** sclereids which are dispersed in the leaf mesophyll, **terminal** sclereids which are confined to the end of small veins and **mixed** pattern containing both terminal and diffuse sclereids and **epidermal** sclereids. Many plant families possess more than one type of sclereids. Sclereids of varied shapes and sizes have noted in families such as Theaceae, Proteaceae. In some species, crystals are also present in the walls of the sclereids and these are referred as crystalliferous sclereids. This type of sclereids has been found in *Araucaria*, *Nymphaea*, *Nuphar*, *Schisandra*, *Welwitschia* etc.

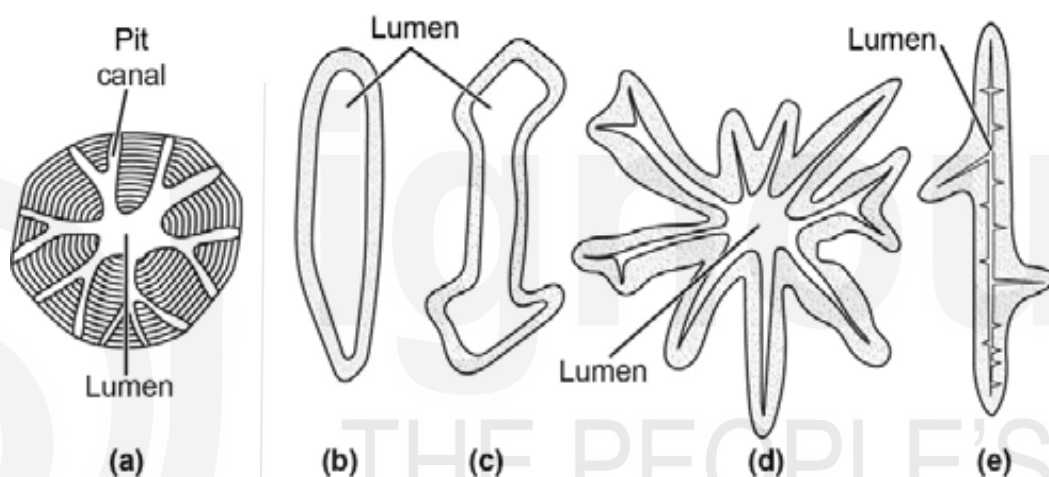


Fig. 1.3: Structure of various type of sclereids a) Stone cell; b) Macrosclereid; c) Osteosclereid; d) Astrosclereid; and e) Filiform sclereid.

### SAQ 1

Differentiate between meristematic tissues and permanent tissues?

## 1.4 COMPLEX TISSUES

These mainly consist of xylem and phloem. Both are composed of different cell types which possess specialized structure and perform specific function. We will study about them in detail.

### 1.4.1 Xylem

It consist of two conductive tissues namely tracheids, vessel elements along with parenchyma and xylem fibers (Fig. 1.4 a). Tracheids and vessels are also referred as conducting tissues or tracheary elements. Tracheary elements consist of elongated cells with rigid and pitted secondary walls. They lack protoplasmic contents at maturity. Vessel elements join end to end to form a continuous tube like structure. They assist in function to conduct water and essential nutrient elements from roots to other parts of the plants.

Tracheids are the major water conducting elements found in vascular plants. They are elongated structures which are imperforate i.e. allow movement of water and mineral nutrients between adjacent cells through pit pores. Water passes from cell to cell through series of pit membranes of bordered pit pairs present along the overlapping and tapered end walls of two adjacent cells.

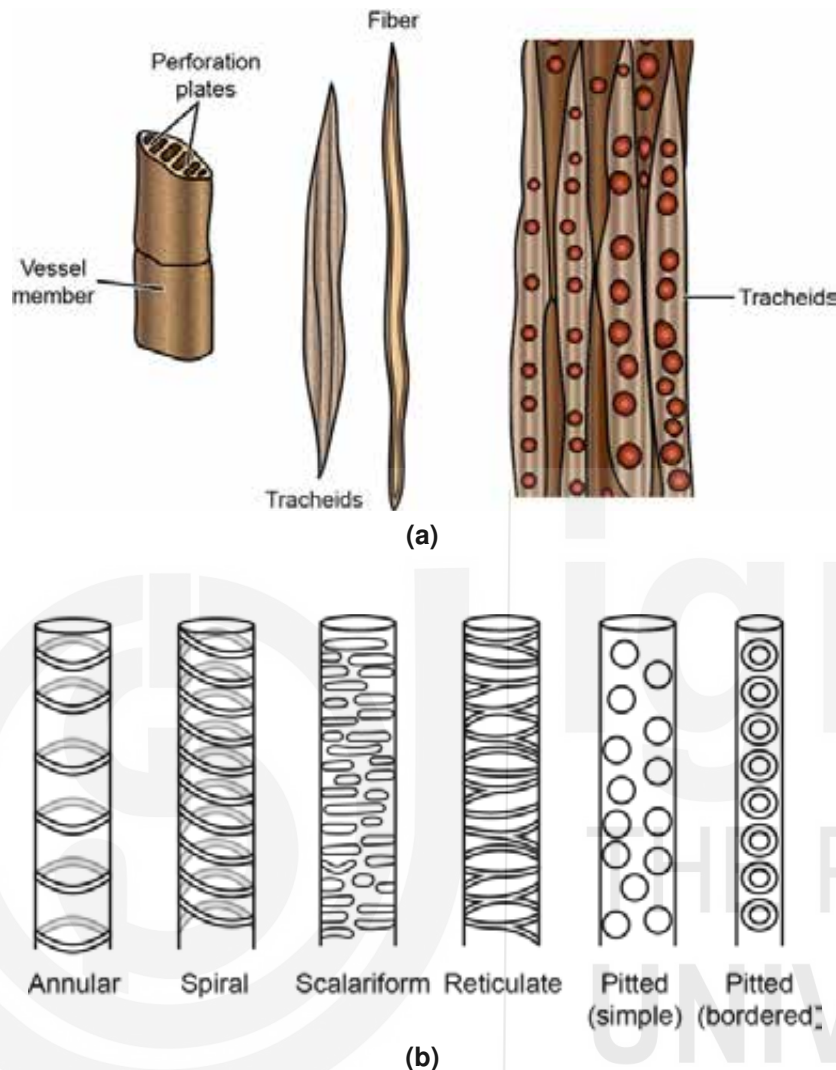


**Fig.1.4: Structure of a) tracheids, Vessels and fibers; b) secondary wall thickenings in tracheary elements.**

Each vessel possesses a stack of vessel elements. Each vessel element has one perforation on each end. The vessels members are attached end to end to form a continuous tube like structure. Vessels are perforate structures i.e. movement of water and mineral nutrients occurs through one or more continuous holes between adjacent cells. The contact area of two adjacent plates is called as **perforation plate**. The plate can be simple or compound. A simple perforation plate is an area of end wall that exhibits large, single, circular or elliptical openings that leave a narrow rim of primary wall remaining. A scalariform perforation plate is a plate consisting of elongated parallel openings i.e. several pores (pit pores with primary cell walls) separated by one or more branched or unbranched bars. These are found in many families such as Betulaceae, Magnoliaceae, Hydrangeaceae and Theaceae. Vessel members differ considerably in their length, width and degree of perforation. Vessels absorb water from parenchyma, tracheids or other vessels and pass on. The pits help in the transfer of water on lateral sides. The wall thickenings noted in the tracheids are also found in the vessels.

During development of trachery elements, mature parenchyma cells stop dividing. The cell with primary cell wall starts elongating, become narrow and develops certain thickenings which are referred as secondary walls. The pattern of wall deposition permits the differential expansion or elongation essential for morphogenesis. The secondary wall is impermeable to water and develop certain thickenings which occur as rings, reticulate, helical or scalariform (Fig 1.4 b).

### **1.4.2 Phloem**

Phloem is a conducting tissue composed of specialised cells called sieve elements, parenchyma and sclerenchyma. Sieve elements consist of two cells- **sieve cells** and **sieve tubes**. Sieve tube in turn is made up of a number of cells each termed as sieve tube member or sieve tube element. They consist of sieve pores which are aggregated to form sieve areas.

Sieve tube members have both sieve areas and sieve plates. Sieve tube members contain elongate cells having thin primary cell walls. These are metabolically active. Pore of the sieve area is lined with a substance called **callose**, a polysaccharide. The sieve elements are also aligned end to end to form a structure called sieve tube. They function to transfer dissolved sugars and organic metabolites to various parts of the plant. **Sieve tube members** are elongate cells whose walls bear differentiated regions occupied by numerous narrow sieve pores filled with protoplasmic connecting strands that link them to adjacent sieve elements. The end wall of the sieve tube element is termed as **sieve plate** (Fig.1.5). The sieve plate is composed of one or more sieve areas with large sieve pores. The protoplasts of two functional sieve elements are interconnected by means of continuous cytoplasmic bridges similar to plasmodesmata. During maturation of sieve tube elements, the plasmodesmata penetrate the enlarged and open sieve plate pores to form continuous system of protoplasm between contiguous sieve tube elements. Sieve plates consist of one or more sieve areas at the end junction of two sieve tube members. A sieve plate composed of single sieve area is a **simple sieve plate** while the end wall containing two or more sieve areas is a **compound sieve plate**. A simple sieve plate is correlated with transversely oriented end walls and compound sieve plates are usually located in various inclined end walls. A unique feature of the sieve tube elements found in dicots and some monocots is the presence of proteinaceous substances called **phloem protein bodies (P protein)**.

Sieve cells may possess one or more sieve areas on its lateral walls. Sieve cells are found confined to gymnosperms and lower vascular plants. They are slender, elongated cells with tapering ends. They possess sieve pores on lateral walls (Fig.1.5). They lack P protein which is found in sieve tubes of angiosperms. These cells possess a complex network of endoplasmic reticulum that is continuous from cell to cell through sieve area pores. These cells are associated with albuminous cells (Strasburger cells). Albuminous cells are not derived from the same mother cell as the associated sieve cell.

Both sieve cells and sieve tube members have parenchyma physically associated with them. The phloem parenchyma cells function primarily as long lived storage cells. Both of these cells help to load and unload sugars into the

cavity of sieve cells or sieve tube members. The parenchyma cells associated with sieve cells are referred as albuminous cells, while those attached with sieve tube members are called as companion cells. The companion cells are small, densely cytoplasmic cells that are ontogenetically derived by unequal division of same initial as the sieve tube element. They communicate with the sieve tube element by means of plasmodesmata pore connection across the common walls. These cells possess a large nucleus at maturity and are rich in organelles such as mitochondria, plastids and endoplasmic reticulum. Companion cells supply the energy to the sieve tube element to drive translocation (Fig. 1.5 a).

Sieve cells are found in primitive i.e. non-flowering vascular plants, while sieve tube members are found only in angiosperms i.e. flowering vascular plants.

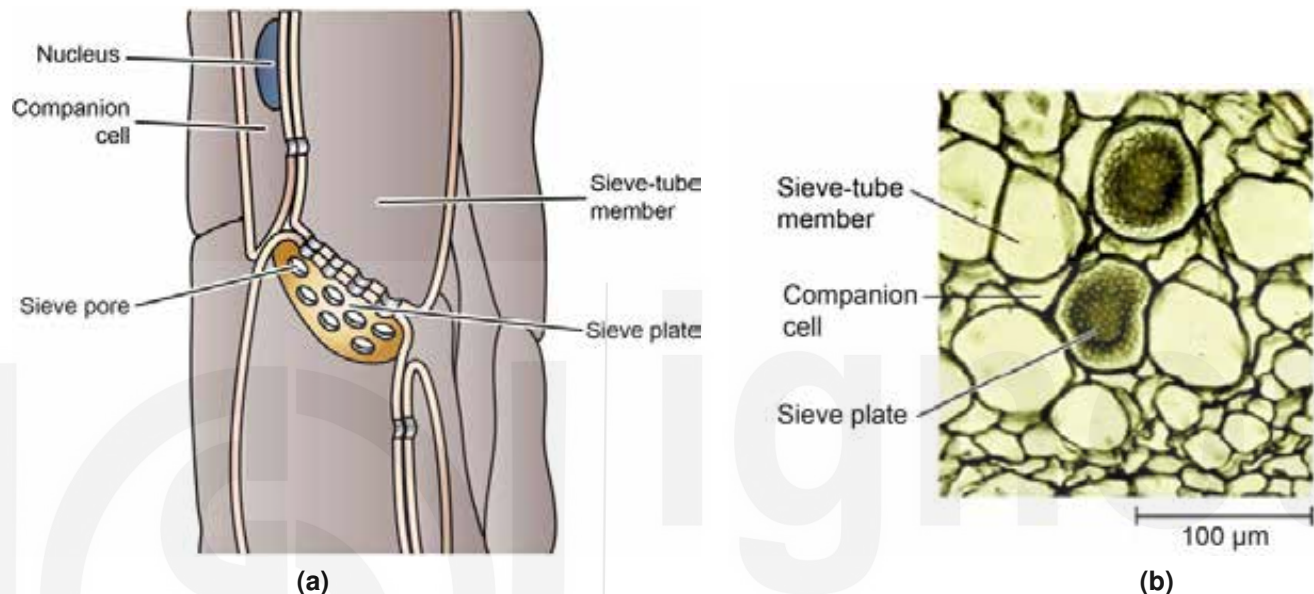


Fig.1.5: a) Longitudinal view; and b) Transverse view of the phloem structure.

## SAQ 2

- a) Fill in the blank(s) with appropriate word(s) :
- The cells having thick lignified walls as referred as.....
  - Cells associated with the sieve tube elements are called as .....
  - ..... are the main conducting tissues in plants.
  - The sieve tube elements found in dicots and some monocots show the presence of proteinaceous substances known as .....
  - Long narrow sclerenchyma cells with tapering ends are referred as .....
  - Each vessel element has one ..... on each end.
  - Tracheids generally show ..... thickenings.
  - In phloem, both sieve cells and sieve tube members have ..... physically associated with them.
  - Pore of the sieve area is lined with a substance called .....
  - The sieve plate is composed of one or more ..... with large sieve pores.

- b) Write the functions of :
- i) chlorenchyma
  - ii) tracheids
  - iii) fibers
  - iv) sclereids
- c) Answer in one word.
- i) A simple tissue having undifferentiated isodiametric cells.
  - ii) A simple tissue having cells with thick, lignified cell walls.
  - iii) Long narrow cells with tapering ends which function in mechanical support in various organs.
  - iv) The parenchyma cells associated with sieve cells.
  - v) Tissues in which the cells divide indefinitely or remain in the active phase throughout the life of the plant.
  - vi) Perforate structures that allow movement of water and mineral nutrients.
  - vii) A sieve plate composed of single sieve area.
  - viii) Sieve cells are mostly found in these plants.
  - ix) A unique proteinaceous substances found in sieve tube elements of dicots and some monocots.
  - x) Small/reduced, isodiametric (cuboidal) irregular shaped sclerenchyma cells having thick lignified cell walls.

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## 1.5 MERISTEMATIC TISSUES

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Meristematic tissues are composed of a group of undifferentiated self-renewing cells which give rise to most of the plant structures. The meristematic cells help in the growth of the plants. In meristematic tissues or meristems, the cells divide indefinitely or remain in the active phase throughout the life of the plant. Meristematic tissues are found near the tips of roots and stems, buds and nodes of stems. The cells of the meristematic tissues are small in size, immature and possess the power of continuous division. Meristematic cells have the ability to enlarge, stretch and differentiate into other types of cells as they mature. The meristematic cells can be oval or rounded or polygonal in shape. They have a large nucleus and lots of vacuoles. They are so minute to be discernible under a compound microscope. Intercellular space between cells is absent.

When a meristematic cell divides in two, the new cell that remains in the meristem is called an 'initial' and the other is called the 'derivative'. As new cells are added by repeated mitotic divisions of the initial cells, the derivatives

are pushed farther away from the zone of active division. They stretch, enlarge and differentiate into other types of tissues as they mature. Meristematic cells are generally small and cuboidal with large nuclei, small vacuoles, and thin walls.

The main characteristics of cells of meristematic tissues :

- i) It consist of living, thin cellulose walled cells.
- ii) The cells contain dense protoplasm and conspicuous nuclei.
- iii) The cells are spherical, oval or polygonal in shape.
- iv) Vacuoles are few and small in size.

Meristems are of two types depending upon their location in the plant body. Namely shoot apical meristem and root apical meristem. The shoot apical meristem (SAM) (Fig.1.6) gives rise to organs like the stem, leaves and flowers, while the root apical meristem (RAM) provides the meristematic cells for the future root growth. The cells of the shoot and root apical meristems divide rapidly and are considered to be indeterminate, which means that they do not possess any defined end fate.

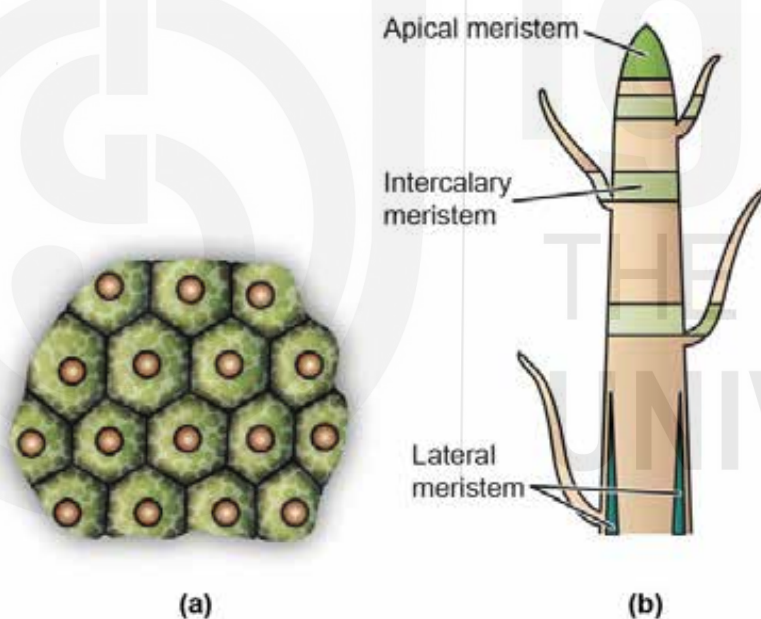


Fig.1.6: a) Structure of meristematic cells; b) location of various meristems.

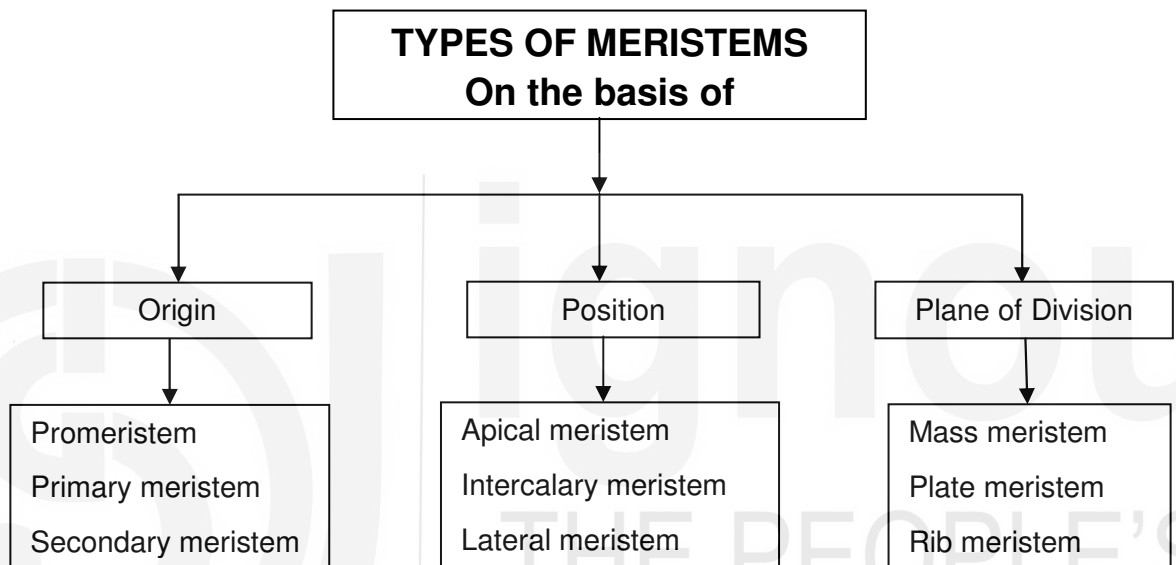
### 1.5.1 Properties of Meristems

Meristems contain a population of cells with characteristics of **stem cells**. The cells divide continuously to replenish meristem and provide cells that will differentiate into plant organs and tissues. The plant meristems have the capacity to differentiate as any cell type. Vegetative meristems are **indeterminate** i.e., they can grow indefinitely. Some plants normally produce a relatively fixed number of nodes, if the meristem is removed and then allowed to reform in culture, they will produce normal number of nodes. Thus node number is a property of the whole plant and not inherent to the meristem. Vegetative meristems are highly **regulative**. If portions are surgically removed, the remainder will reorganize into a functioning meristem.

The activity of vegetative meristems is **repetitive**, often described as meristic (mer meaning unit as in polymer). The meristem produces modular units consisting of a lateral organ (leaf), axillary bud, node and subtending internode. Each unit is called a **phytomer**. Thus primary shoot growth involves the repetitive addition of stem segments and associated leaves to the end of the shoot. You will study about meristem in the coming unit but here we will like you to be introduced to important expressions used in describing meristem.

### 1.5.2 Types of Meristems

The meristems have been classified into different types on the basis of origin, development, position, plane of division and function in the plant body.



a) On the basis of origin and development of initiating cells, meristems have been classified into three types :

- i) **Promeristem or priomordial meristem** - A group of young meristematic cells of a growing organ. It is the early embryonic meristem from which other advanced meristems are derived. In a plant, it occupies a small area at the tip of stem and root. It further divides to form primary meristem. It is made up of thin walled isodiametric cells.
- ii) **Primary meristem** - These are derived from promeristem. Hence they can be referred as derivatives of promeristem. It forms fundamental parts of the plant. They are present below the promeristem at shoot and root apices. These cells divide and form permanent tissues. These include apices of roots, shoots and primordial of leaves or other appendages.
- iii) **Secondary meristem** - It is derived from primary permanent tissues which have the capacity of division. This meristem appears after a certain stage of development of plant organ. It develops from mature tissues which have already differentiated. It is lateral in position. Example- cork cambium, cambium of roots and inter fascicular cambium of stem.

- b) On the basis of their position in the plant body, meristems have been classified into three types :
- i) **Apical meristem** - These are located in the growing points such as apices of primary stem and root.
  - ii) **Lateral meristem** - These are located and arranged parallel to the sides of the organs. They divide periclinally or radially. They help in increasing the diameter of stem or root. Example- vascular cambium, cork cambium.
  - iii) **Intercalary meristem** - the meristem lies between the regions of permanent tissues. It is considered as part of the primary meristem. It is present at the base of the leaves in monocotyledons and internodal region of grasses.
- c) Meristems can also be divided into different types on the basis of plane of division. The plane of division determines the growth pattern in plants.
- i) **Rib or file meristem** - In this meristem the plane of division is restricted to right angles to the longitudinal axis of the cell. This means that the cells divide anticlinally and result in formation of long rows or file of cells. This meristem gives rise to cortex and pith of stem and root.
  - ii) **Plate meristem** - It consist of parallel layer of cells which divide anticlinally and it brings intercalary growth. This meristem occurs in leaves and increases its surface area.
  - iii) **Mass meristem** - In this type of meristem, the cell division occurs in all planes resulting in the formation of massive plant body or organ. This meristem is involved in the development of embryo or endosperm.
- d) Meristem can also be divided into different types on the basis of function. The primary meristem of root and shoot apex have been classified into different types on the basis of their function.
- i) **Protoderm** - The outermost meristematic layer of the growing regions. It develops into outer dermal tissues including epidermis.
  - ii) **Procambium** - It is composed of narrow, elongated, parenchymatous cells. The cells are densely cytoplasmic and contain large nucleus, proplastids and possess meristematic activity. They develop into primary vascular tissue. The peripheral derivatives of procambium are primary phloem and the inner derivatives are primary xylem. The portion of procambium that remains in between primary phloem and xylem differentiates into cambium.
  - iii) **Ground meristem** - It is precursor of ground tissue and consists of large thin walled cells. The cells develop into hypodermis, cortex, pericycle and pith. This meristem is considered as the precursor of fundamental or ground tissue system.

The cells of these zones are produced by divisions in the apical meristem. The tissues in each of these zones differentiate into distinct tissues which mature and compose the primary body of a plant.

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### SAQ 3

- a) Enlist some characteristics of meristematic tissues.
- b) Classify meristems into different types on the basis of their position in the plant body.
- c) Name the following :
  - i) The outermost meristematic layer that develops into epidermis.
  - ii) The meristematic layer that develops into primary vascular tissue.
  - iii) The layer of the meristematic tissue that develops into hypodermis, cortex, pericycle and pith.

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## 1.6 SUMMARY

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- A group of cells of a common origin are termed as tissue. These cells may be similar in structure or may perform similar function. Depending upon the organization of cells, tissues can be of different types.
- The tissues which consist of one type of cells are simple tissues. These include parenchyma, collenchyma and sclerenchyma.
- The tissues which consist of more than one type of cells are complex tissues. These include xylem and phloem.
- Meristematic tissues or meristems are tissues in which the cells remain young and divide actively throughout the life of the plant.
- On the basis of their position in the plant body, meristems have been classified into three types, apical, lateral and intercalary.
- Apical meristem is located at opposite ends of the plant axis in the tips of roots and shoots. Cell divisions and subsequent cellular enlargement in these areas lengthen the above and below ground parts of the plant. The meristems also influence the shapes of the mature plants since the patterns for subsequent growth are laid down in the meristems. These are found at the apices or growing points of root and shoot and bring about increase in length.
- In lateral meristem, cells are arranged parallel to the sides of origin and normally divide periclinally or radially and give rise to secondary

permanent tissues. These increase the thickness of the plant part. The lateral meristems are present on the lateral side of the stem and root of a plant. These meristems help in increasing the thickness of the plants.

- Intercalary meristem lie between the region of permanent tissues and are considered as a part of primary meristem which has become detached due to formation of intermediate permanent tissues. It is found either at the base of leaf e.g. *Pinus* or at the base of internodes e.g. grasses.

## 1.7 TERMINAL QUESTIONS

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- 1) Why are xylem and phloem considered as complex tissues?
- 2) Differentiate between
  - a) primary and secondary meristem.
  - b) companion cell and albuminous cell.
- 3) How is apical meristem different from intercalary meristem?
- 4) With the help of well developed diagrams explain the different components of the water and food conducting tissue in plants.

## 1.8 ANSWERS

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### Self-Assessment Questions

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1. **Meristematic tissue or meristems** : The cells of this tissue are generally young and immature, with the power of continuous division. These tissues have the ability to divide actively throughout the life of the plant.

**Permanent tissue** : The cells of this tissue cannot divide. They have lost the capacity to divide. The cells of this tissue possess living or dead cells which may be thick or thin walled but have well developed organelles.

2.
  - a)
    - i) Sclerenchyma
    - ii) Companion cells
    - iii) Tracheids and vessels
    - iv) Phloem protein bodies (P protein)
    - v) Fibers
    - vi) Perforation
    - vii) Wall
    - viii) Parenchyma

- ix) Callose
- x) Sieve areas
- b)
  - i) These parenchyma cells contain chloroplast and are actively involved in photosynthesis.
  - ii) Tracheids are the elongated structures which conduct water and mineral nutrients in vascular plants. They allow movement of water and minerals between adjacent cells through pit pores.
  - iii) Fibers provide mechanical support to the plant.
  - iv) Sclereids are known to function in mechanical support, protection such as minimizing or deterring herbivory.
- c)
  - i) Parenchyma
  - ii) Sclerenchyma
  - iii) Fibers
  - iv) Albuminous cells
  - v) Meristematic tissues or meristems
  - vi) Vessels
  - vii) Simple sieve plate
  - viii) Gymnosperms and lower vascular plants
  - ix) Phloem protein bodies (P protein)
  - x) Sclereids
- 3. a) Meristematic cells are generally small and cuboidal with large nuclei, small vacuoles, and thin walls. The main characteristics of cells of meristematic tissues are:
  - i) It consist of living, thin cellulose walled cells
  - ii) The cells contain dense protoplasm and conspicuous nuclei
  - iii) The cells are spherical, oval or polygonal in shape
  - iv) Vacuoles are few and small in size
- b) On the basis of their position in the plant body, meristems have been classified into three types
  - i) **Apical meristem** - These are located in the growing points such as apices of stem, root.
  - ii) **Lateral meristem** - These are located and arranged parallel to the sides of the organs. They divide periclinally or radially. They help in increasing the diameter of stem or root. Example- vascular cambium, cork cambium.

- iii) **Intercalary meristem** - This meristem lies between the regions of permanent tissues. It is considered as part of the primary meristem. It is present at the base of the leaves in monocotyledons and intermodal region of grasses.
- c)
  - i) Protoderm
  - ii) Procambium
  - iii) Ground meristem

## Terminal Questions

1. Xylem is composed of more than one type of tissue namely tracheids and vessels. Tracheids consist of elongated cells joined end to end to form a continuous tube like structure. They assist in function to conduct water and essential nutrient elements from roots to other parts of the plants. Vessels are perforate structures attached end to end to form a continuous tube like structure and allow movement of water and mineral nutrients between adjacent cells.

Phloem is composed of specialised cells called sieve elements. Sieve elements consist of sieve cells and sieve tube members. The sieve elements are also aligned end to end to form a structure called sieve tube. They function in transfer of dissolved sugars to various parts of the plant. The parenchyma is also associated with them.

Since both xylem and phloem are composed of more than one type of tissues, they are called as complex tissues.

2. a) **Primary meristem** - These are derived from promeristem. Hence they are also referred as derivatives of promeristem. It forms fundamental parts of the plant. They are present below the promeristem at shoot and root apices. These cells divide and form permanent tissues. These include apices of roots, shoots and primordial of leaves or other appendages.

**Secondary meristem** - It is derived from primary permanent tissues which have the capacity of division. This meristem appears after a certain stage of development of plant organ. It develops from mature tissues which have already differentiated. It is lateral in position. Example- Cork-cambium, cambium of roots and inter fascicular cambium of stem. It develops during the time of injury or wounds.

- b) These cells are associated with sieve cells are referred as albuminous cells (Strasburger cells). Albuminous cells are not derived from the same mother cell as the associated sieve cell.

The cells attached with sieve tube members are called as companion cells. The cells are small, densely cytoplasmic cells and derived by unequal division of same initial as the sieve tube element.

3. Apical meristems are located in the growing points such as apices of primary stem and root while lateral meristem are located and arranged parallel to the sides of the organs.
4. Refer to Section 1.4 and draw diagrams.



# UNIT 2

## MERISTEMATIC TISSUES

### Structure

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|     |                                           |     |                                       |
|-----|-------------------------------------------|-----|---------------------------------------|
| 2.1 | Introduction                              | 2.6 | Theories of Shoot Apical Organization |
|     | Objectives                                |     | Apical Cell Theory                    |
| 2.2 | Apical Meristems                          |     | Histogen Theory                       |
| 2.3 | Lateral Meristems                         |     | Tunica-Corpus Theory                  |
| 2.4 | Intercalary Meristem                      |     | Tissue Differentiation Theories       |
| 2.5 | Theories of Root Apical Organisation      | 2.7 | Summary                               |
|     | Apical Cell Theory                        | 2.8 | Terminal Questions                    |
|     | Histogen Theory                           | 2.9 | Answers                               |
|     | Korper–Kappe Theory                       |     |                                       |
|     | Function of Root Cap and Quiescent Center |     |                                       |

### 2.1 INTRODUCTION

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In the last unit you have studied the different type of simple and complex tissues found in the plants. Higher plants possess small, organized regions of active cell division, cell enlargement, differentiation termed as meristems. The growth and morphogenesis of the plant is controlled by these meristematic regions. The meristematic regions located on the tip of the stem and root is referred as apical meristems. Some meristematic regions are found in the lateral regions and some at regions such as internodes, regions where the leaves attach and leaf bases. These are referred to as lateral and as intercalary meristems. In the present unit we will describe various types of meristematic tissues present in the plants along with their functions. We will also discuss about theories proposed related to organization of root and shoot apex.

## Objectives

After studying this unit you would be able to :

- ❖ describe various types of meristems;
- ❖ discuss the role of various meristems in plants;
- ❖ describe various components of root and shoot apical meristem; and
- ❖ explain various theories related to root apical organisation and shoot apical organisation.

## 2.2 APICAL MERISTEMS

As you know that apical meristem are located terminally in plants. These are found at the apices or growing points/tips of root and shoot (Fig.2.1). They first appear in embryonic root and shoot. All the primary tissues originate from this meristem. Cell divisions and subsequent cell enlargement in these areas lengthen the above and below ground parts of the plant. They help in the growth of the root as well as shoot. Depending upon their position in the plant they have been categorized as shoot apical and root apical meristem.

**Shoot apical meristem**- It is located at the terminal position of the shoot. It is a dome shaped structure or nearly flattened reservoir of embryonic cells present at the terminal end of the shoot/stem. The cells in the region divide continuously to form new tissues and organs. The cells in the region possess the capacity for unlimited growth. This part lies (distal to the youngest) immediately above the leaf primordium. It is variable in shape at different stages of plant development. It is usually radially symmetrical and appears to be more or less convex in a median longitudinal section. The shoot apex shows rhythmic changes before and after the initiation of leaf primordium. It widens before initiation of leaf and again becomes narrow.

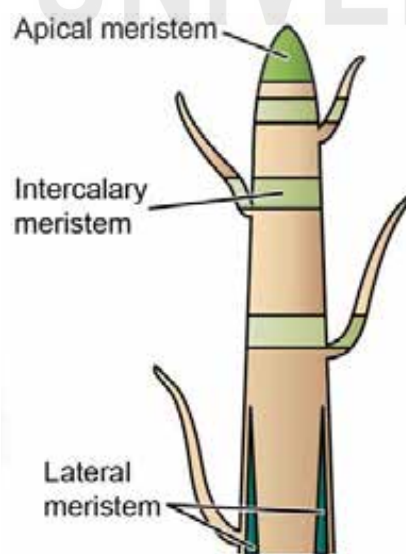


**Fig. 2.1: Position of various meristems in the plant.**

The shoot apical meristem is the source of initiation of all the above ground organs. Cells of the shoot apical meristem serve as stem cells and proliferate and get incorporated into differentiating leaf or flower primordia. In fact, the

primordial of leaves, sepals, petals, stamens and ovaries are initiated at the shoot apical meristem at the rate of one every time interval. This time interval is called a **plastochron**. New leaves are produced at regular time intervals if temperature is held constant. Thus by using indices of leaf plastochron, age of a plant can be determined on the basis of its morphological traits rather than on chronological age. It is of advantage as one can eliminate some differences caused by germination, developmental differences and exponential growth.

**Root apical meristem-** The meristematic cells located at the apex of the root comprises the root apex meristem. This region differentiates into embryonic radicle. The cells of this region are densely cytoplasmic with large nuclei.

## 2.3 LATERAL MERISTEMS

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These meristem are lateral in position lie parallel to the long shoot and root axes (Fig. 2.1). These meristems help in increasing the thickness of the plants. The cells are arranged parallel and normally divide periclinally or radially and give rise to secondary permanent tissues. The vascular cambium and the cork cambium are good examples of lateral meristems. You will study about lateral meristem in Unit 6 of this course.

**Vascular cambium-** Some plants grow in diameter by producing new tissues laterally from a cylinder of tissue called the vascular cambium. This tissue extends throughout the length of the plant from the tips of the shoots to the tips of the roots. It is present in all perennial and some annual plants. The cells of vascular cambium produce secondary tissues after division.

**Cork cambium** is also referred as **phellogen**. They are found in the bark of roots and stems of woody plants where they produce cork cells. The cork cambia originate just under the epidermis of the primary body. In some trees they are produced as long cylinders running parallel to the vascular cambium.

## 2.4 INTERCALARY MERISTEM

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It lies between the region of permanent tissues and is considered as a part of primary meristem which has become detached due to formation of intermediate permanent tissues. It is found either at the base of leaf or at the base of internodes. In *Pinus* it is located at the base of leaf but in grasses it is located at the base of internode. The intercalary meristems help in increasing the length of the internode. Grasses have intercalary meristems located along the stems near the nodes. Cell divisions in this tissue push the stem upward. Monocots do not possess lateral meristems. Hence in these plants, the lateral increase in size is the result of primary tissue cell enlargement but not cell division.

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### SAQ 1

Differentiate between the following:

- Root and Shoot apical meristem.
  - Vascular and Cork cambium.
  - Apical, Lateral and Intercalary meristems.
-

## 2.5 THEORIES OF ROOT APICAL ORGANISATION

All the cells in a given primary root owe their origin to these cells which constitute the so called root apical meristem. The cell(s) present in the meristem are termed as initial(s). Since they are localized in root apices, they are referred to as root-apical initials. Though, all roots are characterized by the presence of such initials, yet their number, location, placement and mode of function are not fully understood. All plant species do not necessarily possess exactly similar root apical structure. A large diversity is recorded in this context. Many attempts have been made in the past to provide an insight into the organisation of root apex.

The meristem of the primary root gets differentiated in the embryonic radical. The cells present in the root apical region are densely cytoplasmic with large nuclei. They are undifferentiated and undergo active division. The mature tissues of the root are derived from these cells or initials. The root apex at the tip is enclosed within the structure called root cap. The apical meristem in root is subterminal in position. This meristem is not associated with the formation of lateral appendages. The meristem does not undergo any rhythmic changes in shape and size of the root apex. The root cap occupies the terminal position (Fig. 2.2). The three tissue systems namely epidermis, cortex and vascular cylinder are located behind the root apex.

Different theories have been proposed by several workers to depict the structure and functional organisation of the root apical meristem. We will now discuss a few of such works.

### 2.5.1 Apical Cell Theory

In roots of certain vascular cryptogams (Example- *Equisetum*, *Ophioglossum*, *Dryopteris*) only a single tetrahedral apical cell is present (Fig. 2.3 a). It is suggested that all the cells in a root are derived from it. This forms the basis of **apical cell theory**. Apical cell theory was proposed by **Hofmeister** (1852) and supported by **Nageli** (1859). A single apical cell is the structural and functional unit. According to this theory a single tetrahedral shaped apical cell has been noted in number of vascular cryptogams. The divisions in the apical cell give rise to tissues of the root. The upper portion of the apical cell gives rise to the tissues forming the body of the root while the lower or the basal side of the apical cell forms the root cap. This concept was not accepted because unlike the presence of a single cell initial in cryptogams, there are infact, a group of apical cells in flowering plants.

### 2.5.2 Histogen Theory

This theory was proposed by **Hanstein** in 1868. He postulated the existence of three cell-initiating centres or regions which he termed as **histogens**. He suggests the existence of layers of meristems or histogens in the root apex. These include **dermatogen**, **periblem** and **plerome**. Each layer has a specific function. The dermatogen gives rise to epidermis, periblem gives rise to cortex while plerome forms the vascular cylinder of the mature root (Fig. 2.2). Later on **calypetrogen** was designated as the fourth histogen. This histogen played a role in formation of root cap. Later on Haberlandt in 1914 proposed the names **protoderm**, **ground meristem** and **procambium** for dermatogen, periblem and plerome respectively.

Several other workers also described the root apex in terms of layer of initial cells or histogens. **Schüepp** in 1926 divided the root apical meristem into different zones on the basis of cellular configuration. These include **type A** - all tissues of the root apex including root cap are derived from a single apical cell as noted in vascular cryptograms; **type B** - there are two group of initials. One that give rise to vascular cylinder and the other group forms the cortex, epidermis and root cap. In **type C** - poorly organized initials give rise to vascular cylinder, cortex and root cap, and **type D**- three groups of initials give rise to vascular cylinder, cortex, epidermis and root cap respectively.

**Guttenberg** (1960) proposed that in the root apex, the meristems of different tissue systems are placed at varying distance from the central initial cells. According to him the root apices are of two types- i) **closed type**- in this type the initials of tissues are discrete and lie immediately adjacent to the central cells. Separate initials give rise to vascular cylinder and cortex, while root cap or protoderm may have common or separate initials; ii) **open type**- in this type of meristem, different tissues are at distance from the central cells. Common initials are found for tissue systems except vascular cylinder. Thus in this system, the earlier described types C and D show closed type organization while A and B show open type of organisation.

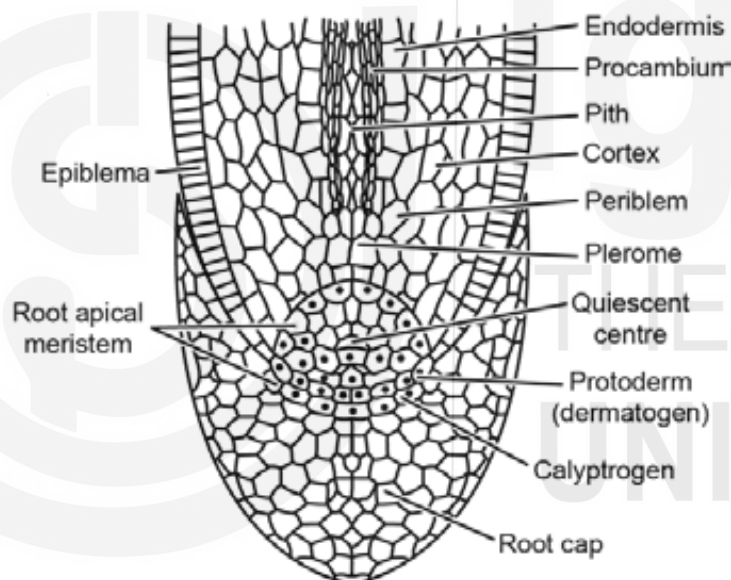


Fig. 2.2: Diagrammatic representation of the root apex.

### 2.5.3 Korper-Kappe Theory

This theory was proposed by **Schüepp** in 1917. He explained the organization of root apex in terms of planes of division. According to him, the cells of the root apex divide in two planes. First cell divides into two by transverse division and then one of the daughter cell divides by longitudinal division. The sequence of division is termed as 'T' division. On the basis of these divisions, two zones Korper and Kappe were differentiated in the root system. In some parts of the root i.e. outer region, the 'T' is straight. After the first horizontal division the daughter cells divide longitudinally. In the inner region, 'T' is inverted (Fig. 2.3 b). The second division takes place in the upper daughter cell. the zone with inverted 'T' type divisions are termed as **Korper** (cap) and those taking place in straight 'T' are termed as **Kappe** (body). In monocotyledons a sharp boundaries between Korper and Kappe has been noted (Fig. 2.3 c).

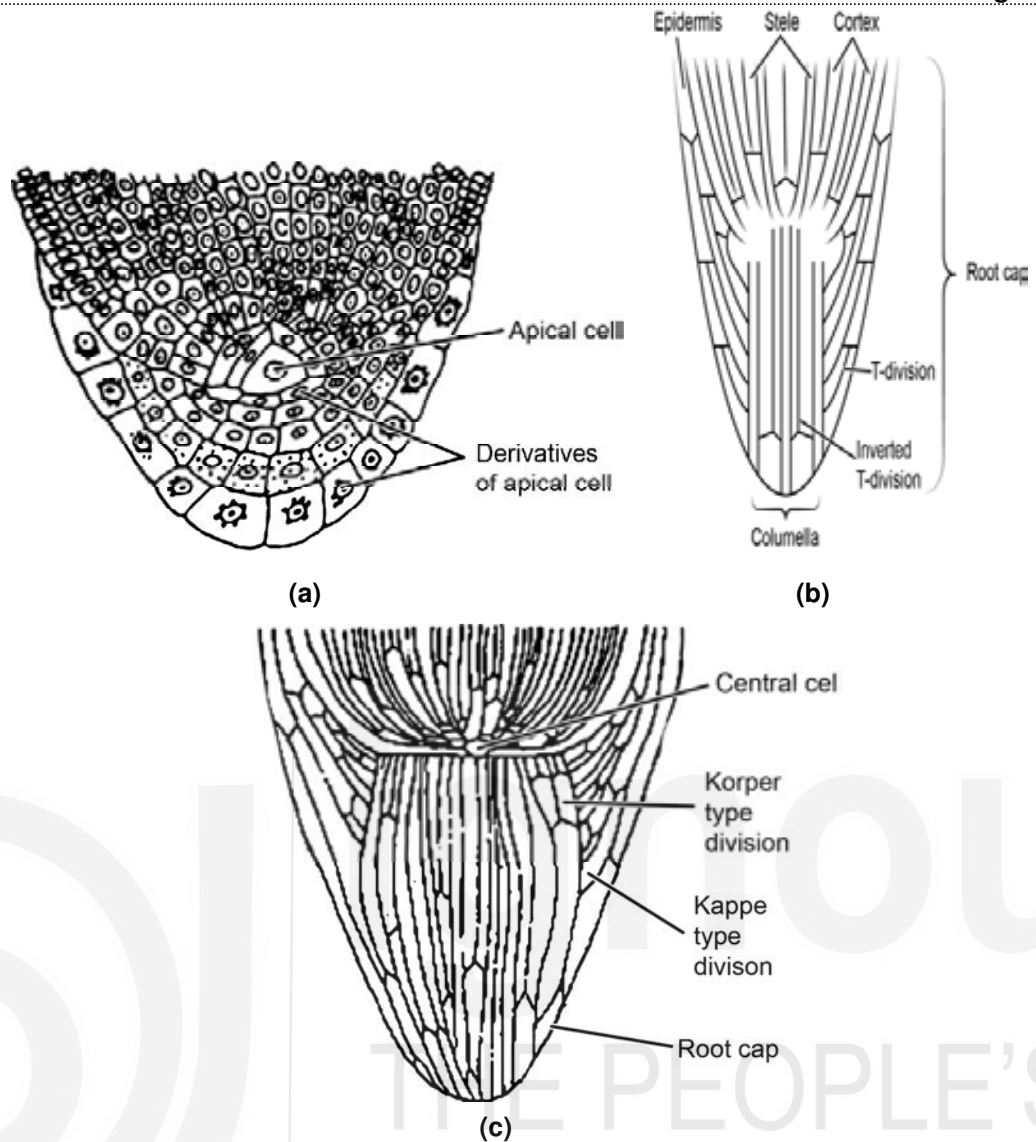


**Fig. 2.3: Representation of root apical meristems** a) Median longitudinal section of the root tip of *Pteris*, showing single apical cell with four cutting faces (one not in plane of section). (Modified from A. J. Eames and L.H. McDaniels, *An Introduction to Plant Anatomy* McGraw - Hill Book Co., Inc., New York); b) T division noted in the root cells; c) Root apex of *Zea mays* in longitudinal section showing pattern of cell lineages, interpreting its organization on Korper-Kappe concept. (Adopted from F.A.L. Clowes, *Endeavour*, 24, 1965).

### 2.5.4 Function of Root Cap and Quiescent Center

#### Root cap

The tip of the root is covered by the group of parenchymatous cells that form the root cap. Root cap occupies terminal position of the root (Fig. 2.4). It protects the meristem and function in regulation of growth, production and secretion of mucilage. The peripheral cells of the root cap secrete mucilage called mucigel thus making outer walls of the root cap are mucilaginous and help to reduce friction between apex of the root and hard soil during root penetration in the soil. It also helps in absorption of water and nutrients.

The root cap originates by the activity of root meristem and consists of centrally positioned longitudinally aligned columella cells and outer peripheral cells. With growth of the root, the root cap cells are pushed through the cap

and eventually sloughed off in great numbers by friction. The columella cells are elongated having dense aggregation of starchy amyloplast that sediment to lower side in response to gravity.

In dicotyledons it arises from same initials which form epidermis while in monocotyledons it arises from separate set of initials. The cells of the root cap become more differentiated as the distance from the root tip increases. If the root cap is removed the cells of the quiescent center divide rapidly to form new root cap.

In open meristem the founder cells in the distal part of the **quiescent center** contribute initials and progeny to the root cap. In closed system, the thick polylamellate wall may accrete (growth or increase by the gradual accumulation of additional layers or matter) between the root and root cap. The root cap does not possess reservoir of cells that replace and rejuvenate its set of initials. Lack of reservoir of cells leads to end of mitosis, endopolyploidy and senescence of the cap followed by damage to the primary root tip. The roots are replaced by secondary roots and fibrous root system gets developed. Monocots generally possess fibrous root system. Woody plants are example of open meristems and distinct caps.

Mitotically active cells of the root apical meristem present in the proximity of the root cap form the region of cell division. Behind this point there is a zone where the cells divide less actively but the rate of expansion or extension increases. The region is referred as the **region of cell elongation** or **radial enlargement** (Fig. 2.4). Another region of maturation comprising of longitudinal cells depicting capacity of tissue differentiation is also evident near the apical meristem. The younger less differentiated cells are present near the root apex while the larger, mature cells are located at distances from the apex. Some workers have shown T divisions in the meristematic cells. The cells divide transversely followed by longitudinal division in one of the daughter cells. Two cells formed by longitudinal division form the progenitor of the longitudinal rows into the root axis and root cap. The upper daughter cells divide longitudinally to form an inverted T. In the cells giving rise to the root cap, the lower daughter cells divide longitudinally to form an upright T.

### Quiescent center

**Clowes** (1956) discovered a central cup like region of cells lying between the root cap and the active meristematic region. **Quiescent center** is referred to hemispherical shaped aggregation of mitotically and metabolically inactive cells positioned just behind the root cap. This is also referred as inactive region of the root (Fig. 2.4). The cells in the zone divide 10 to 20 times slower than the adjacent cells. They do not participate in the formation of mature root tissues. The cells present in this region possess low concentration of DNA, RNA and protein. The cells have less mitochondria, endoplasmic reticulum and dictyosomes. The cells of this region do not synthesize DNA but in some cases may show a slow rate of DNA synthesis and cell cycle. The cells remain arrested in the G1 phase of the mitosis.

This region has been recognized in root tip of large number of plants. It is generally hemispherical in shape and contains several hundred cells.

According to Clowes (1959), the cells of the quiescent center are inactive because of their localization in the apical meristem. The antagonistic direction of cell growth in various parts of the meristem or the presence of rapidly dividing cells around the region could be responsible for the inactivation of the cells of quiescent center. The cells of the quiescent center become active whenever the previous initials are damaged. Thus the center acts as the reservoir of cells resistant to the damage because of their inactive nature. They act as the source of active initials. It has been proposed that when the root cells are exposed to toxic doses of X rays, the meristematic cells stop synthesizing DNA but the cells of the quiescent center become active and synthesize DNA. This is because cells of the quiescent center are resistant to irradiations in comparison to the actively dividing cells.

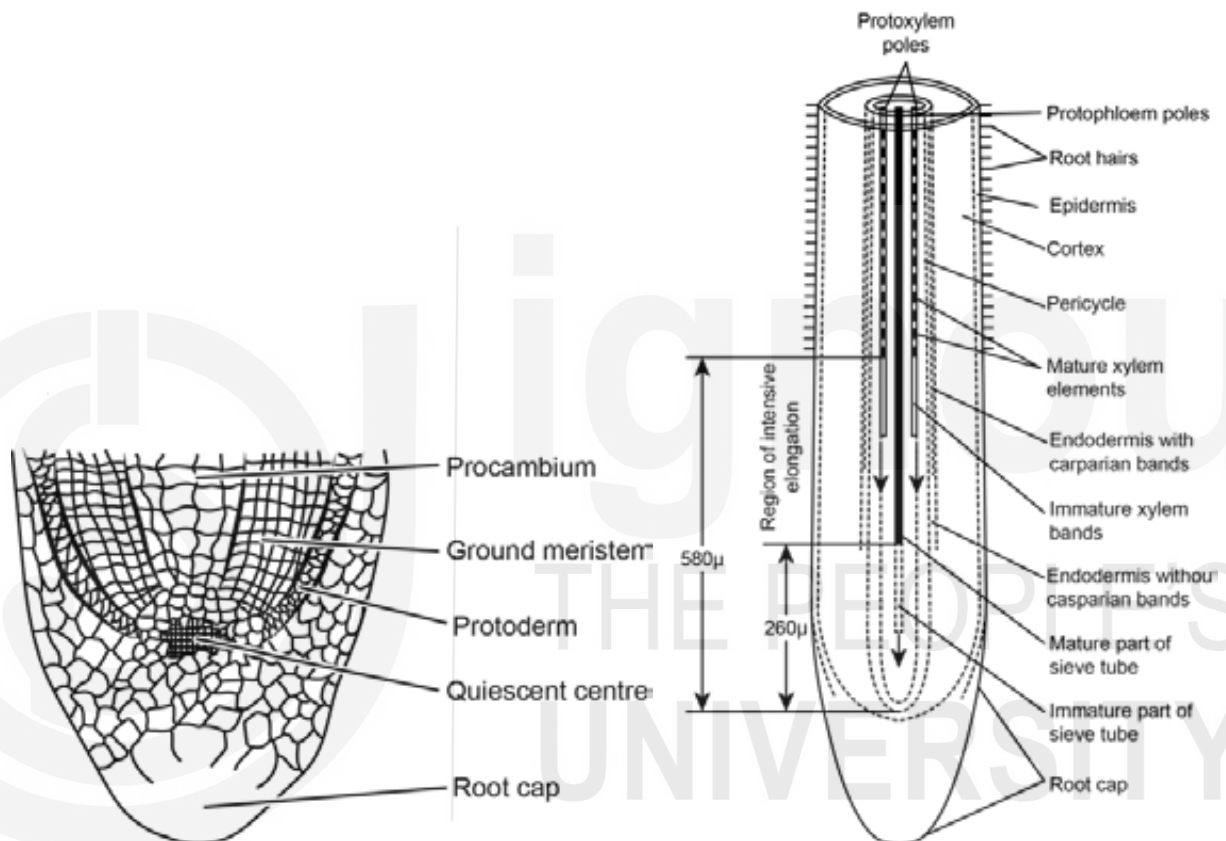


Fig. 2.4: Portion of the root cap showing quiescent center.

### SAQ 2

- a) Answer in one word
- It is located at the terminal position of the shoot.
  - These meristems help in increasing the thickness of the plants. The cells are arranged parallel and normally divide periclinally to give rise to secondary permanent tissues.
  - In roots of certain vascular plants a single tetrahedral apical cell is present which give rise to root tissues.
  - Apical cell theory was proposed by him.
  - In 1868 Hanstein proposed this theory.
  - According to this theory T divisions in the root zone take place.

- b) Write in brief the function of :
- i) Root cap
  - ii) Quiescent center
  - iii) Vascular cambium
- 

## 2.6 THEORIES OF SHOOT APICAL ORGANIZATION

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This meristem occupies terminal position in the shoot i.e. they are located at the apex of shoot. The primary new tissues and plant organs originate from them. It is self determining and autonomous center of the plant. This part lies immediately above the leaf primordia. It is variable in shape and size at different stages of plant development. The shoot apex meristem undergoes rhythmic changes in shape and size before the initiation of leaf primordium. It widens before leaf initiation but becomes narrow after leaf initiation.

The shoot apical meristems are simple structure in vascular cryptogams. The apical cell is pyramidal in shape with three or four faces pointing downward and one face pointing upward forming outer part of the plant. The apical cell divides in an orderly manner (asymmetric division) and produces narrow flat cells. The next division is also asymmetric and small thin walled daughter cells are produced. The process is repeated several times and the packet of cells develop into segments of the shoot.

In seed plants the shoot apical meristem does not show any distinctive cell as in cryptogams. The apical meristem is supposed to be composed of two zones- outer **tunica** and inner **corpus**. They are distinguished from each other on the basis of plane of division. The cells of tunica region divide only with anticlinal walls, walls perpendicular to the surface of tunica. The tunica layer grows as a sheet. When tunica is single layered it is referred as **monostrotose** but when it is two or more layered it is called as **multistratose**.

The corpus is covered over by tunica. The corpus consists of cells which divide in any direction, hence the region can grow in three dimensions. In monocots the periclinal divisions are common in the inner layers of tunica region, while the outer layers undergo anticlinal division.

Several theories have been proposed to explain the organisation and development of shoot apex. There are two views related to shoot apex organization in angiosperms. According to one the apex is a stratified region having distinct cells composed of one or more superficial layers that extend in the meristem region and also enclose subsurface region. The outer cell layers constitute tunica and undergo surface growth. **Tunica** is composed of cells that have a common orientation and undergo anticlinal divisions. In these cells the walls separating the two daughter cells is formed at right angles to the surface. The number of layers comprising the tunica can vary during different stages of development and with the species. Generally the tunica is two –three layered with layers from outside to inside referred as  $L_1$ ,  $L_2$ ,  $L_3$  and so on. The epidermis and the young surface layer are derived from the outer  $L_1$  layer. The inner layers of the tunica give rise to corpus eventually forming the ground

tissue and further differentiation into vascular tissue (Fig. 2.5). The subsurface mass of cells is referred as **corpus**. It undergoes divisions in various planes (anticlinal and periclinal). Because of difference in rate and planes of cell division, the tunica and the corpus regions remain histologically distinct and segregated. The apex maintains a layered organization.

The second interpretation is based on cytologically and histologically defined zones. This is referred as cytohistological zonation and this has been regarded as the fundamental feature of the vegetative shoot apex and is seen during all stages of plant development from embryo to an adult individual.

The boundaries in actively dividing cells have been distinguished on the basis of cell size, shape, degree of vacuolation and plane of cell division. Initial zone called the **central zone** represents a conspicuous group of enlarged initial cells located at the stem apex. The cells undergo less frequent division, possess prominent nuclei and are highly vacuolated. This zone functions as the source of all other cells of the apex. The **peripheral zone** flanking it is derived from the central zone and encircles the apical region. The cells of the peripheral zone are smaller, mitotically active and possess dense cytoplasm. They form the sites of origin of cortex and leaf primordial which arise in ordered ontogenic patterns. The third zone known as the **transition or rib zone** is located at the base of apical meristem. This zone is supposed to arise from the central zone and lies as intermediate region between the initial cells and partially differentiated derivative cells below. The cells in this zone are arranged in longitudinal files as a result of cell division occurring at right angles to the stem axis. The cells of this zone form the central pith of the stem after the cells undergo elongation and expansion. Plants lacking the rib zone possess shortened internodes and congested leaves produced in rosettes.

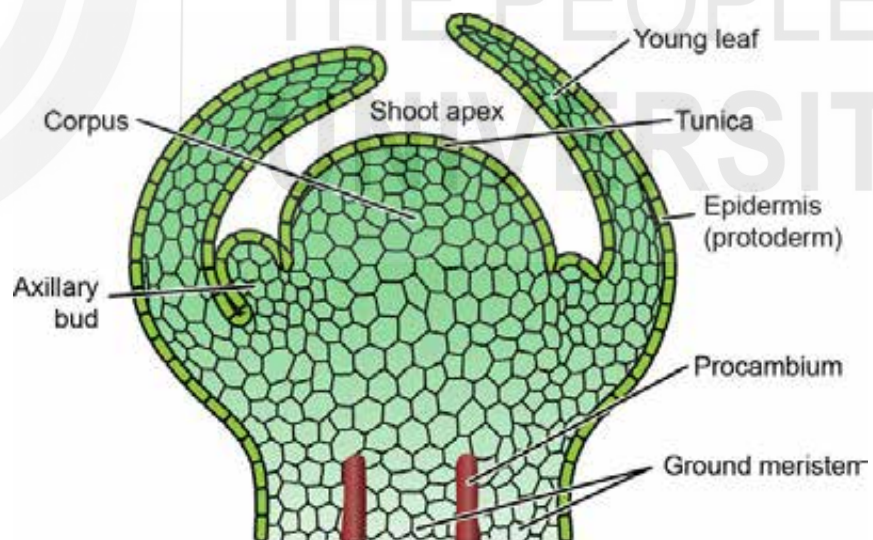


Fig. 2.5: Diagrammatic representation of L.S. of shoot apex.

### 2.6.1 Apical Cell Theory

The theory was proposed by **Nageli** in 1878. It suggests the presence of single tetrahedral apical cell in the shoot apex in most of the vascular cryptograms. According to this theory a single apical cell is the structural and functional unit of the apical meristem. This cell regulates the whole process of growth. This theory holds true for many algae, majority of bryophytes and pteridophytes.

### 2.6.2 Histogen Theory

This theory was proposed by **Hanstein** in 1868. According to this theory, three meristematic zones have been recognized in the shoot apex of the angiosperms. Each layer possesses a unique set of initials and these layers are referred as **histogens** (Fig.2.6). The outermost histogen is termed as **dermatogen**. The middle one is referred as **periblem** while the innermost is called as **plerome**. Each histogen performs a definite function. The dermatogen gives rise to epidermis, the periblem gives rise to cortex while the plerome gives rise to vascular cylinder. Later studies revealed that these histogens have no specific morphological function to perform. The theory failed because in most of gymnosperms and angiosperms these three layers could not be distinguished.

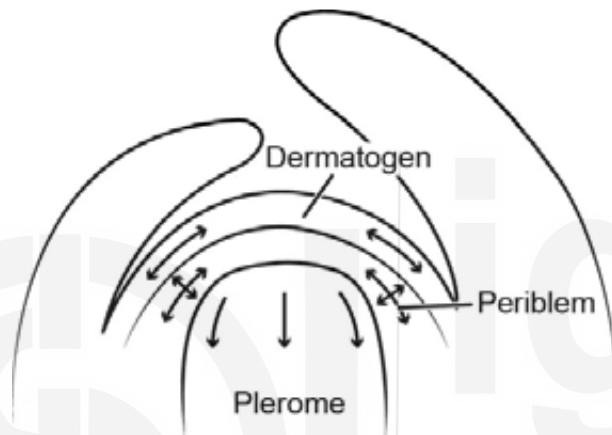


Fig. 2.6: Shoot apex organizations as proposed by Hanstein.

### 2.6.3 Tunica-Corpus Theory

The theory was proposed by **Schmidt** in 1924. The theory proposed that there are two distinct zones occurring in the shoot apex of the angiosperms. The peripheral layer consists of one or more layers of irregularly arranged cells named as **tunica** (Fig. 2.7). The inner core of cells surrounded by tunica form the **corpus**. The two divisions can be distinguished on the basis of plane of cell division. Tunica region comprises of cells characterized by anticlinal division, the cells of the corpus region divide in various planes. This theory does not provide any correlation between layers and formation of tissues. Tunica and corpus layer possess separate initials. These cells are identified by their larger size, vacuolated contents. The number of initials in two zones varies from species to species. The variations in number of tunica layers occurring in different species or even members of same species at different stages of development of shoot apex could result from plastochron periodicity (Schmidt 1924, Reeve, 1942). Hare (1962) noted three to seven layers in the tunica region in *Daphne pseudo-mezerum*. These layers could be attributed to the seasonal growth changes. In some dicotyledonous families such as Malvaceae, Lauraceae the outer layers of the corpus are uniform and resemble those of tunica. The stratified cells that sometimes show periclinal divisions have been considered part of the corpus. Thus the concept become more flexible as the two regions which are treated as morphological entities are subject to fluctuations.

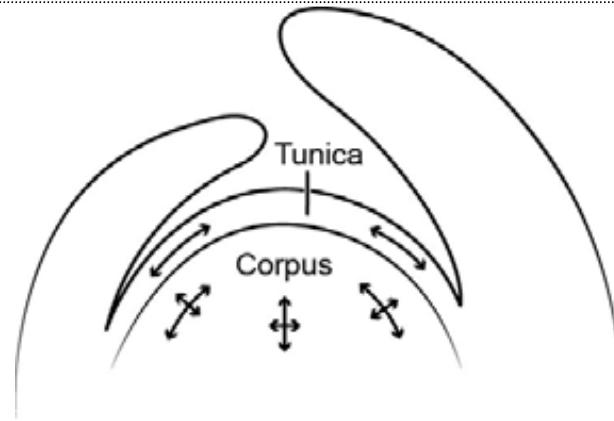


Fig. 2.7: Representation of the shoot apex according to Tunica corpus concept.

### 2.6.4 Tissue Differentiation Theories

The theory was proposed by **Dermen** in 1947. According to this theory the terms tunica and corpus were replaced and referred as **primary histogenic layers**. He recognized three histogenic layers as **L-I**, **L-II** and **L-III** (Fig. 2.8). These three layers exist in various levels of ploidy in the shoot apex. Example- the cells of the L-I may be diploid (2x), those of L-II may be 2x and those of L-III may be 4x. The constitution in terms of ploidy will be 2, 2, 4. The various other combinations such as 2-2-2, 4-2-2, 2-4-4, 4-4-4 and 2-4-2 have also been reported. The epidermis is derived from L-I. The layer L-II forms one to three layered hypodermis in stem or some portion of cortex and vascular tissue in some species. Generally the vascular tissue and pith originate from L-III. This theory has been considered as modified version of Hanstein's theory.

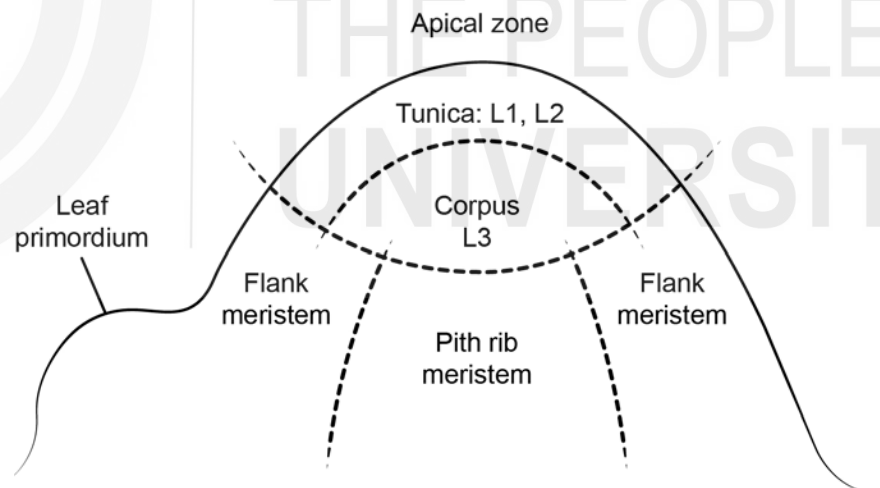


Fig. 2.8: Representation of the shoot apex according to Histogen layer concept.

#### Mantle Core Concept

This concept was proposed by **Popham and Chan** in 1950. They differentiated the shoot apex into two histological zones without considering the plane of division. The **mantle** included the outer layers of the apex and tunica comprised of the layer of cells from mantle which divide anticlinally. The mass of cells surrounding the mantle is called as **core**. Mantle represents the dome-shaped outer layers of the apex, and the core represents the inner cell mass covered by the mantle (Fig.2.9). In this concept the term 'mantle' is used for tunica and the 'core' is used for corpus.

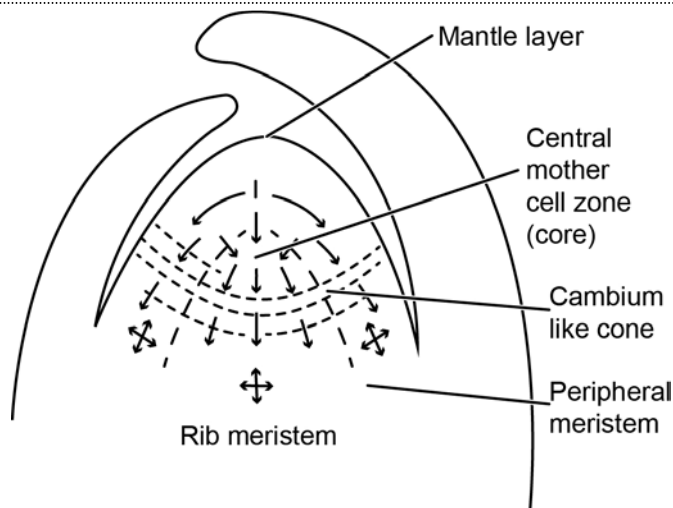


Fig.2.9: Representation of shoot apex according to Mantle-Core concept.

### Promeristem (Primordial Meristem) Theory

It consists of three components that include:

- **Protoderm:** forms the epidermis in stem and piliferous layer in the root. It is located at the outermost layer.
- **Ground meristem:** forms the cortex and the pith. It is located at the centre, (between protoderm and procambium).
- **Procambium:** mainly include primary phloem and primary xylem.

### Anneau initial or *meristeme d'attente* theory

The theory of apical organisation is based on Plantefol's theory of phyllotaxy and put forward by **Buvat** (1952, 1955). The theory was supported by several subsequent French workers. According to this theory, the peripheral and subterminal regions are initiation zones. The distal groups of cells are inert and do not show any histogenic function. The three zones recognised in the apical meristem are **anneau initial** (the peripheral active zone), ***meristeme d'attente*** (the meristem that gets activated during the formation of inflorescence or flower), and ***meristeme medullaire*** (central pith region). These layers show correlation with the tunica and corpus region. The distal inactive zone shows changes in nucleus size, degree of vacuolation, presence of protein, DNA.

The theory became non-acceptable because the centrally situated cells (*meristems d'attente*) have been referred as waiting meristem which was previously considered as apical initials. It has been noted that apices which remain in the vegetative cover show changes in the zonation, functioning and appearance of *anneau initial* and *meristeme d'attente*. These changes occur in the conditions intermediate between the vegetative and reproductive phases.

### Tissue differentiation theory

Three primary meristematic tissues have been recognised in undifferentiated region behind the apical meristem. These undifferentiated tissues are derived from various cell groups or zones of the apex which mature into primary tissues of the shoot. The outermost single layer of cells at the apex is

protoderm and this layer matures into the epidermis of the primary plant body. The procambium also called provascular tissue includes strands of elongated cells that connect to plants mature vascular tissue and differentiate into primary vascular tissues namely primary xylem and primary phloem. Some procambial strands extend into the developing leaf primordium. Procambium has matured into primary xylem and phloem. Some of the procambium also develops into leaf primordium. The remaining cells of the apex form the ground meristem. This meristem is located between the protoderm and procambial strands and fills the center of the axis. It matures into cortex and pith of the plant axis.

### Cytohystological zonation theory

The shoot apex of gymnosperms cannot be interpreted in terms of tunica corpus theory. This is because it does not possess a layer of cells that divide anticlinally. **Foster** (1939) interpreted the shoot apex of *Ginkgo biloba* in terms of certain regions or zones which possess distinct cytological characteristics. These zones have a relationship with the growth processes in the apex. The four growth zones have been recognised by him and are given below:

- **Apical initial group** - this includes group of initials along the apical surface along with some lateral or sub-adjacent derivatives.
- **Central mother cell zone** - This zone lies below the apical initial group and is derived from it. The distal group of cells is lightly stained, vacuolated and show slow activity. The primary walls of the central mother cells are thick walled and pitted.
- **Rib meristem** - It consists of centrally located central mother cells and give rise to pith. The cells are vacuolated and divide transversely to form vertical files. This zone is also called as file or pith meristem.
- **Peripheral meristem (flank meristem)** - This zone originates from the lateral derivatives of the apical initials and partly from the central mother cells. The cells are densely stained and mitotically active. The activity of this zone leads to the formation of leaf primordium (Fig. 2.10). The periclinal divisions in this zone cause elongation of the shoot while anticlinal divisions increase the width.

The four zones are morphologically and biochemically distinct. This type of zonation has been noted in number of angiosperms. The shoot apices of angiosperm exhibit cytohystological zonation in addition to tunica corpus zonation.

### Four zones are recognised namely:

- i) **Tunica initials**-that consist of an apical group of cells,
- ii) **Corpus initials**-those occur below apical initials and are similar to central mother cells,
- iii) A **peripheral zone**, and
- iv) A **rib meristem** (Fig. 2.10).

Tunica initials contribute cells to central mother cell zone and to peripheral meristem. The central mother cell zone donates cells to the rib meristem and pith. The peripheral meristem is highly meristematic and leaf primordia originate from this layer.

In addition, Popham and Chan (1950) described a fifth zone occurring just below the leaf primordium. It is cup shaped and located between the central mother cells, rib and flank meristem. It is called as cambium like zone. It is not a universal feature but is reported in few species such as *Livistona*, *Bellis perennis*, *Chrysanthemum morifolium* and *Ricinus communis*. This zone is short lived and develops during the mid plastochron and disorganizes.

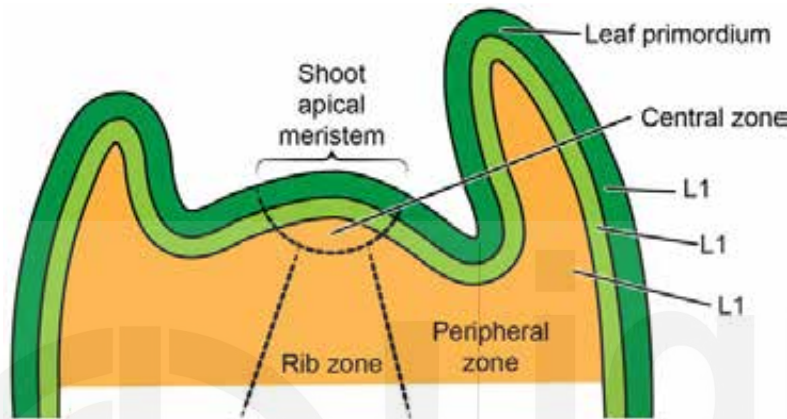


Fig.2.10: Shoot apices of angiosperm showing cytohistological zonation.

### SAQ 3

- a) Fill in the blanks.
  - i) In shoot apex organization the peripheral layer consists of one or more layers of irregularly arranged cells forming the ..... region.
  - ii) ..... meristem is located on the lateral side of the stem and root.
  - iii) The fourth histogen which produced root cap in monocots is known as .....
  - iv) ..... layer of shoot apex forms the base of the epidermis.
  - v) Terminal position in the root is occupied by .....
- b) Define the following terms:
  - i) Tunica
  - ii) Corpus
  - iii) Mantle
  - iv) Protoderm
  - v) Dermatogen

- c) Fill in the blanks.
- i) In shoot apical meristem the inner zone is known as .....
  - ii) When tunica zone is made up of two or more layers of layers it is called .....
  - iii) The third zone located at the base of apical meristem is known as .....
  - iv) Unique set of initials present in the layers are referred as .....
  - v) Popham and Chan in 1950 proposed the ..... concept.
- 

## 2.7 SUMMARY

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- Apical meristems are located terminally in plants i.e. growing tips of root and shoot. All the primary tissues originate from this meristem. Lateral meristem is present on the lateral side of the stem and root. These meristems lie between the regions of the permanent tissue and give rise to secondary permanent tissues. These meristems help in increasing the thickness of the plants. Example- vascular cambium and cork cambium.
- Intercalary meristem lies between the regions of permanent tissues. It is found either at the base of leaf or at the base of internodes. This meristem increases length of the internode.
- The root apical meristem is subterminal in position. The cells present in the region are densely cytoplasmic and undergo active division. The mature tissues of the root are derived from these cells or initials. The root apex is enclosed within the structure called root cap.
- Different theories have been proposed by several workers to depict the structure and organization of the root apical meristem. The apical cell theory proposed by Nageli (1858) suggests that divisions in a single apical cell give rise to root in vascular cryptogams. The upper side of the apical cell gives rise to body of the root while the basal helps in root cap formation. In flowering plants, a group of initials participate in the formation of the root structure. Histogen theory proposed by Hanstein (1868) suggests the existence of three layers of meristems (or histogens) in the root apex. The dermatogen gives rise to epidermis, periblem gives rise to cortex while plerome forms the vascular cylinder of the mature root. Haberlandt (1914) proposed the names protoderm, ground meristem and procambium for these three layers. Later on Schüepf (1917) proposed that root apex is organized in terms of planes of division i.e. kooper-kappe theory concept of root apex organization.
- Root cap occupies terminal position in the root. In dicotyledons it arises from initials that give rise to epidermis. A central cup like region of cells lying between the root cap and the active meristematic region. The cells present in this region possess low concentration of DNA, RNA and protein. The cells of this region do not synthesise DNA. This inactive region of the root is called as quiescent center.

- Shoot apical meristem is located at the terminal position of the shoot. It lies immediately above the leaf primordium. Several theories have been proposed to explain the mode of development of shoot apical meristem. **Apical cell theory** proposed by Nageli (1878) suggests presence of single tetrahedral apical cell in the shoot apex in most of the vascular cryptogams. **Histogen theory** proposed by Hanstein (1868) recognises presence of three meristematic zones in the shoot apex of angiosperms. Each layer possesses a unique set of initials and these layers are referred as histogens. The outermost histogen is dermatogen, middle one is referred as periblem while the innermost is called as plerome. Each histogen performs a definite function. The dermatogen gives rise to epidermis, the periblem gives rise to cortex while the plerome gives rise to vascular cylinder. The theory failed because in most of gymnosperms and angiosperms these three layers could not be distinguished.
- Tunica-corporis theory proposed by Schmidt (1924) suggests the presence of two distinct zones in the shoot apex of angiosperms. The peripheral layer consists of one or more layers of irregularly arranged cells named as **tunica**. The inner core of cells surrounded by tunica form the **corpus**. The two zones can be distinguished on the basis of plane of cell division. Tunica region is comprised of cells characterized by anticlinal division, the cells of the corpus region divide in various planes. The concept becomes non-acceptable because of fluctuations.
- Popham and Chan (1950) introduced the **mantle-core hypothesis**. The mantle included the outer layers of the apex and tunica comprised of the layer of cells from mantle which divide anticlinally. The mass of cells surrounding the mantle is called as **core**.

## 2.8 TERMINAL QUESTIONS

1. Describe in brief the main points of the root apex organization according to Histogen theory.
2. Elaborate the tunica corpus organization of shoot apex in plants.
3. Enlist the salient features of *anneau* initial or *meristeme d'attente* theory.

## 2.9 ANSWERS

### Self-Assessment Questions

1. a) **Shoot apical meristem** - It is located at the terminal position of the shoot. The cells in the region divide continuously to form new tissues and organs. This part lies immediately above the leaf primordium. It is variable in shape at different stages of plant development. It is usually radially symmetrical and appears to be more or less convex in a median longitudinal section.  
  
**Root apical meristem** - It is located at the apex of the root. It is subterminal in position. The mature tissues of the root are derived from these cells or initials. The root apex is enclosed within the structure called root cap.

- b) **Vascular cambium** - It is a lateral meristem that extends throughout the length of the plant from the tips of the shoots to the tips of the roots. The cells of vascular cambium produce secondary tissues after division. It is present in all perennial and in some annual plants.

**Cork cambium (phellogen)** - They are found in the bark of roots and stems of woody plants and produce cork cells. In trees they are produced as long cylinders running parallel to the vascular cambium.

- c) **Apical meristem** - These are located at the apices or growing points/tips of root and shoot. All the primary tissues originate from this meristem. Cell divisions and subsequent cell enlargement in these areas lengthen the above and below ground parts of the plant.

**Lateral meristem** - The meristem lies on the lateral side of the stem and root. The cells are arranged parallel and normally divide periclinally or radially and give rise to secondary permanent tissues. These meristems help in increasing the thickness of the plants. The vascular cambium and the cork cambium are good examples of this meristem.

**Intercalary meristem** - It is found either at the base of leaf or at the base of internodes. It lies between the regions of permanent tissues. It helps in increasing the length of the internode. Grasses have intercalary meristems located along the stems near the nodes.

2. a) i) shoot apical meristem  
 ii) lateral meristem  
 iii) apical cell theory  
 iv) Hofmeister (1852)  
 v) Histogen theory  
 vi) Korper-Kappe theory
- b) i) **Root cap** : Root cap occupies terminal position in the root. If the root cap is removed the cells of the quiescent center divide rapidly to form new root cap. The outer walls of the root cap are mucilaginous and help to reduce friction between apex of the root and hard soil during root penetration in the soil.
- ii) **Quiescent center** : A central cup like region of cells lying between the root cap and the active meristematic region is referred as quiescent center. The cells present in this region possess low concentration of DNA, RNA and protein. This is inactive region of the root since the cells of this region do not synthesise DNA. This region has been recognised in root tip

of large number of plants. It is generally hemispherical in shape and contains several hundred cells. The cells of the quiescent center become active whenever the previous initials are damaged. Thus the center acts as the reservoir of cells resistant to the damage because of their inactive nature.

- iii) **Vascular cambium** : This tissue extends throughout the length of the plant from the tips of the shoots to the tips of the roots. It is present in all perennial and in some annual plants. The cells of vascular cambium produce secondary tissues after division.

3. a) i) tunica

ii) lateral

iii) calyptrogens

iv) dermatogens

v) root cap

b) i) **Tunica** : It is zones occurring in the shoot apex of the angiosperms. The peripheral layer consists of one or more layers of irregularly arranged cells named as tunica. Tunica region comprises of cells characterized by anticlinal division

ii) **Corpus** : It is a zone of cells occurring in the shoot apex of the angiosperms. The inner core of cells surrounded by tunica form the corpus. The cells of the corpus region divide in various planes.

iii) **Mantle** : It is one of the histological zones of the shoot apex. The mantle included the outer layers of the apex and tunica comprised of the layer of cells from mantle which divide anticlinally.

iv) **Protoderm** : It is one of the three meristematic zones or histogens recognized in the shoot apex of the angiosperms. Each layer possesses a unique set of initials. Protoderm is the outermost layer forming the epidermis in stem.

v) **Dermatogen** : It is one of the three meristematic zones or histogens recognised in the root apex of the angiosperms. Each layer possesses a unique set of initials. The dermatogen is the outermost layer that gives rise to epidermis of the mature root.

c) i) corpus

ii) multistratose

iii) transition or rib zone

iv) histogens

v) Mantle core

## Terminal Questions

1. Histogen theory was proposed by Hanstein in 1868. The theory suggests the existence of three layers of meristems or histogens in the root apex. These include dermatogens, periblem and plerome. Each layer has a specific function. The dermatogen gives rise to epidermis, periblem gives rise to cortex while plerome forms the vascular cylinder of the mature root. Later on **calyptragen** was designated as the fourth histogen which produced root cap in monocots. Later on Haberlandt in 1914 proposed the names protoderm, ground meristem and procambium for these three layers respectively.
2. According to Schmidt (1924), two distinct zones occur in the shoot apex of the angiosperms. The peripheral layer consists of one or more layers of irregularly arranged cells named as tunica. The inner core of cells surrounded by tunica form the corpus. The two divisions can be distinguished on the basis of plane of cell division. Tunica region is comprises of cells characterized by anticlinal division, the cells of the corpus region divide in various planes. Tunica and corpus layer possess separate initials. These cells are identified by their larger size and vacuolated contents. The number of initials in two zones varies from species to species. The variations occur in number of tunica layers occurring in different species or even members of same species at different stages of development of shoot apex. Three to seven layers in the tunica region has been noted in *Daphne pseudo-mezerum*. These layers could be attributed to the seasonal growth changes. In some dicotyledonous species such as Malvaceae, Lauraceae the outer layers of the corpus are uniform and resemble those of tunica.
3. The theory of apical organization is based on Plantefol's theory of phyllotaxy and put forward by Buvat (1952, 1955). According to this theory, the peripheral and subterminal regions are initiation zones. The distal group of cells is inert and does not show any histogenic function. The three zones recognised in the apical meristem are **aaneau initial** (the peripheral active zone), **meristeme d'attente** (the meristem that gets activated during the formation of inflorescence or flower), and **meristeme medullaire** (central pith region). These layers show correlation with the tunica and corpus region. The theory became non-acceptable because the centrally situated cells (*meristeme d'attente*) have been referred as waiting meristem which was previously considered as apical initials. Several other workers have shown that central *meristeme d'attente* is capable of dividing actively and giving rise to a vegetative shoot under certain conditions.

# UNIT 3

## ROOT|

### Structure

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|     |                           |     |                    |
|-----|---------------------------|-----|--------------------|
| 3.1 | Introduction              | 3.4 | Specialised Roots  |
|     | Objectives                |     | Food Storage Roots |
| 3.2 | Root                      |     | Aerial roots       |
|     | Structure of Root         |     | Pneumatophores     |
|     | Primary Tissue in Root    |     | Mycorrhiza         |
|     | Origin of Lateral Root    | 3.5 | Summary            |
|     | Dicot and Monocot Root    | 3.6 | Terminal Questions |
| 3.3 | Secondary Tissues in Root | 3.7 | Answers            |

### 3.1 INTRODUCTION

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You have already known that the primary vascular body of a plant develops from an embryo. The embryo has at its opposite poles two growing points: root apical meristem and shoot apical meristem. When a seed germinates, these meristems of the embryo contribute to the establishment of root and shoot system respectively. You have also studied in unit 2 of this course that when these meristems produce new cells, they grow, differentiate and mature into a variety of tissues which are collectively termed as primary tissue.

In certain groups of vascular plants such as dicotyledons and gymnosperms certain secondary tissues, structures replace the primary tissues. These secondary tissues, unlike the primary ones, owe their origin to secondary meristems, the vascular cambium and cork-cambium.

The organisation, development of various kinds of tissues in root and shoot systems of a plant are well coordinated.

Principally, the root system of a terrestrial vascular plant anchors the plant to soil, and takes up water and minerals from it. It also helps in the transfer of the metabolites biosynthesized by aerial parts of the plant to the underground tissues and organs.

In this unit, you will study the organisation, structure, origin and arrangement of various kinds of tissues that makes up a root. You shall also study the functional attributes of various kinds of tissues of both primary and secondary roots and study how an organ modifies its structure to carry out specific function and/or to adjust to the environmental needs.

## Objectives

After studying this unit you would be able to :

- ❖ identify the primary tap root system and adventitious fibrous root systems;
- ❖ know and describe the internal cellular tissue (anatomy) of primary roots and correlate the patterns of placement of various tissues in a root to the functional ability of the organ;
- ❖ know about the origin and functions of lateral roots;
- ❖ comprehend and describe the origin, development of secondary tissues in a root; and differentiate between primary and secondary tissue of a root;
- ❖ recognise and identify the differences between the structures of a dicotyledonous and a monocotyledonous root; and
- ❖ appreciate the close relationship between structure and function and adaptability especially in reference to specialized roots.

## 3.2 ROOT

The body of any primary mature root consists of various kinds of cells types organised into a variety of tissue systems. From where do these cells and tissues arise?

They all are products of some apical meristem located at the terminal, distal, apical end of every primary root axis. Following the cell division of root apical meristem (RAM) cells, the majority of new cells differentiates and matures into the cells, tissue that make-up the primary root. This activity of transformation of RAM into mature tissue system(s) can be observed through various zonations just proximal to the root apex.

The root is usually located in the lower portion of the plant axis. It is generally grows and develops under the surface of soil. The roots are involved in the uptake of water and mineral nutrients, food storage and anchorage. They are present in all vascular plants except the group *Psilotales* (Pteridophyta, the non-seed bearing vascular plants), the plants of which are root less, they are also absent in members of the family Podostemaceae. Many parasitic angiosperms are rootless. The first root of a plant develops from the radicular portion of the embryo. This constitutes the **primary root**. The mature portion of this root produces **lateral roots**. This process is repeated a number of times to produce a **root system**. The primary root is also referred to as **tap root** (Fig. 3.1 a), and is characteristic of **gymnosperms** and **angiosperms**. In monocotyledonous plants the primary root stops growing soon after it is formed and additional roots develop from the hypocotyls and the stem. Such roots and any other roots which develop from regions other than the radicle of the embryo are called **adventitious roots**. Such a root system forms a **fibrous root system** (Fig. 3.1 b). All kinds of roots whether primary, lateral, or adventitious, however, possess a similar structural plan. Figure 3.1 provides a schematic view of various roots. This structure is basic primary and prior to any secondary growth, if any, taking place in a root. Let us study more about it.

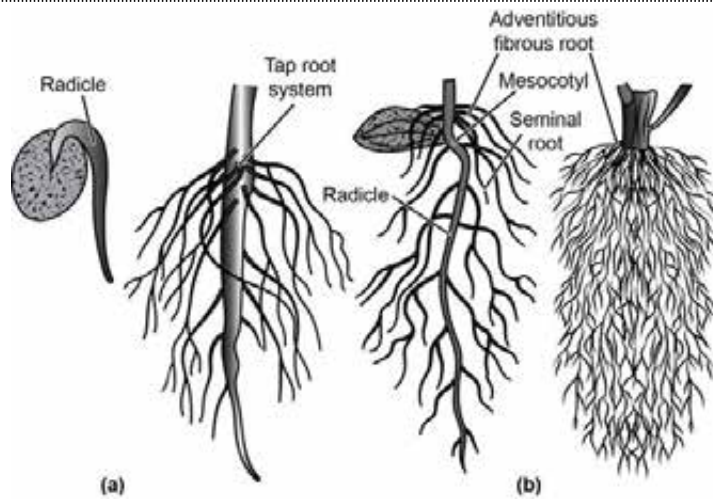


**Fig. 3.1: Development of root systems. a) Germinating dicot seed with growing radical which develops into a tap root system; b) A rice seedling develops extensive fibrous adventitious root system.**

### 3.2.1 Structure of Root

The body of any primary mature root consists of various kinds of cell types organised into a variety of tissue systems. From where do these cells and tissue arise? They all are products of RAM located at the sub-terminal, apical or distal end of every primary root axis.

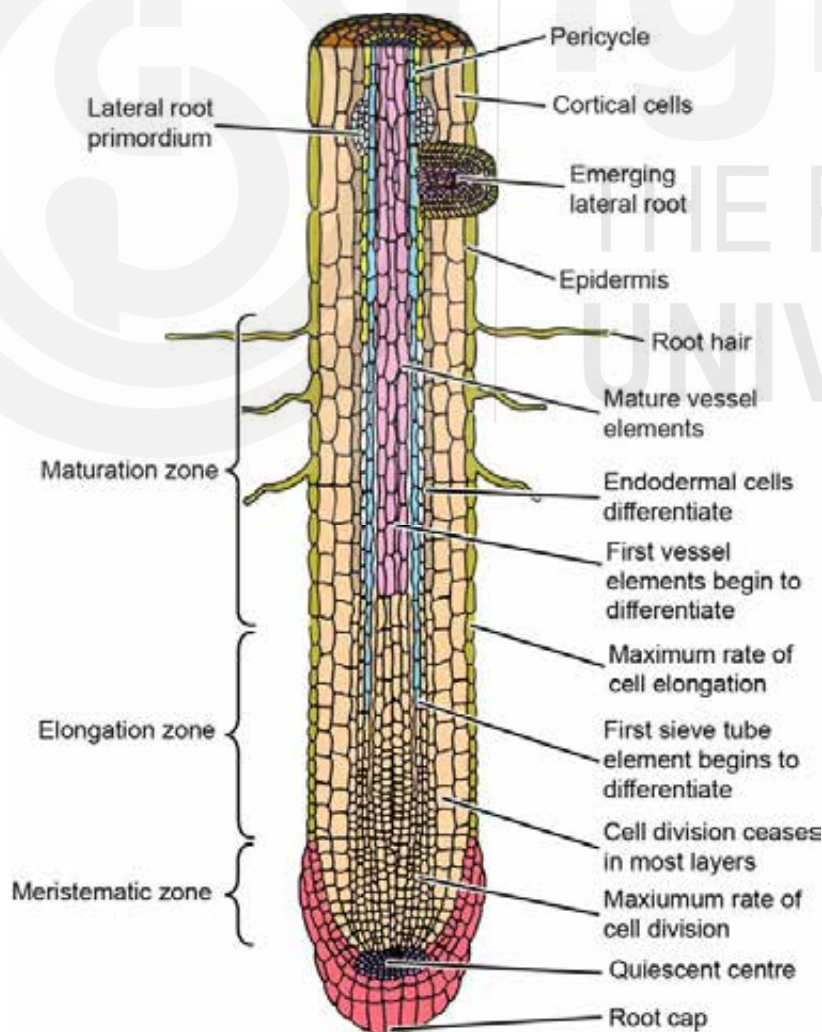


**Fig. 3.2: Diagrammatic representation of various zones and tissue in a developing root (adapted from Easu, Plant Anatomy, 1964).**

Following the cell divisions of RAM cells, some (in fact majority of them) differentiate and mature into the cells, tissues that make-up the primary root. This activity of transformation of RAM products into mature tissues can be observed through various zonations just proximal to the root apex.

We shall discuss the following zones of a root apex in some details. These are: root cap; region of cell division; region of elongation and region of maturation.

The root structure, especially the zonation can best be understood by looking at a longitudinal section passing through apical region (see Fig. 3.2). The various zones that one can demarcate are **root cap**, **region of cell division**, **region of elongation** and **region of maturation**.

### Root Cap

The root apex is enclosed partly within a fully differentiated, mature and multicellular structure called root cap. It occupies most distal position of any root. The cells of root cap are living parenchyma cells which often contain starch grains, and exhibit irregular placement. Whenever the central cells of root cap form distinct and constant structure, they are termed as **columella**.

Root cap protects the root promeristem and aids in the penetration of growing roots into the soil. The root cap cells of certain plants can be removed. Such roots, without their caps, show erratic geotropic responses. It is, therefore, inferred that the root cap controls the geotropic growth of the root.

The cells of root cap are rich in certain solid cell inclusions; termed as statoliths (see Fig.3.3). These are principally starch grains enclosed in amyloplast envelopes. Such cells are called **statocytes** or **statocysts**. It is suggested that statoliths transmit gravitational stimuli to the plasmalemma of the statocytes.

The life span of root cap cells is very short. The outer most cells die, separate, disintegrate and are replaced by new cells almost continuously. New cells are produced by root apical initials. In maize (*Zea mays*), roots kept in water at 23 °C, 3000-7000 cells are produced and sloughed off every 24 hr.

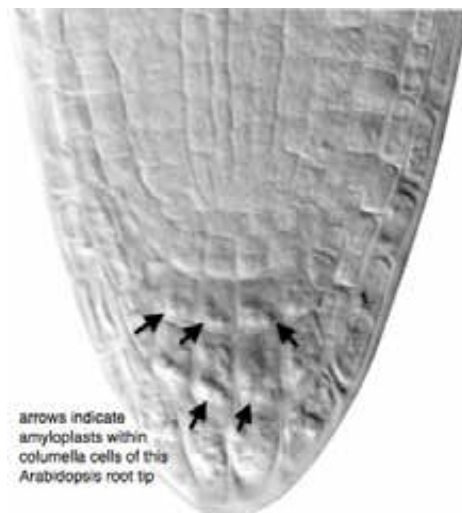


**Fig 3.3 : Amyloplasts in *Arabidopsis* root tip.**

The root cap though characteristic of most roots, is absent in roots of some parasitic and some mycorrhizal roots. In water plants root cap cells degenerate early.

### Region of Cell Division

The cells in the different regions of the root apex divide at different rates. In many roots, the maximum mitotic activity occurs some distance behind the promeristem. Roots may show diurnal periodicity in mitotic activity. In *Melilotus*, mitosis was most frequent at noon and at midnight.

Since root tips show extensive and maximum cell division activity, our knowledge of mitosis in plants is based on the study of this zone of root tips.

### Region of Elongation

Activity in the cells proximal to promeristem and in the region of cell division results in the elongation of root. The cells of this region show distinct vacuolation and decreased mitotic activity. The region is active in absorption of water and minerals from the soil and, hence, is also termed as region of absorption.

### Region of Maturation

This region lies proximal to the region of elongation, and its cells lose their divisional capacity. The various tissues with which one associates a root are present in this and beyond this zone.

### 3.2.2 Primary Tissue in Root

In the root three primary tissue zones can be recognised. They are: **epidermis**, **ground tissue**, and **vascular tissue** (see Fig. 3.4).

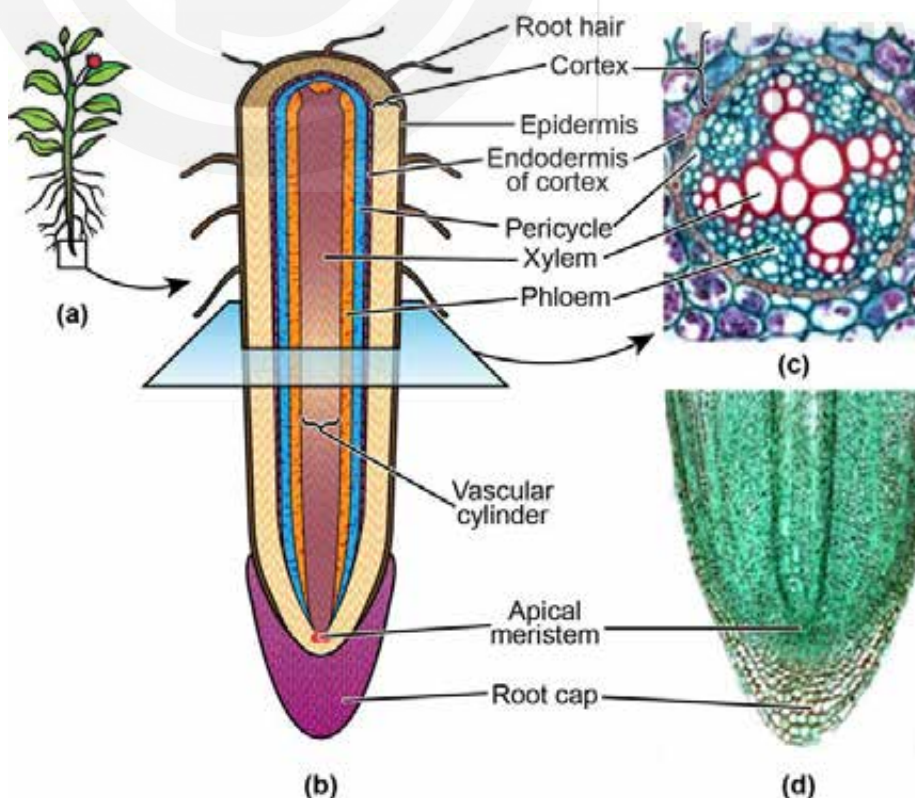


Fig. 3.4: Primary tissues in root.

**Epidermis** : Epidermis is the outermost layer of the primary root. Its cells in the short-lived roots are generally thin-walled. They become thick or even lignified if the epidermis persists for long or when the roots get exposed to the air. The epidermis is usually single layered but in certain aerial roots (e.g. in Orchidaceae and some epiphytes) it could be multilayered and is referred to as **velamen** (see Fig. 3.5).

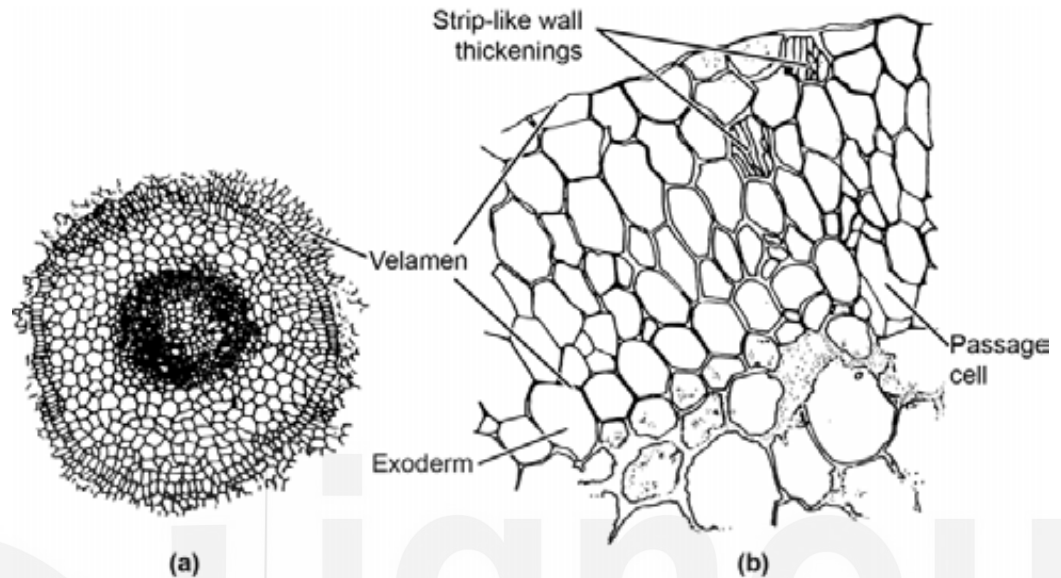


**Fig. 3.5: a) C.S. of the aerial root of an epiphytic orchid showing the presence of velamen; b) A portion of velamen, enlarged.**

Dittmer (1937) estimated 10,000,000,000 root-hair on a single mature rye plant in moist soil or even in humid air.

**Root Hair** : The epidermis of the root is characterised by the development of single-celled outgrowths, the root-hair. They are never formed close to the apical initials. The root-hair rich zone of epidermis is some distance away from the apical initials. Root hair initial is small and as it begins to bulge outward, (Fig. 3.4) its nucleus and almost all the cytoplasm migrates into it. The root hair grows by depositing wall material at the tip and the region closer to the root does not elongate. There is a giant central vacuole, and majority of the cytoplasm forms an extremely thin layer next to wall. If the hair runs into a small soil particle, it may grow in two directions around it, becoming forked. Some desert plants produce more hairs when the soil is dry than when it is moist.

Older portions of roots have never been found to produce root hair.

The function of root hair is not to absorb material directly but rather facilitate absorption by the regular epidermal cells; that is, the presence of root hair greatly alters the environment immediately adjacent to the root-the rhizosphere.

In older parts of the root they die and dry out. The root epidermis of water plants generally lacks root hair. The root hairs are short-lived except in roots which lack secondary-thickening/or in those roots which do not develop periderm.

All the cells of root epidermis do not develop into hair. It is not always possible to distinguish the initials which are destined to differentiate as root hair from the ones which do not do so. However, in *Phleum*, *Hydrocharis*, and *Raphanus*, it is very easy to recognize root-hair initials. Such cells are termed as **trichoblasts**.

**Ground Tissue** : The portion of the root inner to epidermis and outer to the vascular cylinder constitutes the cortex which is multilayered. In dicotyledons and gymnosperms the cortex is mainly parenchymatous. In many monocotyledons, however, where the roots are long-lived, much sclerenchyma develops. Such sclerenchyma occupies peripheral layers.

The innermost layer of the ground tissue develops and differentiates as **endodermis**. The endodermis plays an important role in the lateral transport of water from the cortex to the stele of the primary root. The radial and tangential cell walls of the endodermal cells are deposited with hydrophobic suberin deposits in the form of casparian strips. Certain cells in this layer of endodermis are, however, devoid of such thickenings and depositions. Such cells are called **passage cells**. These passage cells are smaller in size than the adjacent endodermal cells. The number of passage cells in an endodermal ring is variable. However, they are more likely to be located just opposite to the protoxylem elements as seen in a cross section of a primary root.

### 3.2.3 Origin of Lateral Root

#### Origin of Lateral Roots

The primordia of lateral roots are generally formed in the pericycle. The endodermis may also participate in the formation of such primordium e.g., in ferns and other pteridophytes. The origin of lateral roots is thus **endogenous** i.e. from deeper tissues (Fig. 3.6).

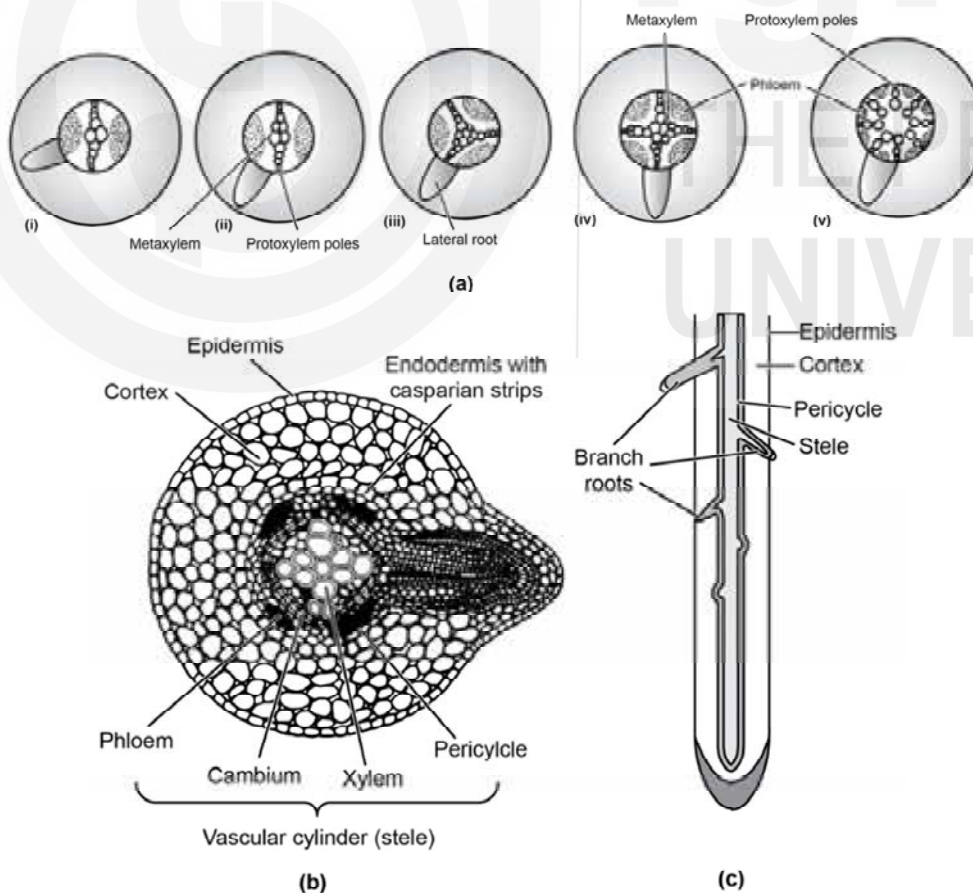


**Fig 3.6:** a) Radial arrangement of vascular tissue in roots as seen in cs. a) (i & ii) Diarch, (iii) Triarch, (iv) Tetraarch, (v) Polyarch; b) the specific region from where lateral root originates; and c) A schematic view of primary and lateral root showing endogenous origin.

The cells of the pericycle initially divide periclinally (i.e, new cell walls are formed parallel to the surface of the root). Further cell divisions are both periclinal and anticlinal. Subsequently, the cells of the endodermis also divide to keep pace with emerging lateral root primordium. The group of cells thus produced develops and organize a new root apical meristematic zone. This zone resembles the apical meristem/root apex of the parent root. Such a new root now formed pushes through endodermis, cortex and epidermis of the parent root in lateral direction and ultimately emerges out. During this emergence, the lateral root displaces and/or destroys the cortical cells.

The position at which the prospective lateral root is initiated is very much distinct in relation to xylem and phloem of the parent root. In diarch roots, they usually occur between xylem and phloem, in triarch and tetrarch roots they develop opposite to protoxylem and in polyarch roots they originate from cells opposite to protophloem (see Fig. 3.6).

In aquatic plants, the lateral roots are formed close to the root apex. One of the essential factors for the development of lateral roots is probably auxin. It specifically stimulates cell division in certain regions of the pericycle.

### **3.2.4 Dicot and Monocot Root**

In the preceding section you have studied that the structure of a primary root can be demarcated into three distinct zones: dermal, ground and vascular. Such an arrangement is common to all kinds of primary roots, with some minor deviations, if any. The anatomical characteristics that distinguish a primary root of a seed plant are:

- i) The cuticle is absent/insignificant.
- ii) The epidermal hairs are unicellular.
- iii) The cortex is parenchymatous
- iv) The endodermis is conspicuous with casparian thickenings.
- v) The vascular bundles are radial and the protoxylem is distinctly exarch.

Above characteristics are common to both the roots of a dicotyledonous plant and a monocotyledonous plant. However, certain major anatomical features distinguish a dicot root (primary) from a monocot root. Let us list these major distinct features:

#### **Dicot root (Fig. 3.7 a)**

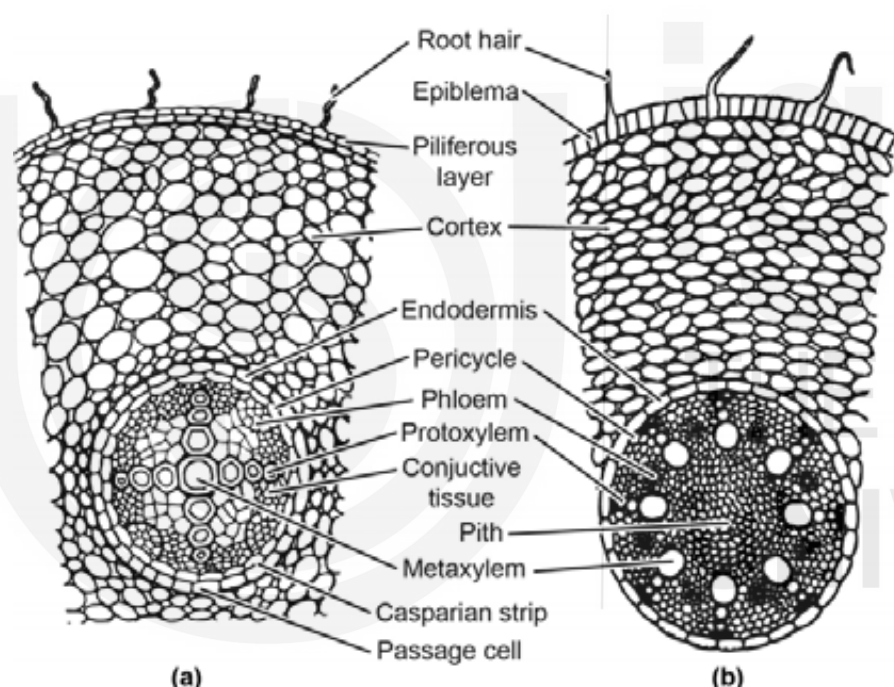
- i) Xylem poles/bundles vary from 2 to 6 (diarch to hexarch), rarely more.
- ii) Pith is small, insignificant or even absent.
- iii) To begin within younger roots the vascular cambium is absent. But, appears later as the root grows. Thus, can undergo secondary growth.

#### **Monocot root (Fig. 3.7 b)**

- i) Xylem poles/bundles are numerous varying upto (20 or so). They are termed polyarch.
- ii) Pith is large and well-developed.
- iii) The cambium is absent throughout the life of the root. Thus, never exhibit secondary activity.

**Table 3.1: Comparative internal tissue organization of a primary dicotyledonous and monocotyledonous root.**

|                         | <b>Dicot root</b>                                              | <b>Monocot root</b>                                                |
|-------------------------|----------------------------------------------------------------|--------------------------------------------------------------------|
| <b>Epidermis</b>        | Thin/thick walled                                              | Relatively thick walled                                            |
| <b>Cortex</b>           | Mostly parenchymatous, sometimes outer cells sclerenchymatous  | Peripheral cells generally thick walled, often sclerenchymatous    |
| <b>Vascular bundles</b> | Diarch to hexarch                                              | Often polyarch                                                     |
| <b>Pericycle</b>        | Gives rise to lateral roots, vascular cambium and cork cambium | Produce only lateral roots                                         |
| <b>Cambium</b>          | Develops later to produce secondary tissue                     | Absent, even in those whose stems show abnormal secondary activity |
| <b>Pith</b>             | Small or absent                                                | Large and well developed                                           |

**Fig. 3.7: a) TS of Dicot root; and b) TS of monocot root.**

### SAQ 1

- a) Fill in the blank space(s) with appropriate word(s):
- The first root of plant that develops from the radicular portion of the embryo is known as .....
  - A root that originates from any place other than the radicle of an embryo is called .....
  - All the cells of a mature primary root owe their origin to .....
  - Lateral roots are produced from the ..... region of primary root.

- b) Choose the correct alternative provide in the parantheses:
- i) The function of the root hair is to (absorb/facilitate) water uptake.
  - ii) Passage cells are characteristically present in (exodermis/epidermis).
  - iii) The radical vascular bundles of a root possess (endarch/exarch) protoxylem.
  - iv) A root with polyarch xylem is likely to possess (insignificant/conspicuous) pith.
- c) Differentiate between:
- i) Dicot root and Monocot root
  - ii) Epidermis and Endodermis
  - iii) Pericycle and Endodermis

---

### 3.3 SECONDARY TISSUES IN ROOT

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Usually the taproot and the main lateral roots of gymnosperms and woody dicotyledons and rarely the smallest root branches develop secondary thickenings. In herbaceous dicotyledons, however, the secondary growth may be absent or is negligible, e.g., *Ranunculus*, or well developed as in *Pisum* and *Cicer*. Monocot roots do not develop secondary structures.

The process which leads to the development of secondary structures and formation of secondary tissues is called secondary growth. The initiation of secondary growth in the roots is quite distinct from the one encountered in stems which you shall study in Unit 4.

Let us now look at the events which lead to the initiation of secondary growth in a typical dicotyledonous root. As mentioned earlier in this chapter, the primary root does not possess any vascular cambium. However, certain procambial cells lying below the metaphloem (as seen in C.S.) or parallel or inner to metaphloem (as seen in L.S.) remain undifferentiated. Initiation of secondary growth starts from these cells which differentiate into **vascular cambium** (see 3.8 a, b). The number of such isolated vascular cambial strands is two, three, and four in diarch, triarch and tetrarch roots, respectively. Polyarch roots, characteristic of monocotyledons only, do not undergo secondary activity. Once formed these vascular cambium meristem divide periclinally to cut off cells on its either side. Thus at this stage the secondary tissues are being formed although in patches.

In next event, the pericycle elements lying opposite to protoxylem differentiate into vascular cambium (Fig. 3.8 c). The number of such patches (vascular cambium of pericyclic origin) again corresponds to the number of protoxylem points.

Very soon thereafter, the vascular cambia produced beneath metaphloem and above protoxylem join at several points to form an undulating cambial ring. Later, this ring assumes a circular outline (see Fig. 3.8 d).

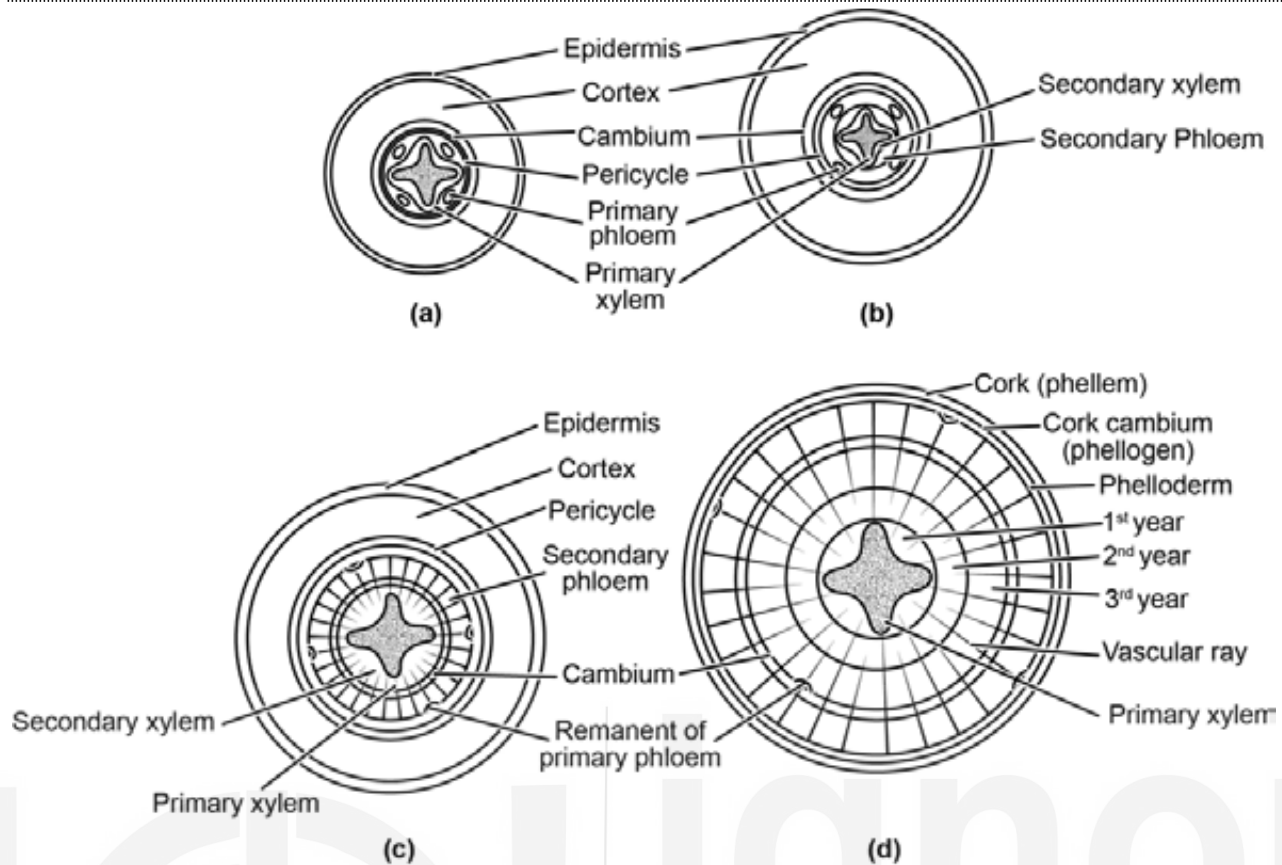


**Fig. 3.8: Diagrammatic representation of secondary growth in a typical dicotyledonous root. a) Primary root; b) Beginning of secondary activity; c) protoxylem differentiate into vascular cambium; and d) Old roots showing development of secondary tissue.**

The tissue cut off by the vascular cambium towards outside is called secondary phloem and the one cut off towards inside is **secondary xylem**. The general pattern of the composition, development and structure of these secondary tissues is similar to the one observed in stem. Interestingly, in root even after secondary growth, the primary xylary elements are not lost (Fig.3.9).

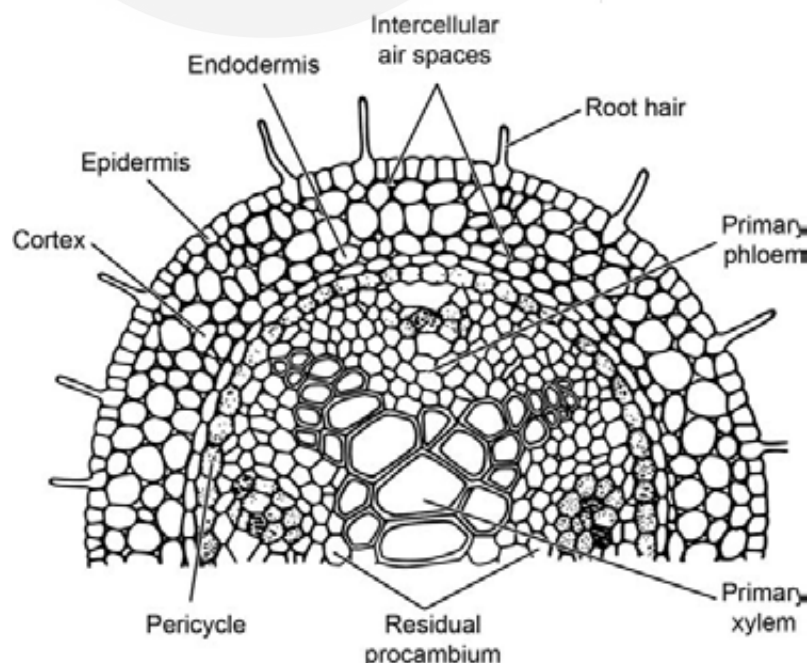


**Fig. 3.9: Cross section of the secondary root showing primary xylary tissue.**

## Periderm

In herbaceous dicotyledons where secondary growth is very little or meagre, the tissues outside the stele remain intact, and an exodermis may develop beneath the epidermis that provides mechanical strength.

However, in woody dicotyledons the prolonged and sustained activity of vascular cambium results in enormous amounts of secondary tissue, especially secondary xylem. This addition of tissues increases the girth of the root. This increased volume puts pressure on the outer primary tissues such as cortex and epidermis. Before these tissues are sloughed off, they are replaced by a more efficient, protective covering tissue, the **periderm**. Periderm in root mostly originates in pericycle. However, the origin of periderm from cells outside the stele has also been reported. The root periderm may form, at places, **lenticels** for good aeration. Once a periderm is formed, the primary tissue beyond it is sloughed off.

In roots of certain families of angiosperms such as Hypericaceae, Myrtaceae, Onagraceae and Rosaceae, the periderm is made up of two types of cells, suberised and non-suberised. Single-layered suberised cells are sandwiched between multilayered non-suberised cells. Such a periderm is called **polyderm**.

A comparison of structure of a primary and a secondary root is provided in Table 3.2.

**Table 3.2: Comparison of structures of a primary and a secondary root.**

|                         | Primary root                                                                                                           | Secondary root                                                                                                                                                                   |
|-------------------------|------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Epidermis</b>        | Cuticle thin/absent. Hair unicellular and simple.                                                                      | Epidermis may be completely sloughed off                                                                                                                                         |
| <b>Cortex</b>           | Generally parenchymatous not much differentiated but with prominent intercellular spaces, may perform storage function | May get completely sloughed off                                                                                                                                                  |
| <b>Endodermis</b>       | A complete ring with casparian bands with passage cells                                                                | Usually not discernible                                                                                                                                                          |
| <b>Pericycle</b>        | Single/few layered, parenchymatous                                                                                     | Differentiate into vascular cambium, loses its identity                                                                                                                          |
| <b>Vascular bundles</b> | Radial stele, 1-6 xylem/phloem strands, protoxylem and protophloem exarch, (centripetal development)                   | Radial arrangement lost; Primary phloem obliterated, primary xylem retained even after extensive secondary growth, Secondary tissue cut off both centripetally and centrifugally |
| <b>Pith</b>             | Small or absent                                                                                                        | Absent                                                                                                                                                                           |
| <b>Vascular cambium</b> | Absent                                                                                                                 | Originates in patches: forms complete ring, functions prominently                                                                                                                |
| <b>Secondary xylem</b>  | Absent                                                                                                                 | Cut off by vascular cambium towards inside centripetally, once formed retained for ever; has axial                                                                               |

|                         |        |                                                                                                                                                                          |
|-------------------------|--------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                         |        | and ray system; conducts water, minerals, provides strength; very large.                                                                                                 |
| <b>Secondary Phloem</b> | Absent | Cut off by vascular cambium towards outside centrifugally, fragile accumulates marginally, older part degenerates has axial and ray systems conducts organic metabolites |
| <b>Periderm</b>         | Absent | Formed after the activity of vascular cambium replaces epidermis                                                                                                         |
| <b>Lenticels</b>        | Absent | Protective in function, may be formed by phellogen; helps in gaseous exchange                                                                                            |

## SAQ 2

a) Define the terms :

- i) Secondary growth
- ii) Secondary Xylem
- iii) Periderm
- iv) Polyderm

b) Match the tissues mentioned in the **Column I** with the functions they perform as mentioned in the **Column II**.

| <b>Column I</b>       | <b>Column II</b>                                       |
|-----------------------|--------------------------------------------------------|
| i) Pericycle          | a. Development of periderm                             |
| ii) Phellem           | b. Initiation of Lateral root                          |
| iii) Vascular Cambium | c. Help in gaseous exchange                            |
| iv) Lenticels         | d. Production of wood                                  |
| v) Phellogen          | e. Replace epidermis for protection of secondary organ |

## 3.4 SPECIALISED ROOTS

In this unit you have so far read about the structure and organisation of a typical root which performs the basic function of anchorage and uptake and translocation of water and minerals from the soil. However, in nature, we come across roots that perform a wide range of functions. Consequently, their structure and organization are modified. The basic plan, however, remains the same. We shall now look at some such modified roots and their adaptive features. The roots that we will discuss are **food-storage** roots, **aerial** roots, **pneumatophores** and **mycorrhiza**.

### 3.4.1 Food Storage Roots

In primary roots the food is mainly in the form of starch which is stored in thick cortex (Fig. 3.10). After secondary growth, the food is generally found stored in secondary xylem and secondary phloem parenchyma. Usually, roots contain much more parenchyma than stems (Fig. 3.11).

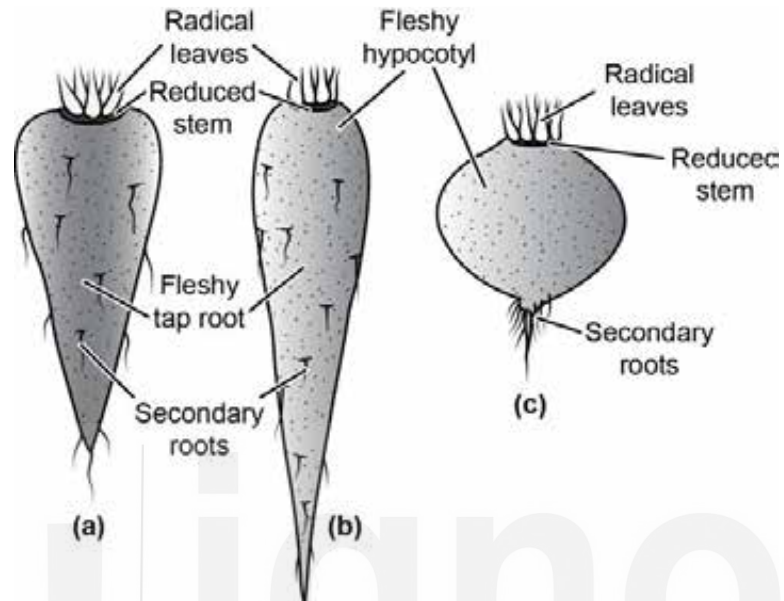


Fig. 3.10: Storage roots a) *Daucus carota*; b) *Raphanus sativus*; c) *Brassica rapa*.

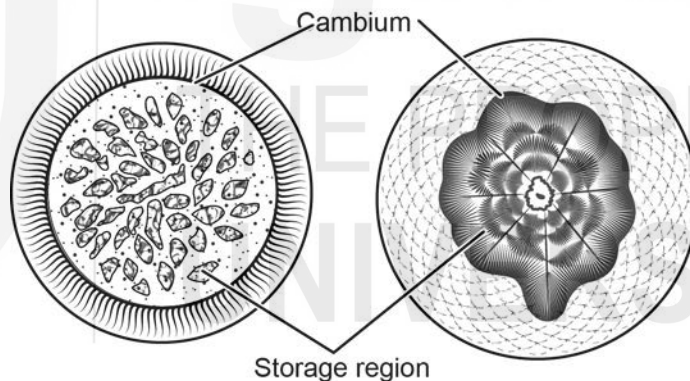


Fig. 3.11: Transverse section of the storage roots of *Ipomoea batatas* and *Daucus carota*.

In plants such as *Raphanus sativus* (radish), *Brassica rapa* (rape), *Daucus carota* (carrot), *Beta vulgaris* (sugar beet), and *Ipomoea batatas* (Sweet potato), roots develop into a thick food storing fleshy organ. In such roots hypocotyl and tap root become thickened following secondary growth.

Tracheary elements are produced in small amount and secondary xylem axial parenchyma is produced in large quantity (to store food) thus making the organ fleshy (see Fig. 3.10 and 3.11).

In beet root *Beta vulgaris* hypocotyl and root become fleshy as a result of anomalous thickening (see Fig. 3.12). The vascular cambium formed originally functions only for a short duration. Thereafter, numerous, successive cambia are initiated exterior to the latest formed secondary phloem. All these cambia function normally but produce more of parenchymatous than any other kind of cells. Sugar is the main food stored.

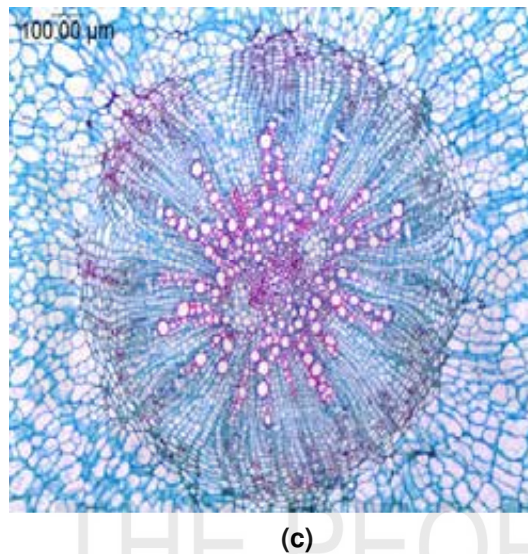
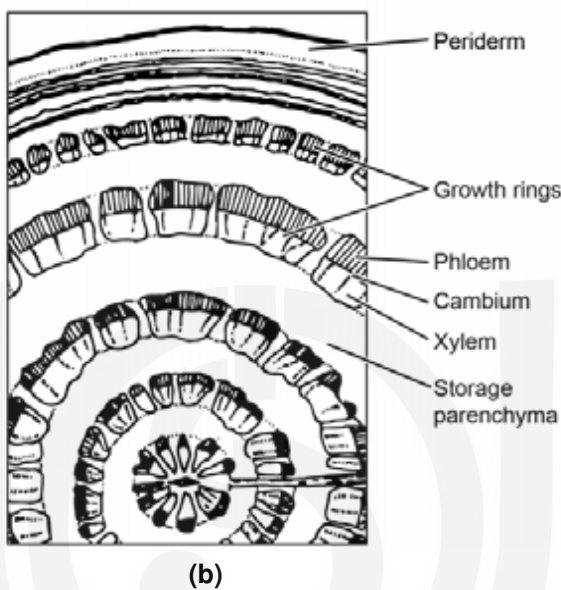
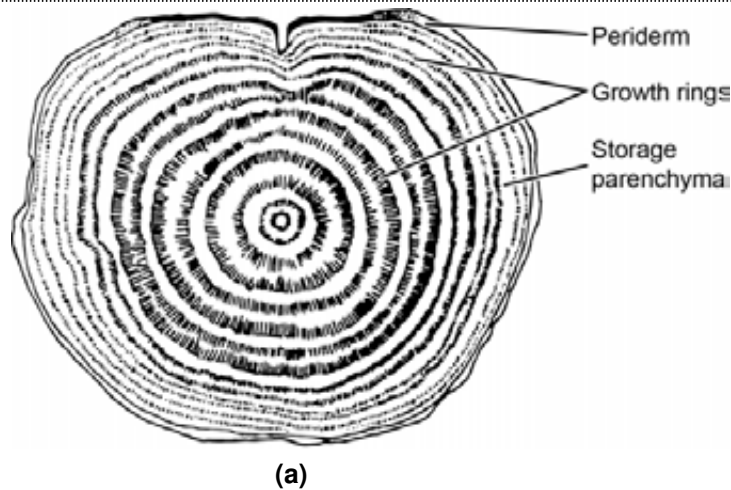


**Fig.3.12: a) Transverse sections of storage root of *Beta vulgaris* growth rings; In b) a portion is magnified; and c) Photograph of TS of *Beta vulgaris*.**

In sweet potato (*Ipomoea batatas*) an irregular shaped fleshy food storing root is formed. To begin with normal secondary growth takes place. Then the cells around any vessel or vessel group form a ring of vascular cambium. Such a cambium produces more and more of secondary xylem parenchyma. This process is repeated many a times resulting in an irregular outline.

You will study in detail about the abnormal secondary activities in such food storage roots in the Unit 6 of this course.

### **3.4.2 Aerial Roots**

Roots produced from stem or branch that remain free in the air are called aerial roots. They are reported mostly from a diverse group of tropical plants viz. *Ficus* spp., epiphytic tropical Araceae and Orchidaceae. When these roots touch soil, they serve as **prop** roots. If they attach to some solid substratum, they are called **climbing** or **adhesive** roots. The adaptive features of such roots include photosynthetic ability. In orchids the roots possess multilayered epidermis, the **velamen** (see Fig. 3.13). The cells comprising velamen are dead, possess band-like thickened wall and are filled with air when the air is dry. The innermost cell layer of velamen is termed exodermis. The smaller thin-walled cells of this layer are called passage cells.

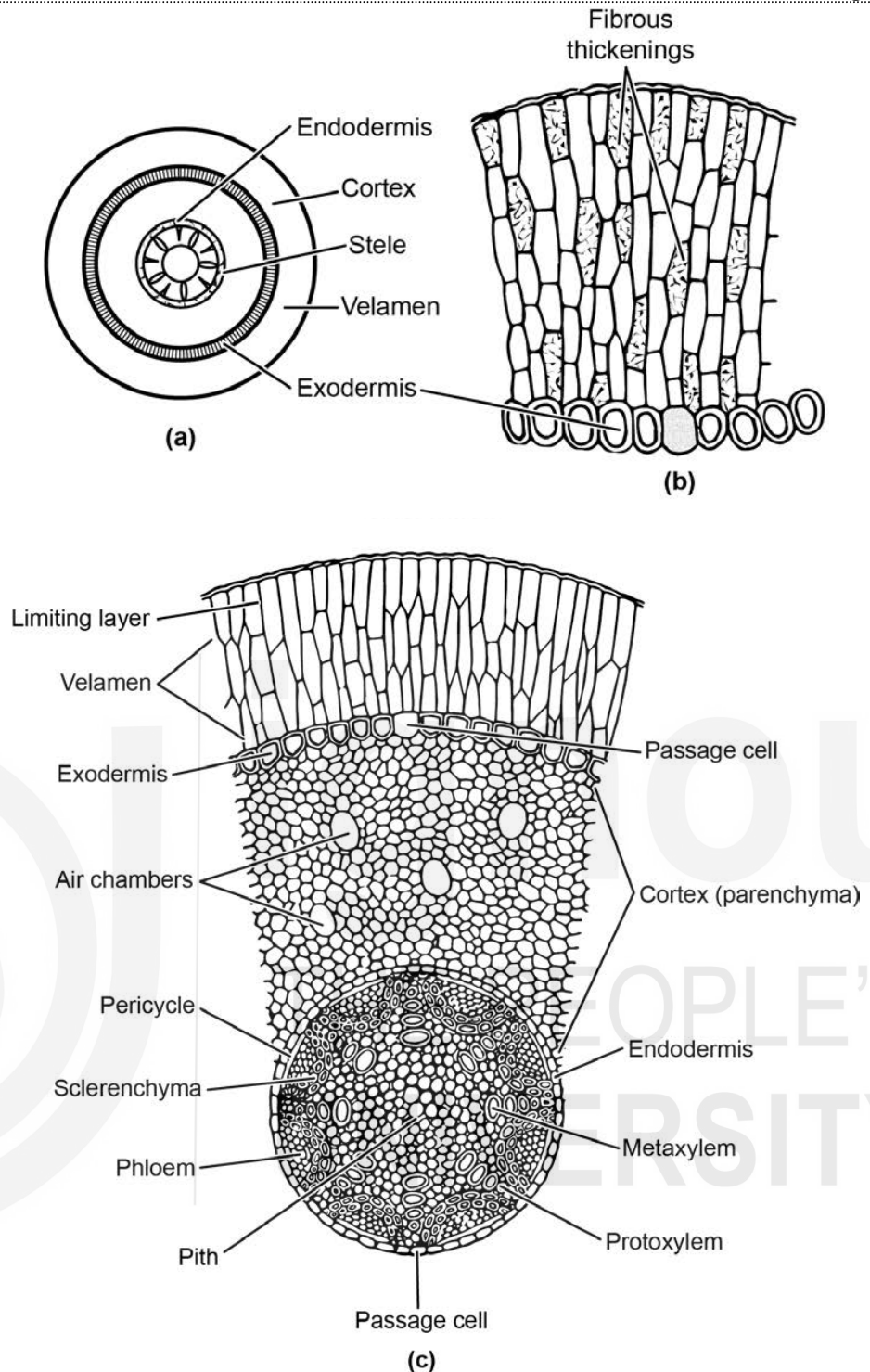


**Fig. 3.13: T.S. of orchid root a) T.S. of root (diagrammatic); b) T.S. of *Dendrobium*; c) Velamen and exodermis enlarged.**

### **3.4.3 Pneumatophores**

They are also known as breathing roots (see Fig. 3.14 and 3.15). They are found in plants growing in marshy places with scanty oxygen e.g., mangroves. Unlike normal roots, they grow vertically upward thus becoming negatively geotropic. They absorb oxygen from the atmosphere through specifically located lenticels at the tips (e.g. *Avicennia*). The peripheral cells develop as cork. The cortex shows well developed intercellular spaces. In a cross section (Fig. 3.15) you will see that the narrow stele is surrounded by a very wide aerenchyma produced by phellogen (e.g. *Rhizophora*).

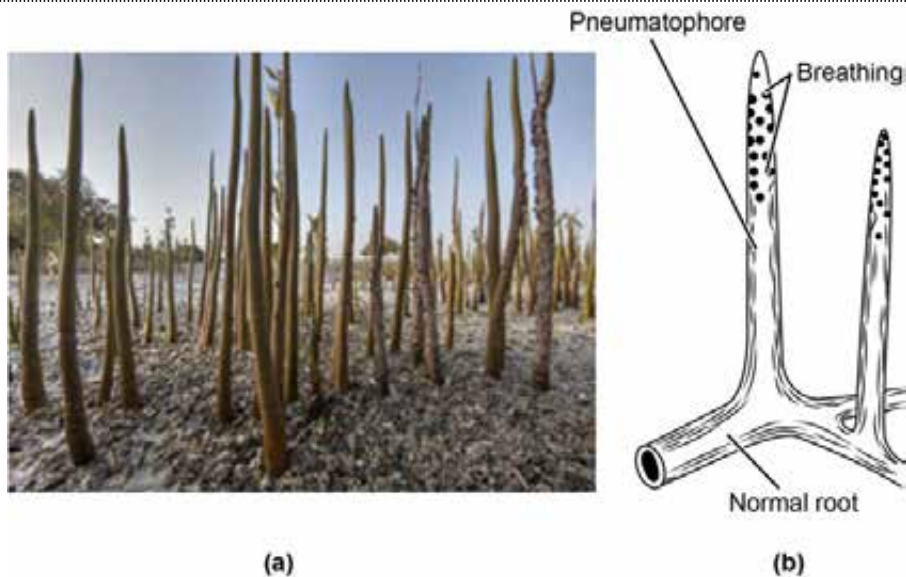


Fig. 3.14: Pneumatophores. a) Pneumatophores at the base of a mangrove tree; b) A single pneumatophores.

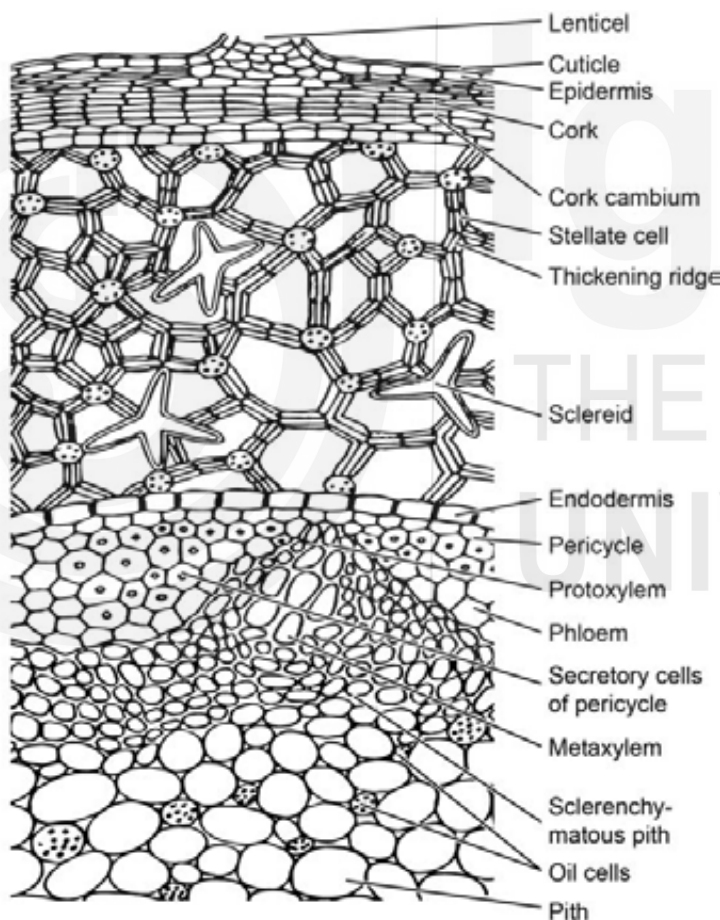


Fig. 3.15: A portion of a breathing root in transverse section.

### 3.4.4 Mycorrhiza

The epidermis and cortex of the root of many plants are often associated with soil fungus. The association between the fungal hyphae and the roots of higher plants is called **mycorrhiza** (Fig. 3.16). Usually, this association is symbiotic. Both the higher plants and the fungus derive benefit from such association. There are two kinds of mycorrhiza: **ectomycorrhiza** and **endomycorrhiza**.

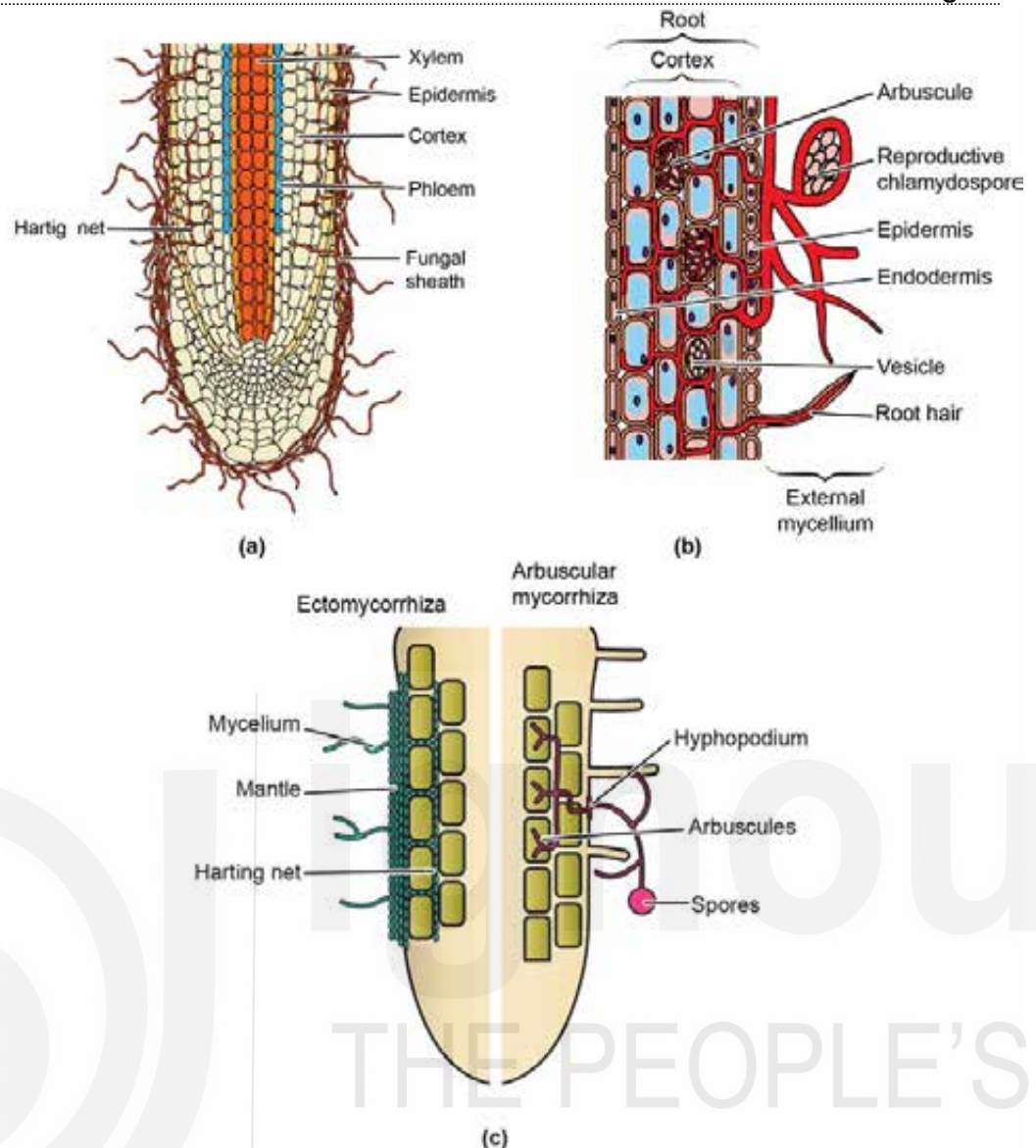


**Fig. 3.16: Diagrams of mycorrhizae. a) Ectomycorrhiza based on a micrograph of Meyer (1973); b) Endomycorrhiza based on a micrograph of Cox and Sanders (1974); c) A schematic representation of mycorrhizae.**

**Ectomycorrhiza :** In this association, the fungus produces mycelium on the root surface. The hyphal strands penetrate the root between the cortical cells and form a net (Hartigs net). It is common in roots of several trees such as *Pinus*, *Abies*, *Cedrus*, *Quercus*, *Populus*, *Salix*, *Eucalyptus* and *Betula*.

**Endomycorrhiza:** In this association, the fungus forms an inconspicuous mycorrhiza on the root surface but invades the interior of root cells. Roots of *Orchidaceae*, *Ericaceae*, *Acer* and *Liriodendron* have such an association.

Detailed observations with electron microscope show that in the endomycorrhiza the plasmalemma of the host cells surrounds the individual branches of the fungal hyphae, forming a structure called **arbuscule**.

The endomycorrhizae involving nonseptate fungi are dominant type, and possibly up to eighty per cent of all terrestrial plants have such association. These are called vesicular – arbuscular mycorrhizae or V. A mycorrhizae because once the fungus penetrates the host it produces characteristic vesicles and arbuscules.

The host root gets nutrients from soil through fungus and the host provides the fungus with carbohydrates, amino acids, vitamins and other substances. The host cortex cells do not consequently store any starch. It is found that because of mycorrhizal association the host is less susceptible to drought.

---

### SAQ 3

Provide short explanatory notes for the following statements:

- Secondary roots of radish and rape are thick, fleshy but poorer in tracheary elements.
  - Multiple growth rings are observed in a transverse section of a beet root.
  - Parenchymatous cortex is characteristic of pneumatophores.
- 

## 3.5 SUMMARY

---

In this unit you have studied that :

- The primary plant body consists of root and shoots systems. The former consists of tap and adventitious roots. All the mature cells within them owe their origin to cell(s) of root apical meristem present in the root apex.
- A typical root has: root cap; region of cell division; region of elongation, and region of maturation. The root cap is credited with geotropic growth of the root. The three primary tissue zones of a root are recognised as epidermis, ground tissue and vascular tissue. Root hairs develop from epidermis and may help in uptake of water and minerals from the surroundings. Rarely, the epidermis is multi-layered (e.g., aerial roots of orchids). The cortex is multilayered, often parenchymatous and helps in water transport. An endodermal layer demarcates the stele from the cortex. The developmental pattern of the vascular tissue is diverse. Both primary xylem and primary phloem develop centripetally, therefore, both protoxylem and protophloem elements are exarch. The primary xylem and phloem alternate with each other. Diarch to hexarch roots are found in dicotyledons while polyarch roots are characteristic of monocotyledons. Monocot roots also possess large, conspicuous pith. Lateral roots are endogenous in origin and arise from pericycle. There is distinct relation between the site of lateral root initiation and the kind of vascular tissue organization.
- Monocot roots do not show any secondary activity. In dicotyledonous and gymnosperm roots, vascular cambium initiates at multiple places and then join to produce a ring. The vascular cambium produces secondary xylem towards inside and secondary phloem towards outside. The former accumulates over the years whereas the latter often degenerates. Irrespective of the extensive secondary activity, the primary xylem is always seen at the centre of the root. To offset increasing girth, the periderm replaces the epidermal system as outer protective system.
- Roots often get modified to perform various functions. Some of them are roots such as: food storage roots; pneumatophores; aerial roots; and mycorrhiza.

### 3.6 TERMINAL QUESTIONS

1. Write **notes** on the following:
  - a) Root cap
  - b) Trichlobast
  - c) Periderm
  - d) Velamen
2. Describe chronologically the events that enable primary dicot root become secondary roots. Support your answer with suitable labeled diagrams.
3. Differentiate between:
  - a) Ectomycorrhiza and Endomycorrhiza
  - b) Primary root and Secondary root (anatomical)
4. Make labeled diagrammatic sketches of :
  - a) Various zones and tissues in a developing primary root.
  - b) Origin of lateral roots in primary roots with: diarch, triarch and polyarch vascular bundles.

### 3.7 ANSWERS

#### Self-Assessment Questions

1.
  - a)
    - i) tap root
    - ii) adventitious root
    - iii) root apical meristem
    - iv) pericycle
  - b)
    - i) facilitate
    - ii) exodermis
    - iii) exarch
    - iv) conspicuous
  - c)
    - i) Refer to Subsection 3.2.4.
    - ii) Refer to Subsection 3.2.2.
    - iii) Refer to Subsection 3.2.2.
2.
  - a)
    - i) Refer to Section 3.3.
    - ii) Refer to Section 3.3.
    - iii) Refer to Section 3.3.
    - iv) Refer to Section 3.3.
  - b)
    - i) b; ii) e; iii) d; iv) c; v) a

3. a) **Hint** : Storage of food; Refer to Subsection 3.4.1.
- b) **Hint** : Additional vascular cambia development: Refer to Subsection 3.4.1.
- c) **Hint** : respiration; saline environment Refer to Subsection 3.4.3.

## **Terminal Questions**

1. a) Refer to Subsection 3.2.1.
- b) Refer to Subsection 3.2.2.
- c) Refer to Subsection 3.3.
- d) Refer to Subsection 3.4.2.
2. Refer to fig. 3.7 (a-d) and Section 3.3.
3. a) Refer to Subsection 3.4.4.
- b) Open-ended; Hint: Table 3.2.
4. a) Hint : Fig. 3.2; open-ended.
- b) Refer to Subsection 3.2.3.
- Hint Fig. 3.6 a
- Hint Fig. 3.6 b
- Hint Fig. 3.6 e

## **Acknowledgments**

- Fig. 3.3** : (<https://plantphysprimer.com/author/scwolver/>)
- Fig. 3.4** : <https://image.slidesharecdn.com/lecture23-130809173454-phpapp02/95/lecture-23-15-638.jpg?cb=1376069764>
- Fig. 3.6 b** : <https://www.google.com/url?sa=i&source=images&cd=&ved>
- Fig.3.11 c** : [http://www.phytoimages.siu.edu/imgs/Cusman1/r/Chenopodiaceae\\_Beta\\_vulgaris\\_46802.html](http://www.phytoimages.siu.edu/imgs/Cusman1/r/Chenopodiaceae_Beta_vulgaris_46802.html)
- Fig. 3.13 a** : <https://i.pinimg.com/originals/d1/8d/08/d18d084661c3a516e3ba6c875c24776b.jpg>

## Structure

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|     |                           |     |                                |
|-----|---------------------------|-----|--------------------------------|
| 4.1 | Introduction              | 4.4 | Specialized Stems              |
|     | Objectives                |     | Rhizome                        |
| 4.2 | Stem-Primary              |     | Tuber                          |
|     | Structure of Stem         |     | Bulbs                          |
|     | Primary Tissue in Stem    |     | Corms                          |
|     | Dicot and Monocot Stem    |     | Runner, Offset, Stolon, Sucker |
| 4.3 | Secondary tissues in Stem |     | Cladophyll                     |
|     |                           | 4.5 | Summary                        |
|     |                           | 4.6 | Terminal Questions             |
|     |                           | 4.7 | Answers                        |

## 4.1 INTRODUCTION

---

In higher plants, the meristem cells(s) located at the distal, apical end of the main axis or the branches of the shoot constitute **shoot apical meristem (SAM)**. All the tissues of a shoot system originate from the cells of SAM. It can be stated that the entire shoot system owe their origin to the SAM that is first established in an embryo. The primary function of the SAM is to produce two components of a shoot system. Firstly, the main axis, the stem, also called caulis or cauline and secondly, the laterals of limited growth; the leaves, also known as phylloid or foliar organs.

In this unit, you shall study about the organization and internal structure of the main axis, the stem. The anatomy of the laterals, the leaves shall be dealt in next Unit 5.

## Objectives

---

After studying this unit you would be able to :

- ❖ appreciate the concept of shoot system;
- ❖ differentiate between the axis and lateral and correlate their origin and relationship to SAM;

- ❖ describe the internal make-up (anatomy) of stem;
- ❖ correlate the pattern of placement of various tissues in the stem to their functional abilities;
- ❖ differentiate between primary and secondary structures of the stem;
- ❖ recognize and identify the differences between the stems of a dicotyledonous and a monocotyledonous plant; and
- ❖ appreciate the close relationship between structure, function and adaptability especially in relation to rhizome, tuber, bulbs, corms, suckers and cladophylls.

## 4.2 STEM-PRIMARY

Before you study about the anatomy of stem, you are advised to look at the Fig. 4.1. It diagrammatically depicts the relationship between the shoot apex, SAM the main axis (stem), the laterals of limited growth (leaves) and the laterals of unlimited growth (axillary buds, the potential new axis) and also with the root system. It also correlates the structures-function relationships as well as the internal tissue topography.

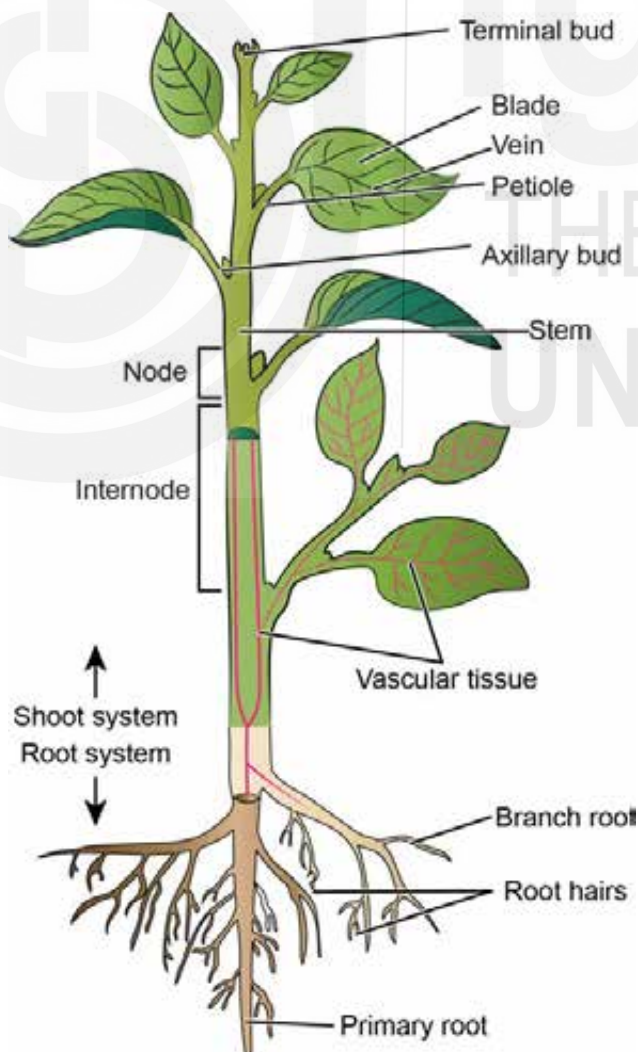


Fig. 4.1: Ground plan of the shoot system and the root system in a typical dicotyledonous plant.

## 4.2.1 Structure of Stem

The aerial parts of a vascular plant consist of an axis, the **stem**. It bears lateral organs. The erect stem usually is **orthotropic**. It could also be **decumbent** (growing dropping downward), or **plagiotropic** (showing horizontal growth); The laterals are of two kinds: i) the leaves with limited/determinate growth, and ii) the bud with unlimited/indeterminate growth. The leaves are usually dorsiventral; buds, however, possess radial symmetry. The stem together with laterals, the leaves and buds constitute the **shoot** (see Fig. 4.1). The portions of the stem at which leaves occur are called **nodes**. The leafless portion of the stem in between any two consecutive nodes is termed as **internode**.

## 4.2.2 Primary Tissue in Stem

The primary stem possesses three fundamental tissue systems: **dermal**, **vascular** and **ground** tissue. These are formed from **protoderm**, **procambium** and **ground** meristems, the three important derivatives of shoot apical meristem (Fig. 4.2).

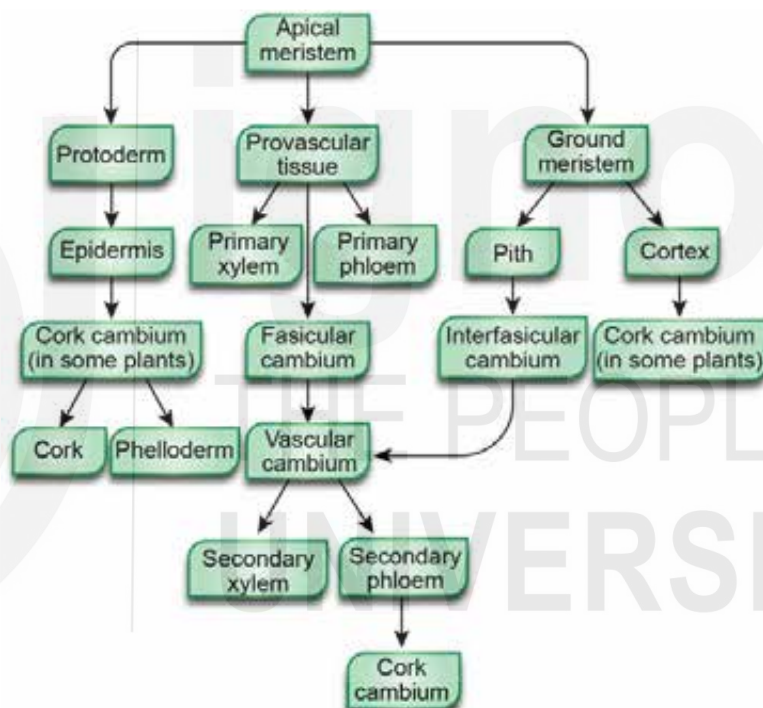


Fig 4.2: Meristems and their derivatives.

### Dermal Tissue

The stem is bounded by an **epidermis** which is a layer of closely arranged, thin-walled achlorophyllous living cells. In plants that occur in water or deeply shaded habitat the epidermal cells may possess chloroplasts. The outer wall of epidermal cells is covered with cuticle. Photosynthetic stems bear stomata in their epidermis. Various kinds of trichomes may also be present.

### Ground Tissue

All the cells of the organ other than those in epidermis and vascular tissue are regarded as ground tissue. In the stems of gymnosperms and dicotyledons, the ground tissue can be demarcated into **cortex** and **pith** (medulla). The former lies in between the epidermis and vascular tissue and the latter occupies the centre. In stems of monocotyledons, however, there is no real distinction between cortex and pith.

## Cortex

Cortex comprises many layers of cells which are primarily parenchymatous. However, in many, especially younger, growing stems of dicotyledons the outer few layers (i.e., below the epidermis) are differentiated as collenchymas (you recall that collenchyma serve as tissue for mechanical strength in growing organs). This collenchyma can either form a continuous cylinder (e.g., *Helianthus*, *Salvia*) or more commonly occur as bands in projecting ribs (e.g., Umbelliferae, Cucurbitaceae). These peripheral layers may contain chloroplasts to carry out photosynthesis. Such tissue is termed chlorenchyma. Apart from collenchyma, the strengthening tissue or sclerenchyma (usually fibers) may occur near the periphery of stem especially in the monocotyledons.

In many plants such as *Casuarina*, *Capparis*, *Cystisus* and *Asparagus* which have much reduced leaves, the major photosynthetic function is taken over by the stem.

The cells of the cortex may contain starch (e.g., most young stems) crystals (e.g., *Ricinus*, *Colocasia*) sclereids (e.g., *Trochodendron*) or these may be rich in oleoresins (e.g., *Zingiber*) or may secrete oil (e.g., *Helianthus*).

The innermost cell layer of cortex is termed **endodermis**. It may not be as conspicuous as in the roots. It is often not discernible in aerial stems; however, it is very conspicuous in *Piper* stem. In cortex of underground stems, endodermis is well developed.

In young stems of certain plants (e.g., *Ricinus*, *Phaseolus*), the innermost cortical layer has abundant starch grains and is called **starch sheath**.

**Pith:** The central portion of the stem, the pith is parenchymatous. Occasionally it may be lignified. It is very conspicuous in the primary stems of gymnosperms and dicotyledons.

## Vascular Tissue

There is a lot of variation in the arrangement of vascular tissue in stem. In dicotyledons, the vascular tissue develops in the form of complete or broken cylinder between cortex and the pith.

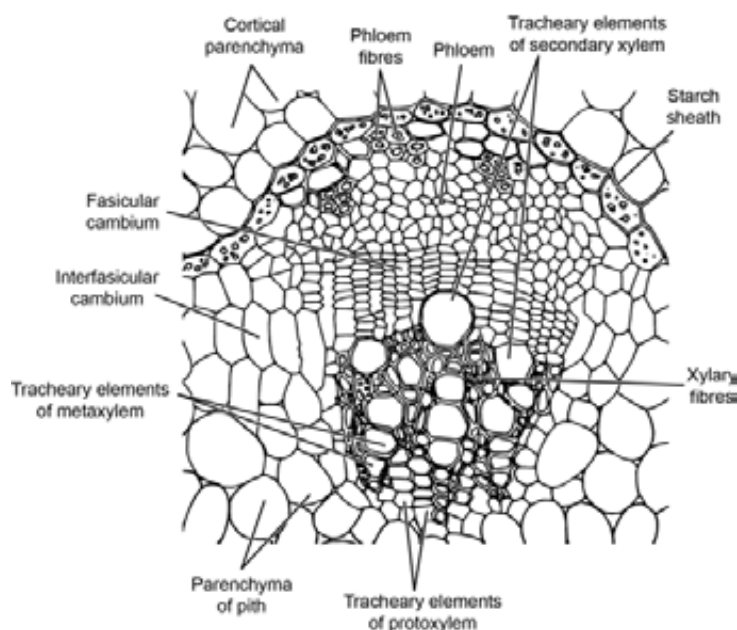


Fig 4.3: Portion of a cross section of well developed vascular bundle.

When broken, this cylinder has many individual discrete bodies called **vascular bundles** (Fig.4.3). In between vascular bundles is present interfascicular parenchyma.

In contrast to root, where xylem and phloem alternate, in the stems the xylem and phloem differentiate and lie on the same radius. The phloem differentiates outer side (epidermis) and the xylem towards inner (pith) side. Such vascular bundle is called **collateral** (e.g., *Helianthus*, *Ranunculus* (Fig. 4.4. a, b). When phloem differentiates on either side of the xylem the vascular bundle is **bicollateral** (e.g., *Cucurbita*). When in a vascular bundle xylem surrounds phloem completely, it is called **amphivasal** (Fig.4.4 i, j) (e.g., *Cucurbita*, *Acorus*, *Dracaena*). **Amphicribal** vascular bundles are those in which phloem completely surrounds the xylem. They are common in many pteridophytes. (see Fig. 4.4 g, h).

When in a vascular bundle cambium differentiates and occupies position in between xylem and phloem, the vascular bundle is termed **open** (Fig. 4.4 a, b). A vascular bundle can be both open and closed. In bicollateral vascular bundles where both outer and inner cambia are present, it is only the outer cambium (between xylem and outer phloem) that is functional (Fig. 4.4 e, f).

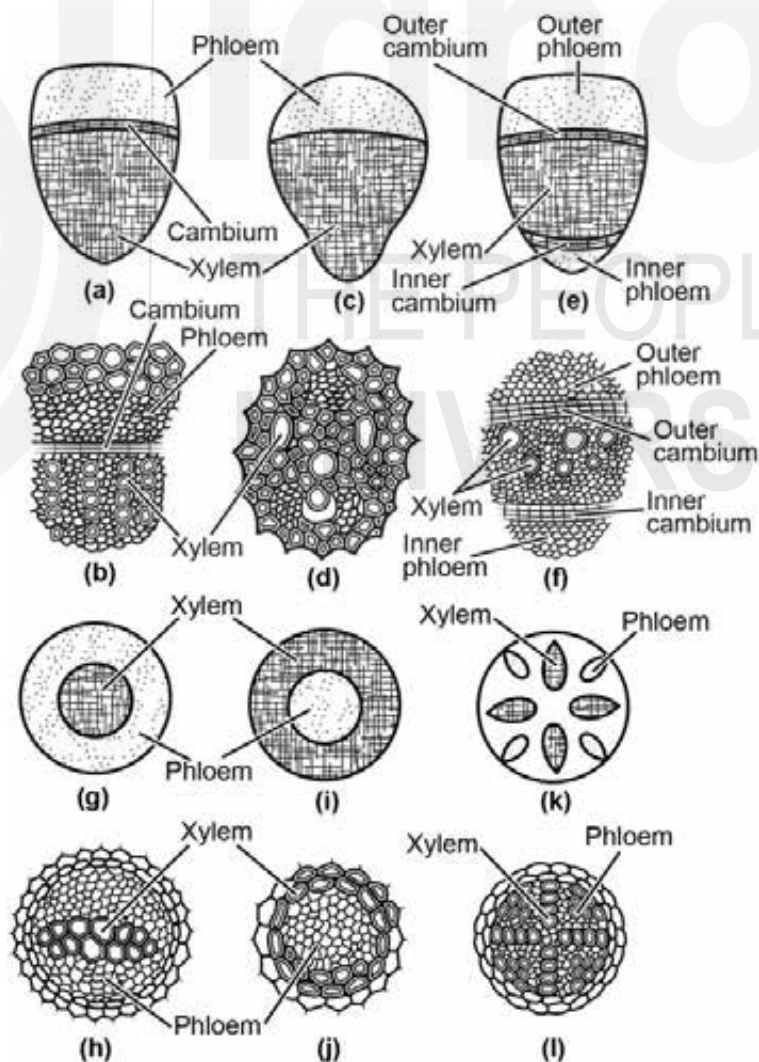


**Fig. 4.4: Different types of vascular bundles. a and b) conjoint, collateral and open; c and d) conjoint, collateral and closed; e and f) conjoint, bicollateral and open; g and h) concentric and amphicribal; i and j) concentric and amphivasal; k and l) radial.**

In the stems of monocotyledons a large number of closed vascular bundles are seen scattered throughout the ground tissue. The xylem elements may form the letter Y, U or U (Fig. 4.5). The protoxylem in many of these vascular bundles gets disintegrated as the stem matures. It leaves behind a protoxylem cavity/canal/lacuna.

In monocotyledons, the vascular bundles may be capped or encircled by thick walled sclerenchyma fibres. Only those stems that possess open vascular bundles can undergo secondary growth.

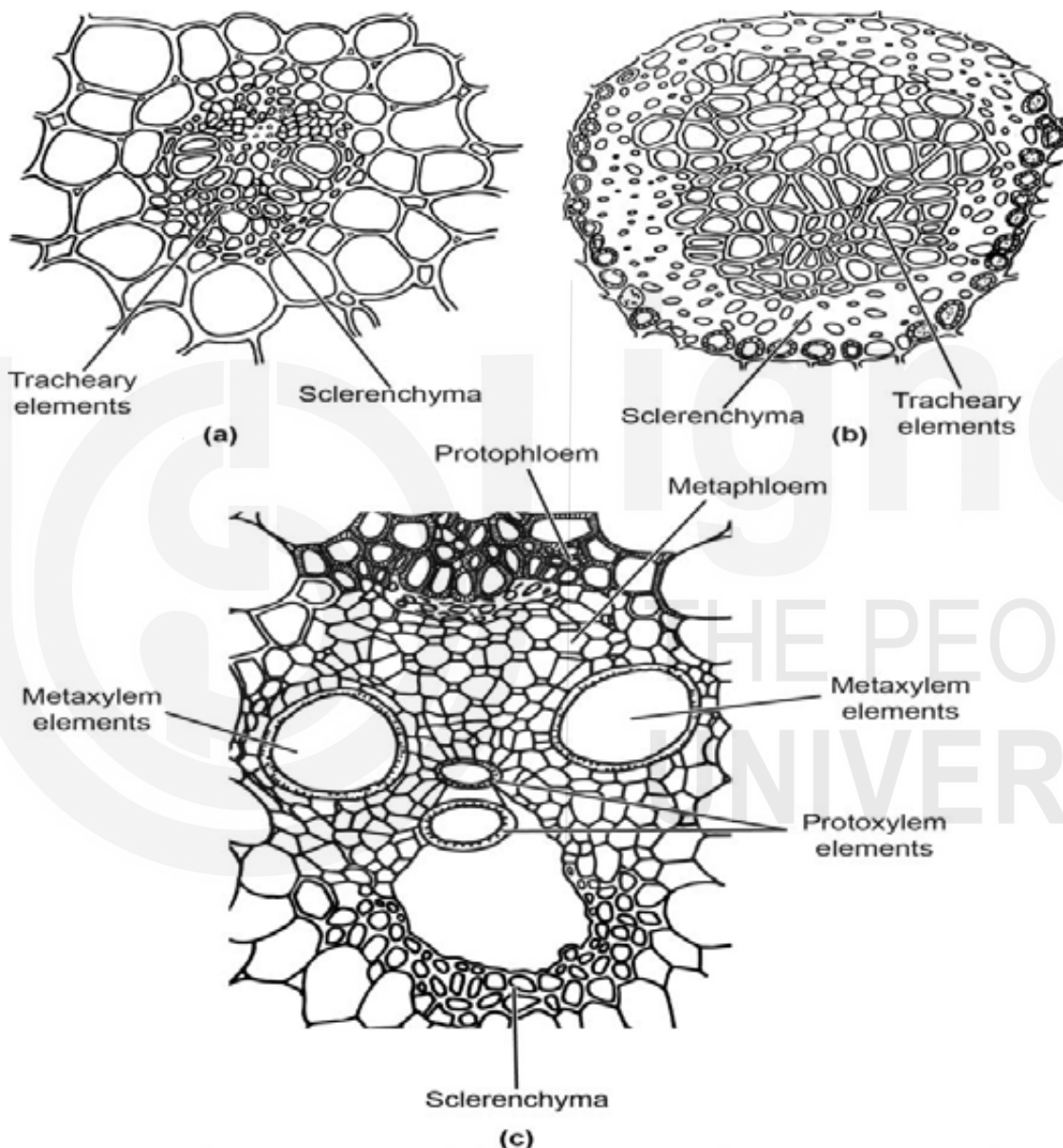


**Fig. 4.5: Cross-sections through the vascular bundles of different types.**

a) *Xanthorrhoea* leaf showing V-shaped xylem; b) *Kingia* stem showing U-shaped xylem; c) Y shaped xylem in *Zea* stem.

### 4.2.3 Dicot and Monocot Stem

Plants differ from one another in their anatomical characters. These characters are not absolute. Many variations/exceptions do occur. A summary of some distinctive features is given below in Table No. 4.1.

**Table 4.1: Salient differences between dicot and monocot stem.**

|                            | <b>Dicotyledon stem</b>                                                                                                                                                                                                | <b>Monocotyledon stem</b>                                                                                                                                                                                                                     |
|----------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Epidermis                  | Distinct with/without trichome, stomata, rarely chlorophyllous                                                                                                                                                         | Generally thick walled, prominent                                                                                                                                                                                                             |
| Hypodermis                 | Many or may not be distinct, if present usually collenchymatous                                                                                                                                                        | Generally present, sclerenchymatous                                                                                                                                                                                                           |
| Cortex                     | A few to many layered, parenchymatous, may have sclerenchyma                                                                                                                                                           | The cells following hypodermis are not differentiated and extended from hypodermis to the centre of the axis, it is known as ground tissue. (Parenchymatous/ sclerenchymatous)                                                                |
| Endodermis                 | Generally not distinct, mostly represented by cells, broken or complete ring                                                                                                                                           | Not present                                                                                                                                                                                                                                   |
| Pericycle                  | Present between the protophloem and endodermis, parenchymatous                                                                                                                                                         | Not present                                                                                                                                                                                                                                   |
| Interfascicular Parenchyma | A strip of parenchyma between vascular bundles                                                                                                                                                                         | Not present                                                                                                                                                                                                                                   |
| Pith                       | A large, conspicuous, central cylinder, parenchymatous, may be idioblastic sclerenchyma                                                                                                                                | Not distinguished                                                                                                                                                                                                                             |
| Vascular bundles           | a) Conjoint collateral, open with endarch protoxylem<br>b) Many, arranged usually in a ring<br>c) Almost all of them are uniform in size<br>d) Phloem parenchyma present.<br>e) Bundle sheath absent, poorly developed | a) Conjoint collateral; closed with endarch protoxylem<br>b) Many, scattered throughout the ground tissue<br>c) Larger towards centre and smaller towards periphery<br>d) Phloem parenchyma absent<br>e) Well developed bundle sheath present |

Observe Fig. 4.6 (a) and 4.6 (b) for a comparative internal organization of a typical dicotyledonous and a monocotyledonous stem.

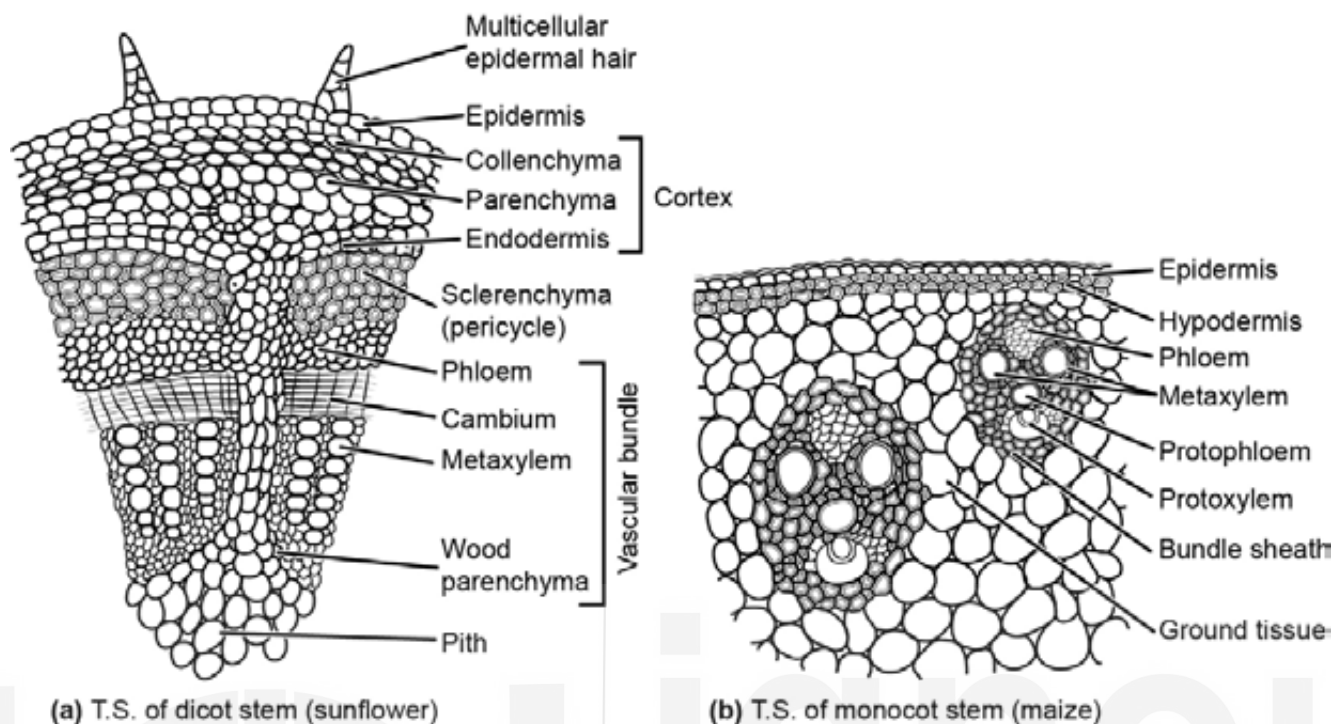


Fig 4.6: a) TS of Dicot; b) TS of Monocot stem-a portion enlarged.

### SAQ 1

- a) Fill in the blanks with appropriate word(s):
- A stem exhibiting horizontal growth is termed.....
  - The outer cell-wall of the epidermis is covered with .....
  - The ground tissue lying between the epidermis and the endodermis is called .....
  - In pteridophytes the commonest kind of vascular bundle is .....
  - Conjoint, collateral, closed vascular bundles with endarch protoxylem are characteristics of ..... stem.
- b) Match the terms mentioned in the **Column I** with the structures enlisted in the **Column II**.

#### Column I

- Phloem on either side of xylem
- Vascular bundles arranged in a ring
- Protoxylem cavity
- Laterals of limited growth
- Shoot system

#### Column II

- Leaves
- Monocot stem
- Dicot stem
- Stem and Leaves
- Bicollateral

### 4.3 SECONDARY TISSUES IN STEM

Most stems increase in their girth by secondary activity. Such activity is common in gymnosperms and dicotyledons, and is brought about by two kinds of lateral meristems; the **vascular cambium** and the **cork-cambium**. As a result of the secondary activity by the former the diameter of the stem increases considerably. Because of such increased girth, the primary tissues such as epidermis and cortex may be partially or completely sloughed off. It may also result in partial or complete obliteration of pith. Epidermis when sloughed off is often replaced by another protective cover, the **periderm** (formed due to the activity of cork-cambium). Since you are reading in detail about vascular cambium and cork-cambium and their activity in Unit 6 of this Volume, these are not being discussed here.

### 4.4 SPECIALISED STEMS

You have by now become familiar with the structure and organization of a stem which generally grows under normal environmental conditions. However, in a number of plants, the stem undergoes specialised modification so as to survive the specific unfavorable environmental conditions. We shall look at some such modifications in this section. In majority of these plants the modifications, in addition, make the organ a perennating one.

#### 4.4.1 Rhizome

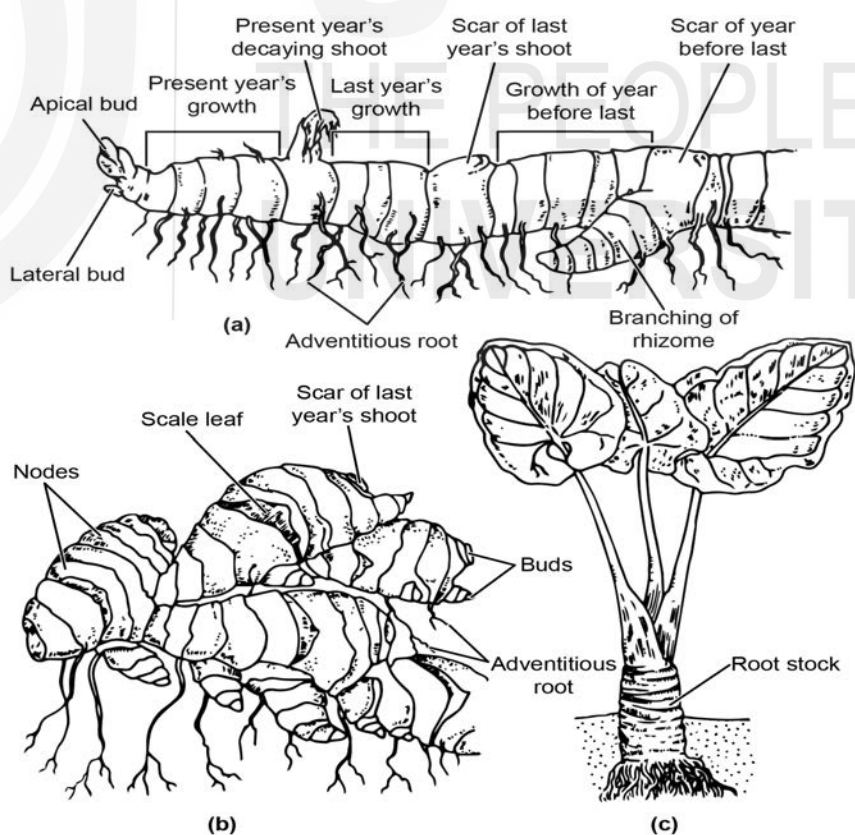


**Fig. 4.7: Rhizome.** a) A four-year old rhizome of a wild plant. The apical bud will develop next year's shoot while growth will be continued by the lateral bud in the direction of the arrow. The stem is, therefore, sympodial; b) Rhizome of ginger; c) Rootstock (vertical rhizome) of *Alocasia indica*.

Rhizomes are underground dorsiventral stems or branches growing horizontally under the surface of the soil (Fig. 4.7). They possess nodes and internodes. Nodes bear brown scaly leaves. It has both axillary as well as apical buds. Adventitious roots develop at the nodes. Sometimes they may bear contractile roots. Rhizomes are generally fleshy due to storage of food materials. They grow by an apical meristem which gives rise to a shoot. This shoot apex dies very soon and the growth of rhizome is continued by axillary bud. Such growth is called sympodial. Two very good examples of rhizome are ginger (*Zingiber officinale*) and turmeric (*Curcuma longa*).

#### 4.4.2 Tuber

Tuber is a general term applied to any fleshy part of the plant which may store food. They may be stem tubers or root tubers. The most common example of stem tuber is potato (*Solanum tuberosum*), Fig. 4.8 a, c). When a potato is grown from eye buds, the lower portion of its stem is covered by soil. Axillary or adventitious branches arise from this underground part of the stem. These branches swell into tubers due to accumulation of food substances (mostly starch), and arrest its growth. The tuber grows very slowly, and bears both nodes and internodes. The nodes are distinguished by the presence of scale leaves (at young stage) and **eyes** (rudimentary bud) in their axils. The eyes are arranged spirally and are more crowded towards the distal end (also called 'rose end'). The distal end is terminated by an-apical bud. The tuber possesses a corky skin produced by phellogen. Some other examples of plants which form tubers are: *Cyperus rotundus* (weed), vegetable, artichoke (*Helianthus tuberosus*, Fig. 4.8 b) stores inulin and Chinese artichoke (*Stachys tuberifera*) stores stachyose.

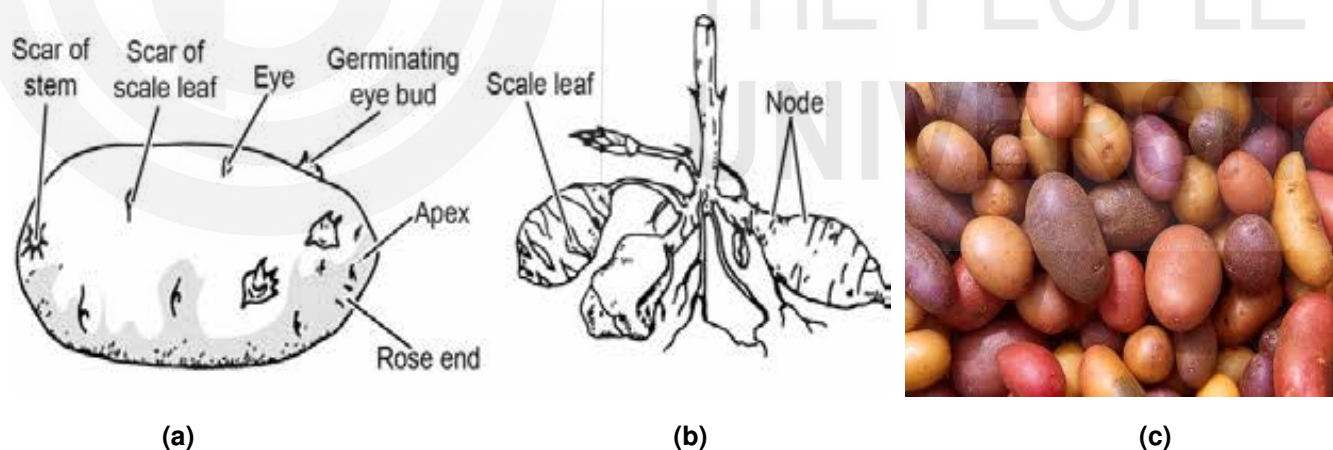


Fig. 4.8: Tuber: modified stem. a) *Solanum tuberosum*; b) *Helianthus tuberosus*; c) potato tubers.

#### 4.4.3 Bulbs

A bulb is a modified axis with a much reduced stem (disc) and **fleshy scale leaves** growing from it. The disc has a convex or conical shape with extremely compressed internodes; the nodes produce fleshy scale leaves which store food. At the time of flowering the apical bud develops into a scape. Daughter bulbs may be formed from axillary buds. Adventitious roots arise from the undersurface of the disc. Two types of bulbs are distinguished on the basis of arrangement of the fleshy leaves (see Fig. 4.9).

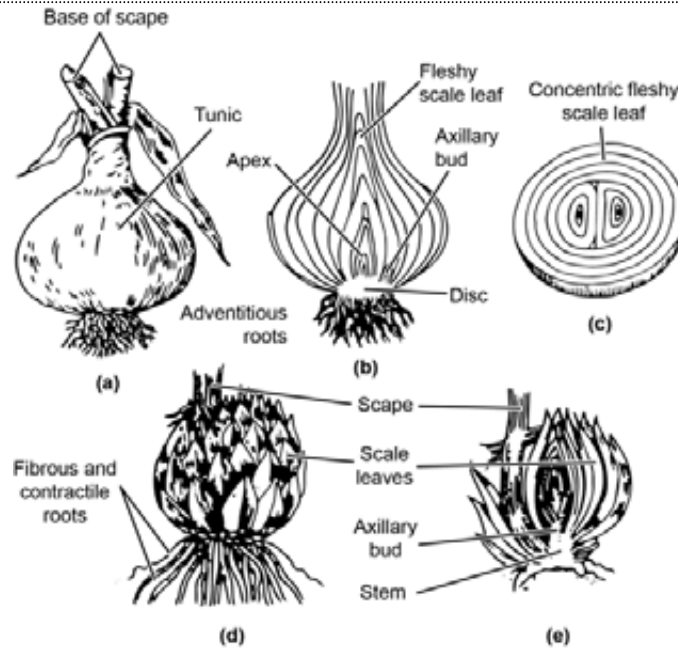


**Fig. 4.9: Bulbs-modified stem, a) Tunicated bulb of onion; b) L.S. of bulb, c) T.S. of bulb, d) Scaly bulb of lily, e) L.S. of scaly bulb.**

- i) **Tunicated bulbs:** Here, scale leaves are arranged in a concentric manner as seen in cross section. The whole bulb is covered with dry membranous scale leaves which form the tunic. Such bulbs are found in onion (*Allium cepa*); tulip (*Tulipa*); hyacinth (*Hyacinthus*) and tuberose (*Polyanthes*) (See Fig. 4.9 a, b, c).
- ii) **Scaly or imbricate bulbs:** The scale leaves are not concentric but are arranged loosely like a petal of a flower, overlapping each other at the margins. They are not compact but are covered by a common tunic. Garlic (*Allium sativum*) and lilies (*Lilium* spp.) have such bulbs (See Fig. 4.9 d, e).

#### 4.4.4 Corms

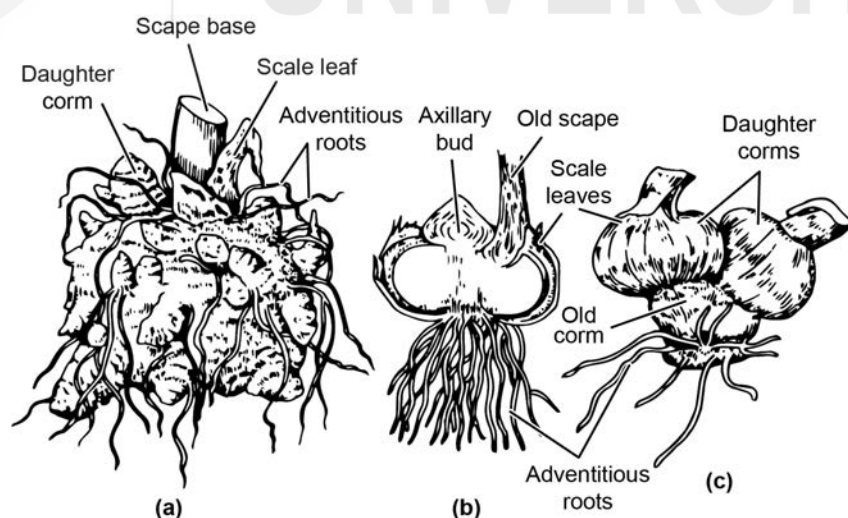


**Fig. 4.10: Corm-modified stem. a) Corm of *Crocus* with daughter corms; b) L.S. of *Crocus* corm; c) Corm of *Amorphophallus campanulatus*.**

Corms are also called solid bulbs. They are much condensed vertical root stocks with a very large apical bud and some scale leaves. Adventitious roots grow either from the base or from all over the body of the corm.

*Amorphophallus campanulatus* corm is a huge condensed internode with numerous adventitious buds and roots all over its body. New daughter corms are produced by the accumulation of food at the base of the shoot forming a new internode. Saffron (*Crocus sativus*) also bears and grows by corms (see Fig. 4.10).

#### 4.4.5 Runner, Offset, Stolon, Sucker

Plants with weak herbaceous habit propagate quickly by means of special branched stem which gives rise to new plants. Here, though the individual plant is short-lived, the colony is perennial. These modified branches either grow along the surface of the soil or water, or may be partially or wholly underground.

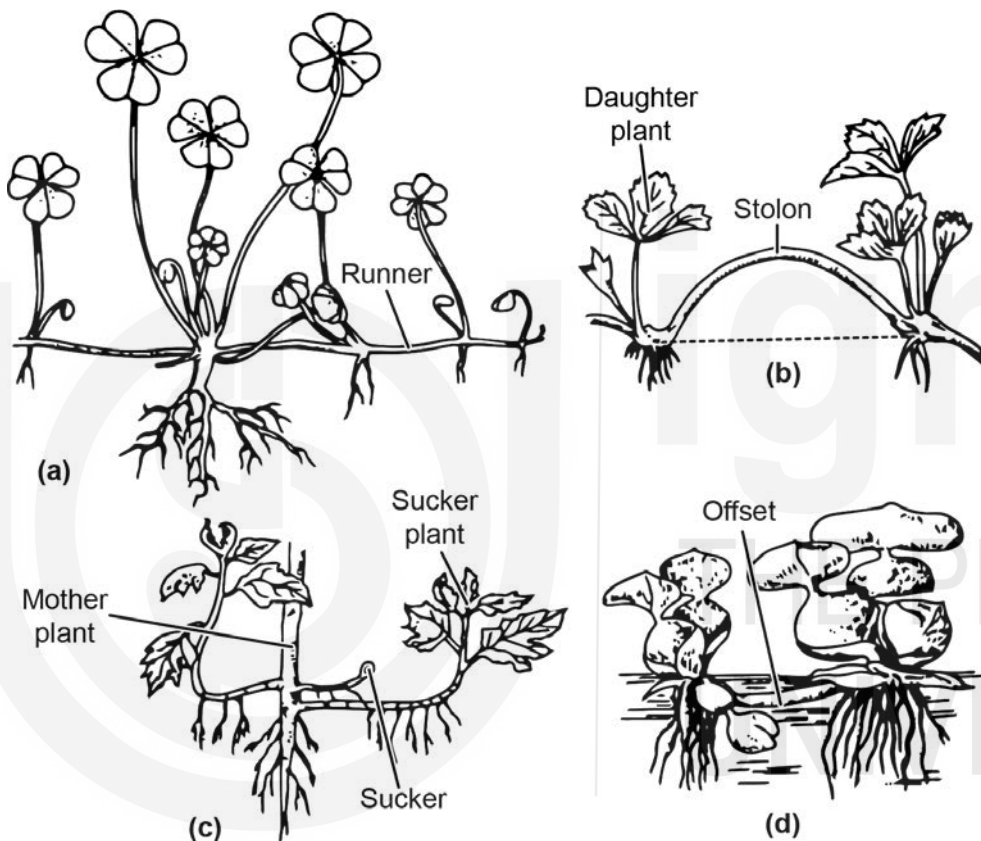


**Fig. 4.11: Modifications of Stem: a) Runner of *Oxalis corniculata*; b) Stolon of *Mentha* sp. c) Sucker of *Chrysanthemum* sp. d) Offset of *Eichhornia* sp.**

**Runner :** Creeping plants such as doob grass (*Cynodon dactylon*), *Oxalis* and *Fragaria*, form runners. Here, the axillary buds from the lowest leaves give rise to slightly modified branches. The basal internodes of the bud elongate and horizontally trail along the ground soil. In this way the bud is carried to distances away from the parent plant. The process continues (see Fig. 4.11 a).

**Offset:** Offset are found in aquatic plants. They are also a kind of runner, except that they are shorter and thicker. Water hyacinth (*Eichhornia crassipes*) grows by offset (Fig. 4.11 d).

**Stolon:** It is a special type of runner which does not grow horizontally from the beginning. At first it grows upward like ordinary branches and then arches down to meet the soil. After striking the soil daughter plants are formed. *Mentha* (Fig. 4.11 b) and some members of Rosaceae bear natural stolons.

**Sucker:** Sucker is an underground runner which soon grows up and forms a daughter plant after striking roots. Examples of sucker producing plants are *Chrysanthemum* and *Mentha arvensis* (Fig. 4.11 c).

#### 4.4.6 Cladophyll

Cladophyll is also called **Phylloclade**. They are modifications encountered in xerophytic plants. The modifications help plant to minimize water loss. The growth of leaves is checked and this reduces transpiration. The stem becomes flattened or swollen. It is chlorophyllous and serves as a photosynthetic organ. Such flattened or swollen stem structures are called phylloclade or cladophyll (Fig. 4.12). The flat, fleshy portion is internode, and the leaves at the nodes are metamorphosed into spines or reduced to small scaly leaves. Phylloclades commonly occurs in the families Cactaceae, Euphorbiaceae, and in *Muehlenbeckia*, *Casuarina* and *Ruscus*. Phylloclade possessing only one internode is termed **cladode** (e.g., *Asparagus*)

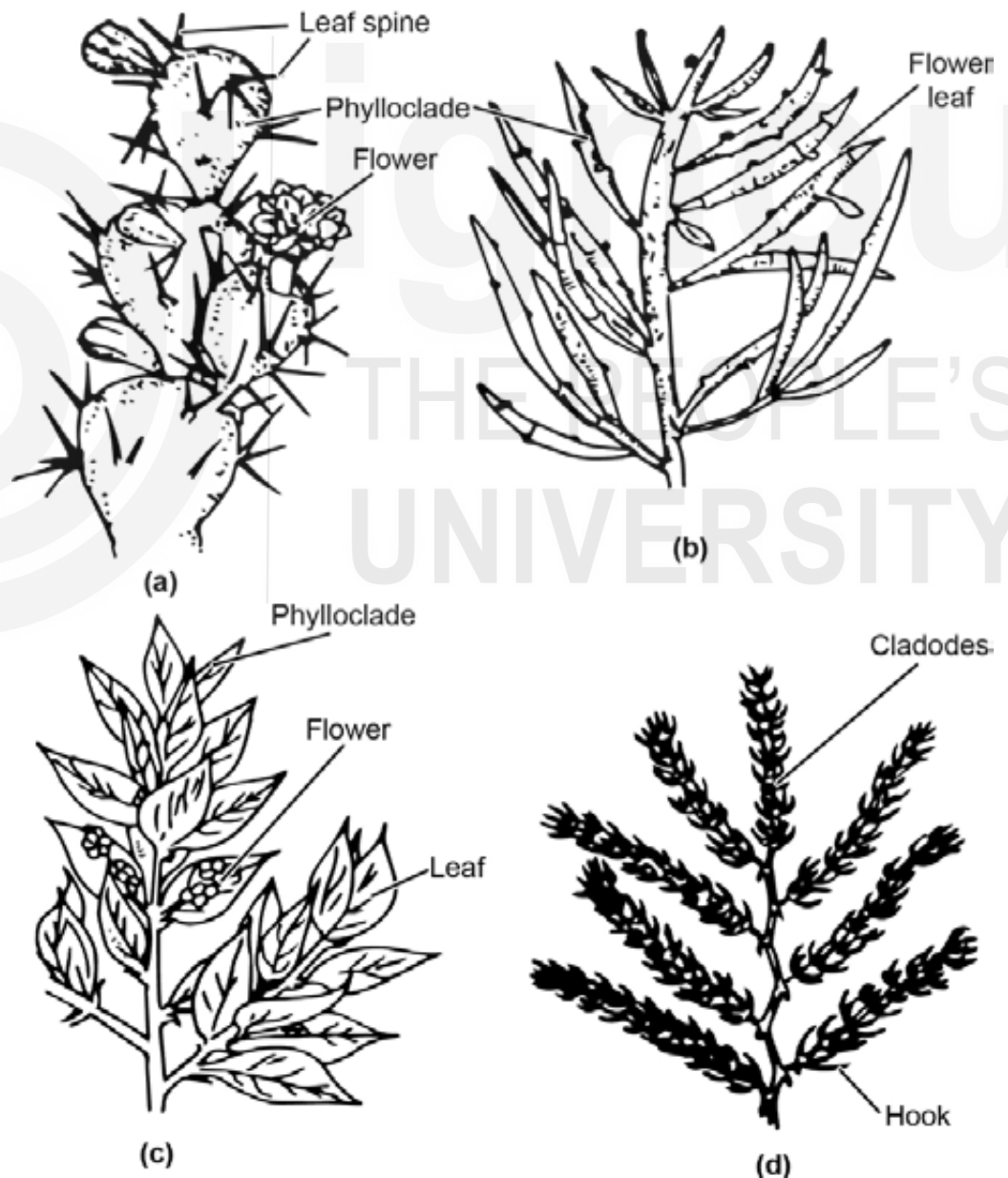


Fig.4.12: Phylloclade, a stem modification a) *Opuntia*; b) *Muehlenbeckia*; c) *Ruscus*; d) *Asparagus*.

---

## SAQ 2

1. Choose the correct alternative from the two provided in the parathenses:
    - a) The growth in a rhizome is through (axillary/apical) bud.
    - b) Eye buds are characteristics of tubers of (potato/sweet potato).
    - c) Corms are also known as (fleshy/solid) bulbs.
    - d) A phylloclade possessing only one node is called (cladode/cladophyll).
    - e) (*Chrysanthemum*/*Muehlenbeckia*) is an example of sucker.
- 

## 4.5 SUMMARY

---

- The shoot system consists of an axis, the stem and the laterals, the leaves (determinate growth) and the branches (indeterminate growth). The shoot arises because of the activity of shoot apical meristem localized within the shoot apex. Every shoot apex at regular intervals produces leaf primordia. These primordia bear bud(s) in their axils. The site of leaf initiation is called node. The region between any two consecutive nodes is termed as an internode.
- The primary stem has three fundamental regions: epidermis, ground tissue and vascular tissue. The epidermis is generally single layered and may possess trichomes and stomata. A conspicuous cuticle is always present. The ground tissue is differentiated as cortex and pith in gymnosperm and dicotyledons whereas such demarcation is absent in monocotyledons. The cortex may sometimes possess cells which are chlorophyllous, collenchymatous, or sclerenchymatous, or may be rich in ergastic substances. The endodermis is only partially discernible in aerial stems while it is well developed in underground stems. The endodermis may be modified as starch sheath.
- The vascular tissue of stem consists of discrete vascular bundles. These are generally conjoint, collateral (or bicollateral), open or closed but always with endarch protoxylem. The vascular bundles could be amphivasal or amphicribal. The primary phloem development is centripetal whereas primary xylem develops centrifugally.
- Stems of gymnosperm and dicotyledons exhibit secondary activity, which is conspicuously absent in monocotyledons because the bundles lack cambium. The development of interfascicular cambium marks the onset of secondary activity. The inter and intra fascicular cambia join and form a continuous ring. The vascular cambium once formed produces secondary xylem towards inside and the secondary phloem towards outside.
- Stems also get modified to perform various functions. Rhizome, tuber, bulb and corms are modified underground stems for storage and perennation. Runner, stolon, offset and suckers and sub-aerial modifications for vegetative propagation. Cladophyll, phylloclades are modifications associated with xeric environment.

## 4.6 TERMINAL QUESTIONS

---

1. Define the following terms:
  - a) Internode
  - b) Tunicated bulb
  - c) Cladode
  - d) Decumbent
  - e) Offset
  - f) Shoot
  - g) Conjoint vascular bundle
  - h) Amphivasal vascular bundle
2. With the help of a flow chart describe the origin of various kinds of tissues of a stem from a shoot apical meristem.
3. You are provided with a transverse section of primary stem. List the characteristic features that you would expect to observe under a microscope to conclude that the given slide belongs to a dicot stem.
4. Mention the relationship between shoot-apical meristem, stem, leaf and axillary bud.
5. Draw labeled sketches of the following:
  - a) Vascular bundle of maize stem
  - b) Amphicribal vascular bundle
  - c) T.S. dicot stem
  - d) L. S. of onion bulb
  - e) Phylloclade of *Ruscus*

## 4.7 ANSWERS

---

### Self-Assessment Questions

---

1.
  - a)
    - i) plagiotropic
    - ii) cuticle
    - iii) cortex
    - iv) amphicribal
    - v) monocot
  - b) i) e; ii) c; iii) b; iv) a; v) d
2.
  - a) axillary
  - b) potato
  - c) solid
  - d) cladode
  - e) *Chrysanthemum*

## **Terminal Questions**

1.
  - a) Refer to Subsection 4.2.1.
  - b) Refer to Section 4.4.3
  - c) Refer to Section 4.4.6
  - d) Refer to Subsection 4.2.1.
  - e) Refer to Section 4.4.6.
  - f) Refer to Section 4.2.1.
  - g) Refer to Section 4.2.2
  - h) Refer to Subsection 4.2.2.
2. Refer to Subsection 4.2.2 and fig 4.2
3. Hint: Refer to Table 4.1.
4. Hint: Fig. 4.1; Refer to Sections 4.1 and 4.2.
5. Refer to Figures:
  - a) 4.6 b
  - b) 4.4 g, h
  - c) 4.6 a
  - d) 4.9 b
  - e) 4.12 c

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## Structure

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|     |                        |     |                             |
|-----|------------------------|-----|-----------------------------|
| 5.1 | Introduction           | 5.4 | Specialised leaves          |
|     | Objectives             |     | Tendrils                    |
| 5.2 | Leaf                   |     | Thorns, Spines and Prickles |
|     | Morphology of a leaf   |     | Storage leaves              |
|     | Internal Structure     | 5.5 | Summary                     |
| 5.3 | Dicot and Monocot leaf | 5.6 | Terminal Questions          |
|     | Structure of Stomata   | 5.7 | Answers                     |
|     | Functions of Stomata   |     |                             |

### 5.1 INTRODUCTION

---

The leaf is an important component of a shoot system. It arises from the activity on the flanks of a shoot apical meristem in the form of a protrusion. Such young leaf primordium later matures into a lateral organ, the leaf, of limited growth. Its primary function is photosynthesis. Its relationship with the primary axial stem is very complex. Generally, the part of the stem axis where a leaf makes the contact is termed node.

The leaves on a stem axis of a shoot system arise in a predictable, sequence. The terms phyllotaxy or phyllotactic refers to the pattern of arrangement of leaves (as well as the other lateral appendages) on a cauline/stem axis. A phyllotaxy pattern is unique to every species.

The leaf represents an unique organ fulfilling a rather specific function for which it is specialized both structurally and physiologically.

We shall discuss the structural aspects of the leaf in this unit. It includes external and internal features, structural adaptations in some common but important kinds of photosynthetic leaves.

We shall also discuss some kinds of specialised modifications of leaves with specialized ecological adaptive advantages.

## Objectives

---

After studying this unit you would be able to :

- ❖ comprehend the leaf concept;
- ❖ correlate the interrelationship of the morphological units, the shoot apical meristem, stem or cauline axis, the lateral organ of limited growth, the leaf, and shoot system;
- ❖ know about the morphology of a typical dorsiventral, simple leaf;
- ❖ differentiate between the morphology and anatomy of a dicotyledonous and a monocotyledonous leaf;
- ❖ describe the structural and function of stomata; and
- ❖ appreciate the close relationship between structure, function and adaptability of some specialized kinds of leaves such as: tendrils; spines; thorns and storage leaves.

## 5.2 LEAF

---

The leaf is an organ of determinate growth and dorsiventral symmetry. Its flattened shape is well suited to its photosynthetic function.

Leaves are classified as microphylls and megaphylls (macrophylls). Both types of leaves originate from basically similar primordia at the shoot apex.

Microphylls are of small size because of their failure to undergo any extensive subsequent growth. They occur in Psilotales, club mosses and some other pteridophytes.

Megaphylls or foliage leaves, as they are better known are common to flowering plants. They range from a few millimeters in length to about 2 meters in some palms and bananas. Floating leaves of *Victoria amazonica* (Fig.5.1) (giant water lily) may have lamina of about 2 meters in diameter.



Fig.5.1: Leaf of *Victoria amazonica*.

Cataphyll is a term applied to certain kinds of leaves. The early development of a cataphyll is overly similar to a foliage leaf. However, a mature **cataphyll** differ from a true foliage leaf in having

- fewer or no stomata;
- poorly developed mesophyll with little or no intercellular space between the cells;
- almost no significant thickening along the mid-veins, and
- poorly developed venation.

Another kind of a leaf is **scale** leaf. A Scale leaf is technically a **cataphyll**. During its development from foliar primordia, they exhibit repeated expansion laterally and axially, and distinct inhibition of growth in the distal regions of the developing leaf. In additions, the early growth in proximal part is accompanied by sclerification and / or other protective characteristics. A scale leaf development is commonly the first plan for the formation of a terminal bud.

**Foliage** leaf is the commonest kind of a **true** leaf. It is typically photosynthetic organ of the plant. We shall discuss its structure in detail in subsection 5.2.1, of this unit. This also represents photosynthetic adult leaf.

In some species, the leaves in the younger phase of a plant differ both in morphology and internal organisation from the adult foliage leaves of the same plant. Such leaves are called **juvenile** leaves.

With so many kinds of leaves being discussed above, you might ask? What exactly is a leaf? How to define it? The problem becomes even more difficult because of its peculiar place and mode of its origin. Also, because of its close physical and ontogenetically relationship with cauline or stem axis.

A partly facetious, synthesised definition of a leaf is provided in the Box 5.1

#### Box 5.1: Leaf concept.

A leaf can be described as:

“A lateral outgrowth from a stem, constituting one discrete element of the foliage of a plant which usually performs the function of photosynthesis. They arise as an outgrowth of shoot apical meristem in regular succession. They typically possess a flattened blade attached to the stem by a petiole. In a transection, it possesses an adaxial and an abaxial epidermis perforated by stomata. In between the epidermis lie photosynthetic cells, the mesophyll rich in both chloroplasts and prominent intercellular space. It also possesses an intricate network of veins, veinlets and vascular bundles dispersed within the mesophyll. Interestingly, the whole structure being distinguishable from a leaflet a cladophyll or a phylloclade by possession of a shoot bud in its axil between its base and the adjacent stem.”

Even the above cumbersome definition fails to encompass all kinds of leaves that we observe in nature. For example the ‘needles’ of *Pinus*, the leaves of gymnosperms, especially *Picea* do not possess any axillary buds at their bases. We may suggest that the above description / definition of a leaf given in box 5.1 is more of a generalisation with some exception.

### 5.2.1 Morphology of a Leaf

We shall discuss in this sub-section the morphology of a typical dicotyledonous, simple, dorsiventral, petiolate leaf. (Variations in forms; sizes and structure may occur in nature).

**Foliage leaf** is a typical foliage leaf (see Fig. 5.2) has got three parts: a) leaf base, b) petiole, the stalk of the leaf, and c) leaf lamina or blade.

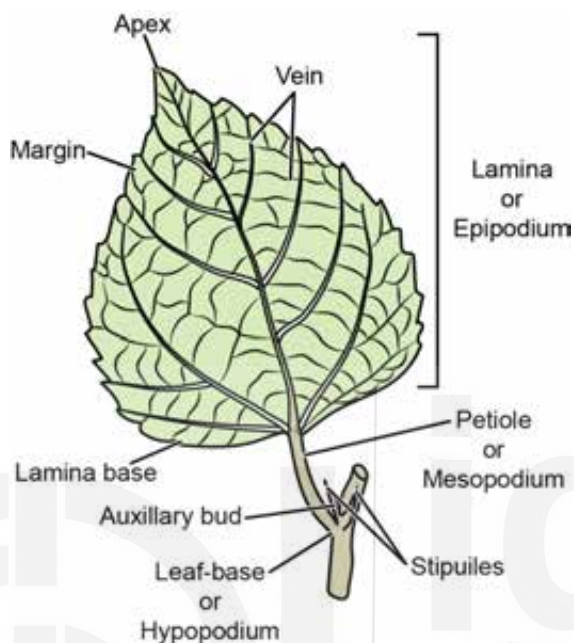


Fig. 5.2 Parts of a typical leaf.

The leaf base attaches the leaf to the stem. When a petiole is present, the leaf is called **petiolate**. A leaf without petiole is called **sessile**. There are various kinds of modifications of leaf bases and petioles. Here we will discuss about the lamina since this is mainly associated with photosynthesis and gaseous exchange.

Leaf lamina is normally a flat structure. The upper surface, which faces the axis of the stem, is termed **adaxial**. The lower surface, which is away from the axis, is known as **abaxial**. Such leaves are called **dorsiventral** (bifacial) and are common to most dicotyledons. In monocotyledons and shade plants the leaf is placed in such manner that both surface receive equal light and there is no difference between the two surfaces. Such leaves are called **isobilateral** (monofacial). The leaves with cylindrical outline are termed as **centric** (e.g. onion).

### 5.2.2 Internal Structure

Internally the lamina of a leaf consists of three basic kinds of tissue: dermal (epidermis), ground (mesophyll) and vascular (veins). Let us know more about each.

#### Dermal Tissue (Epidermis)

The epidermis constitutes the dermal tissue of a leaf. Usually a single layer of epidermal cells is present. However, leaves of *Ficus*, *Nerium* and *Piper*, show a multiple epidermis. In such leaves adaxial epidermis may have more layers

than the abaxial epidermis. Whenever the number of epidermal layers on abaxial surface is more a sub-stomatal crypt is usually present, as in the leaf of *Nerium oleander* (Fig. 5.3).

Stomata are the most characteristic feature of the epidermis of any leaf. They may be present on both the sides of the leaf (as in isobilateral leaves) or may be restricted to abaxial surface (as in most dorsiventral leaves). Rarely, as in the floating leaves of *Nymphaea*, the stomata are located only on the adaxial epidermis.

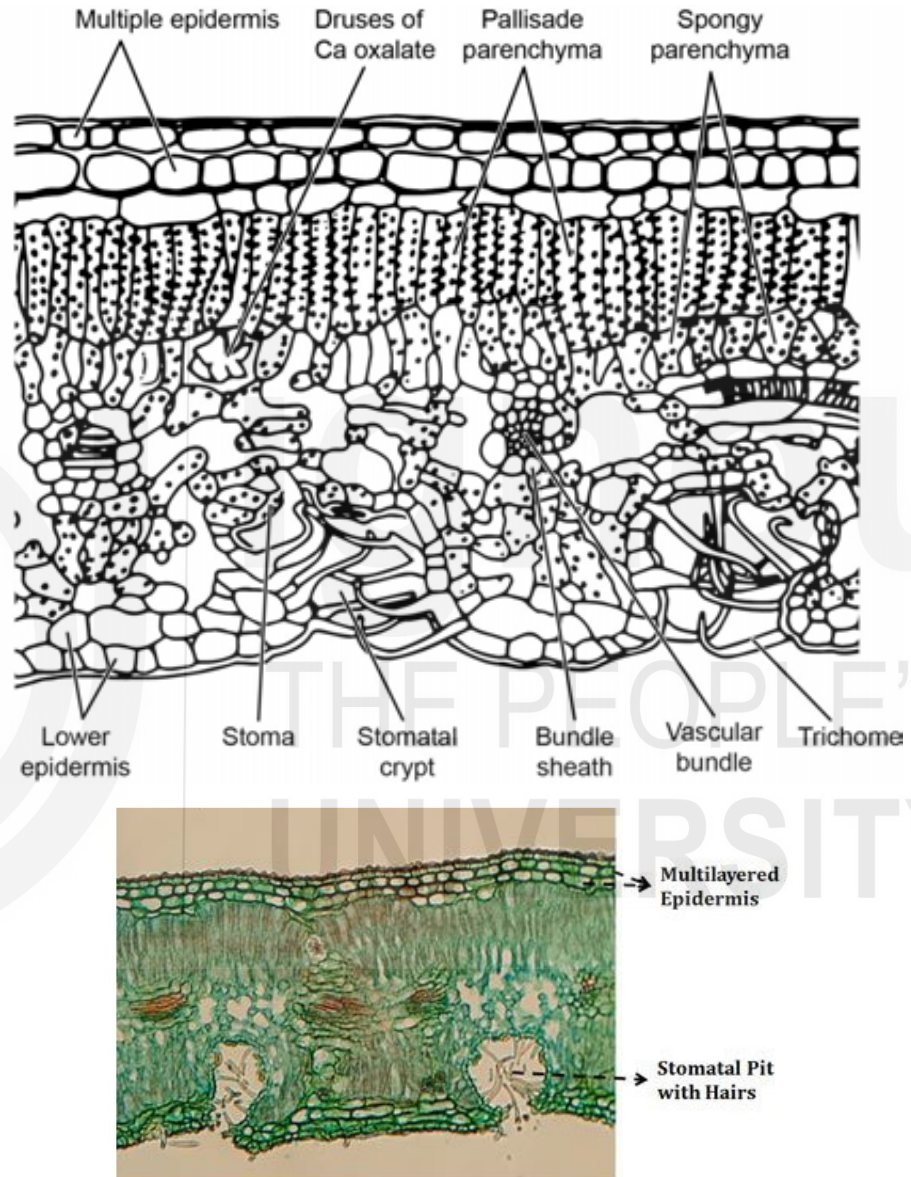


**Fig. 5.3 : Vertical section of *Nerium* leaf.**

Epidermal cells do not contain well developed plastids. Plastids are characteristically present in the guard cells of stomata. Such plastids have only few grana. *Phyllospadix*, which grows in sea water, possesses chloroplasts in the epidermal cells.

Epidermis of many species has trichomes. Both, covering and glandular trichomes occur in the leaves. Trichomes exhibit a considerable range of form. In certain graminaceous leaves some of the epidermal cells are modified in **bulliform cells** such cells are hygroscopic (Fig. 5.5).

Epidermal cells may contain crystals (e.g. *Tamarix*, *Plumbago capensis*); cystolith of calcium carbonate (e.g. *Ficus elastica*); lignin (e.g. *Quercus*, *Nerium*, *Cycadaceae*, needle of conifers); cutchouc (e.g. *Eucalyptus*); silica (e.g. *Equisetum*, Graminaeae, Cyperaceae); and mucilage (e.g. Euphorbiaceae, Malvaceae).

### Ground Tissue (Mesophyll)

The ground tissue of a leaf lamina is highly specialised to carry out photosynthesis. The cells are rich in chloroplasts and comprise the mesophyll. The mesophyll is differentiated in two kinds of cells, palisade and spongy parenchyma. The palisade cells are cylindrical and elongated as seen in vertical section of a leaf. They could be one to few layered. The spongy parenchyma consists of loosely arranged irregular cells with air spaces. It is generally present below the palisade parenchyma. In dorsiventral leaves (see Fig. 5.4). The palisade parenchyma is restricted to adaxial surface.

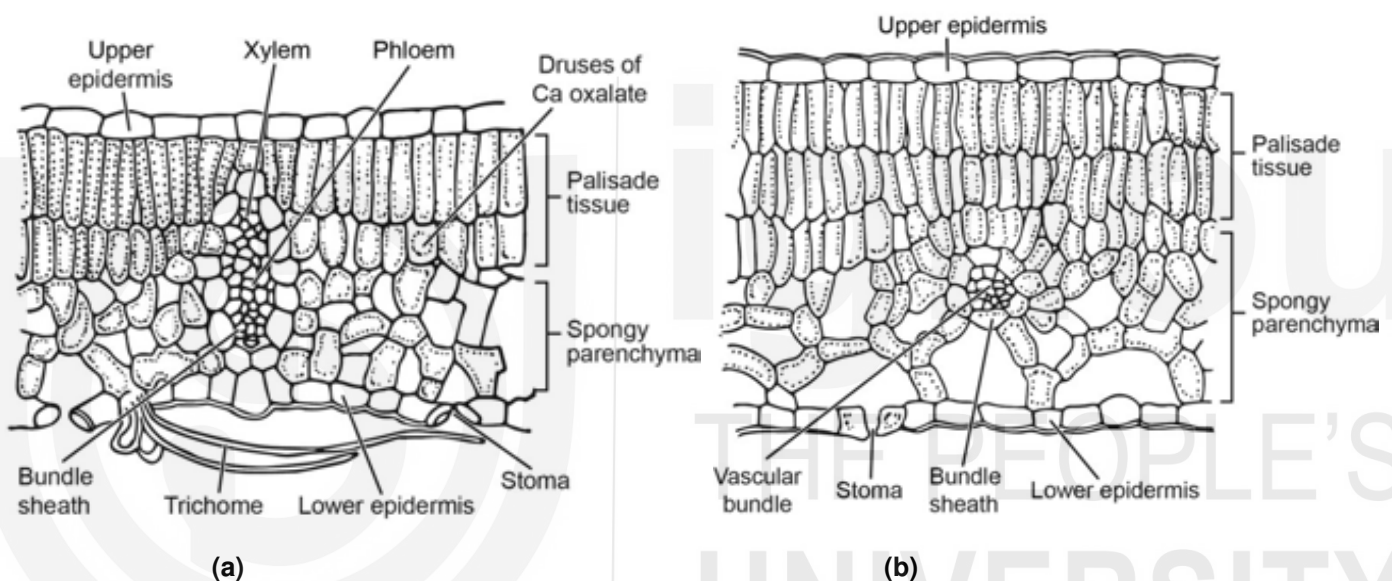


Fig. 5.4: Portions of vertical section of dorsiventral leaves a) *Quercus*; b) *Malus*.

However, in isobilateral leaves, the palisade parenchyma occurs on both the surfaces (see Fig. 5.5). In cylindrical leaves as in *Hakea*, the palisade tissue occurs all along the periphery.

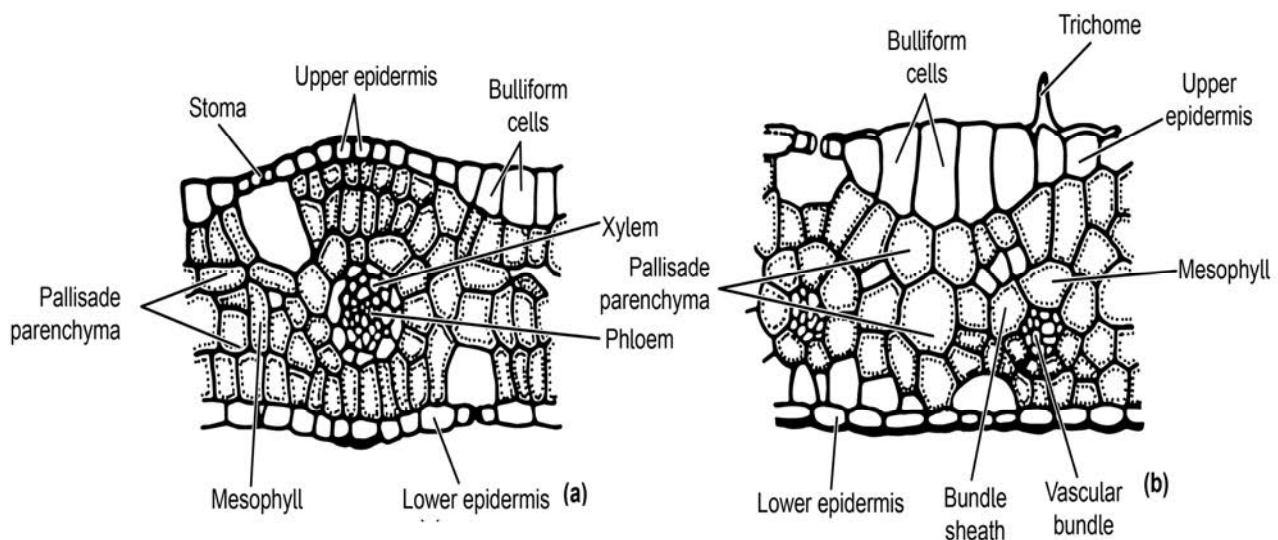


Fig. 5.5: Portions of vertical section of isobilateral leaves a) *Avena*; b) *Zea*.

You will see lots of variations in structure and distribution of mesophyll in the leaves.

**Bundle Sheath:** In some plants, the cells surrounding the vascular tissue in a leaf lamina though of similar origin are morphologically different from adjacent mesophyll cells. These cells are large and contain fewer chloroplasts. They may be thick-walled. These cells constitute the **bundle sheath** (see Fig. 5.6) When these cells extend up to the leaf surface, then they are called **bundle-sheath extension**.

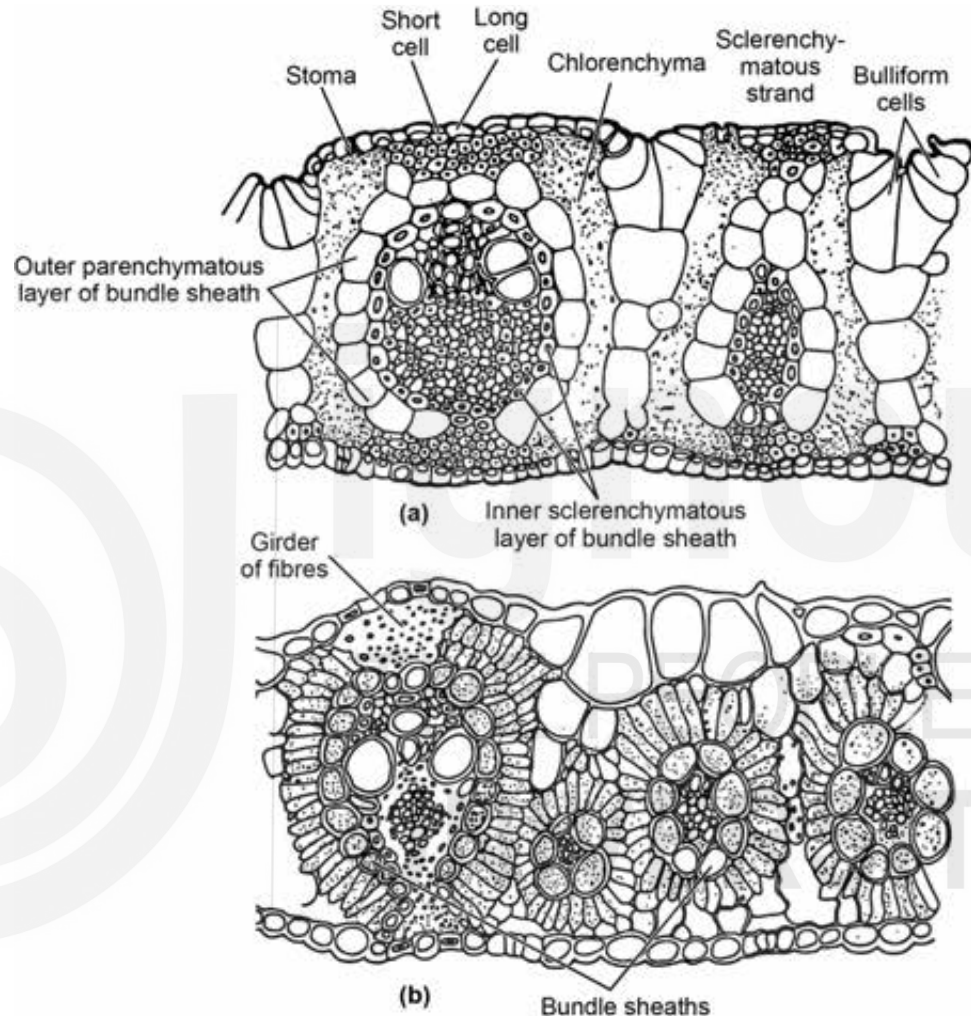


**Fig. 5.6: Portions of vertical sections of grass leaves a) *Desmostachya bipinnata* in which the bundle sheath consist of two layers, the outer parenchymatous and the inner sclerenchymatous; b) *Hyparrhenia hirta* in which the bundle sheath consist of single layer of chloroplast containing cells.**

Whenever the bundle-sheath cells contain starch, these are termed as **starch sheath**. When they possess casparian strips, they form endodermis.

The bundle sheaths are very conspicuous and well-studied in  $C_4$  plants. Studies with electron microscope reveal that the chloroplast in the bundle sheath cells of *Amaranthus edulis* and *Atriplex lentiformis*, are large and have grana and abundant starch grains. Fewer and smaller starch grains are reported in the mesophyll cells of the same leaves. Chloroplasts in bundle sheath cells of tropical grasses, however, have little or no grana at maturity.

## Vascular Tissue

The vascular tissue of a leaf is in continuation with that of the stem on which they are borne. Each leaf receives from one to many vascular traces from the stem. The traces may continue unbranched throughout the entire length of the leaf or may alternatively branch or even anastomose. The vascular bundle of a leaf is called a **vein**. The ramification and the network of these veins in a leaf are called **venation**. Lower vascular plants have **dichotomous venation** (e.g. fern leaves). Venation is **reticulate**, net-like in dicotyledons. In monocotyledons, on the other hand, the leaves show **parallel venation** (see Fig. 5.7).

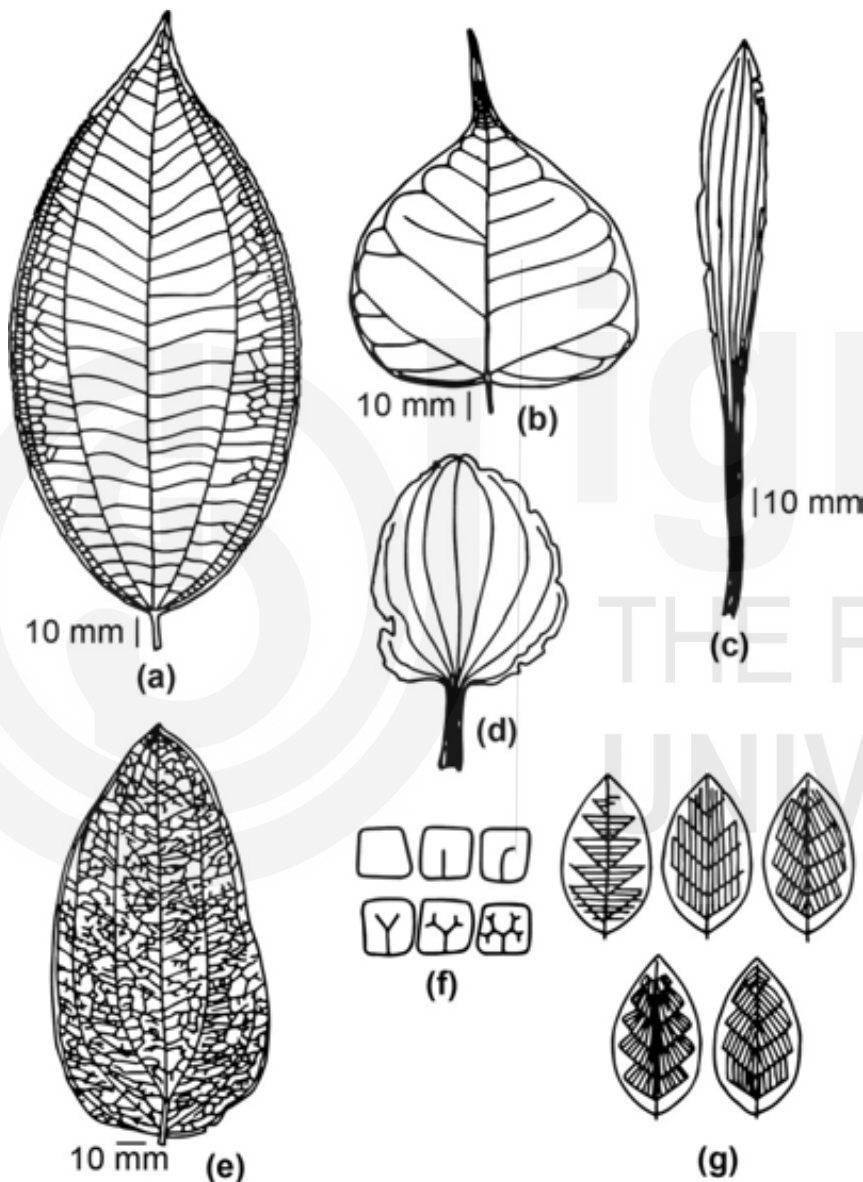


**Fig 5.7:** a) *Clidemia hirta* (D); b) *Ficus religiosa* (D); c) *Plantago lanceolata*, parallel veined (D); d) *Plantago major*; e) *Smilax* sp., net-veined (M); f) typical areole patterns showing ultimate veinlets; g) variations of one type of secondary vein layout. (f and g after Hickey 1973) (D)=dicotyledon, (M)=monocotyledon.

The smallest area of the leaf tissue surrounded by veins is known as **areole**. Areole varies in shape and sizes. Leaves of certain succulents do not form an areole. The vascular bundle is generally collateral with xylem on adaxial side and phloem towards the abaxial side.

A vascular cambium, if present, is restricted to the bundles of mid-vein and that too in the dicotyledons. Vascular bundles in the mid-rib region may be arranged in a ring (*Vitis*, *Liriodendron*) or in a semi-circle (*Abrosia*), or may be irregularly distributed (*Helianthus*). The petiole when present bears more or less similar anatomical features as seen in the internode of the plant.

### SAQ 1

- a) Fill in the blanks with proper word / words:
- Young leaf primordium arises as a small protuberance in .....
  - In a cataphyll the mesophyll is ..... developed.
  - Epipodium is another term for .....
  - Stomatal crypts are located on ..... epidermis of *Nerium* leaves.
  - In an isobilateral leaf palisade parenchyma is present on ..... side(s) of lamina.
- b) State whether the following statements are true or false. Write letter (T) for truth or letter (F) for false in the space provided:
- Lots of stomata are present in the cataphyll. [ ]
  - Juvenile leaves have similar morphology as those of foliage leaves. [ ]
  - Mesophyll is differentiated into palisade and spongy parenchyma in a bifacial leaf. [ ]
  - Bulliform cells are present in the abaxial epidermis of grass leaves. [ ]
  - Multiple adaxial epidermal layers are found in *Ficus* leaves. [ ]
- c) Draw a diagram of a foliage leaf and label the various parts.

## 5.3 DICOT AND MONOCOT LEAF

In the preceding section we have discussed the internal organization of tissues within a leaf. You must have noticed significant variations in the different examples that were discussed and observed in various figures 5.1 to 5.7.

Although, the variations were related to the ecological environment where a particular plant species inhabits there also exist some fundamental characteristics that can be assigned to major taxonomic units (taxa) such as dicotyledons and monocotyledons as far as the internal structure of the leaf is concerned. The Fig. 5.8 and Table 5.1 provides a summary of such differences.

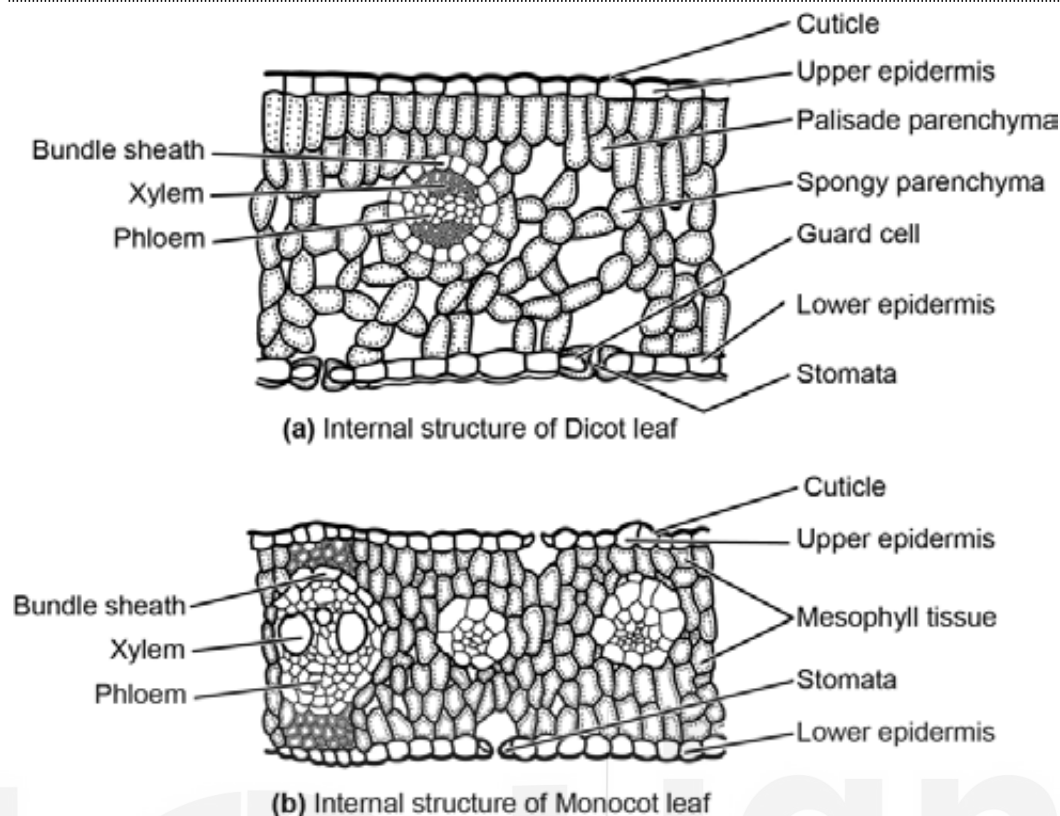


Fig 5.8: Internal Structure of monocot and dicot leaf.

Table 5.1: Comparison between a Monocotyledon and Dicotyledon Leaf.

|                     | Monocotyledonous Leaf                                                                                                                                          | Dicotyledonous Leaf                                                                                                                    |
|---------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------|
| Epidermis           | Only single layered, xerophytic grasses have large cells with flexible cell walls helping the leaves to roll in dry weather, these are called bulliform cells. | Usually single layered or sometimes multilayered, bulliform cells absent                                                               |
| Stomata             | On both sides of the leaf, generally arranged in parallel rows.                                                                                                | Generally restricted to abaxial surface                                                                                                |
| Palisade Parenchyma | On both the surfaces.                                                                                                                                          | Generally restricted to abaxial epidermis                                                                                              |
| Spongy Parenchyma   | Sandwiched between two palisade parenchyma zones.                                                                                                              | Conspicuous, large body towards the abaxial surface                                                                                    |
| Venation            | Generally parallel reticulate in <i>Smilax</i> , <i>Arum</i> , some Orchidaceae members, generally isobilateral, (also called unifacial)                       | Generally reticulate, parallel in <i>Plantago</i> , <i>Geropogon</i> , <i>Trapopogon</i> Generally dorsiventral (also called Bifacial) |

### 5.3.1 Structure of Stomata

An aperture (pore) along with two guard cells surrounded by subsidiary cells constitutes a **stoma** (*pl. stomata*). Each stoma is characterised by the presence of two specialised cells, called guard cells. These guard cells possess an aperture or opening between them. The changes in shape of

guard cells bring about opening or closure of their aperture (Fig. 5.9). The pair of guard cells may be surrounded by certain number of cells arranged/placed in particular manner as seen/visualized in aerial view. These cells differ in shape and sizes from the majority of other epidermal cells (sometimes referred to as ordinary epidermal cells). Such cells are called subsidiary cells.

A unit of two guard cells surrounding subsidiary cells constitutes a stoma. In event of absence of any distinct subsidiary cells, a stoma consists of only two guard cells and the aperture. The opening and closing of a stomatal aperture is controlled both by its entire unit-stomatal aperture guard cells and all the subsidiary cells constitute, physiologically a stomatal apparatus.

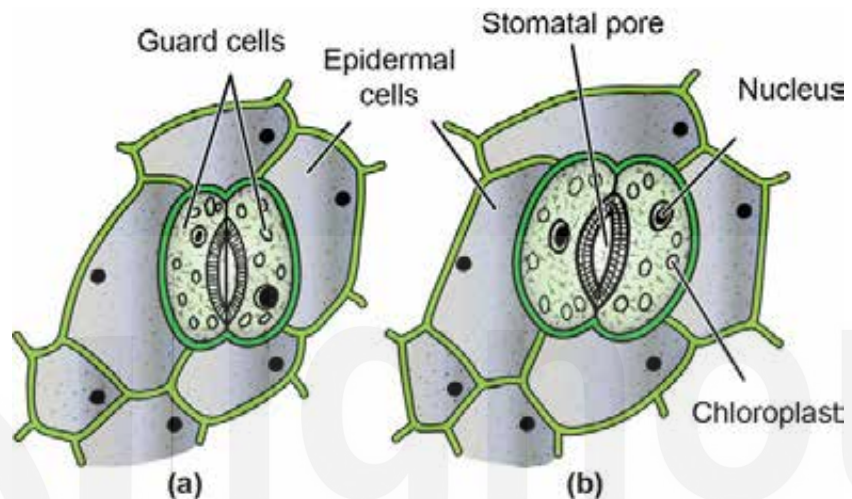


**Fig 5.9: Structure of stomata.**

The epidermis of leaves and many other aerial parts of primary organs of plants (such as hypocotyls, young stems, petioles, peduncles, and floral appendages) generally possess stomata. Stomata may also occur in some underground organs, particularly rhizomes. They are also sometimes reported in some primary roots, e.g., *Ceratonia siliqua*.

The stomata are not uniformly distributed in all aerial parts of a plant or across the plants. They are most prominently present in the leaf epidermis. They may occur in both the abaxial as well as only in adaxial epidermis of a leaf (amphistomatous); as in most isobilateral leaves. They may occur only in abaxial epidermis (hypostomatous) as in many dorsiventral leaves e.g. *Mangifera*, *Bryophyllum*. Rarely, they may be reported only from adaxial epidermis, epistomatous, as in leaves of *Nymphaea*, *Nelumbo*. When present in both the epidermis, their frequency may not be always uniform. The frequency may vary from 500 to 2000 of stomata per millimeter square of leaf surface as in most mesomorphic plants. In the leaves of shade loving plants the stomatal frequency is lower than in the leaves of sun-loving plants.

It is viewed from the above the leaf surface, a guard cell usually appears as kidney-shaped (reniform) or bean-shaped. However, the shape as seen in the section transverse to its longest dimension varies widely with the taxon. The two oppositely placed guard cells generally provide a biconvex outline to a stomatal aperture.

The cell walls of the guard cells are not uniformly thickened. Generally, the thinner cell walls are adjacent to the poles. However, the cell wall that forms

the margins of the stomatal pores usually has a thickened ridge or lip (Fig. 5.10 a). The ridges of the two adjacent guard cells can overlap for a bit tightly to seal the pore. It is assumed that when turgour changes, the guard cell change their shapes because of their non-uniform cell wall thickness.

The guard cells of grasses (Poaceae) however, are not kidney shaped. As observed from the surface, guard cells look narrow in the middle and enlarged at both the ends, dumbbell shaped (Fig 5.10 b).

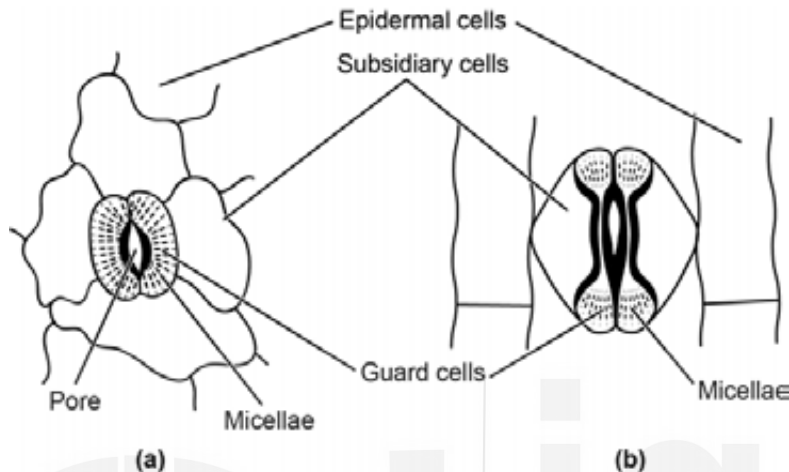


**Fig. 5.10: Stomata: a) in a dicot leaf; and b) Gramineae stomata.**

The guard cell of all the plants are covered with the cuticle that extends over the surface facing stomatal pore and the substomatal chamber. Stomata may also be completely covered with wax each guard cell has a prominent nucleus, numerous chloroplasts that accumulate starch.

The stomata are classified both by their morphology and by ontology.

When the stomata bear reniform guard cells, the stomata are classified as:

- i) **Gramineae** : When the guard cells are dumb-bell shaped. There can be various sub-types depending upon presence / absence of and number of subsidiary cells surrounding guard cells e.g. Grasses (fig. 5.10 b). When guard cells are kidney shaped, the stomata could be:
- ii) **Anomocytic** : When two guard cells are not surrounded by any subsidiary cells. e.g. *Ranunculus*, *Boerhaavia* (Fig. 5.11).
- iii) **Anisocytic** : When the two guard cells are surrounded by 3 subsidiary cells and each of them of different sizes. They are characteristically present in leaves of family Brassicaceae, *Bryophyllum*, *Kalanchoe* (Fig. 5.11).
- iv) **Paracytic** : When the two guard cells are surrounded by 2 subsidiary cells placed parallel to the long axis of the stomatal aperture, e.g. In the leaves of genera belonging to Rubiaceae; *Phaseolus* (Fig. 5.11).
- v) **Diacytic** : When the two guard cells are surrounded by 2 subsidiary cells placed at right angles to the plane of stomatal aperture. Such stomata can be observed in the members of the family Caryophyllaceae (Fig. 5.11).

- vi) **Tetracytic:** When the two guard cells are surrounded by four subsidiary cells, of which two are polar and two are laterally placed. They are characteristically present in *Rhoeo*, *Tradescantia* (Fig. 5.11).
- vii) **Actinocytic:** When two guard cells are surrounded by a circle of radially elongated subsidiary cells, which form a ring around guard cells (Fig. 5.11). Such stomata can be observed in the leaves of *Vitis*.

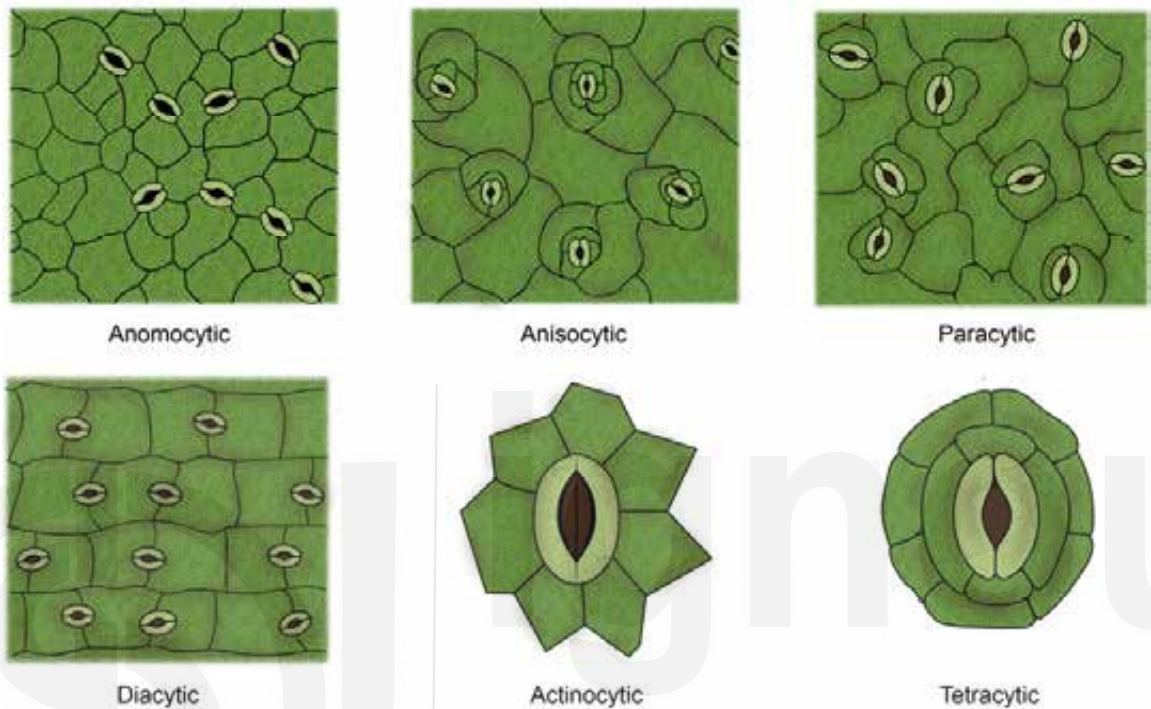


**Fig. 5.11: Mature stomatal types. (Adapted from Vascular Plant Systematics by Radford *et al.* Integrative Plant Anatomy by William C. Dickison, 1999. Harcourt Academic Press).**

Figure 5.11 shows the various kinds of such stomatal types. In addition, there are many additional types of stomata. A stoma has its origin in the primordium stage of a leaf. The young protoderm cell(s) of the leaf may mature into an ordinary epidermal cell or it may divide to form a small, cell and a large cell. The former called meristemoid it the cell which by series of cell-division forms a stoma / guard cells. The larger product may form a subsidiary cell or differentiate into an ordinary epidermal cell. Based on Ontogeny the stomata can be classified as:

- i) **Mesogenous:** When both guard cells as well as all the subsidiary cells are derived from the same single meristemoid cell, the development of stomata is called mesogenous.
- ii) **Perigenous:** When all the subsidiary cells are derived from protodermal cells other than the one that forms guard cells (guard cell mother cell). Also, known as haplocheilic.
- iii) **Mesoperigenous:** When at least one of the subsidiary cells has common origin with the guard cells, while other(s) subsidiary cell(s) are of different origin.

### 5.3.2 Functions of Stomata

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Stomata are essential to the survival of land plants because they minimise the transpirational water loss while still permitting the intake of CO<sub>2</sub> needed for photosynthesis. They do so by regulating the effective stomatal aperture diameter.

The maintenance of the stomatal pore size is an integrated response to:

- The CO<sub>2</sub> concentration in the intercellular gas spaces of mesophyll;
- The saturation deficit of the air outside;
- The water-stress in the leaf; and
- The general water status of the plant.

The stomata thus constitute a highly variable resistance to the movements of gases between the interior atmosphere of the organ and the ambient air. Thus, stomata can be regarded as the tissue type that controls water economy and photosynthetic efficiency of the green plants.

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#### SAQ 2

- a) Choose the correct alternative provided in the parenthesis:
- Leaves of *Nymphaea* are (hypostomatous/epistomatous).
  - The guard cells of Poaceae are (reniform/dumbbell) shaped.
  - Anisocytic stomata possess (3/4) subsidiary cells.
  - Perigenous ontogeny of stomata is also similar to the (haplocheilic/syndetocheilic)
  - Members of the family *Caryophyllaceae* possess (diacytic / paracytic) stomata.
- b) Define the following terms:
- Anomocytic stomata
  - Reniform
  - Stomatal aperture
  - Stomatal apparatus
- 

## 5.4 SPECIALISED LEAVES

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In the preceding sections you have studied about the structure of a typical leaf. However, under certain conditions the leaf undergoes some modifications to suit its environment.

### 5.4.1 Tendrils

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In many plants climbing plants, the leaf or portion of leaf gets modified as tendril. The tendril is a supporting organ for the plants. In *Lathyrus* the entire

lamina becomes a tendril. Terminal leaf-lets become tendril in *Pisum*. The leaf apex of *Gloriosa superba* gets transformed into tendril. The tendril of cucurbits may be a prophyll. See Fig. 5.12 for some kinds of tendrils.

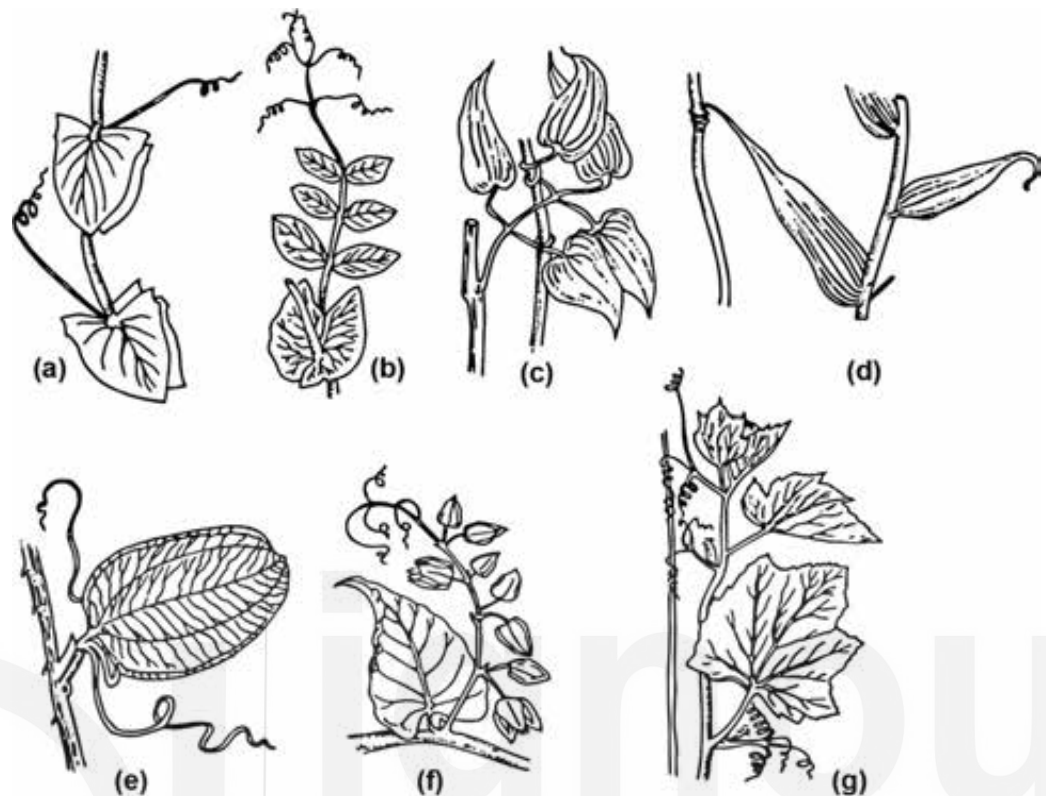


Fig. 5.12: a) Leaf tendrils of *Lathyrus aphaca*; b) Leaflet tendril *Pisum sativum*; c) Leaf petiole tendril of *Clematis* sp; d) Leaf apex tendril of *Gloriosa superba*; e) Stipular tendril of *Similax*; f) Inflorescence stalks of *Antigonon*; g) Tendril in *Cucurbita* leaf.

#### 5.4.2 Thorns, Spines and Prickles

In common language the terms, thorns, spines and prickles are used more or less interchangeably. In botanical terms, however, they are classified on the basis of their origin (ontogeny).

The **thorns** are derived from shoots. They may or may not be branched. They may or may not have leaves and they may or may not arise from buds. Thorns in *Citrus* are smooth. *Gymnosporia buxifolia* thorns arise from buds. Thorns of *Carissa bispinosa* are branched.

The **spines** are derived from leaves (either entire leaf or from some part of it, e.g., from petiole or a stipule). Consequently they are termed petiolar spines (as in *Fouquieria*); leaflet spines (as in *Phoenix*), or stipular spines as in *Euphorbia*. The spines of some cacti occur very densely on the stem surface. Some cacti such as *Opuntia* possess **glochids**. Glochids are spines that possess barbs along its length. The prickles are derived from epidermis tissue so they can be found anywhere on the plant. Prickles are commonly found on stems of Roses. Raised prickles on stem are characteristic of *Caesalpinia decapetala*. *Solenum viarum*, *S. xanthocarpum* leaves possess leaf prickles.

The thorns and spines differ from prickles in possessing vascular bundles within them. The figure 5.13 exhibits certain kinds of thorns, spines and prickles.

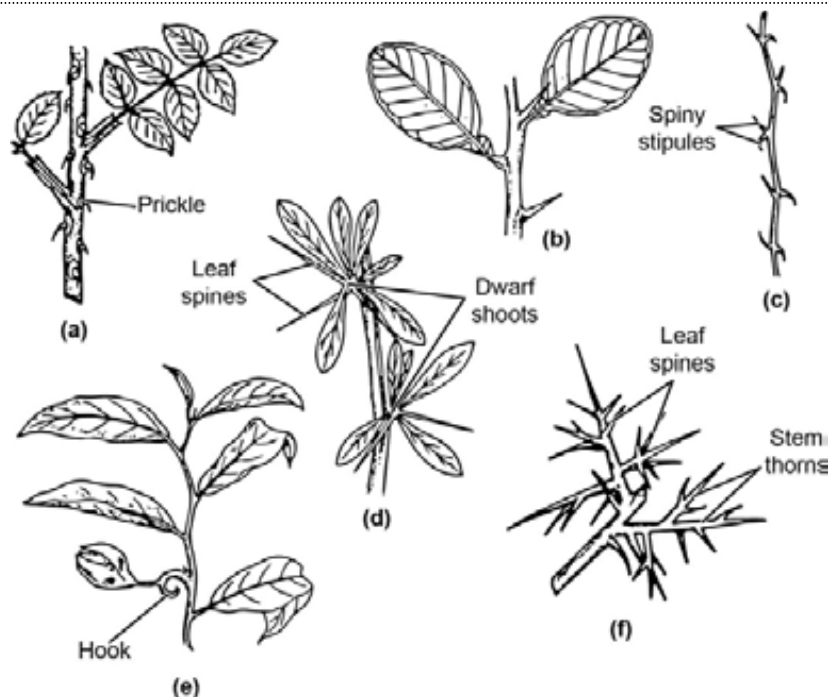


**Fig. 5.13: Spines and prickles in leaf:** a) Curved prickles of climbing roses; b) Spinuous prophylls in *Citrus*; c) Spiny stipules of *Zizyphus*; d) Large stem spines and small leaf spines in *Ulex*; e) Spiny hook on peduncles of *Artabotrys*; and f) Leaf spines and stem thorns in *Berberis*.

### 5.4.3 Storage Leaves

Some leaves, especially in xerophytes and halophytes, become fleshy because of storage of water mucilage and food reserves. Such leaves contain a special storage tissue. Common examples are the leaves of *Portulaca oleracea*, *Aloe*, *Agave* and *Bryophyllum* (Fig 5.14).

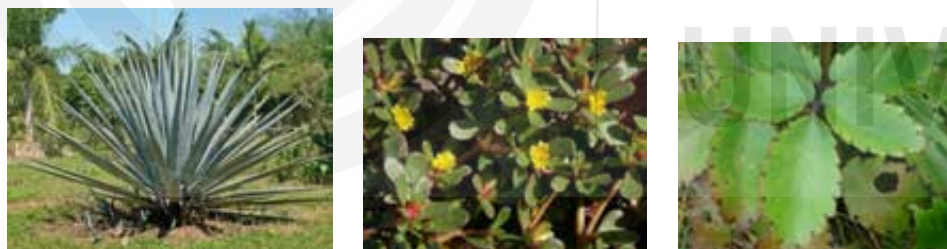


**Fig 5.14: Storage leaves in *Agave*, *Portulaca*, *Bryophyllum*.**

### SAQ 3

Match the characters mentioned in column I with the examples provided in column II:

#### Column I

- i) Tendril in *Lathyrus* leaf
- ii) Prickles
- iii) Stipular spines
- iv) Leaflet spines
- v) Storage leaves

#### Column II

- a. *Solanum melongena*
- b. Leaves of *Phoenix*
- c. Entire lamina
- d. Leaves of *Bryophyllum*
- e. Leaves of *Euphorbia*

## 5.5 SUMMARY

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- Leaves are lateral organs produced at node by the shoot apical meristem. They are determinate in growth, dorsiventral in symmetry and photosynthetic in function. A leaf has three parts: leaf base, petiole and lamina. A leaf could be sessile or petiolate. The lamina has two surfaces, adaxial and abaxial. When two faces have different structures they are called dorsiventral and when no such difference occurs they are termed isobilateral.
- Internally, the leaf also has dermal, ground and vascular tissue. The epidermis has cuticle, stomata, trichomes and could be single or multilayered. The ground tissue is modified as chlorenchymatous mesophyll. The mesophyll, in turn is differentiated into palisade and spongy parenchyma. The vascular supply constitutes venation. Smallest area of leaf tissue surrounded by veins is called aerole/or aerola. The venation could be dichotomous, reticulate (as in dicots) or parallel (as in monocots). A conspicuous bundle sheath may surround the vascular bundle. It can have different structure in C3 and C4 plants.
- The epidermis of the aerial parts of the green plant is perforated with stomata. Stomata are most prominently present in the leaves. A stoma consists of a pair of guard cells, the stomatal aperture and the subsidiary cells that surround it. The number and the origin of subsidiary cells may vary with taxon. The guard cells are mostly reniform. Dumb-bell shaped guard cells are characteristic of grasses. The turgour of guard cells determine whether the stomatal aperture may open or close. Thus, the stomata are important in regulating the entry of CO<sub>2</sub> from air to the interior of the leaf during photosynthesis and also regulate the loss of water from the interior of leaf to the external atmosphere.
- Leaves in some plants are modified to perform specific functions. Some such leaves are: tendrils; spines; thorns; prickles; storage leaves.

## 5.6 TERMINAL QUESTIONS

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1. Write a note on spinose structures.
2. Describe the functions of stomata.
3. List in a tabular form the comparative features of dicotyledonous and monocotyledonous leaves.
4. Classify the stomata on the basis of:
  - i) Ontogeny
  - ii) Morphology
5. With the help of labelled diagram describe the structure of a stoma.
6. Differentiate between:
  - i) Scale leaf vs Cataphyll
  - ii) Bifacial leaf vs Isobilateral leaf
  - iii) Bundle sheath vs Starch sheath

- iv) Tendril vs Storage leaves
- v) Reticulate venation vs Parallel venation.

## 5.7 ANSWERS

### Self-Assessment Questions

1.
  - a)
    - i) Shoot apical meristem
    - ii) Poorly
    - iii) Lamina
    - iv) Abaxial
    - v) Both
  - b)
    - i) F; ii) F; iii) T; iv) T; v) T
  - c) Hint: Fig. 5.1
2.
  - a)
    - i) epistomatous
    - ii) dumb-bell
    - iii) 3
    - iv) haplocheilic
    - v) diacytic
  - b)
    - i) Subsidiary cells, many; all similar: Refer to Subsection 5.3.1.
    - ii) Kidney-bean-shaped: Refer to Subsection 5.3.1.
    - iii) Opening between a pair of guard cells: Refer to Subsection 5.3.1.
    - iv) 2 guard cells; stomatal aperture; subsidiary cells: a physiological unit: Refer to Subsection 5.3.1.
3.
  - i) c; ii) a; iii) e; iv) b; v) d

### Terminal Questions

1. Refer to Subsection 5.4.2, Hint: Thorns, Spines, Prickles.
2. Refer to Subsection 5.3.2.
3. Refer to Table 5.1 and Refer to Subsection 5.2.2.
4. Refer to Subsection 5.3.1
  - i) Perigenous; Mesogenous; Mesoperigenous; Haplochellic; Syndetochellic.
  - ii) Morphology: Graminaceous; anomocytic; anisocytic; diacytic; paracytic; actinocytic; tetracytic.
5. Refer to Subsection 5.3.1 and Fig. 5.9 & 5.10

6.
  - i) Refer to Sub Section 5.2
  - ii) Refer to Sub Section 5.2.1.
  - iii) Refer to Sub Section 5.2.2.
  - iv) Refer to Sub Sections 5.4.1 and 5.4.3.
  - v) Refer to Sub Section 5.2.2.

### **Acknowledgement**

**Fig. 5.1** : <https://thumbs.dreamstime.com/b/victoria-regia-13988371.jpg>

**Fig. 5.3** : <https://i.pinimg.com/originals/d5/6f/dd/d56fdd89b50045d17f1aa071ecd69171.jpg>

**Fig. 5.9** : <https://files.askiitians.com/cdn1/images/2014422-75056254-7681-14>

