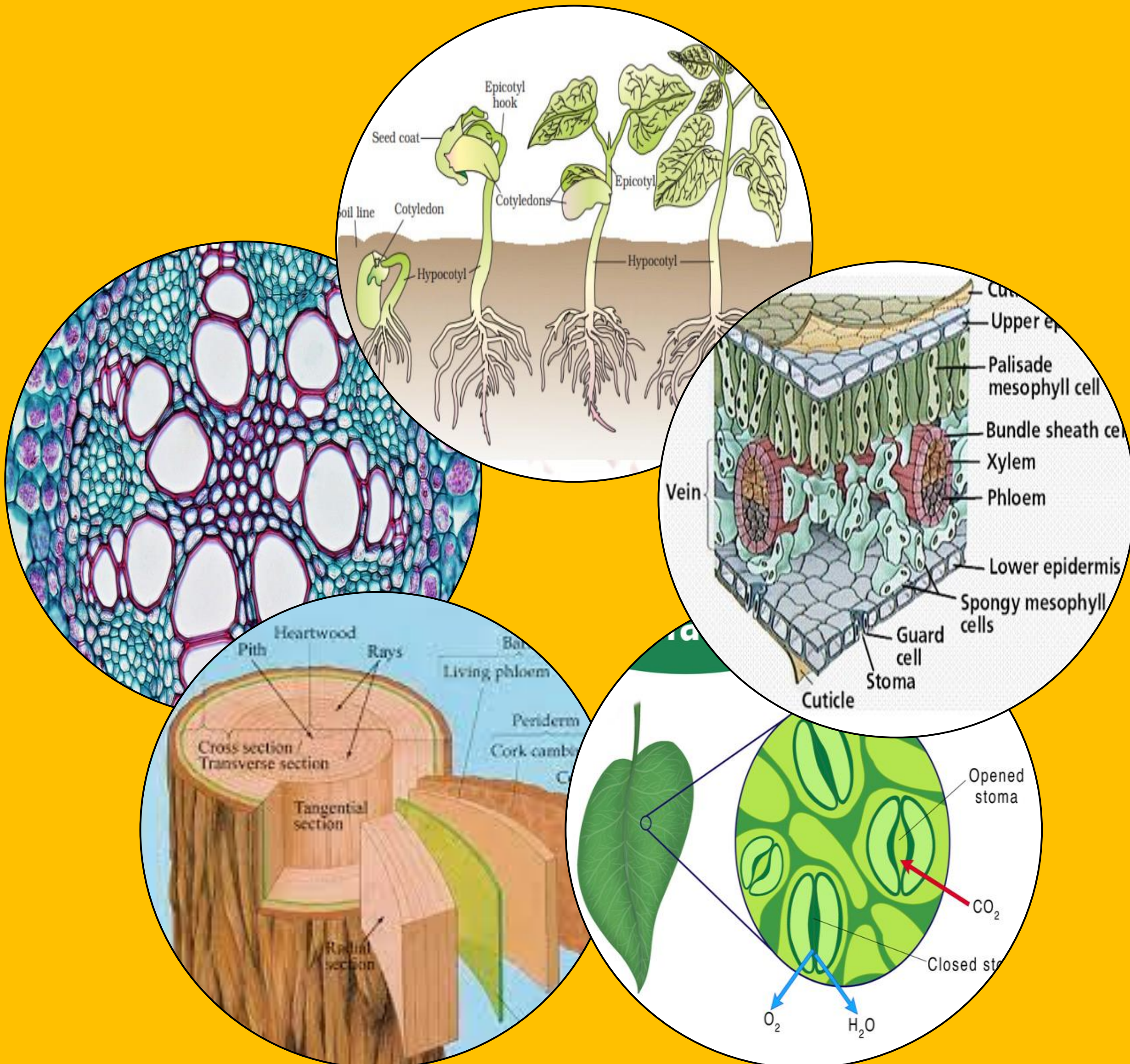
MSCBOT-508

M. Sc. II Semester

PLANT DEVELOPMENT



DEPARTMENT OF BOTANY

SCHOOL OF SCIENCES

UTTARAKHAND OPEN UNIVERSITY

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Phone No. 05946-261122, 261123
Toll free No. 18001804025
Fax No. 05946-264232, E. mail info@uou.ac.in
htpp://uou.ac.in

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Chief Course Editor

Editorial Board

Dr. Pushpesh Joshi
Assistant Professor (AC)
Department of Botany
School of Sciences
Uttarakhand Open University, Haldwani

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BLOCK-1-PLANT DEVELOPMENT: BASIC ASPECTS

UNIT-1: TISSUE SYSTEM

Contents:

1.1 OBJECTIVES

Following are the objectives of tissue system:

1. To identify the various types of plant tissue.
2. To study positional, structural and functional differences of these tissues.
3. To state significance of each tissue of the plant.

1.2 INTRODUCTION

Plant tissue is a collection of similar cells performing an organized function for the plant. Every plant tissue is specialized for a unique purpose and can be combined with other tissues to create organs such as leave, flowers, stems and roots. A plant tissue system is defined as a functional unit, connecting all organs of a plant. There are two types of tissues named as meristematic and permanent tissues. Meristematic tissues are divided on the basis of their origin and positions.

While permanent tissues are of two types, simple and complex. The simple tissues are made of only one type of cells. e.g. parenchyma, sclerenchyma, collenchyma. The complex tissues are made of more than one type of cells. Complex tissues are dermal, ground and vascular tissues. Tissues protect the plant organs from injury, help in various cellular metabolism like photosynthesis, regeneration, respiration and provide flexibility and elasticity to the plant. Meristematic tissues help in the growth of the plant.

1.3 TISSUE SYSTEM

The tissues in the plant body are classified on the following basis: according to their position in the plant, the cell types of which they consist, their function, the manner and place of their origin and their stage of development. The classical classification of the main plant tissues is based primarily on the segregation of cell complexes below the promeristem, structure and function are also taken into consideration later on structural tissues, on the basis of physiological similarity or topographical continuity, in reference to division of labour are organized into tissue system.

According to Sach’s (1875) convenient classification based on topographic continuity of tissues. The body of vascular plant is composed of three tissue systems – the dermal, the vascular and the fundamental (or ground) tissues. The precursors of these tissue systems are meristem.

1. **The Dermal or Epidermal tissue system**: The dermal system forms the outer protective covering of the plant and is represented in the primary plant body by epidermis. During secondary growth, the epidermis may be replaced by another dermal system, the periderm with the cork cells forming the new protective tissues.

Plant Tissues

(1) Meristematic Tissues	
(a) Meristems based on Origin	i) Primary meristem
	ii) Secondary Meristem
(b) Meristems based on position	i) Apical Meristem
	ii) Intercalary Meristem
	iii) Lateral Meristem
(c) Meristems based on cell division	i) Mass Meristem
	ii) Rib Meristem
	iii) Plate Meristem
(d) Meristems based on function	i) Protoderm Meristem
	ii) Ground Meristem
	iii) Procambium Meristem

(2) Permanent Tissues		
(a) Simple Tissues	i) Parenchyma	
	ii) Collenchyma	
	iii) Sclerenchyma	
(b) Complex Tissues	i) Xylem	1. Tracheid
		2. Vessels
		3. Xylem fibers
		4. Xylem parenchyma
	ii) Phloem	1. Sieve cells
		2. Sieve Tubes
		3. Companion cells
		4. Phloem fibers
		5. Phloem Parenchyma
(c) Secretory Tissues	i) Laticiferous tissues	
	ii) Glandular tissues	

2. **Ground or Fundamental tissue system**: It extends from epidermis upto the centre of axis (excluding vascular tissue). The ground tissues constitute cortex, hypodermis, general cortex, endodermis, pericycle and pith.

3. **Vascular tissue system**: It consists of a number of vascular bundles which are found to be distributed in the stele. The stele is the central cylindrical portion of the stem and root (Pteridophytes). Each vascular bundle consists of xylem and phloem tissue with or without cambium. The vascular bundle elements are derived from the procambial strands of the primary meristem.

1.3.1 Origin and Development

A vascular plant comes into existence from a single unicellular zygote. The zygote develops into the embryo and ultimately into the mature sporophyte or plant body. In the higher plants, division of labor exists and due to this the tissues are arranged in system, known as the tissue system. The cells are associated in different ways and form tissues. In the higher plants, cells are of different types and they combine to form tissues in such a way that different parts of the same organ are different from each other. The arrangement of cells and tissue in the plant body maintain topographic continuity. These units of tissues are known as tissue systems.

Structural development, zonation and differentiation:

Shoot Apex organization – It is present above the youngest leaf primordia. It consists of meristematic cells. Lateral branches of stem and leaves are formed by the activity of shoot apex.

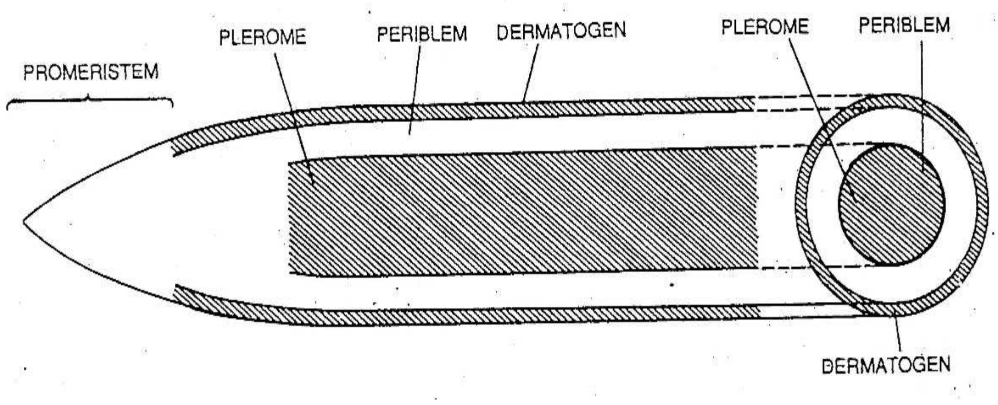


Fig.1.1: The shoot apex: diagram showing histogen region (L.S. and T.S.)

Theories to explain the Shoot Apex organization:

a. **Apical cell theory**: sIt was proposed by Hofmeister (1857) and supported by Nageli (1878). According to this theory a single apical cell leads to the development of entire plant body. This theory is applicable to algae as well as to most of bryophytes and pteridophytes.

b. Histogen theory: Hanstein (1868) proposed this theory. According to this theory the apical meristems of stem on division forms three regions – the dermatogen, periblem and plerome. Dermatogen forms outer most layer epidermis, periblem forms cortex and plerome forms central cylinder which get differentiated into endodermis, pericycle, vascular bundle and pith (Fig. 1.1).

c. Tunica corpus theory – It was proposed by Schmidt (1924). It is based on plane of division of cells. According to this theory, shoot apex consist of two distinct layers as:

Tunica – It is single layered and forms epidermis. The cells of tunica are smaller than carpus and divide in two planes.

Corpus – It represents the central core with larger cell. The cells divide in all planes (Fig. 1.2).

Sometimes tunica is multilayered, only outer layer forms epidermis and the remaining layers with corpus from central mass of shoot. In sugarcane there is no distinction of tunica and corpus.

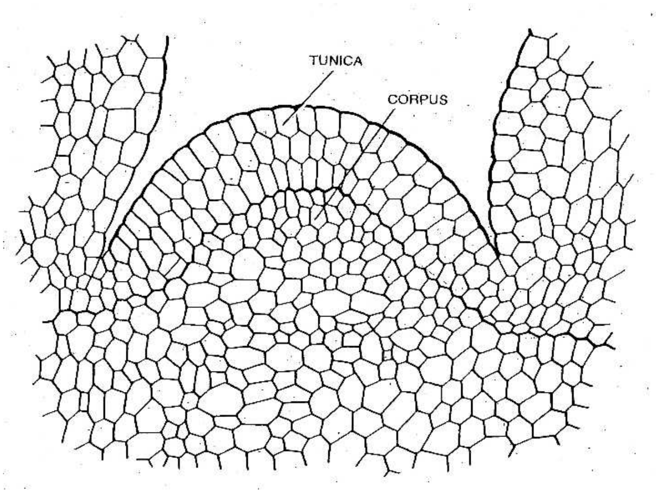


Fig. 1.2: Apical meristem (L.S. through shoot apex showing Tunica and Corpus)

Modification of Tunica- Corpus concept:

According to Phlipson (1947) the corpus has three regions: (a) Central zone (b) Basal zone (c) Peripheral zone.

Propham and chan (1951) divide the apex into four region: (a) Mantle (b) Subapical initial (c) Central meristem (d) Peripheral meristem

Gifford and Corson (1971) again reviewed the zonation of shoot apex in dicots.

Significance of the Tunica – Corpus theory:

This theory served well in the establishment of meristematic pattern of the shoot apices of seed plants. The tunica corpus theory is of topographical value in studies of detailed development. The lateral organs of the stem, i.e. leaves, branches and floral organs arise near the apex and this theory explained well for the development of these organs.

Root Apex organization: Root apex consists of mass of meristematic cells. Root apex is not responsible for the formation of lateral roots. Root meristem becomes subterminal in position due to root cap or calyptra. If root cap is independent in origin, it arises from calyptrogen. If it is not independent in origin, it arises from the dermatogen. There are three groups of initials in root apex of angiosperms (Fig. 1.3).

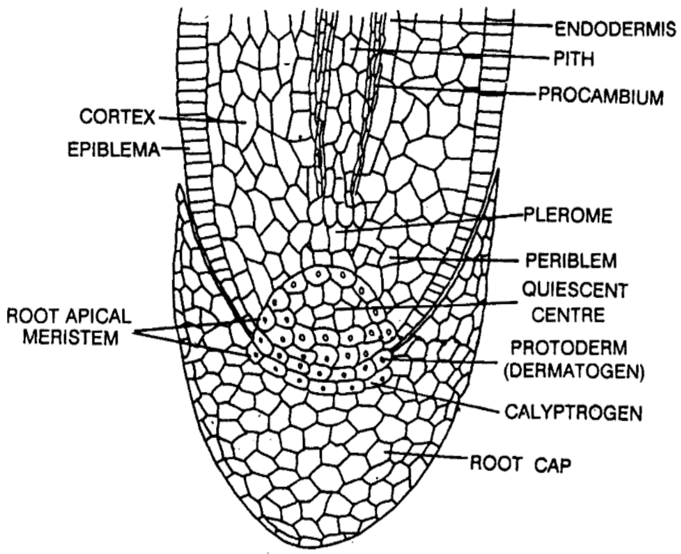


Fig: 1.3: The root apex (L.S. of root tip of Zea mays)

a. **Terminal:** groups form dermatogen and root cap in dicots but acts as calyptrogen to form root cap only in monocots.
b. **Middle:** group of cells from periblem in dicots and periblem and dermatogen in monocot roots.
c. **Innermost:** group of cells form plerome.

Theories to explain Root Apex organization:

1. **Korper–Kappe theory:** It was proposed by Schuepp (1917). This theory is comparable with the tunica and corpus theory of shoot apex. Korper means body and Kappe means cap. It is based on differences in the planes of cell division. According to this theory the cells in the root apex divide in a pattern called T-division.

2. **Quiescent cell theory:** This theory was given by Claws in 1961 in *Maize*. According to this theory root apex consists of an inverted cup like structure the quiescent centre. The cells of this region are with very low mitotic activity. They have low amount of RNA, DNA and protein. They are surrounded by layer of actively dividing cells which are responsible for the formation of different structure of roots.

1.3.3 -Structure and function of Primary and Secondary Tissues

The primary tissues include the surface layer or epidemies, the primary vascular tissues, xylem and phloem Which conduct water, food and the ground tissues. The secondary tissues arise from lateral meristems and their formation is mainly responsible for the growth in thickness of stems and roots.

1.4 -Permanent tissues:

The permanent tissues have lost the ability to divide. They are classified into two major groups simple and complex tissues. The simple tissues are made of only one type of cells. They are parenchyma, collenchyma and sclerenchyma type. The complex tissues are made of more than one type of cells. They include xylem and phloem. Xylem and phloem are further divided.

Characteristic features, functions and distribution of permanent tissues are following:

Simple Tissue - They are made of only one type of cells. They are of following types-

(1)**Parenchyma -** Characteristic features of parenchyma are-

(a) The cells are nearly isodiametric.

(b) The cellwalls are thin. These are made of cellulose, hemicellulose and pectin substances.

(c) Parenchymatous cells are living and therefore contain cytoplasmic organelles and nucleus.

(d) They act as storage tissue.

(e) Parenchyma forms a major part of the cortex and pith of roots and stems.

Distribution- They are found in pith, mesophyll of leaves, the pulp of fruits, endosperm of seeds, cortex of stems and roots, also occur in xylem and phloem.

Types of parenchyma (Fig. 1.4):

Chlorenchyma – Parenchymatous cells contain chloroplast. They are of two types-

a) Palisade parenchyma- They are radially elongated and contain many chloroplasts situated closer to the cell wall.

b) Spongy parenchyma- The cells of different shapes and sizes occurring in the mesophyll of the leaf, they contain chloroplasts and leave many intercellular spaces.

Aerenchyma: Parenchymatous tissues with large intercellular spaces formed due to partitions.

Storage parenchyma: Parenchymatous cells which can store reserve food like starch, amides, proteins, fats etc.

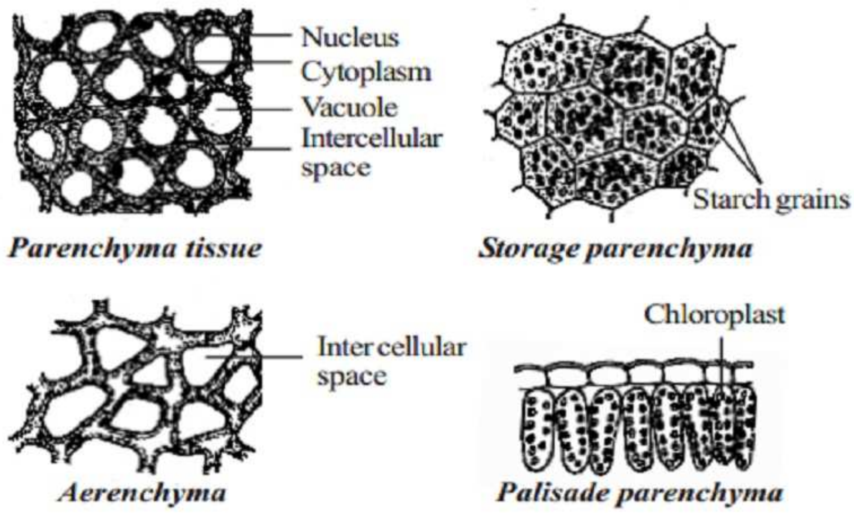


Fig. 1.4: Different types of parenchyma

Functions of parenchyma:

1. Stores food and nutrients.
2. Involved in growth and development.
3. Provide mechanical rigidity to the plants.
4. They are the site of all metabolic activities.
5. In leaves, these cells are also responsible for photosynthesis and exchange of gases.
6. Involved in the movement of water and other nutrients.

(2). Collenchyma- It shows following characters:

a. The cell shape varies from isodiametric to elongated.
b. The cell walls are unevenly thickened. The walls are made of cellulose, pectin and other wall substances, but no lignin.
c. If the thickening occurs in the corners, these are called angular collenchyma. In some other cells, the thickening appears on the tangential walls. This type is called lamellar collenchyma.
d. Collenchymatous cells retain active protoplast at maturing and capable of further growth and division.

Distribution: Cells are present at the periphery of herbaceous stems, petioles (e.g. *Begonia)* and in the ribs of some leaves (e.g. *Nerium).* They are also found in the floral parts, fruit and aerial root and petioles.

Types of Collenchyma (Fig. 1.5)

Annular: They are uniformly thickened collenchymatous cells and appear as circular in cross section.

Angular: Collenchyma tissue in which cell walls are thick at angles where several cells are joined together.

Lamellar: Collenchyma tissue in which tangential walls of the cells are thickened.

Lacunar: In this type intercellular spaces become thick due to deposition.

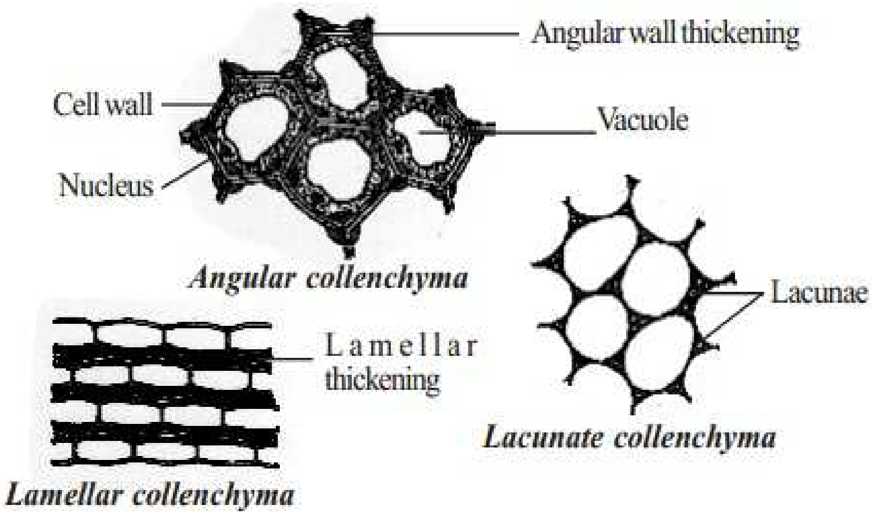


Fig: 1.5 – Different types of collenchyma

Functions of Collenchyma:

(i). They provide mechanical support mainly in primary plant parts such as young stem, roots andleaves.
(ii).They are more flexible than schlerenchyme. Hence, they can bend the plant parts without breaking the structure.
(iii). It permits the growth and elongation of plant parts.
(iv). Collenchyma with chloroplasts can perform photosynthesis.

(3) Sclerenchyma: Sclerenchyma shows following characters –

(i). It is supporting tissue,the cells are devoid of protoplast and hence,they are dead.
(ii).Sclerenchymatous fiber is a long and thick cell, many times longer than broad.
(iii). The ends of the fiber taper into sharp points.

(iv). The cell walls are mainly made of lignin, cellulose, pectin and hemi cellulose.
(v). The thick walls have many slit like pits. Bordered pits may be present.
(vi). The lumen or cell cavity is very narrow.
(vii). The fibers are mostly unicellular but may also be multicellular.

Distribution-They are distributed in cortex, pericycle of stem, pith, xylem, phloem, stones of fruits and in seed coats.

Types of sclerenchyma (Fig. 1.6)

Fiber: An elongated tapering sclerenchyma a cell with more or less thick, lignifiedsecondarywalls, generally dead at maturity.

Sclereid: They vary in shape and size but not elongated. The walls are thick and lignified with simple pits.

Sclereid may be of the following types:

1. Stone cells: They are short, roughly isodiametric sclereid and similar to parenchymatous cells.
2. Macrosclereid (Rod cells): Rod like and found in seed coat of leguminous plants.
3. Osterosclereid (Prop cells): These are rod like with dilated ends or barrel shaped. E.g. leaves and seed coat of many monocots.
4. Asterosclereid (Star cells): They are star shaped. e.g. stem and leaves ofxerophytes (dicots).
5. Tricho sclereid (Internal hair): Long hair liked branched sclereid. e.g. Hydrophytes and found in aerial root of *Monstera.*

Functions of Sclerenchyma

1. It provides mechanical strength and protection to the plant.
2. It makes the plant body rigid, flexible and elastic.
3. Act as the components of vascular tissue system (Xylem and phloem).
4. Vessels and tracheid of Xylem are sclerenchymatous cells.
5. It forms hypodermis of xerophytes (prevent water loss).
6. Helps in fruit dehiscence and dispersal.

Complex tissues - Complex tissue is a group of more than one type of cells that function together as a unit. e.g. xylem and phloem.

(1) **Xylem** - Xylem term introduced by Nageli (1858). It isGreek word xylos which means wood. This tissue is mainly responsible for conduction of water. Xylem also acts as supporting tissue.

Xylem consists of tracheary elements like tracheid, vessels, fiber and xylem parenchyma. Xylem is of two types:

(a) Primary xylem (derived from procambium)
(b) Secondary xylem (derived from vascular cambium)

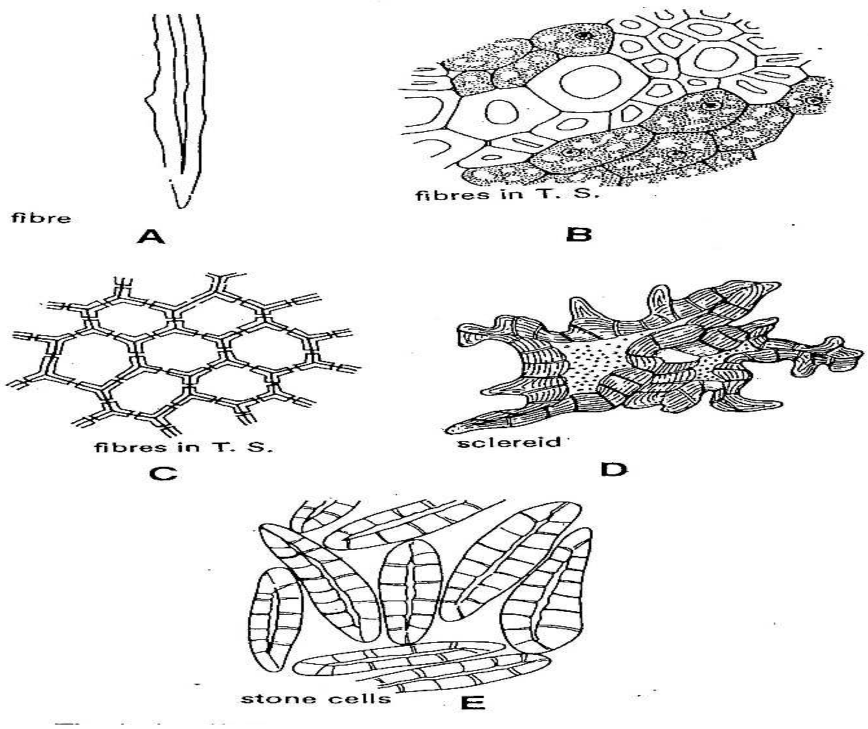


Fig 1.6: Different types of sclerenchyma

Elements of xylem (Fig. 1.7)

(a) **Tracheid** - The cells of tracheid are much elongated with tapering ends. These cells are dead with large and emptylumen. The walls are lignified, thickening may be annular, spiral or scalariform in primary xylem and pitted in secondary xylem ormetaxylem (Fig 1.7). They serve for storage of water and give mechanical support to the plant.

(b) **Vessels**- A tube like series of vessel members, the common walls of which are perforated. Vessels are found in angiosperms only. In gymnosperms, vessels are present only in order Gnetales. Vessel walls are lignified. The end walls show variety of perforation. The perforated part of the end wall is called the perforation plate. The secondary walls are pitted. The pits may be either simple or bordered pits. The pits may be arranged in a single row (uniseriate) or may be present in two or more rows (multiseriate). The adjacent vessel members show common pit pairs.

(c) **Xylem fibers**- These are most elongated cells found in xylem and are pointed at both ends. Xylem fibers are dead cells and sclerenchymatous in nature. They have thicker wall and narrow lumen in comparison to tracheid. The cell wall of fiber is lignified. Xylem fibers are of three kinds:

i. **Fiber tracheid**- These fiber like tracheid occur in the wood. They are thick walled with pointed ends and lenticular slit like apertures.
ii. **Libriform fiber**- These thick-walled fibers occur in the wood. They have simple pits and are the longest cells in the wood.
iii. **Gelatinous fibers-** These fibers have thickest cell wall and lumen is absent. The cell wall contains more alpha cellulose and poor in lignin.

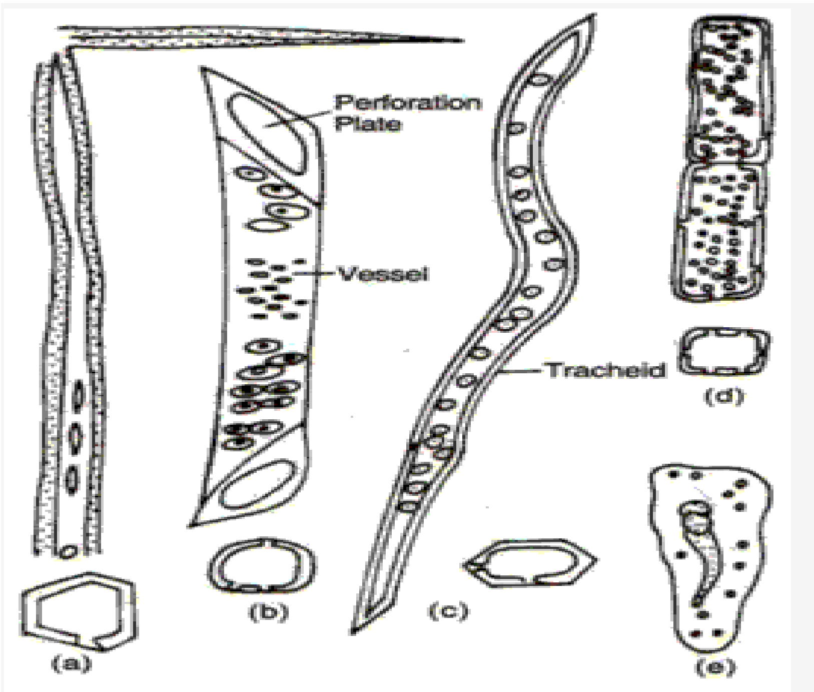


Fig. 1.7: Elements of xylem: (a) Tracheid, (b) Vessels, (c) Fibres, (d) Parenchyma

(d) **Xylem parenchyma**- These are living and thin walled cells which store starch, oil and many other ergastic substances. They are further divided into – (a) Axial and (b) Ray parenchyma.

Functions of xylem:

(i). Xylem is water and mineral conducting tissue. It transports water and minerals from roots to stem and leaves.
(ii). Along with phloem make vascular tissue.
(iii). Provide mechanical support to plants.
(iv). It is also used to replace water loss during transpiration and photosynthesis.

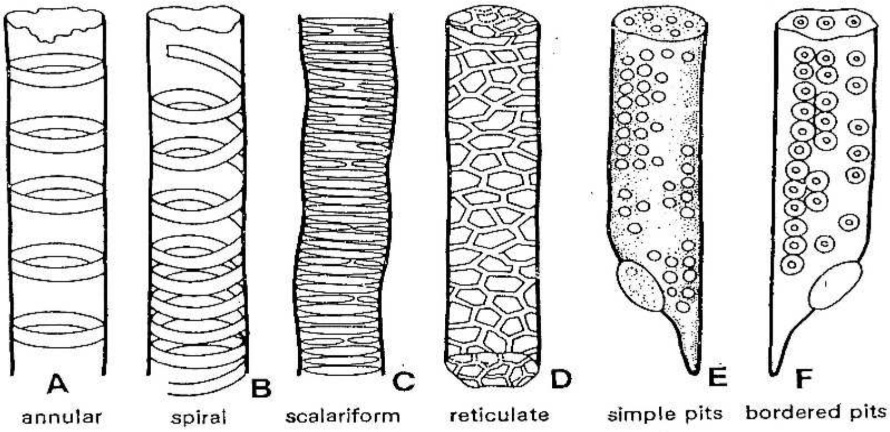


Fig. 1.8: A to F, Wall thickenings of tracheary elements

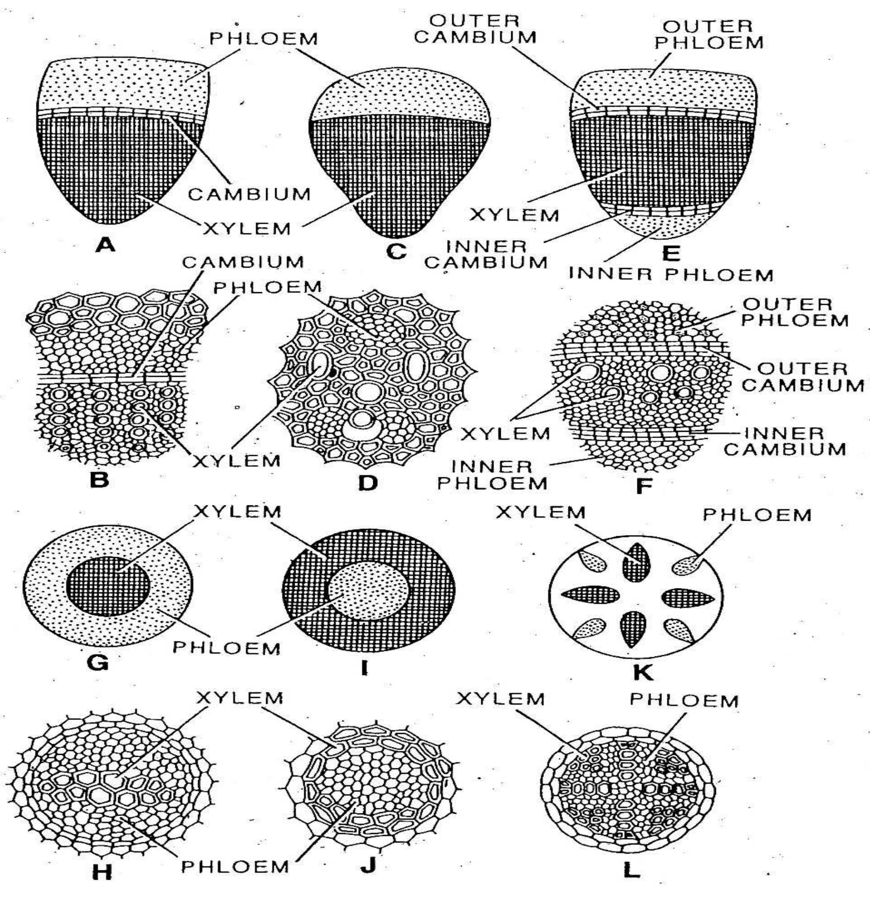


Fig: 1.9 – Types of Vascular bundles:A-B: Conjoint, Collateral and open; C-D: Conjoint, Collateral and closed; E-F: Conjoint, Bicollateral and open; G-H: Concentric and amphicribral; I-J: Concentric and amphivasal; K-L: Radial

(2) **Phloem -** Phloem is the major food conducting tissue of the vascular plants. Phloem like xylem isa complex tissue and consist of the following elements - (a) Sieve elements (b) Companian cells (c) Phloem fibers and (d) Phloem parenchyma. In the pteridophytes and gymnosperms only sieve cells and phloem parenchyma are present. In some gymnosperms, sieve cells, phloem parenchyma, phloem fibers, sclereid and secretory cells are present.

Elements of phloem: The following are major components of the phloem (Fig. 1.10 & 1.11):

(a) **Sieve cells –** These sieve elements lack sieve plates at their end walls. Sieve areas, however, are present all over the walls.

(b) **Sieve tube-**They are slender, elongated living cells with a thin cellulose wall and are placed end to end. The protoplast has a large vacuole and a thin layer of cytoplasm. Nucleus is absent. It is only living cell in plant which lack nucleus at maturity.

(c) **Companion cells –** are associated with sieve tubes and lie side by side with them. These are thin walled elongated cells. These cells help the sieve tube in the conduction of food.

(d) **Phloem parenchyma –** It consists of some parenchymatous cells which may be elongated, pointed, cylindrical or sub spherical in shape. They contain oil, starch, latex etc. They lie by the side of sieve tubes. Their function is translocation of sugars and proteins, storage of proteins and transfer of food from sieve tubes of medullary rays and wood parenchyma.

(e) **Phloem fiber -** It develop from parenchyma cells of nonfunctioning phloem. Phloem fiber occurs in primary and secondary phloem. The walls of fiber may be lignified or nonlignified. Only simple pits are found on the walls of fibers. They have been used as in the manufacture of cords, ropes, mats and clothes. In early times, fiber used as bast or bass, so they are also known as bast fibers.

Position of phloem – They are of following types

(i). **External phloem**: Primary phloem situated outside the primary xylem of a bicollateral vascular bundle. e.g. stem of*Cucurbita.*

(ii).**Internalphloem** (Intraxylary phloem): Primary phloem situated inside the primary xylem of a bicollateral vascular bundle.

(iii). **Included phloem** (Inter xylary phloem): Secondary phloem embedded in the secondary xylem of certain dicots. e.g. *Salvadora*.

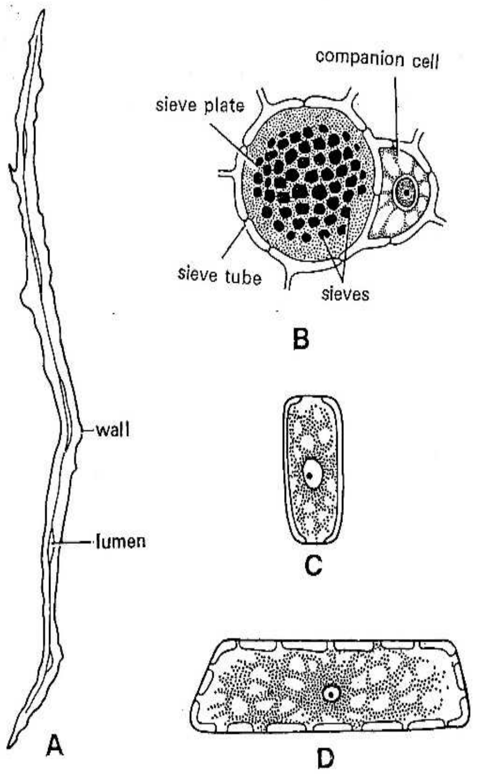


Fig.1.10: A-D Elements of phloem

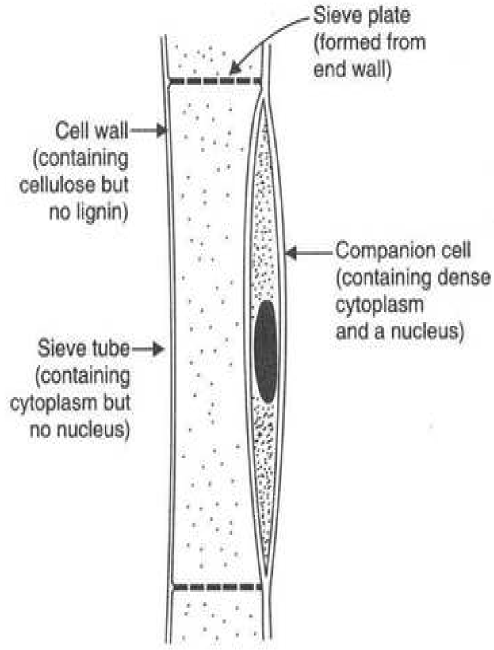


Fig.1.11: Sieve tube and companion cell

Size and differentiation of phloem:

Metaphloem – It is a part of primary phloem which develops after the formation of protophloem. They are large in size.

Protophloem – It is a part of primary phloem. They develop earlier than the metaphloem and are small in size.

Primaryphloem – The phloem developing from the procambium during primary growth. The first formed phloem elements are protophloem followed by formation of metaphloem.

Secondary phloem – the phloem which develops from the vascular cambium during secondary growth of the plant.

Functions of phloem–

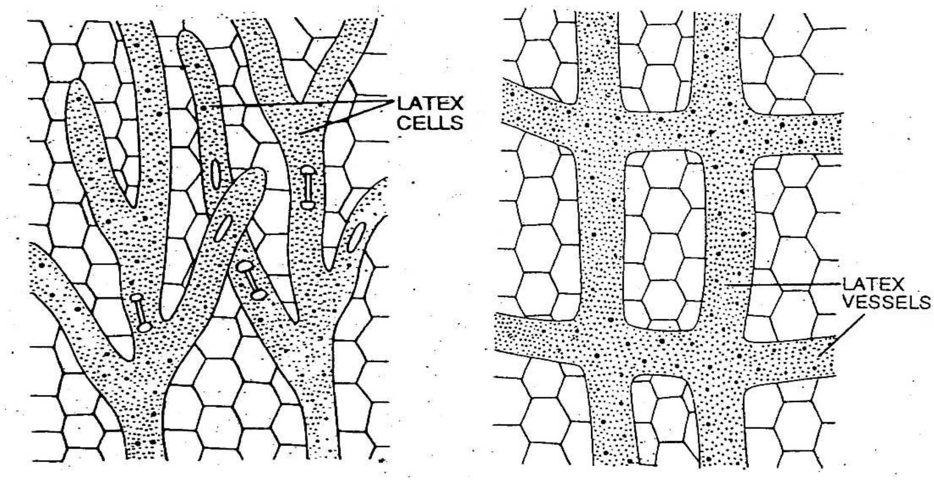
(i) Phloem is the vascular tissue, incharge of transportand distribution of the nutrients.

(ii) It is also a pathway to signaling molecules and has a structural function in plant body.

Secretory tissue - The tissues that are concerned with the section of gums, resins, volatile oils, nectar, latex and other substances are called secretory tissues. They are further subdivided into two groups – (a) laticiferous tissues (b) glandular tissue

(a) **Laticiferous tissue** – Latex is present in the families of many flowering plants. This substance may be white, yellow or pinkish in colour. This is a viscous fluid and established to be colloidal in nature. Many substances like sugars, proteins, alkaloids, enzymes, rubber etc. are present in it. e.g. *Ficus, Hevea, Carica* etc. The latex is present in laticiferous ducts, which is of two types – latex cells and latex vessels.The function and the contents of the two are same but they differ in their nature and morphology. They have numerous nuclei along the cell wall. They may act as food storage organs or as reservoirs of waste products.

Latex cells (Non articulate latex ducts) – These ducts are independent unit branches and originate as minute structures, elongate and spread in all directions of the plant body by repeated branching but do not fuse together. e.g. *Calotropis, Nerium, Euphorbia* (Fig. 1.12 A).



(A) Latex cells (B) Latex vessels

Fig: 1.12 – Laticiferous tissue

Latex Vessels (Articulate latex ducts)- In many plants, the laticiferous system is formed from rows of cells laid down in the meristem of the stem or root. The cell walls between these cells are dissolved so that continuous tubes are formed and known as latex vessels. They are made up of many cells, so they are named as articulated laticiferous. e.g. members of the family Euphorbiaceae, Asteraceae etc (Fig. 1.12 B).

(b) Glandular tissue – This tissue consists of special structures, the glands. These glands contain some secretory or excretory products. The glands may consist of isolated cells or small group of cells with or without a central cavity. They are of two types –

External glands – are found on the surface of plant body in the form of outgrowths. Thus, they are present on the epidermis. Examples – Hydathodes, Nectar glands, Stinging hairs, Glandular hairs, Digestive glands.

Internal glands – These glands are found inside the plant bodies. These glands consist of a single cell or group of cells or whole tissue. Examples – Oil glands, Mucilage secreting glands, Resin glands, Tannin glands, Gum secretary glands etc.

External glands -

Hydathodes – These are specialized structures present in many angiosperms (Grasses), through which exudation of water taken place. So,they are also called water stomata or water pores. They are presented on the leaf margins. The exudation of water as drops from the tip or margins of the leaves is called guttation. The process of guttation is facilitated by the hydathodes. They also have an indirect role in ascent of sap. Hydathodes has an opening through two guard cells. Guard cells do not show any movements. The guard cells open into an opening called stomatal cavity. This cavity is followed by thin walled colourless compact and dense cells with intercellular spaces. This tissue is known as epithem. Such hydathodes found in Potato, tomato etc (Fig. 1.13).

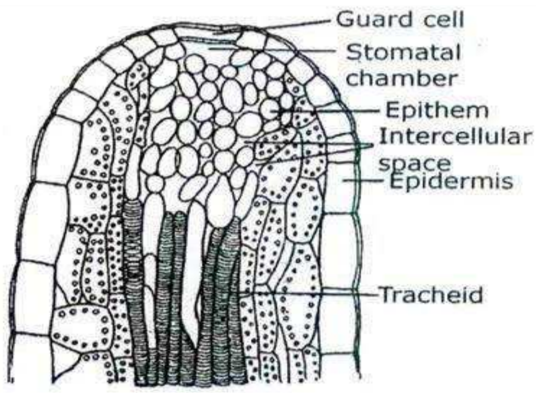


Fig: 1.13 - *Hydathode*

Glandular hair – They are small hair having a single or multicellular stalk. They are found on epidermis and have single celled head. Head secretes slime or mucilage. e.g. *Cannabis* (Fig. 1.14 A).

Stinging hair – These hairs are found on the lower surface of leaf and stems. Stinging hairs have a gland at base, which secretes a poison. This poison causes irritation and blisters on the skin. e.g. *Urtica.*

Nectaries – These are special glands usually located on the floral parts. They secrete the sugary substances nectar or honey and thus attract the pollinating insects. These glands are superficial consisting of epidermal cells. In somecase the cells forming the more mitochondria and endoplasmic reticulum. Cuticle is absent. Floral nectaries (found on flowers) are found in *Polygonum*, *Theasinensis* (Tea) etc. Extra floral nectaries (present on stems or leaves) are found in *Catheranthus*.

Digestive glands – These glands are found in insectivorous plants and responsible for extra – cellular digestion of insects. They secrete proteolytic enzyme, which can digest insects in insectivorous plants, e.g. *Drosera, Nepenthe*s. Etc (Fig. 1.14 B).

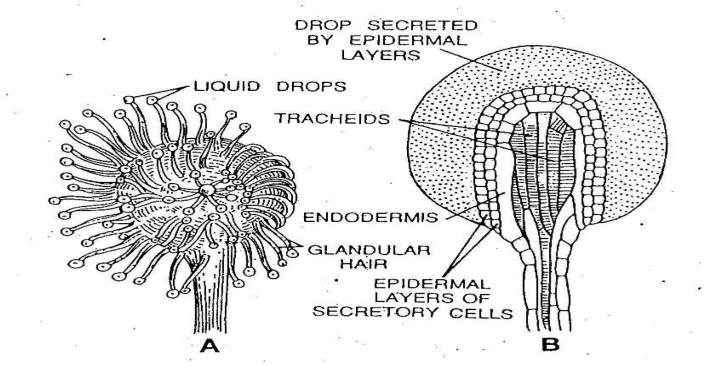


Fig: 1.14 – Glands (A: Glandular hairs of Drosera, B: Digestive gland of Drosera)

Internal glands

Resin duct – They are elongated tube-shaped intercellular spaces surrounded by epithelial cells which secrete resin into the canal. They are usually found in wood. Resin is antiseptic, aromatic and prevents the development of fungi and insects. e.g. *Pinus*

Oil glands – These glands contain essential oil. Oils are volatile and odoriferous. These glands originate due to split of certain cells, but they are formed in abundance by the breaking down of cells containing the volatile oil. On the disintegration of the cells the oil stores up in the large cavities of glands. e.g. *Citrus, Eucalyptus*.

1.4 MERISTEMATIC TISSUE

It is group of cells which is always in a state of active cell division or the cells are always keep on dividing. e.g. Root tip meristems, stem tip meristem, cambium, leaf tip meristem etc (Fig. 1.15).

Characteristic features of meristems are

(1) Cells are isodiametric, thin walled, have dense protoplasm and without intercellular spaces.

(2) The nucleus is quite large and conspicuous. Endoplasmic reticulum and mitochondria are not fully developed.
(3) The cells have thin cellulosic cell wall.
(4) They lack crystals, plastids and are present in proplastid stage.
(5) Metabolically, these are the most active cells. Rate of respiration is very high.

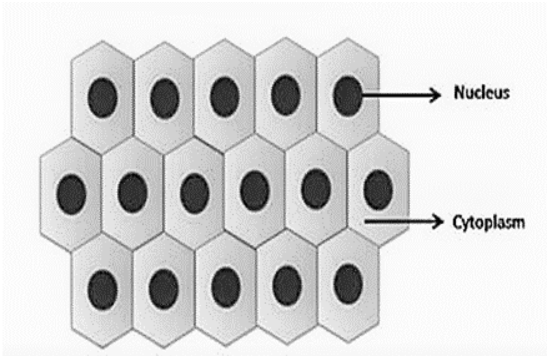


Fig: 1.15 – Meristematic cells

Classifications of meristems

(1) Meristem based on origin and development :

(a) **Promeristem (Primordial meristem):** A group of cells which represent primary stages of meristematic cells. Example – Root and shoot apex.
(b) **Primary meristem:** They are present right from embryonic stage in plants and remain active throughout the life of plants. They are found below the promeristem at shoot and root apices, at the apex of leave and in intercalary parts. They give rise to primary permanent tissues.
(c) **Secondary meristems:** They are developed at a later stage in the life-cycle of plants. They give rise to secondary permanent tissues. Examples –cambium, cork cambium etc.

(2) Meristem based on plane of cell division:

(a) **Mass meristem –** The cells divide anticlinally in all planes, so mass of cells is formed. e.g. formation of spores, cortex, pith, endosperm.
(b) **Plate meristem** - Thecells divide anticlinally in two planes, so plate like area increased. e.g. formation of epidermis and lamina of leaves.
(c) **Rib or file meristem –** The cells divide anticlinally in one plane, so row orcolumn of cells is formed. e.g. – formation of lateral root, filamentous algae.

(3) **Meristem based on function**:

(a) **Protoderm –** They are outermost meristematic cells and form epidermis and epidermal tissue system.

(b) **Ground meristem –** They form cortex, hypodermis, endodermis, pericycle and pith.
(c) **Procambium –** They are innermost meristematic cells and forms primary and secondary vascular tissues.

(4) Meristems based on position plant body:

(a) **Apical meristem –** It is made up of round cells (pro meristem). These tissues are found at the apices of stem and root. They are responsible for increase in length of roots and stem.
(b) **Intercalary meristems –** They are part of apical meristem and intercalated between permanent tissue. They bring about elongation of plant parts. It occurs in the leaves and internodes of many monocots. e.g. – stem of grasses and *Equisetum.*
(c) **Lateral meristem –** These meristems are present along the lateral side of stem and roots. They divide in tangential plane giving rise to secondary permanent tissues to the inside and outside and lead the increase in thickness or girth of the plant body. e.g. – Intra fascicularand interfascicular cambium, cork cambium.

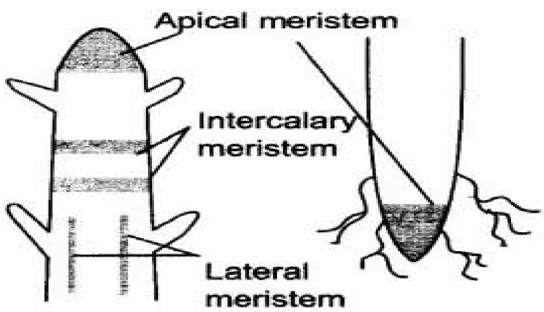


Fig: 1.16 – Location of meristematic tissue

1.5 SUMMARY

Plants are muticellular eukaryotes with tissue systems made of various cell types that carry out specific functions. Plant tissue systems are divided into meristematic and permanent tissues. Meristematic tissues continue to divide and take part in growth of the plant. Meristematic tissues are classified on the basis of character like stage of development (Promeristem), position in plants (Apical, Intercalary & Lateral), origin (Primary and Secondary meristem), function (Protodermis, Procambium & Ground meristem) and plane of cell division (Mass, Plate & Rib meristem). The permanent tissue ceases to divide, assume the permanent form and classified into simple, complex and special types. Tissues help in providing the elasticity and flexibility to the organs. They divide to produce new cells and help in the growth of the plants. They help in various cellular metabolisms.

1.6 GLOSSARY

Tissues: Masses of cells which are similar in origin, structure and function.
Tissue system: Tissue in a plant or plant organ structurally and functionally similar.
Chlorenchyma: Parenchymatous tissue containing many chloroplasts.
Aerenchyma: Parenchymatous tissue with large intercellular spaces formed due to positions.
Fiber: An elongated tapering sclerenchyma cell with more or less thick, lignified secondarywalls, generally dead at maturity.
Starch grains: Insoluble carbohydrate, occur in the form of small grains, varied in shape, simple or compound.
Epidermis: Outer layer of cells which is primary in origin.
Stomata: An opening in the epidermis.
Xylem: A tissue in the vascular plants that carries water and dissolved minerals from the root and provides support for softer tissue
Vessels: are sort of pipes having perforation at both ends. (Found in xylem).
Phloem: Food conducting tissue of vascular plant.
Lignified wall: An incrustation of lignin (Polyphenolic polymer) in the cell wall.

1.7 SELF-ASSESSMENT QUESTIONS

1.7.1 Give one-word answer for the following questions:

(a) Parenchyma with intercellular air cavity is called __________.
(b) Extra cellular digestion is found in ______________.
(c) Bast fibers are ___________.
(d) Tunica-corpus theory was proposed by __________.
(e) Quiescent center is present in ___________.

1.7.2 Fill in the blanks:

(a) Group of thin walled, isodiametric cells, are capable of division are known as _________.
(b) The conducting cell of _________ are called tracheary elements.
(c) The zone of slowly dividing cells in root apex is called _________.
(d) Dermatogen, periblem and plerome are the three builder ones according to ____concept.
(e) Leaves of grasses increase in length due to activity of __________ meristem.

1.7.3 Multiple choice questions:

(1) The hydathode are:
(a). Oil secreting glands (b). Water secreting glands
(c). Mucilage secreting glands (d). Honey glands

(2) Latex vessels are found in:
(a). *Papaver* (b). *Calotropis*
(c). *Banana* (d). All of the above

(3) The parenchymatous tissue is:
(a). Dead (b). Thin walled and living
(c). Thick walled (d). Made up of cellulose

(4) Root apex differs from stem apex in:
(a). Having Plerome (b). Having Dermatogen
(c). Having periblem (d). Having root cap

(5) The presence of vessels and companion cells are characters of :
(a). Gymnosperms (b). Angiosperms
(c). Ferns (d). Pteridophytes

1.7.1 Answer key: (a) Aerenchyma (b) Insectivorous plants (c) Sclerenchyma cells in phloem (d) Schmidt (1924) (e) Root apex

1.7.2 Answer Key: (a) Meristematic (b) Xylem (c) Quiescent center (d) Histogen (e) Intercalary

1.7.3 Answer Key –:1(b); 2(b); 3(b); 4(d); 5(b)

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1.9 SUGGESTED READINGS

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1.10 TERMINAL QUESTIONS

1.10.1 Short answer type questions

Q.1 Describe different type of meristems found in the stem of angiosperms. Discuss their role in plant life.

Q.2 Write a detailed note on – (1) Laticiferous ducts (2) Hydathodes (3) Nectaries

Q.3 Describe the characteristic features and position of the following – (a) Parenchyma (b) Collenchyma (c) Phloem

Q.4 Give an account of structure and distribution of Meristematic tissue in angiosperms.

Q.5 How would you differentiate the following: (a) Vessels and Tracheid (b) Collenchyma and Sclerenchyma (c) Xylem and Phloem.

1.10.2 Long answer type questions

Q.1 What do you understand by a tissue? Describe types of tissues found in Angiosperms.

Q.2 Give an account of position, structure and function of xylem in plants.

Q.3 Classify tissue systems. Describe briefly the different tissue systems with help of neat diagrams.

Q.4 Write a short note on ‘Epidermal tissue system’ of plants.

Q.5 Write a note on types of vascular bundles in plants.

UNIT-2: VASCULAR SYSTEM

Contents:

2.1 OBJECTIVES

After reading this unit student will be able to:

- Understand the basic concepts of vascular system in plants,
- know about Xylem, its components and their functions,
- know about Phloem, its components and their functions and
- Understand Secondary growth in plants.

2.2 INTRODUCTION

The vascular system of a plant is the tissue and series of tubes and veins that move nutrients collected by the roots to the stem and leaves. A plant's vascular system is absolutely essential for the life of a plant, as nutrients wouldn’t move any further than the roots without it. The system runs up the stems or in the inner bark of trees to move nutrients upward in order to support the leaves. It’s a complex series of veins that extend throughout the plant, leave stems, and into the leaves themselves. Monocots or grasses consist of scattered vascular bundles while dicots, which are more complex plants, have continuous vascular systems surrounding their central paths. In trees, the central path of the vascular system runs through the inner bark and that’s why girdling or stripping of a ring of bark will cut off the flow of nutrients and ultimately kill the tree. In some perennials, the vascular system may include the entire stem, but in most cases it does not and rather runs along the inside of the outer epidermal layer.

2.3 VASCULAR SYSTEM

Vascular bundles found in stelar part constitute vascular tissue system. The special parts surrounded by endodermis which included vascular bundles, pericycle, pith forms the stele. Xylem, phloem and cambium are the major parts of the vascular bundle. Vascular bundle may be of following types (Fig. 2.1):

(i). **Radial:** When the xylem and phloem are arranged on different radii alternating with each other e.g., Roots.

(ii). **Conjoint:** When the xylem and phloem combine in the same bundles are present on the same radius. e.g. Stem. Conjoint vascular bundles may be –

   a. **Collateral:** Xylem is towards innerside and phloem towards outside.
   b. **Bicollateral:** When phloem is present on both side of xylem. e.g. members of Cucurbitaceae.
   c. **Open:** When cambium is present between xylem and phloem. e.g. dicot stem.
   d. **Closed:** When cambium is absent between xylem and phloem. e.g. monocot stem.

(iii). Concentric: When one vascular tissue surrounds the other. They are of two types-

a. **Amphicribal or Hadrocentric:** The xylem is surrounded on all sides of phloem. e.g. Ferns.
b. **Amphivasal or Leptocentric:** The phloem is surrounded on all sides by xylem. e.g. *Yucca, Dracaena*.

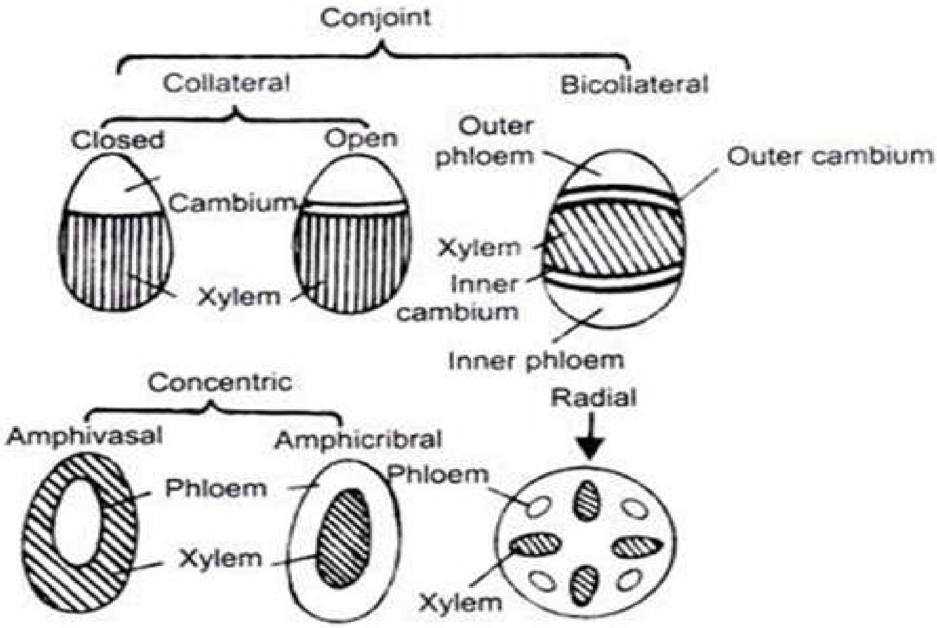


Fig. 2.1: Types of vascular bundles

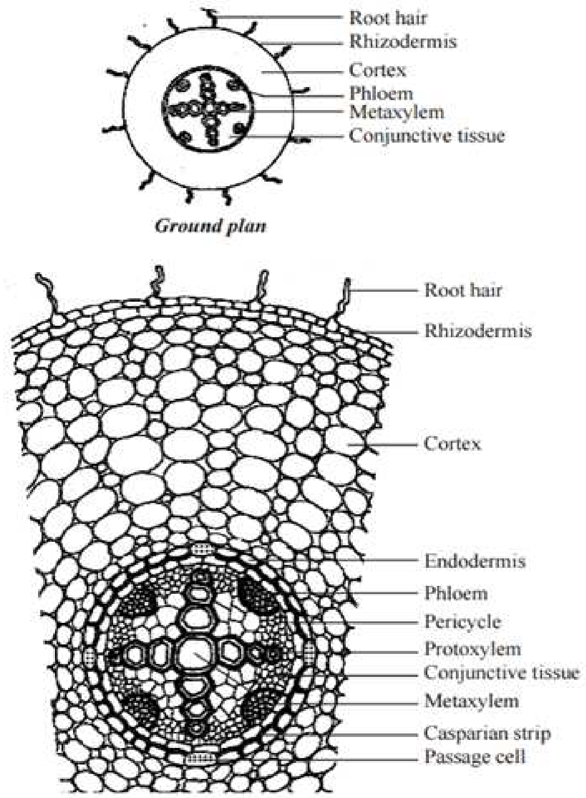
2.3.1 Anatomy of Root

The three zones that can be distinguished in a root are (Fig. 2.2 and 2.3):

(i) **Epidermis:** It is single layered (uniserate) and consists of tightly placed, thin walled uncutinized cells. This epidermis layer is called as epiblema, pilliferous layer or rhizodermis. Epiblema in younger roots bears uniancellular root hairs (water absorbing organs).

(ii) **Cortex:** It consists of thin walled parenchymatous cells with intercellular spaces. In most monocots and some dicots cortex layer below epidermis become suberised to form protective tissues called exodermis. The cells of cortex store food material (e.g. carrot). The inner most layer of cortex develops into **endodermis**. It is made up of closely packed living cells characterized by the presence of band like thickening made of suberin and lignin on their radial and transverse walls. These bands or strips are called casparian bands or strips. Some cells of endodermis lying opposite to protoxylem remain thin walled and are called **passage cells** which allow radial diffusion of water.

(iii) **Vascular bundles:** Vascular bundles are radial and exarch (the protoxylem is situated away from the centre of axis). In exarch vascular bundle protoxylem elements develop in region away from the centre of the axis and later formed metaxylem develop progressively towards the centre of axis. So it is called as centripetal. The centre of monocot root is occupied by parenchymatous cells called **pith**.



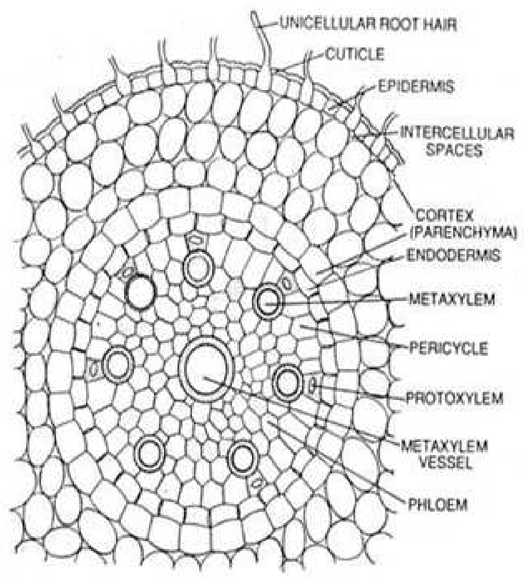


Fig. 2.2- T.S. of Dicot root

Fig.2.3: T.S. of Monocot root

Table 2.1: Anatomical similarities and differences between dicotyledonous and Monocotyledonous roots

S.No.	Characters	Dicotyledonous root	Monocotyledonous root
1.	Hairs	Unicellular	Unicellular
2.	Cortex	Large	Large
3.	Cambium	Develops water and, therefore secondary growth takes place	Does not develop at all and hence there is no secondary growth
4.	Pericycle	Lateral root formation and sometimes in the origin of cambium	Only lateral root formation
5.	Vascular Bundles	Radial, xylem exarch, 2-6 in number	Radial, xylem exarch more than 6
6.	Pith	Reduce or absent	Well developed

2.3.2 Anatomy of Stem

Dicot stem consists of following layers (Fig. 2.4):

(i) Epidermis: It is the outermost layer consisting of single layer of closely arranged cells with cuticle (cutinized). It bears multicellular hairs.

(ii) Cortex: It is differentiated into hypodermis, general cortex and starch sheath. Hypodermis is collenchymatous. General cortex lying inner hypodermis is made up of parenchymatous cells with intercellular spaces. The upper-most layer of cortex is called starch sheath (endodermis).

(iii) Vascular bundles: The starch sheath separates the vascular tissue from the cortex. The vascular tissues are present in the form of vascular bundles consisting of phloem and xylem. Vascular bundles are conjoint, collateral or bicollateral, open and endarch and are arranged in ring (Eustele).

(iv) Pith: It is the central portion of stem consisting of parenchymatous cells with intercellular spaces. Narrow radially elongated parenchymatous cells extend from pith towards the periphery are called medullary rays. The main function is food storage.

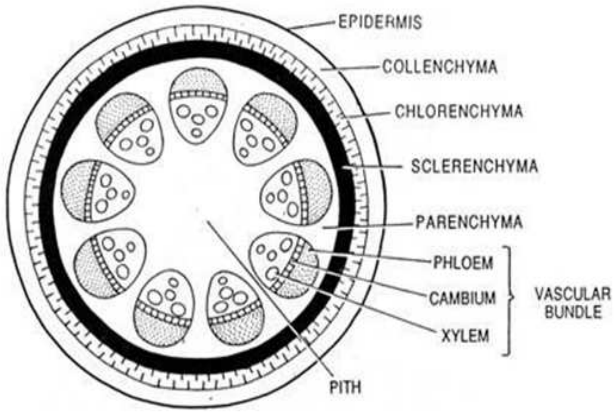


Fig. 2.4 T.S. of Dicot stem

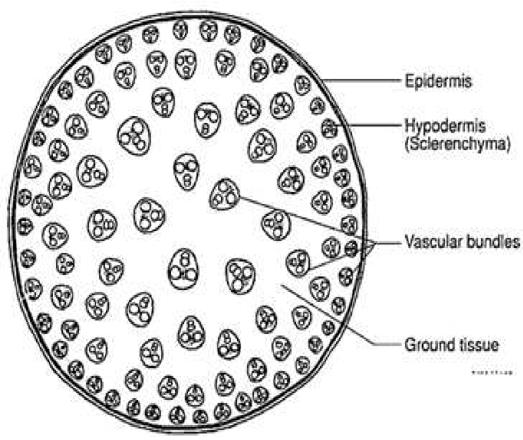


Fig. 2.5: T.S. of monocot stem

Monocot stem consists of following layers (Fig. 2.5):

(i). Epidermis: It is outermost layer consist of compactly arranged parenchyma cells which are usually covered with cuticle.

(ii). Hypodermis: Cells of hypodermis are sclerenchymatous providing mechanical strength to the stem.

(iii). Ground tissue: All the tissue internal to hypodermis represents the ground tissue. It is made up of parenchymatous cells rich in food reserve like starch.

(iv). Vascular bundles: They lie scattered in the ground tissue. Each vascular bundle is surrounded by 2 or 3 layered sclerenchymatous sheath called as bundle closed and endarch

(Atactostele). Vessels arranged in V shaped manner. Lysigenous water cavity or canals are present below protoxylem.

Table 2.2: Anatomical similarities and difference between dicotyledonous and monocotyledonous stems

S.No.	Characters	Dicotyledonous stem	Monocotyledonous stem
1.	Hairs	Multicellular	Multicellular
2.	Hypodermis	Collenchymatous	Sclerenchymatous
3.	Ground Tissue	Differentiated into a) Cortex b) Pericycle c) Pith d) Medullary rays	Undifferentiated
4.	Vascular Bundles	a) Number not very large b) Arranged in a ring c) Collateral d) Open e) Xylem endarch f) Phloem parenchyma is present g) Xylem vessels arranged in radial rows h) Water cavity is absent i) Bundle sheath is absent	a) Numerous b) Scattered c) Collateral d) Closed e) Endarch f) Phloem parenchyma is usually absent or restricted g) Xylem Y shaped h) Water cavity is present i) Bundle sheath is present

2.3.3- Anatomy of Leaf

Dicot leaf: In cross section of leaf following parts can be made out (Fig. 2.6):

(i) **Epidermis:** The upper and lower surfaces are covered by the epidermis. Cells of epidermis are parenchymatous and are closely packed together without any intercellular spaces. Mostly the stomata are restricted to lower surface of leaf, such leaf is called **hypostomatic**. The outer walls of the epidermal cells are thickened and cutinized (cuticle) which prevents the loss of water.

(ii) **Mesopohyll:** Between the two epidermal layers there are numerous parenchyma cells which constitute the mesophyll. In dicots, there are two distinct layers of mesophyll the **palisade** (upper layer consisting of closely arranged column shaped cells containing abundant chloroplasts) and **spongy tissues** (the lower layer of irregular shaped cells containing fewer chloroplasts).

(iii) Vascular bundles: Vascular bundles in the leaf are located in the midrib and the veins. Vascular bundles are conjoint, collateral and closed. Bundles are surrounded by a compact layer of parenchymatous cells which is called **bundle sheath**. The xylem (protoxylem) is towards upper epidermis (adaxial) and the phloem on the lower side (adaxial).

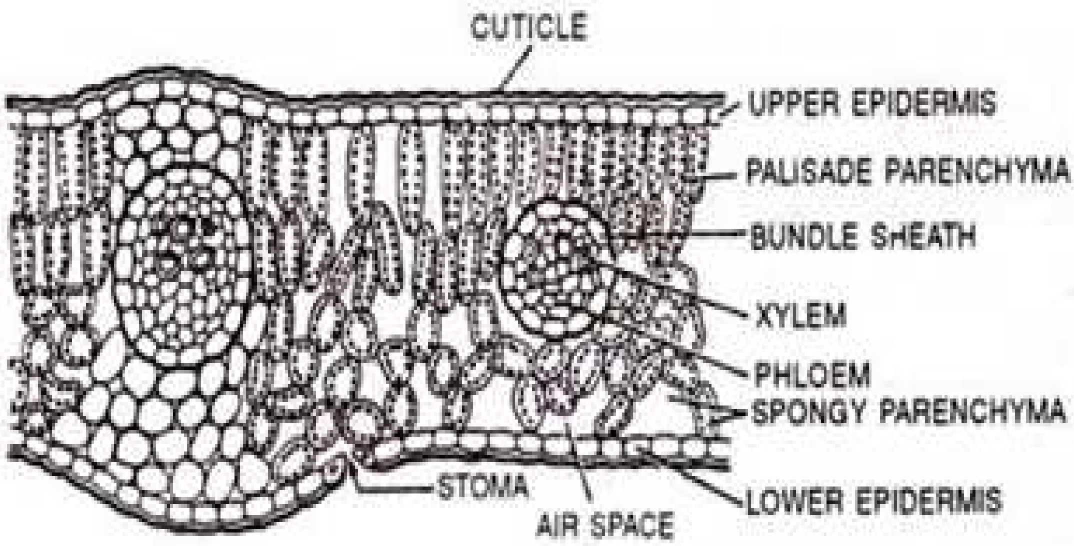


Fig. 2.6: T.S. of Dicot leaf

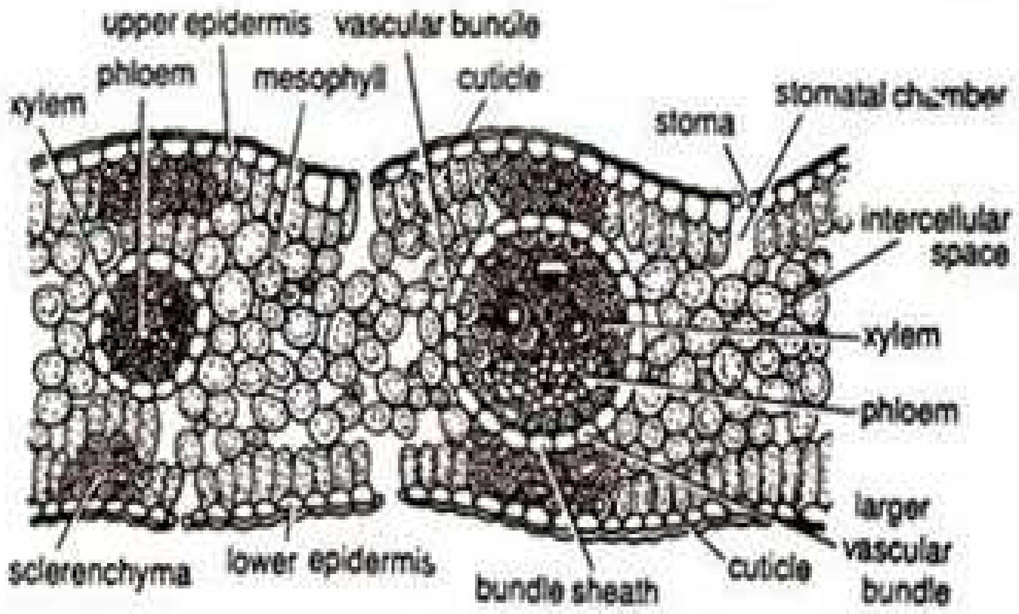


Fig. 2.7: T.S. of Monocot leaf

Monocot leaf (isobilateral leaf)

Like the dicot leaf, it can also be differentiated into three types of tissues (Fig. 2.7):

(i) **Epidermis:** It consists of upper and lower epidermis, both of which may be interrupted by equal number of stomata so, this leaf is amphistomatic. Both the epidermal layers are cutinized. In some grasses e.g. *Poa, Agropyron* epidermal cells are large with thin flexible, walls which are called as **motor** or **bulliform** cells. These cells help in the rolling of leaves.

(ii) **Mesophyll:** Mesophyll cells are not differentiated into palaside and spongy parenchyma. These cells are made up of parenchyma cells which have choloplast.

(iii) **Vascular bundles:** They are arranged in parallel manner. Vascular bundles are conjoint, collateral, closed and enclosed by a bundle sheath. The xylem is towards the upper side (adaxial surface) and phloem on the lower side (abaxial surface).

Table 2.3: Differences between dicot and monocot leaves

S.No.	Characters	Dicot leaf	Monocot leaf
1.	Type of leaf	Dorsiventral	Isobilateral
2.	Stomata	Usually more on lower surface (hypostomatic)	Equal on both upper and lower surface (Amphistomatic)
3.	Mesophyll	Differentiated into palisade parenchyma and spongy parenchyma	Undifferentiated and made up of spongy parenchyma
4.	Bundle sheath	Made up of parenchyma cells just above and below the vascular bundle. Some parenchyma or collenchyma cells are present upto epidermis	Made up of parenchyma cells but just above and below the vascular bundle. Sclarenchyma cells are present upto epidermis
5.	Bulliform cells	Absent	Present

2.4 XYLEM

Xylem (**Hadrome)** is chief water conducting element and is considered with the upward conduction of water and minerals. On the basis of origin xylem is of two types:

(i). **Primary xylem**: It is derived from procambium during the formation of primary plant body. It differentiates into **protoxylem** (first formed and consist of tracheary elements and xylem parenchyma) and **metaxylem** (later formed and consist of tracheary elements, xylem parenchyma and fibres). The cells of metaxylem are bigger in size than protoxylem.

(ii). Secondary xylem: It is formed from cambium during secondary growth. It is well differentiated into two systems.

A- Axial or vertical system

1 Tracheary element (Tracheids and vessels) → For conduction of H_2O

2 Xylem or wood fibre→ For support

3 Xylem parenchyma →For storage of food

B- Ray or Horizontal system

Ray parenchyma →For storage of food

Xylem consists of following types of cells (Fig. 2.8 & 2.9):

1. **Tracheids:** They are elongated cells with pointed chisel like ends. Cell wall of cells is tough, thick, and lignified. Thickening may be annular, spiral reticulate, scalariform and pitted. Cells are dead at maturity and have bodered pits. In pteridphytes and gymnosperms wood mainly consists of tracheids (no vessels). In Angiosperms tracheids are associated with vessels. The main function is conduction of water. The tracheids are most primitive type of conducting elements in xylem.

2. **Vessels or Tracheae:** They are also elongated tube like, formed from a row of cells placed end to end. The partition walls are either perforated or disappear altogether resulting in an elongated tube. Walls are thick, lignified and may have annular, spiral, reticulate or scalariform thickening. Vessels are dead at maturity and without nuclei. In Pteridophytes and Gymnosperms vessels are absent (Non porous wood). Sometimes primitive vessel are present in pteridophytes such as some species of *Selaginella, Equisetum, Pteridium* and in Gymnosperms such as *Gnetum, Ephedra* and *Welwitschia* (Gnetales).

   Vessels are characteristic of Angiosperms (porous wood). But they are absent in members of Winteracene, Tetracentraceae and Trochodendraceae. (Vesselless families), order Ranales (*Trochodendron, Tetracentrom, Drimys, Pseudowintera*) etc. The main function is conduction of H_2O. Vessels are advanced type of conducting elements. On the basis of distribution and size of vessels, porous wood is of two types:

   (i). Diffuse porous wood (Primitive): Vessels of same size are uniformly distributed throughout the growth or annual ring e.g. *Pyrus, Betula*.

   (ii). Ring porous wood (Advanced): Large vessels are formed in early wood when the need of water is great and small vessels are formed in late wood e.g. *Quercus, Morus.*

3. **Xylem fibres**: These cells are elongated and pointed at both the ends. Cell wall is highly lignified having simple pits. They are commonly found in secondary xylem. They may be:

(i). **FibreTracheids**: Fibres like tracheids with bordered pits.

(ii). **Libriform fibre**: They have extremely thick walls and simple pits. They provide mechanical support.

4. **Xylem parenchyma**: They are living parenchymatous cells associated with xylem. They may occur as axial parenchyma or ray parenchyma. When parenchyma is diffused or not associated with vessels, they called as **apotracheal parenchyma** and when parenchyma surrounds or associated with vessels, they are called as **paratracheal parenchyma.**

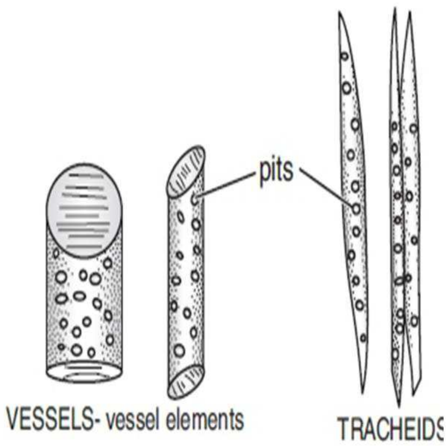


Fig. 2.8: Tracheids and Vessels

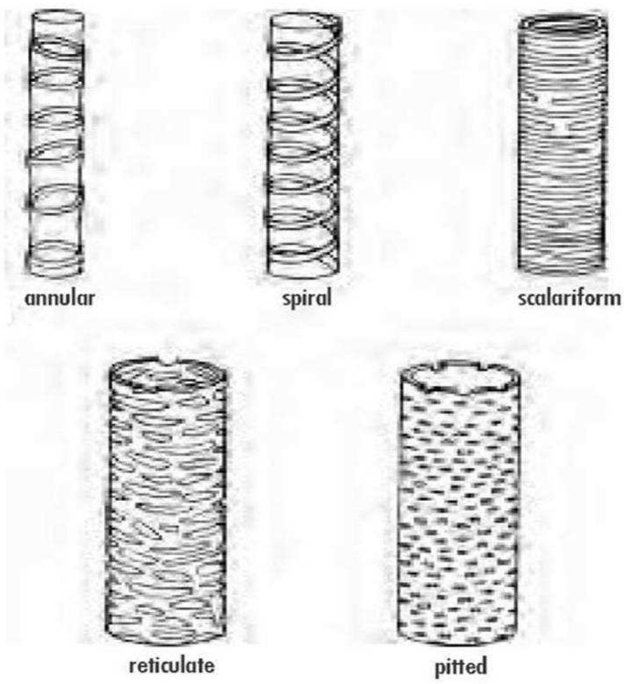


Fig. 2.9-Different forms of Tracheids and Vessels

2.5 PHLOEM

Phloem (Bast or Leptom) is a conducting tissue meant for transporting food in both downward and upward directions.

Types of Phloem

a. On the basis of position:

(i). **External Phloem**: It is normal type and present outside the xylem e.g., mostly Angiosperms and Gymnosprerms.

(ii). **Internal or Intraxylary phloem**: It originates from procambium and is primary phloem which occurs on innerside of primary xylem e.g., Members of Apocynaceae, Asclepiadaeae, Convolvulaceae etc.

(iii). **Included or Interxylary phloem**: It originates from cambium and is secondary phloem which occurs in groups within the secondary xylem e.g., *Leptadaenia*, *Chenopodium, Boerhaavia, Amaranthus* etc.

b. On the basis of origin:

(i). **Primary phloem**: It develops from procambium. It does not show radial differentiation or rays absent. It is differentiated into **protophloem** (consists of sieve elements and and parenchyma) and **metaphloem** (develop after protophloem and consists of sieve elements, parenchyma and fibre). During the primary growth the protophloem elements are crushed by surrounding tissues and disappear. This process is known as obliteration.

(ii). **Secondary phloem**: It develops from cambium during secondary growth. It consists of two distinct systems such as:

(a) Axial or vertical system

1-Sieve elements → For conduction of food (sieve tube and companion cells)

2- Bast fibre→ For support

3- Bast parenchyma →For storage of food

(b) Ray or Horizontal system

Ray parenchyma →For storage of food

Components of phloem

(i) Sieve elements: Sieve elements may be arranged in the form a **sieve tube** as in angiosperms or may be alone. They are then called sieve cells. A sieve tube is composed of a vertical row of elongated cells called **sieve tube members**. They are living and have thin cell walls. Young sieve-tube members have plenty of protoplasm, nucleus and various organelles. When they mature the protoplast is greatly modified, the organelles are reduced in size and the nucleus disintegrates. A mass of fibres or tubules called **slime** or **P-protein** have been observed to be present in the central part of sieve elements. Mature sieve tubes have the characteristic perforated **sieve plates** at the end or side of the walls. The end walls may be transverse or oblique. The protoplasts of adjacent sieve elements are connected with each other by means of cytoplasmic strands which pass through the pores of the sieve plate (Fig. 2.10).

Sieve tube members are believed to be living and functional for only three years and new elements are added every year. A carbohydrate known as **callose** is deposited around the margins of pores of the sieve plate during the winter. The deposit is called **callus** or **callus pad**. Often it plugs the pores completely. In spring, however, it dissolves. The callus is permanently deposited in old sieve tubes. Sieve tubes conduct food material in longitudinal directions.

While sieve tubes with large perforations in the sieve plates and companion cells are characteristic of angiosperms, the phloem of pteridophytes, and gymnosperms have only **sieve cells**, and no companion cells. The sieve cells have perforated **sieve areas** throughout the end walls as well as the lateral walls.

(ii) Companion cells: A companion cell and a sieve element are sister cells since both of them arise from the same procambial cells. While the sieve element undergoes a lot of modifications as it matures, the companion cell retains the original structure with the nucleus and the organelles remaining within plenty of cytoplasm. In all the angiosperms a sieve element is always associated with companion cell. Like the former it is also thin-walled and elongated. The companion cell is believed to play an important role in regulating the function of a sieve element. Companion cells do not occur in the phloem of pteridophytes and gymnosperms.

(iii) Phloem Parenchyma: They are very common in the phloem tissue. They are living, thin-walled cylindrical cells. While they occur in pteridophytes, gymnosperms and dicotyledons, they are absent in a majority of monocotyledons. When present they are restricted to the periphery of phloem strands. They conduct substances to short distances. They store food.

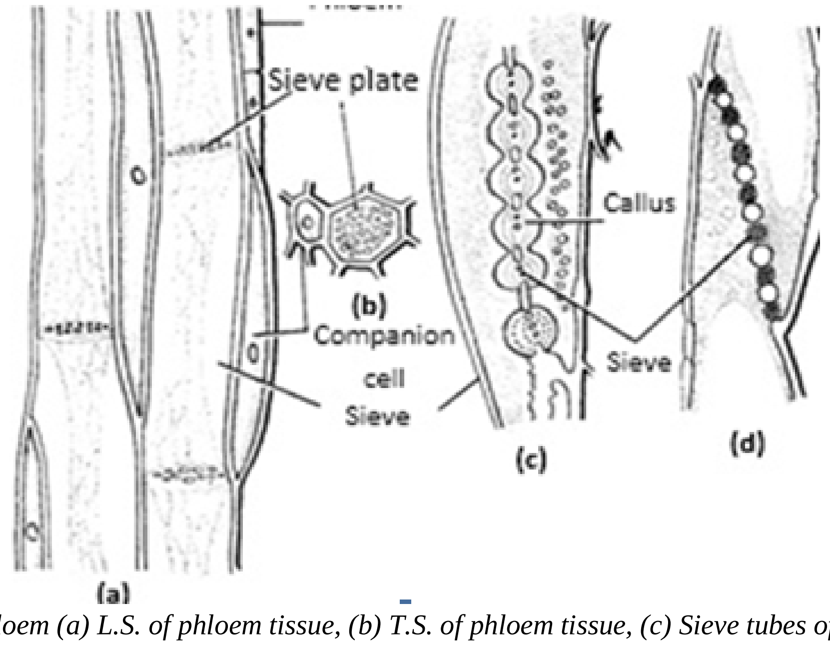


Fig. 2.10: T.S. of Phloem (a) L.S. of phloem tissue, (b) T.S. of phloem tissue, (c) Sieve tubes of Vitis, (d) L.S. of sieve plate

(iv) Phloem Sclerenchyma: They are also known as **bast fibres**. They are elongated thick-walled dead cells and give rigidity to the phloem. They are more common in the secondary phloem. They give the famous jute, and flax fibres.

The phloem is usually differentiated into two parts, **protophloem** and **metaphloem**. The former has narrow sieve elements and no companion cells. The protophloem degenerates after some time in a phenomenon termed **obliteration**. The phloem fibres, however, remain on the outer sides of the vascular bundles of many plants as bundle caps. The metaphloem consists of well developed long-lived sieve elements. The fibres are usually absent in the metaphloem of the dicotyledons. The metaphloem becomes inactive and may be partially or completely crushed as a result of secondary growth.

2.6 CAMBIUM

Growth of plant axis in thickness or girth resulting from the activity of lateral meristem i.e. vascular cambium and cork cambium is called secondary growth.

2.6.1 Secondary growth in a Dicot stem

In old dicotyledonous stems and roots two types of meristems are active. While the primary (apical) meristems are active since the beginning and cause the elongation of the stem and the root the secondary (lateral) meristems become active only in the old age and cause increase in the thickness. The lateral meristem comprises the cambium and the cork-cambium. They cut new tissues on the outer and the inner sides and add them to the primary tissues to cause increase in the girth of the stem and the root. The increase in thickness as a result of addition of secondary tissues cut off by the cambium and the cork-cambium in the stelar and the extra-stelar regions respectively is called secondary growth (Fig. 2.11).

The secondary growth in the dicotyledonous stem involves two distinct parts: (a) formation and activity of cambium ring and (b) origin and activity of-cork-cambium.

(a) Formation and activity of the cambium ring

(1). Formation of Cambium Ring

The cambium is initially limited only to the vascular bundles. Such a cambium is called the **fascicular cambium** (fascicle=bundle). The parenchymatous cells of the medullary rays lying in line with the fascicular cambium become meristematic and give rise to the **interfascicular cambium**. The interfascicular and the fascicular cambia join with one another to form a complete cambium ring. All the cells of the cambium ring look uniformly thin-walled and brick-shaped in a cross-section. A longitudinal view of the cambium, however, shows the cells to be of two kinds in structure and function. They are known as **fusiform initials** and **ray initials**. The fusiform initials are spindle-shaped elongated cells while the ray initials consist of small isodiametric cells packed in regular groups.

(2). Activity of Cambium

The fusiform initials give rise to the secondary tissues, viz., vessels, tracheids, fibres, parenchyma, sieve-tube members and companion cells which are all arranged in vertical rows. The ray initials produce the phloem and xylem rays which are arranged in horizontal manner.

A fusiform cell of the cambium divides by a tangential wall to form two daughter cells. While the inner daughter cell gets modified into a **secondary xylem** cell, the outer daughter cell divides again to produce two cells, the outer of which gets modified into **secondary phloem** cell. The inner of the two cells remains meristematic and continues the process of addition of secondary xylem and secondary phloem cells on the inner and outer side respectively.

The amount of secondary xylem produced by the cambium ring is much more than the amount of secondary phloem. The cambium ring is, therefore, gradually pushed outward. As the stem increases in thickness and circumference cambium ring also increases its circumference by means of radial division and enlargement of its cells. As a result of addition of secondary tissues the primary xylem is pushed into the pith and the primary phloem and the surrounding tissues are pushed to the outside and are gradually crushed. The ray initial cuts off the secondary medullary rays which are described below.While the cambium is active throughout the year in tropical regions, it is inactive during the winter in the temperate regions.

Secondary Phloem: The amount of secondary phloem is comparatively much less than that of the secondary xylem. It takes over the physiological functions of the primary phloem when the latter is crushed. The secondary phloem consists of vertical rows of sieve tubes, companion cells, phloem parenchyma and fibres, and **horizontal rows of phloem rays**. The secondary phloem is more complex than the primary phloem. It consists of larger number of shorter sieve-tubes, companion cells, phloem parenchyma and more abundant phloem sclerenchyma (bast fibres). The bast fibres of the secondary phloem give rise to excellent textile fibres of jute, flax, etc.

The **phloem rays** are continuous with the **xylem rays**. They are either one-layered thick (**uniseriate**) or two to many-layered thick (**multiseriate**) and one to many layers in height. They conduct food from phloem to the cambium and the living cells of the xylem in a radial and inward direction.

Secondary Xylem: The secondary xylem is much larger in amount and constitutes the main bulk of woody stems. It is composed of vertical rows of vessels, tracheids, xylem parenchyma and xylem fibres and radial rows of xylem rays. The vessels are shorter but larger in number in the secondary xylem. Annular and spiral thickenings are absent in the vessels. Pitted vessels are abundant. The secondary xylem elements besides conducting water and dissolved minerals also give mechanical support to the plant

The **xylem rays** along with the phloem rays constitute the **vascular rays** or the **secondary medullary rays**, which run in a radial direction. The xylem rays are also either uniseriate or multiseriate. They conduct water from the xylem to the cambium and phloem. They also help in the storage of food and in easy exchange of gases with the outer atmosphere.

Annual Rings: In sub-tropical and temperate regions where seasonal variations are well pronounced the growth of a dicotyledonous stem is not uniform throughout the year. The cambium is very active during the favourable spring season, when it cuts off large-sized secondary xylem elements. This type of secondary xylem is called the **early** or **spring wood**. During the unfavourable season, the late summer or autumn, the cambium is less active and cuts off xylem elements of smaller diameter. This is called the **late** or **autumn wood**. The periodical activity of the cambium, thus results in distinct growth layers or rings of secondary xylem. These are called **growth rings**. The growth rings of spring wood and autumn wood produced in a year constitute an **annual ring**.

If the spring wood elements are much larger than those of the autumn wood, they are usually arranged in the form of rings. This type of wood is called the **ring porous**. If all the vessels are of uniform diameter in the wood and there is only a gradual change in the size of the elements the wood is called the **diffuse porous**.

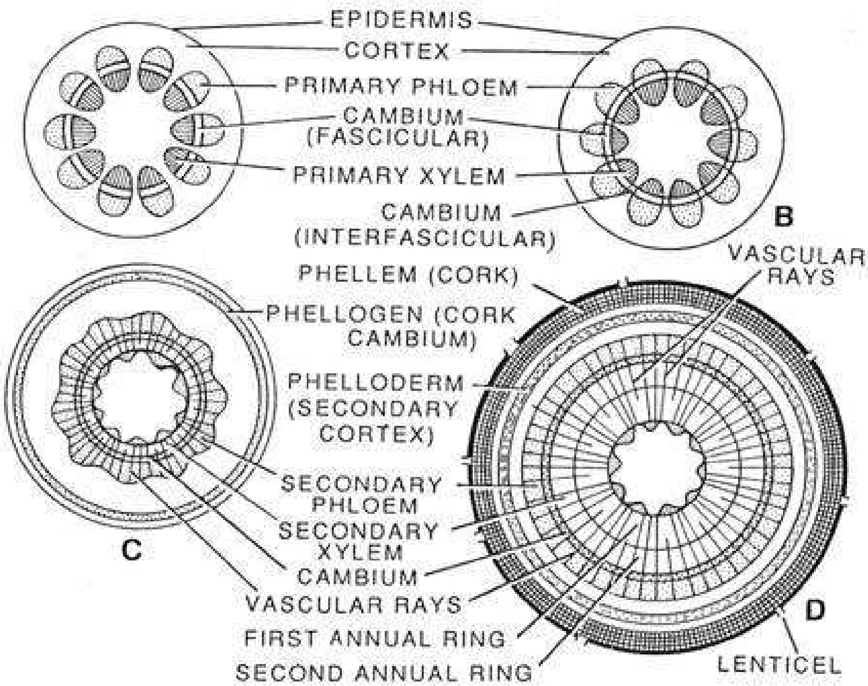


Fig. 2.11: Stages in the secondary growth of a Dicot stem

Heartwood and Sapwood: In a very old stem the secondary xylem elements in the inner (central) part turn darker in, colour and are called the **heartwood** or **duramen**. It consists of dead elements which have a deposit of gums, resins, oils, tannins in their walls and lumens. The heartwood is, therefore, very strong and durable and imparts great amount of mechanical strength to the stem. The cells of the xylem parenchyma and ray parenchyma often produce ball on-like infoldings into the lumen of secondary xylem elements of the heartwood. These infoldings are called **tyloses**. The tyloses contains resin, starch, etc. They are very large in size and often block the cavities of the xylem elements as a result of which the heartwood is no more capable of conducting water. The heartwood is resistant to attack by micro-organism and insects.

The **sapwood** or the **alburnum** is the light-coloured peripheral part of the secondary xylem. It consists of dead tracheids, vessels, and fibres and some living cells. The sapwood elements continue to perform the function of conducting water and solutes etc. They also give mechanical support to the stem. The gymnospermic wood is called **softwood** and angiospermic wood is called **hardwood**.

(b) Origin and activity of the Cork-cambium

(1) Origin of the Cork-cambium

The activity of the cambium resulting in addition of a huge mass of secondary tissues in the stelar region cause lot of pressure on the peripheral tissues of the stem. The peripheral tissues including the epidermis, therefore, often get ruptured. Some of them get flattened and persist for a long time. The stem develops a new lateral meristem in the peripheral part which cuts off new cells to replace the worn out outer part. It also causes growth in the peripheral part so that it can keep pace with the-expanding inner part. Such a secondary meristem is called **cork cambium** or **phellogen** (phellos=cork; gen=producing).

The place of the origin of the cork-cambium differs in different plants. It can arise in the epidermis, hypodermis or the cortex. One or more layers of cells become meristematic. The meristem is composed of thin-walled living cells.

(2) Activity of the Cork-cambium

The meristematic cells cut off new cells on both the inner and the outer sides. The inner cells are modified into the **secondary cortex** or **phelloderm** and the outer cells into the **cork** or **phellem**. The phellem, phellogen and phelloderm constitute the **periderm**.

Secondary Cortex: It consists of few layers of living parenchyma cells. They are usually thin-walled. Sometimes they become thick-walled and have pits. The cells of the secondary cortex often contain chloroplasts and are, therefore, capable of photosynthesizing.

Cork: The cells of the cork are added on the outer side of the cork-cambium. The cork cells are brown coloured and are large and rectangular. They are arranged in a very compact manner in radial rows. They have no intercellular spaces. They are thick-walled dead cells and have a deposit of **suberin**.

The cork is produced in a continuous manner and is considerably thick in some plants. This is why removal of the thick bottle cork from the cork of oak plant immediately results in its replacement by the cork cambium.

The suberized cells of the cork are absolutely impervious to water as a result of which water and food cannot diffuse through it to the outer tissues. The outer, tissues are, therefore, killed and are removed in the form of **bark**. The cork-cambium, cork and the secondary cortex together constitute the periderm.

Bark: The bark is the outer protective portion of the dicotyledonous stem. It constitutes the entire dead tissues present outside the vascular cambium. The bark can be thin or thick depending upon whether the cork-cambium arises in the epidermis, hypodermis, deeper in the cortex or secondary phloem. The bark accordingly includes the cork, the epidermis, hypodermis, a portion of the cortex or even a portion of the secondary phloem.

There are two types of bark: the **ring-bark** and the **scale-bark**. If the bark is removed in the form of a complete ring or sheet it is called the ring-bark, as for example in *Betula* (birch/ Bhojpatra). If the bark is removed in the form of scales it is termed the scale-bark. The bark is formed in a ring if the cork cambium arises in the form of a complete ring. The bark is sealy if the cork cambium arises in strips.

Lenticels: The bark often forms lenticels for exchange of gases on its external surface. These are the lenticels which are meant for an easy exchange of gases between the inner tissues of the stem and the atmosphere. In a lenticel the cork cambium cuts off on the outer side a mass of eel is called **complementary cells** in place of compactly arranged cork cells.

The complementary cells are small and rounded and have a very loose arrangement. They enclose large intercellular spaces between them. A portion of epidermis and the stoma below which a lenticel usually develops finally disappear. This facilitates the exchange of-gases between the plant and the atmosphere. There may be a periodical blocking of the lenticels during the winter.

Some dicotyledonous stems like *Boerhavia*, *Aristolochia*, *Bougainvillea* show anomalous secondary growth.

2.6.2 Secondary growth in Dicot root

Dicotyledonous roots like the dicotyledonous stems increase in thickness as a result of addition of secondary tissues cut off by the cambium and the cork cambium (Fig. 2.12).

(a) Origin and activity of the Cambium

(1). Origin of the Cambium Ring: The dicotyledonous roots lack a cambium. The secondary growth, therefore, has to be preceded by the origin of a complete ring of cambium.

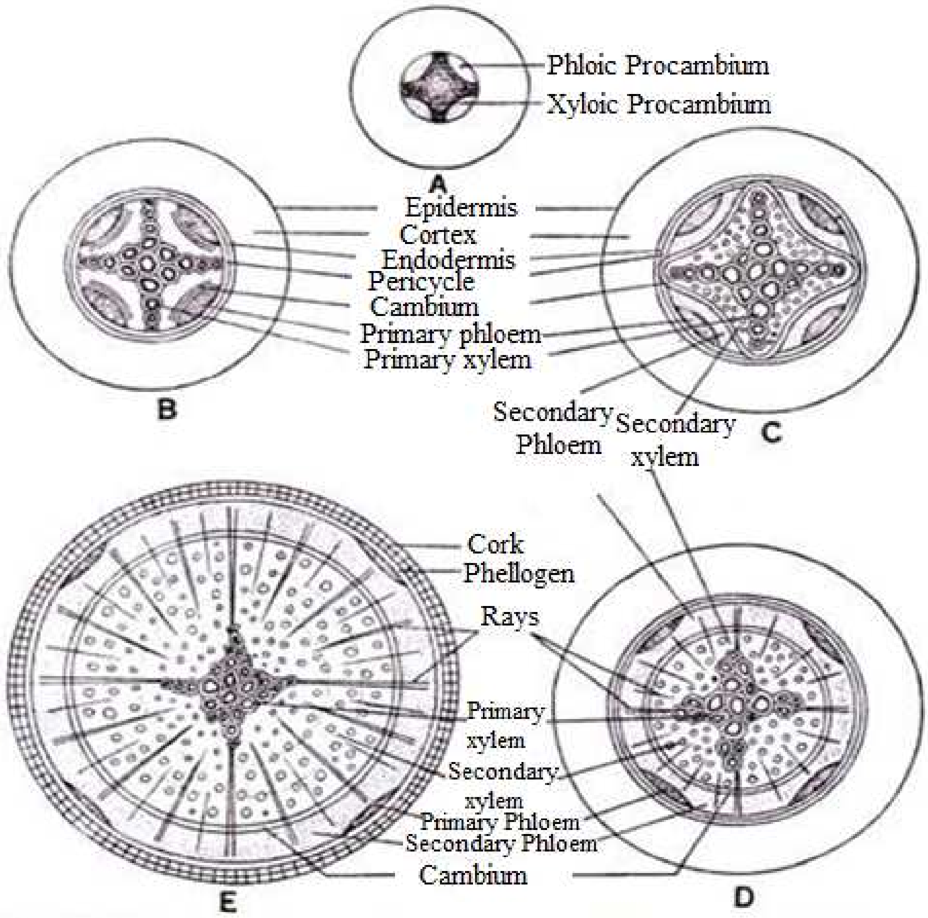


Fig. 2.12: Stages in the secondary growth of a Dicot root

The **conjunctive tissues** on the inner side of the phloem become meristematic and give rise to as many strips of cambium as are the patches of phloem. Later the conjuctive cells present between the phloem and xylem patches become meristematic and give rise to strips of cambium. Now the conjuctive cell arching over the xylem and the cells of the pericycle also become meristermatic to produce new strips of cambium. Finally, all the cambium strips get connected with one another to form a continuous and wavy band of cambium.

(2). Activity of the Cambium Ring: The wavy band of cambium becomes active only in those parts which lie on the inner side of the phloem patches. These cambium strips cut off secondary xylem elements only on the inner side as a result of which the cambium and the phloem are gradually pushed on to the outer side. This sort of unequal behaviour of the cambium results in the conversion of its wavy band into a circular ring of cambium. Once the cambium assumes a circular outline it becomes uniformly meristematic and starts cutting off cells both on the inner and the outer sides. Except in the regions of the medullary rays the inner cells get modified into secondary xylem and the outer cells into those of the secondary phloem.

Secondary Xylem: The cambium is more active on the inner side as compared to the outer side and, therefore, the amount of secondary xylem produced on the inner side is considerably more than that of the secondary phloem. Addition, of the wood on the inner side pushes the cambium and the phloem on the outer side and the primary xylem on the inner side.
The secondary xylem contains many large vessels and xylem parenchyma. The xylem sclerenchyma is comparatively few in number.

Secondary Phloem: The amount of secondary phloem is few layers in thickness. It is composed of plenty of sieve tubes, companion cells and phloem parenchyma. The phloem has little amount of sclerenchyma.

Medullary Rays: Opposite the protoxylem elements the cambium cuts off only parenchyma cells on both the sides. These cells constitute multi-layered rows of radially arranged **medullary rays**. Initially the number of medullary rays is equal to the number of xylem patches or vascular bundles but later some more medullary rays are also formed by the cambium. These later formed rays are however much smaller in length and lesser in thickness.

2.6.3 Origin and activity of the Cork-cambium

Addition of secondary tissues in the central part of the root exerts lot of pressure on the peripheral tissues which get ruptured. A new meristem, therefore, known as cork-cambium, develops in the single layered **pericycle** to replace the lost peripheral part of the root.

Table 2.4: Anatomical differences between stems and roots

S.No.	Characters	Stems	Roots
1.	Hairs	Multicellular	Unicellular
2.	Epidermis	Protective	Absorptive
3.	Cuticle	Present	Absent
4.	Ground Tissue	Differentiated in dicot stems only	Differentiated in both dicot and monocot roots
5.	Endodermis	Usually not distinct	Always distinct
6.	Vascular Bundles	Conjoint	Limited in number
7.	Xylem	Endarch	Exarch
8.	Pith	Large or absent	Small or well developed

The cork-cambium or the **phellogen** is few layers in thickness and is composed of thin walled rectangular cells. It cuts off cells on both the outer and the inner sides. The cells on the outer side are modified into brown coloured suberized cork cells and on the inner side remain thin walled parenchymatous secondary cortex. The cork and the secondary cortex are also known as **phellem** and **phelloderm** respectively. The cork, cork cambium and secondary cortex together constitute the **periderm**.

The **bark** of a root is comparatively thinner. Lenticels are fewer in number. The endodermis, primary phloem and the primary cortex are completely disorganized and lost.

2.7 SUMMARY

Vascular system in plants, assemblage of conducting tissues and associated supportive fibres. Xylem tissue transports water and dissolved minerals to the leaves, and phloem tissue conducts food from the leaves to all parts of the plant. The condition of the xylem, the woody elements in the stem, defines several categories. The protostele has a solid xylem core; the siphonostele has an open core or one filled with generalized tissue called pith. The discontinuous vascular system of monocots (e.g., grasses) consists of scattered vascular bundles; the continuous vascular system of dicots (e.g., roses) surrounds the central pith.

Vascular bundles run longitudinally along the stem. Vascular rays extend radially across the stem, assisting in conduction from the vascular bundles to tissues alongside them. The vascular tissues and supporting tissues constitute the stele. Several kinds of vascular bundles are recognized. In the collateral pattern, the phloem lies only on one side of the xylem, usually toward the stem exterior. This arrangement is typical of the dicots, the majority of flowering plants, such as roses, apples, oaks, pines, etc. If phloem is on the outer and inner faces of the xylem, the bundle is bicollateral. A concentric bundle has xylem entirely surrounded by phloem (amphicribal condition) or phloem entirely surrounded by xylem (amphivasal condition). Closed bundles lack cambium and are unable to continue growth laterally. They are typical of monocots, such as grasses, lilies, and palms, in which they are scattered in two or more rings in the stem.

2.8 GLOSSARY

Abaxial: Surface directed away from the axis.
Adaxial: Opposite to abaxial. Directed towards the axis.
Bicolateral vascular bundle: Avascular bundle with phloem on both side of xylem.
Bundle Sheath: Layers of parenchyma or sclerenchyma cells surrounding vascular tissues.
Callose: An occasional carbohydrate which is of periodic occurrence on sieve plates, but also observed in parenchymatous cells after injury.

Cambium: A meristem having products of divisions arranged orderly in parallel files. This is applied to two lateral meristems, the vascular cambium and the cork cambium. Secondary growth takes place due to cambium.
Endarch xylem: Xylem strands in which the maturation of the cells progression centrifugally, in other words, the oldest elements (the protoxylem) are closest to the centre of the axis.
Exarch xylem: Xylem strand in which the maturation of cells progresses centripetally, the oldest elements (protoxylem) are farthest from the centre of the axis. It is typical of roots in seed plants.
Heartwood (Duramen): The central portions of wood which have ceased to conduct and contain no living cells and in which reserve material have been removed or converted into heartwood substance. Generally darker in colour than sapwood.
Interfascicular cambium: Vascular cambium originating between vascular bundles, in the interfascicular parenchyma.
Nonporous wood: Secondary xylem without vessels.
Phellogen: Also cork cambium. A lateral meristem giving rise to cork and phelloderm.
Sapwood: Also called alburnum. The more superficial paler, softer wood in trees which contains living cells and reserve material.
Sieve tube: A series of sieve elements consisting of elongated cells placed end to end forming lines of conducting interconnected through sieve plates.
Tracheary elements: A general term for water conducting cells, tracheid or vessel member.
Xylem Ray: That part of a vascular ray which is located in the secondary xylem.

2.9 SELF ASSESSMENT QUESTIONS

2.9.1 Multiple choice questions:

1. Branch of botany deals with the internal organization of plants is
   (a) Ecology (b) Physiology
   (c) Cytology (d) Anatomy

2. Vessels differs from tracheids
   (a) Because they conduct water
   (b) That they consist of vertical row of cells with cross walls dissolved
   (c) In being living
   (d) Derived from a single cell

3. Cork of commerce is derivative of or cork is formed from
   (a) Vascular cambium (b) Fascicular cambium
   (c) Inter fascicular cambium (d) Phellogen

4. In root xylem is
   (a) Exarch (b) Endrach
   (c) Mesarch (d) None of the above

5. Fasicular cambium found in dicotyledonous stem is a
   (a) Primary meristem (b) Apical meristem
   (c) Secondary meristem (d) Intercalary meristem

6. Periderm includes
   (a) Cork, dermatogens and cortex
   (b) Cork and secondary phloem
   (c) Cork cambium, cork and secondary cortex
   (d) None of the above

7: Phloem parenchyma is absent in
   (a) Phloem fibres (b) Sieve tubes
   (c) Companion cells (d) Phloem parenchyma

8. Amount of phloem is double the amount of xylem in
   (a) Collateral vascular bundle (b) Bicollateral vascular bundle
   (c) Concentric vascular bundles (d) Conjoint vascular bundles

9. Tyloses are found in
   (a) Xylem vessels (b) Secondary xylem parenchyma
   (c) Alburnum (d) Duramen

10. Commercial cork is obtained from
   (a) *Pinus* (b) *Mangifera indica*
   (c) *Ficus religiosa* (d) *Quercus suber*

2.9.2- Fill in the blanks

1. Vessel less angiosperms belong to the family________
2. The conducting cells of ________ are called tracheary elements.
3. Medullary rays are absent in ________ stem.
4. All the tissues outside the vascular cambium constitute ________
5. Sieve tubes become functionless when________ is deposited on sieve plate.

2.9.3- True and False

1. The cambium ring in roots is partly primary and partly secondary in origin.
2. The phellogen in roots arises from pericycle.
3. The most active zone in the root is endodermis.
4. Vascular cambium is secondary in origin and secondary in function.
5. Only dicot stems show secondary growth.

2.9.1 Answers Key: 1(d); 2(b); 3(d); 4(a); 5(a); 6(c); 7(a); 8(b); 9(d); 10(d)
2.9.2 Answers Key: 1. Tetracentraceae; 2. Xylem; 3. Monocot; 4. Bark, 5. Callose.

2.9.3 Answers Key: 1. False, 2. True, 3. False, 4. False, 5. False

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2.12 TERMINAL QUESTIONS

2.12.1 Short answer type questions:

Q.1 Write short notes on the following:

(i) Annual Rings (ii) Cork cambium

(iii) Suberin (iv) Sieve elements

Q.2 Differentiate between the following:

(i). Tracheids and Vessels

(ii). Xylem and Phloem

(iii). Heartwood and Sapwood

2.12.2 Long answer type questions:

Q.1 What is vascular system in plant? Describe its different types.

Q.2 Describe xylem in detail with its function.

Q.3 Describe phloem in detail with its function.

Q.4 Discuss the cambium in detail.

Q.5 What is secondary growth? Describe it with reference to Dicots.

UNIT-3: STOMATA AND TRICHOMES

Contents:

3.1 OBJECTIVES

The objectives of the present unit are:

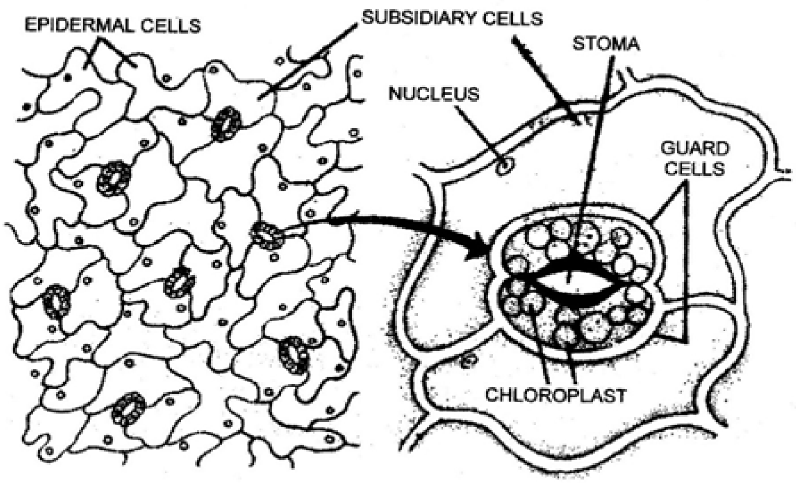
- To know the distribution and structure of stomata and Trichomes.
- To study the different types of stomata and hairs.
- To study the importance of trichomes and stomata in the life cycle of plants.

3.2 INTRODUCTION

The epidermis is the outermost layer of all plant organs and acts as a first contact point with their surroundings. Epidermis plays a key role in plant – environment interactions and is essential for the maintenance of physically favourable conditions. Trichomes are epidermal outgrowths and play diverse roles in the defense against biotic and abiotic stresses. The epidermis also contains stomata (minute pores), that regulates gas exchange and contributes directly to the control of water status.

3.3 STOMATA

Stomata are small pores in the epidermal layer of plant tissues. They are most abundant on leave but may also occur on any other part of the plant except roots (Fig. 3.1). The number of stomata present in the epidermis of leaves ranges from a few to over a 100000 per cm square. They occur on both upper and lower surfaces of the leave. In many woody species, they are confined only to the lower surface, while in aquatic plants, they are confined to the upper surfaces.



(a) (b)

Fig.3.1: (a) Epidermis of leaf showing stomata and (b) Stomata magnified

3.3.1 Types of Stomata

(A) On the basis of position and distribution of Stomata on both the surfaces of the leaf, plants may be of following types:

1. **Water lily type**: In free floating hydrophytes, Stomata are confined only to upper surface of the leaf. Such leaves are called epistomatous.
2. **Potamogeton type**: In submerged hydrophytes, Stomata are entirely absent but when present they are non-functional**.**
3. **Apple and mulberry type**: In this type, Stomata are found only on the lower surface (abaxial side). Such leaves are called hypostomatous. e.g., Walnut, Peach.
4. **Potato type**: In potato type, stomata are found more in number on the lower surface (abaxial side) than on the upper surface (adaxial side).
5. **Oat type**: In most of the monocots like Maize stomata are found equally distributed on both surfaces. Such leaves are called amphistomatous.

(B) Structurally the stomata may be of different types. They are generally found in dicotyledons (Fig. 3.2):

1. **Ranunculaceous or Anomocytic type**: In this type stomata are surrounded by limited number of subsidiary cells, which are quite alike from the remaining epidermal cells. The subsidiary cells are five in number.
2. **Cruciferous or anisocytic**: In this type stomata remains surrounded by three accessory cells of which one is smaller than the other two.
3. **Rubiaceous or paracytic**: Here stoma is surrounded by two subsidiary cells which are parallel to the long axis of the pore and guard cells.
4. **Caryophyllaceous or diacytic**: In this type the stomata remains surrounded by a pair of subsidiary cells and whose common wall is at right angles to the guard cells.
5. **Gramineous**: In this type stoma possesses guard cell of which the middle portions are much narrower than the ends. They are much found in Gramineae and Cyperaceae of monocotyledons.

Van Mohl (1856) prepared a stomatal clock and observed that stomata open in day light and close in night (Fig. 3.3).

(C) Loftfield (1921), On the basis of daily movement of stomata classified plants into three categories:

1. **Potato type**: In this type, stomata are found open all the day and night except for a few hours during the day time (after sunset) or during night. e.g., Potato, Onion.
2. **Alfalfa type**: The stomata are open throughout the day and night. This type of stomata is found in thin leaved mesophytes. e.g., Pea, Beans, Radish etc.
3. **Barley type**: The stomata are open only for a few hours during the day time. e.g., *Wheat, Maize* etc. (Cereals)

(D) Considering variable behaviour of stomatal movements five categories have been recognized:

1. **Photoactive movement**: Stomatal movement is controlled by light. They remain open during day time and closed at night.
2. **Scoto-active movement**: In this type stomata remain closed during day time and open during night. Such type of stomata is found in Succulent plants.
3. **Hydro-active movement**: Here stomata open due to excessive loss of water from epidermal cells and close due to turgid conditions of epidermal cells. This type of movement is found during mid-day.
4. **Autonomous movement**: In this type, stomata is open and close at a rate of 10-15 minute interval showing rhythmic pulsation.
5. **Passive and active movement**: Active (opening) and passive (closing) is caused by the turgor changes in the guard cells.

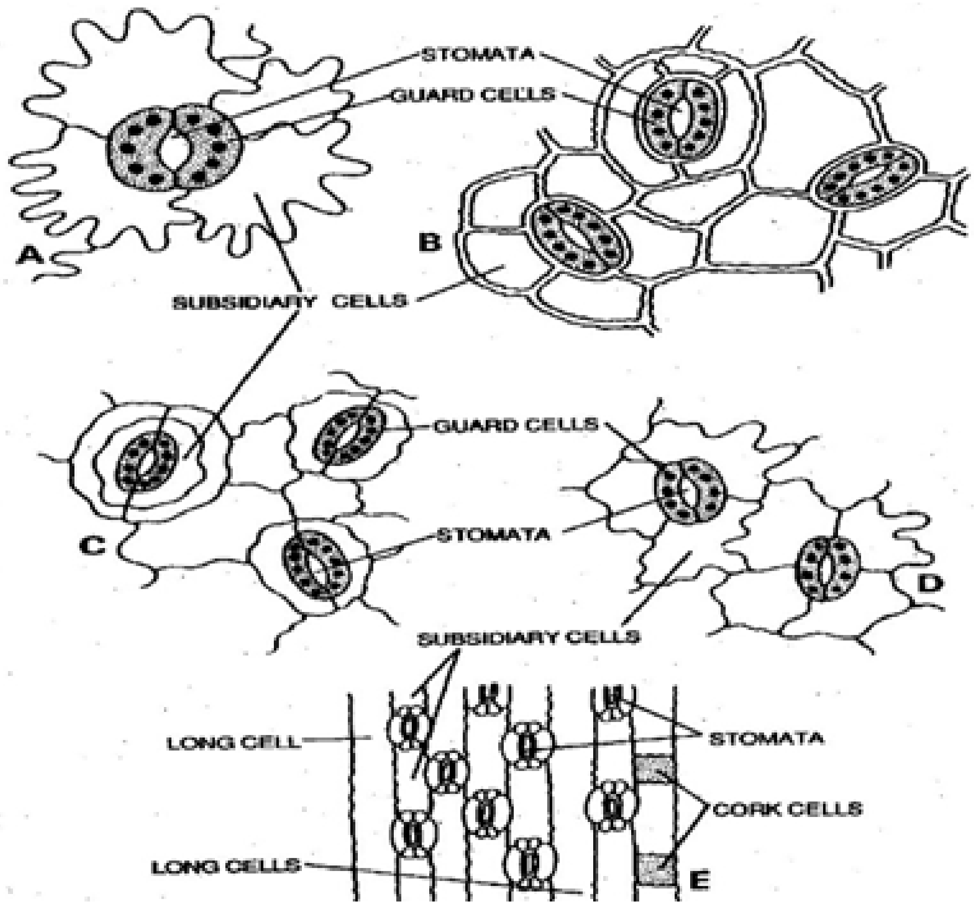


Fig. 3.2: Types of stomata: A. Anomocytic, B. Anisocytic, C. Paracytic, D. Diacytic, E. Gramineous

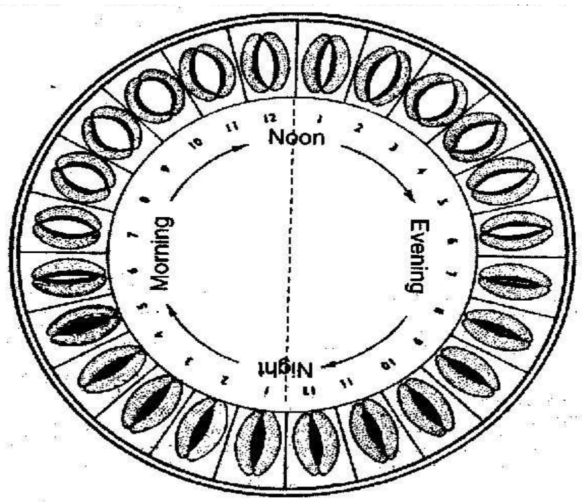


Fig.3.3: Stomatal clock in average plant

3.3.2 Structure of Stomata

Each stomata is made up of two specialized epidermal cells, called guard cells, each is kidney shaped or semicircular (Fig. 3.4). Between each pair of guard cell is a small opening or pore, through which gases enter and water evaporates. Guard cells and pore make one stoma. Guard cells are surrounded by epidermal cells, which are known as accessary or subsidiary cells. The chloroplast of guard cells contain both chlorophyll “a” and “b”. Guard cells are characterized with endoplasmic reticulum and chloroplasts. There is protoplasmic connection between guard cell and neighbouring epidermal cells through which air movement of dissolved molecules and ions takes place. The cell wall of guard cells adjacent to the stomatal pore is less elastic and thick than the wall adjacent to the surrounding epidermal cells. Due to variations in the thickness, elastic part of the wall of the guard cell is stretched largely and inelastic thicker part is stretched to small extent. Due to this an elliptical pore between two guard cells is formed. Subsidiary cells differ from other epidermal cells. They are suspended completely or partly, above the substomatal cavity. They function as elastic buffers between guard cells and epidermal cells.

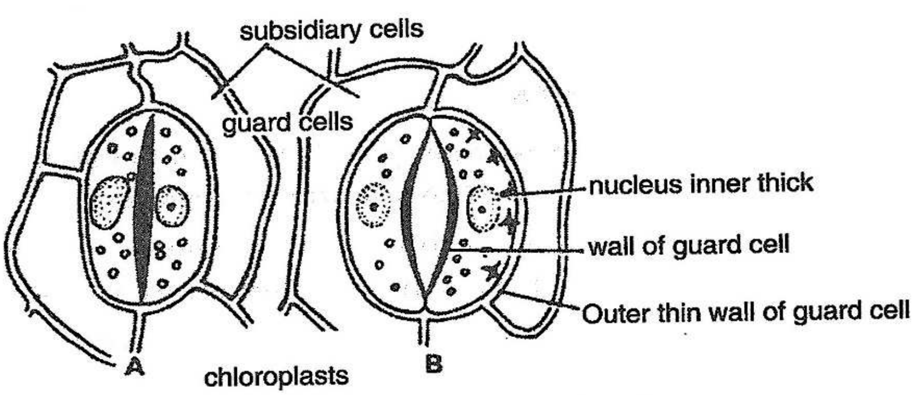


Fig.3.4: Closed and open stomata

3.3.3 Importance / Function of Stomata

Mechanism of stomatal opening and closing

The mechanism of the closing and opening of the stomata depends upon the presence of sugar and starch in the guard cells. During day time the guard cells of the stomata contain sugar synthesized by their chloroplasts. The sugar is soluble and increases the concentration of the sap of guard cells, due to higher concentration of the cytoplasm of guard cells, the water comes to them from the neighbouring cells by osmosis and they become turgid, with the result the stomata remain open.

In the night or in the absence of light the sugar present in guard cells converts into the starch. The starch is insoluble, and this way the cell sap of the guard cells remains of much lower concentration than those of neighbouring cells, and the neighbouring cells take out the water from the guard cells by osmosis making them flaccid and the stomata closed.

The conversion of sugar into starch during night and vice-versa in day time depends upon the acidity (pH) and alkalinity of the cell sap of guard cells. During night there is no photosynthesis and the CO_2 accumulates in the guard cells, converting the cell sap into weak acidic starch. During daytime the carbon di-oxide is used in the process of photosynthesis, the cell sap becomes alkaline and the starch converts into sugar (Fig. 3.5 & 3.6).

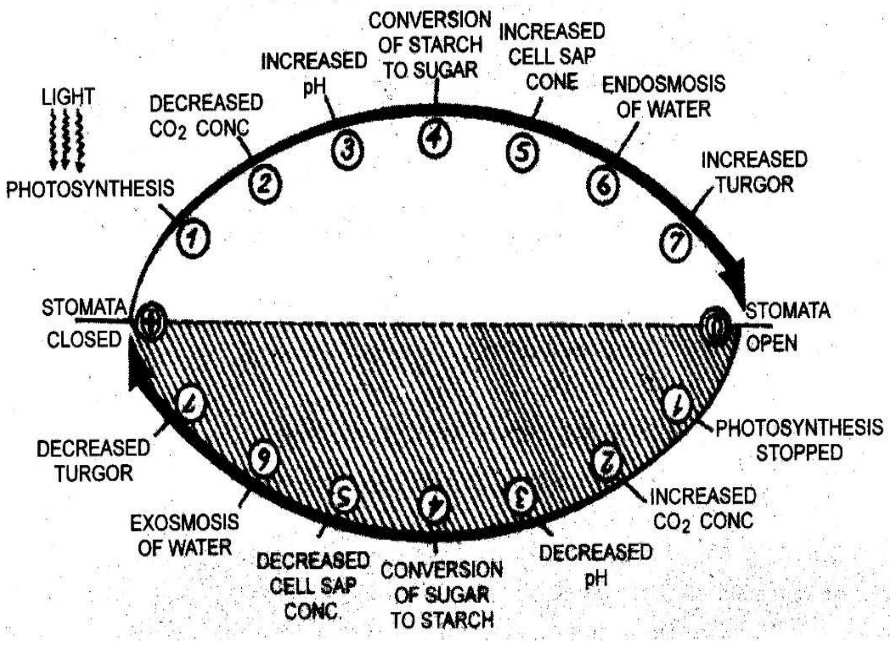


Fig.3.5 Summary diagram showing the mechanism of opening and closing of stomata

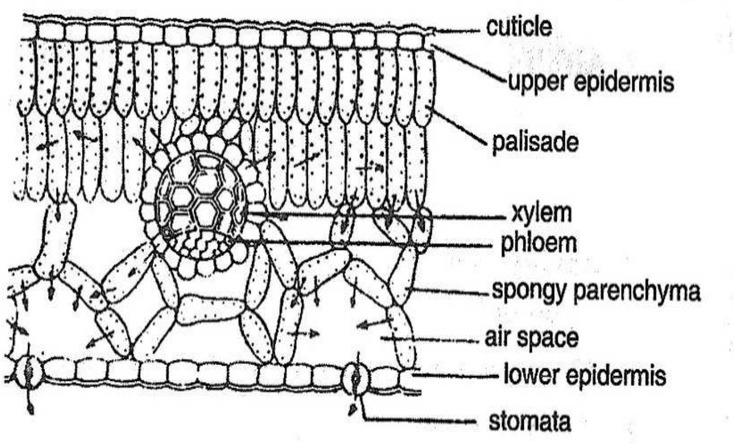


Fig.3.6: V.T.S. of leaf showing the movement of water

Theories regarding mechanism of Stomatal opening and closing

There are two main theories regarding it:

1. **Starch- Sugar inter conversion theory**: According to Lloyd (1908) the turgor change for stomatal movement is brought about by the osmotic effect of conversion of starch to sugar and vice-versa in the guard cells. Amount of starch in guard cell increases during night (closed stomata) and decreases during day (stomata open).

   Effect of pH - According to Sayere (1926) and others, a change in pH affects the opening and closing of stomata. Light increases the H^+ ion concentration and darkness lowers it.

   When the pH is high the enzymatic conversation of starch to sugar is favoured and at low pH, a reverse process of starch synthesis is favoured. This increase in pH is also due to the consumption of CO_2 in photosynthesis.

   Effect of ATP- According to Steward in 1964 that ATP is essential for providing energy for opening and closing stomata.

2. **Active K^+ transport mechanism**: Japanese scientists, S. Imamura and M. Fujino in 1959-1967 put forward active K+ transport mechanism for opening and closing of stomata.

   According to this theory, the accumulation of K^+ in the guard cells as occur in light increases negatively the osmotic potential of the guard cells. This causes opening of stomata. According to this theory, the accumulation of K^+ in the guard cells as occur in light increases negatively the osmotic potential of the guard cells. This causes opening of stomata.

It has been proved that the accumulation of K^+ ions brings the opening of stomata and loss of K^+ ions, the closing of stomata.

During day light
↓
Accumulation of K^+ ions by the guard cells
↓
Increased solute concentration
↓
Decrease water potential
↓
Endosmosis of water
↓
Increased turgidity
↓
Stoma open

In dark, K^+ moves out of the guard cell and their turgidity decrease. This causes stomata closure.

During night / Dark
↓
Loss of K+ ions by the guard cells
↓
Decreased solute concentration
↓
Increased water potential
↓
Exosmosis of water
↓
Decreased turgidity
↓
Stoma closed

When leaf is exposed to light malic acid appears in the guard cells. This malic acid is then dissociated into malate and H^+ ions. The H^+ ions thus produced are then exchanged with K^+ ions enters the guard cells. Then K^+ ions join with malate to from potassium malate. In the presence of potassium malate, water moves inside the guard cells from the adjoining epidermal cells, which results increase of turgor of pressure in the guard cells inducing opening of stomata. During night, the reversal of $H^+ \rightarrow K^+$ pump decreased K^+ ion concentration in the guard cells. This lowers the osmotic pressure of the guard cells inducing closing of stomata through exosmosis.

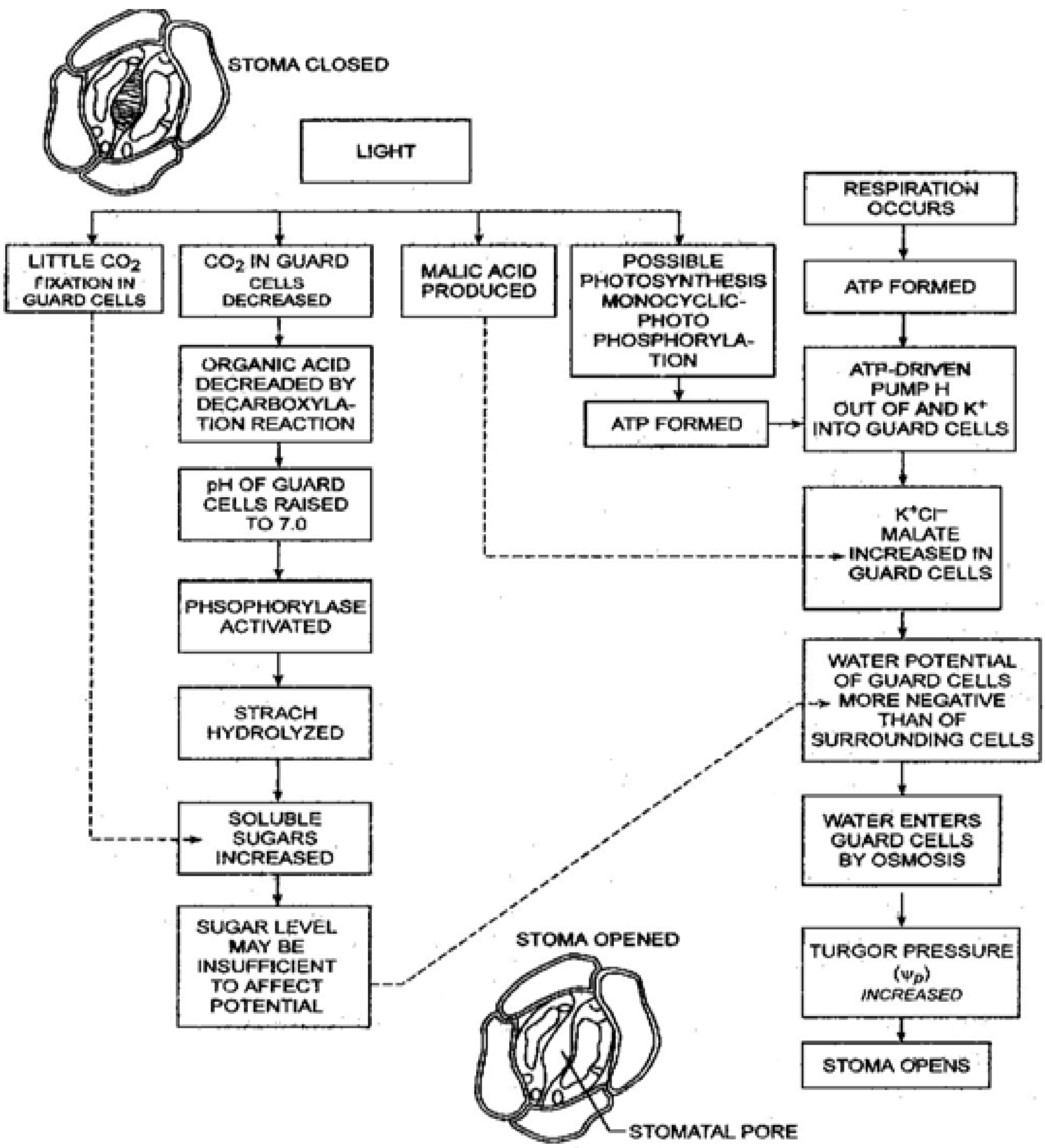


Fig.3.7: Mechanism by which guard cells open and close the stomata

Other theory of Stomatal mechanism

1. **Theory of photosynthesis in guard cells**: Van Mohl (1856) observes that stomata open in light and close in the night. The chloroplast present in the guard cells photosynthesize in the presence of light resulting in the production of carbohydrate due to which osmotic pressure of guard cells increases Endosmosis takes place from subsidiary cell to guard cells. This increases turgor pressure in guard cells and due to this pressure stomata open (Fig. 3.7 and 3.8).

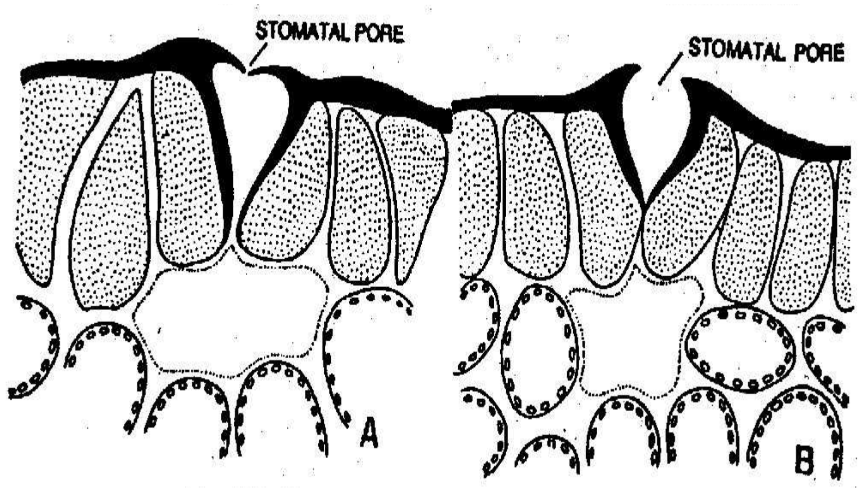


Fig.3.8. A. Closed stomatal pore, B. Opened stomatal pore

2. **Theory of Glycolate metabolism:** Zelitch (1963) proposed that production of glycolic acid in the guard cells is an important factor in stomatal opening. Glycolate is produced under low concentration of CO_2. According to him glycolate gives rise to carbohydrate, thus raising the osmotic pressure and also that it could participate in the production of ATP Which might provide energy required for the opening of stomata.

Role of plant hormones in stomatal movements:

1. Presence of Cytokinin is needed for the active uptake of K^+ ions.
2. Presence of Abscissic acid (ABA), a plant growth inhibiting hormone favours closing of stomata by blocking uptake of K^+ ions by guard cells in the dark. It also prevents efflux of H+ ions from guard cells. ABA and CO_2 conc. together help in lowering the pH in guard cells and making the medium acidic. This helps in closing of stomata. ABA acts as stress hormone during drought conditions.

Factors affecting Stomatal movement:

1. Light greatly influences the opening and closing of stomata. It stimulates production of malic acid due to conversion of starch to sugar. Stomata are not open in UV light and green light but remain open in the blue and red regions of spectrum.
2. Stomata open with rise in temperature and close at lower temperature as light and temperature are directly related.
3. Potassium chloride causes opening of stomata.
4. The increase of organic acid content in the guard cells causes stomata to open.
5. At low concentration of CO_2 the stomata open. With increase in the concentration of CO_2, the stomata begin to close.
6. Water is responsible for causing changes in the turgor pressure.

3.4 TRICHOMES OR HAIRS

Some of epidermal cells of plants grow out in the form of hairs or trichomes. They may be found singly or in groups. Hairs may be unicellular or multicellular and found in various forms. They vary from small protuberances of the epidermal cell to complex branched or stellate multicellular structures (Fig. 3.9). The cells of the hairs may be dead or living. Very soon they (hairs) lose their protoplasm in their cells.

3.4.1 Types of hairs

1. **Stinging hairs:** They are one of the most interesting types of the trichomes. It contains a poisonous liquid and consists of basal bulb like portion from which a stiff, slender and tapering structure is given out. This tapering structure ends in a small knob like sharp point. The tip is usually somewhat oblique, and as the body of an animal or human being comes in its contact with some force, the tip is broken off, and the sharp pointed end readily penetrates the skin of the animal, and fluid is being transferred from the basal knob of the hair to the body of the animal.

2. **Glandular hairs**: Many plants possess glandular hairs. These hairs may secrete oil, resin or mucilage. A typical glandular hair possesses a stalk and an enlarged terminal portion, which may be referred to as gland. The glandular hairs may be uni or multicellular. Active secretory cells of glandular trichomes have dense protoplasts and elaborate various substances, such as volatile oils, resins and mucilages, and gums. These substances are excreted and accumulate between the walls and cuticle. Their final removal from the hair occurs by rupture of the cuticle.

3. **Scale or peltate hair:** A common type of trichome is the scale, also called peltate hair (from the latinpeltatus, target-shaped or shield like, and attached by its lower surface). A scale consists of a discoid plate of cells, often borne on a stalk or attached directly to the foot.

3.4.2 Structure of trichomes

Morphologically, trichome may be classified into different categories. One common type is referred to as **hair**. The hairs may be subdivided into (i) **unicellular**, and (ii) **multicellular types**. The unicellular hairs may be unbranched or branched. Multicellular hairs may be uniseriate or multiseriate. Some multicellular hairs are branched in dendroid (tree-like) manner, others have branches oriented largely in one plane (stellate hairs).

The cell wall of trichomes are commonly of cellulose and covered with a cuticle. They may be lignified. Plant hairs often produce thick secondary walls as, for instance, the cotton seed hairs or the climber hairs of *Humulus.* The walls of trichomes are sometimes impregnated with silica or calcium carbonate. Their contents are varied in relation to function. Cystoliths and other crystals may develop in hairs. Trichome is initiated as a protuberance from an epidermal cell, it elongates and if it develops into a multicellular structure various divisions may follow the initial elongation.

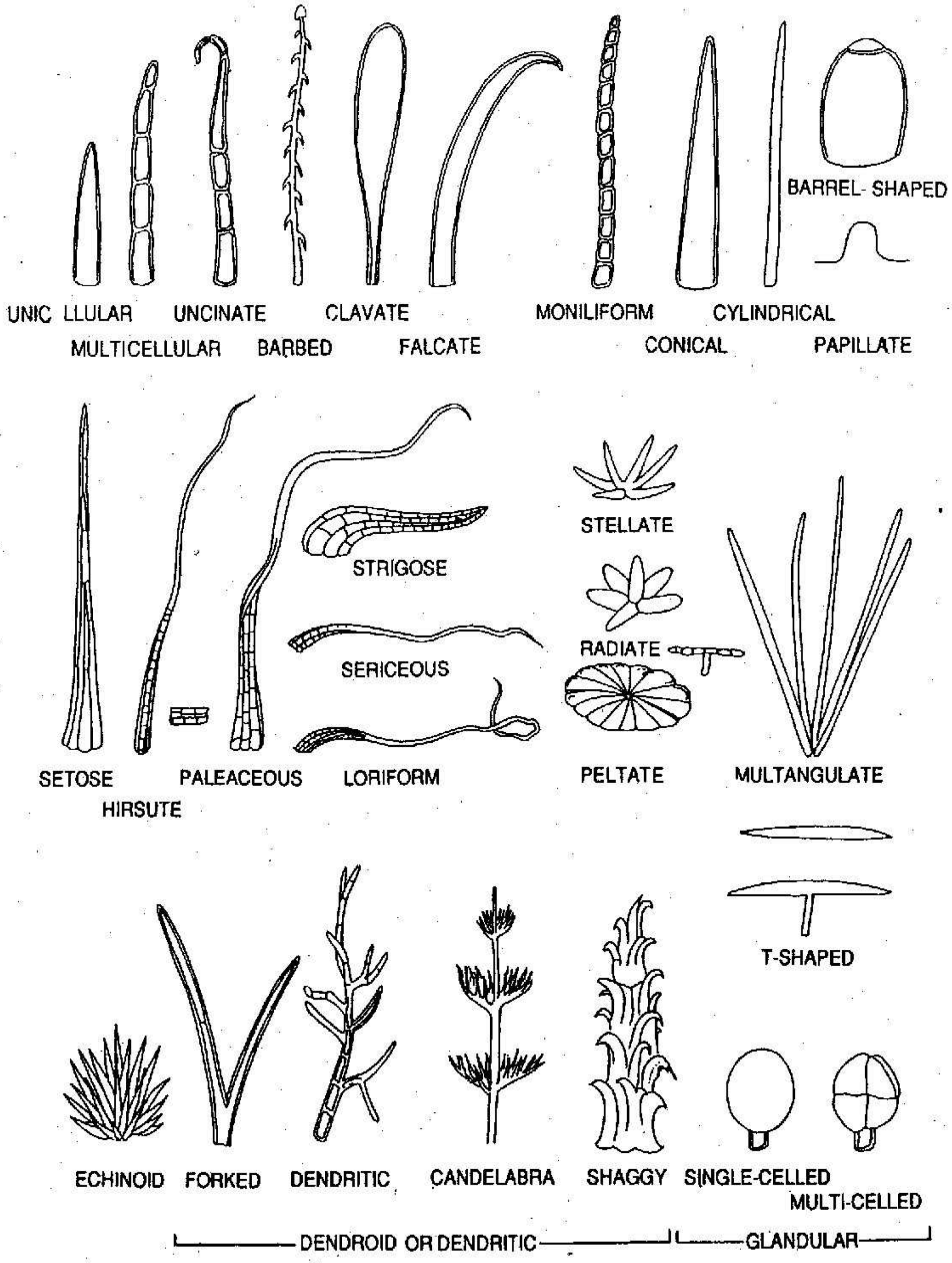


Fig.3.9: Different types of trichomes

3.4.3 Importance / Functions of Trichomes

1. A trichome type have been successfully used in the classification of genera and even of species in certain families and in the recognition of interspecific hybrids.
2. Generally a dense covering of woody trichomes controls the rate of transpiration.
3. They also reduce the heating effect of sunlight.
4. They aid in the protection of plant body from outer injurious agencies.

3.5 SUMMARY

Stomata are widespread in the plant kingdom and are found in great abundance on the epidermal surface of leave. They are microscopic and are bordered by two guard cells, which control the opening and closing of the stomatal pore. Stomata are physiologically of great significance to plants. It is though the stomatal pore that gas exchange takes place, CO_2 and O_2, important in photosynthesis and respiration. A significant amount of water absorbed by plants is lost as vapour through open stomata during the course of stomatal transpiration.

Some of the epidermal cells of most plants, grow out in the form of hairs or trichomes. They may be single or in groups, unicellular or multicellular and occur in various forms. Trichomes control the rate of transpiration, reduce the heating effect of sunlight and give protection to the plant body from outer injurious agencies. They have been used in the classification of genera and some of the species.

3.6 GLOSSARY

Stomata: A pore in the epidermis of a plant.
Trichome: A plant hair
Transpiration: The loss of water vapour from a plant, especially through the stomata.
Dicotyledons: One of the two divisions of the Angiosperms.
Turgor pressure: The hydrostatic pressure setup within a cell by the water present acting against the elasticity of the wall.
Epidermis: The outer single layer of cells on an organ.

3.7 SELF- ASSESSMENT QUESTIONS

3.7.1. Fill the blanks

1. Glycolate hypothesis for opening of stomata was proposed by __________
2. If the atmospheric pressure increased, transpiration __________
3. The opening of stomata is under the control of __________ cells.

4. In mesophytes transpiration takes place mainly through _________
5. Modified epidermal cells encircling guard cells are called _________

3.7.2. True or False

1. In CAM plants stomata open during day.
2. The transpiration rate of a plant is affected by stomatal frequency.
3. The ABA content of guard cells decrease under condition of water stress.
4. The stomata that open at night are called as scoto active.
5. The chloroplasts of guard cells are perfectly nonfunctional.

3.7.3. Give answer in one word

1. Name the monovalent metallic cation involved in opening and closing of stomata.
2. Name the instrument which is used for measuring the humidity of air.
3. If abscissic acid is sprayed on leaves the stomata will _____.
4. Name the process in which water from plants is lost in liquid from ______.
5. Water potential in plant tissues is usually.
6. Which hairs may secrete oil, resin or mucilage.

3.7.1 Answers Key: (a) Zelitch (b) decrease (c) guard (d) stomata (e) subsidiary cells

3.7.2 Answers Key: (a) False (b) True (c) True (d) True (e) False

3.7.3 Answers Key: (a) K^+ (b) Hygrometer (c) close (d) Guttation (e) Negative (f) Glandular

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3.10 TERMINAL QUESTIONS

3.10.1 Short answer type questions

Q.1 Describe the structure of typical stomata.
Q.2 How does it open and close?
Q.3 Explain the phenomenon of foliar transpiration
Q.4 Write note on roles of stomata.
Q.5 Write a short note on the following - (a) Stinging hairs; (b) Glandular hairs

3.10.2 Long answer type questions

Q.1 Discuss the stomata in detail. What are their type and function?
Q.2 Describe in detailed about the mechanism of opening and closing of stomata?
Q.3 Explain the role of light and CO_2 in the mechanism of opening and closing of stomata.
Q.4 Discuss the involvement of K^+ and H^+ in opening and closing of stomata.
Q.5 What is trichome? Give a detailed account on the types of trichome studied by you.

BLOCK-2- SECONDARY GROWTH

UNIT-4: WOOD DEVELOPMENT AND NODAL ANATOMY

Contents:

4.1 OBJECTIVES

The present topic provides an overview of wood development in angiosperms and nodal anatomy of plants. After reading this topic you will learn about:

- Properties and mechanism of wood formation
- Anatomical characteristics of the wood
- Classification of wood
- Nodal anatomy in leaf traces and leaf gaps
- Branch traces and branch gaps
- Phylogeny of nodal anatomy

4.2 INTRODUCTION

Wood is a fibrous and porous mechanical tissue found in the stem and root of trees and other woody plants. It is an organic material - a natural composite of cellulose fibers that are strong in tension and embedded in a matrix of lignin that resists compression**.** The secondary xylem formed as a result of activity of the cambium and known as wood. Technically, it is secondary xylem and universally developed in all the gymnosperms and angiospermic plants. The consistent formation of secondary xylem is responsible for the increment in diameter or girth of tree trunk. The main function of the wood in the tree is conduction of water and giving mechanical strength. Wood is available in various colours, patterns, structures and odors. It is strong in relation to its weight, insulator of heat and electricity and has desirable acoustic properties.

Wood is produced by approximately 25,000 to 30,000 plants, including the herbaceous species. Although a less count (estimated 3,000 to 4,000 species) is suitable for commercial purpose. Wood is a material of cosmopolitan in their distribution, great economic importance and can be sustainably managed as a renewable resource in contrast to petroleum ores and coal. Wood has been used science thousands of years back as fuel substance, as a structural material, for making apparatuses and armaments, paper and furniture. As a material, wood has been in service since humans appeared on earth. Recently it emerged as a feedstock for the production of purified cellulose and its derivatives, such as cellophane and cellulose acetate. Despite of the advancement of technology and strong competition from synthetic and advanced materials, wood still uphold their place and its roles and its serviceability is growing through new uses. Furthermore, to its well-known byproducts such as lumber, plywood and furniture, it is also utilized as a raw material for wood-based panels, pulp and paper industries and many other chemical products. By means of its harvesting in forests, transportation, processing and its trade and use, wood provides jobs and supports economic development. Revealing of this importance is the continued high demand for wood and wood products.

4.3 PROPERTIES OF WOOD

The various properties of wood determine its functions qualities and suitability for diverse purpose. By virtue of its mechanical properties, wood is able to resist the different external forces which tend to effect its shape and size and produce deformations.

4.3.1 Surface characteristics

Some important surface properties which give the key identification features of the wood are given:

(i). **Colour and figure:** The colour and figure of wood determines the aesthetic value and are differ in different woods. For example the colour of sap wood is distinct which may be yellow, grey, red and pink. The colour of the heart wood is also variable. It may be rose red (red ceder), purple (black walnut), black (citrus), golden yellow (red mulberry) and wine red (mahogany) in colour.

(ii). **Odor:** Odor is also a peculiar characteristic feature of some trees. Odor depends upon volatile compounds present in the wood. The characteristics odour is due to deposition of infiltration products in the heart wood. Some wood with distinct odour are red cedar, white cedar, fir, sandal wood, cypress etc.

(iii). **Luster:** Luster of wood depends upon the ability to reflect the light. For example quarter sawn timber or lumber reflects more light than flat sawn timber. Woods with less infiltration substance are more lustrous. Among soft woods bald cypress and red cedar are the most lustrous woods. Among hard woods white ash and sweet gum are the most lustrous woods.

4.3.2 Physical properties

(i). The important physical properties which impart internal resistance force in the wood are-
Strength: Strength of the wood determines the economic importance of the wood. The wood strengths is influenced by the direction of the grain and various external and internal forces. Several types of strength are recognized. They are crushing strength, tensile strength, shearing strength, bending strength etc.

The crushing strength is the measure of its ability to resist a load that tends to crush the wood. Wood with good crushing or compressing strengths is generally used in the form of column are posts to give support to house, garage etc. Tensile strength is the measure of its resistance to forces that tend to pull the wood apart. Shearing strength is the measure of resistance offered to opposite force which tends to tear it apart. Bending force is the measure of resistance to forces that cause the beam of break.

(ii). Stiffness: Stiffness is the measure of a wood's ability to resist forces that tend to change its shape.

(iii). Toughness: Toughness is the measure of the capacity of the wood to withstand repeated, sudden, sharp blows or shock. A tough wood will not split on ear easily. Woods of red ceder, beech etc are shock resistance. The toughness of the wood depends mainly upon the amount of wood and composition of cell walls.

(iv). Hardness: Hardness is the ability of wood to resist indentation, abrasion and wear. The woods of oak and black locust are hard. The harness is influenced by number and arrangement of wood fiber, presence of knots and decayed areas.

(v). Cleavability: Cleavability refers to the comfort with which the wood can be split into two. Woods with high cleavability are suitable for conversion into fire wood.

4.3.3 Other properties

(i). Moisture content: Wood is hygroscopic in nature. The moisture content of fresh timber varies from 30% to 200%. In soft wood, sap wood is more moisture than heart wood. In hard wood no such differenced is occurred. The soft wood from conifers contains high moisture. The hard wood from willow, poplars, elm and butter nut contains high moisture. The wood water occurs in two forms.

They are hygroscopic water and free water. The free water is present in cell cavities. It evaporates when wood is exposed to drying. It has very little influence on the properties of wood. Hygroscopic water is present in the cell walls. The loss of this water results in the shrinkage of the cell walls. The cell walls undergo contraction. As a result, the cells become more compact. The fiber becomes stiffer and stronger.

(ii). Density: It refers to the actual amount of cell wall material per unit volume. The amount of infiltration products is also taken into accounting determining the density of the wood. It is expressed in terms of specific gravity. It is the ratio of the weight of a piece of wood of the weight of equal volume of water. For example the wood density of Teak (a hardwood) is considered approximately 41-61 lb/ft^3 while another hardwood named Balsa have only 7-9 lb/ft^3.

(iii). Durability: It is refers to the ability of the wood to resist the attack of wood decaying organisms. Wood of red ceder, cypress, red wood, black walnut etc is the good example of wood durability. Wood of willow, cotton wood are susceptible to decomposition.

(iv). Thermal properties: Wood is poor conductor of heat, electricity and sound. Dry wood is the poorest conductor of the heat. Dry wood is completely resistance the passes of electricity current. The moisture content present in the wood makes it partial conductor of electricity.

4.4 MECHANISM OF WOOD FORMATION

The growth of the tree is the result of production of new cells by tissues termed meristems. Meristems consist of cells that are undifferentiated and retain the ability to divide and produce new cells. The increase in the height of tree stem is designated as primary growth and is the result of cell production by apical meristems located at the tip of the stem. Just below the apical meristems, some of the cells form a lateral meristem called the cambium. Secondary growth (to diameter), begins with formation of the cambium. Longitudinal cells of wood are produced by cambial cells designed as fusiform initials and transverse by ray initials. Cambium initials divide periclinally, namely with walls parallel to the cambium layer, and produce xylem and phloem mother cells. The phases of development of wood cells are: cell division, cell enlargement, cell wall thickening, lignification and death.

The first phase, cell division, occurs when a cambial initial divides, forming two cells. The outermost cell remains meristematic and the innermost cell develops into a mature wood cell. During the enlargement phase, the cell grows in length and diameter. Softwood cells increases only in radial direction. During the enlargement phase, a very thin and plastic cell wall (primary wall) encases the protoplasm. During next phase, wall thickness is increased by the addition of secondary wall. Lignification involves the formation of lignin between the newly formed cells and within their cell walls. For most wood cells, death occurs immediately after lignification. However, for those wood cells that perform the function of storage, this step is postponed for an indefinite period. Cells performing the support and conduction roles usually pass through the five phases of cell development in 14 to 21 days.

4.5 ANATOMICAL CHARACTERISTICS OF WOOD

In woody angiosperms and gymnosperms cambium continuous to produced inwardly secondary xylem and outwardly secondary phloem year after year, so that the stem increases progressively in thickness. However, the amount of secondary xylem produced far exceeds that of the secondary phloem. Moreover, it persists and eventually forms the great bulk of plant body while the secoundry phloem is pushed farther out and is gradually crushed and sloughed off the tree. In some long-lived trees (*Sequoiadendron giganteum*, *Pinus aristata* etc) secondary growth has been occurring for several thousand years.

If there were to be no secondary growth, lumber would not exist. The secondary xylem of the dicotyledonous plant is considerably more complex, consisting of cell types such as vessel, tracheids, fibers, xylem parenchyma and rays of different sizes. The first three components run longitudinally, the rays run horizontally, and xylem parenchyma may occur either as an occasional longitudinal cell or as the chief or exclusive component of the rays. Tracheids perform both the functions of support and conduction, vessels are mainly conductive tissue, fibres are chiefly supportive tissue, ray cells are for horizontal transmission and xylem parenchymas is for storage and to a limited extend for conduction. It is estimated that 90% of the wood is made of tracheids, and the remainder is composed of ray parenchyma and longitudinal parenchyma cells, as well as resin ducts in certain species.

The vessels when viewed in transverse section appear as holes or pores which gives the wood a designation termed porous. The distribution of the pores within the growth rings is a characteristics feature of woods. In many woods (*Acer, Populus, Betula*etc) the vessels are more or less uniform in size or diameter and are distributed randomly throughout the growth rings. Such woods are describes as being diffuse porous. In others the vessels of early wood are distinctly large than those produced in the late wood or they may be restricted to the early wood. Such a condition illustrates ring porous vessel distribution examples are *Fraxinus, Quercus, Robinia* etc.

Rays and parenchyma occupy a higher proportion of wood volume in angiosperms. Rays are usually multiseriate. Many dicotledonous wood contain gum ducts, but lack the resin canals so characteristic of gymnosperms.

The structure of gymnospermic wood on the other hand is much simpler and homogenous than that of angiosperms consisting almost entirely to tracheids with bordered pits. A significant feature of the wood is the absence of vessels (except Gnetales) and the relatively small amount of wood parenchyma, the latter forming an epithelial lining around the resin ducts which may eventually become blocked by enlarging epithelial cells (a tyloses like intrusion called tylosoiders). Rays are thin (for the most part uniseriate) with one row of cells, becoming multiseriate wherever there is intrusion by the resin canal. Another conspicuous feature of gymnosperm is the hardness of wood. In the lumber trade gymnosperm wood is designated as softwood.

4.6 CLASSIFICATION OF WOOD

According to the seasons, location and type of plants the wood can be categorized in different category.

4.8.1 Classification based on seasons

i. **Spring wood**
ii. **Autumn wood**

The cambium becomes more active during the spring season and forms plenty xylems vessels with wider cavities called spring wood or early wood. Its development takes place during the favorable season. This wood presents at the beginning of the annual ring and comprises major part of it. It contains larger and wider elements while tracheiary elements are less thickened in this wood. Spring wood is characterized by fewer xylem fibers, lower density and lighter in colour.

The activity of cambium slows down during the winter season which gives rise to narrow xylem elements known as autumn wood or latewood. The autumn wood is produced in unfavorable season. It is present at the end of the annual ring and makes only a thin strip in the annual ring. The autumn wood also contains cavities of xylem vessel but is narrow. It has abundant of xylem fibers and tracheiary elements are comparatively more thickened. Autumn wood is characterized by higher wood density and darker in appearance.

One spring wood ring and one autumn wood ring collectively formed an annual ring or growth ring. By counting the number of annual rings in the cut stem, the age of the tree and be calculated (Fig. 4.1).

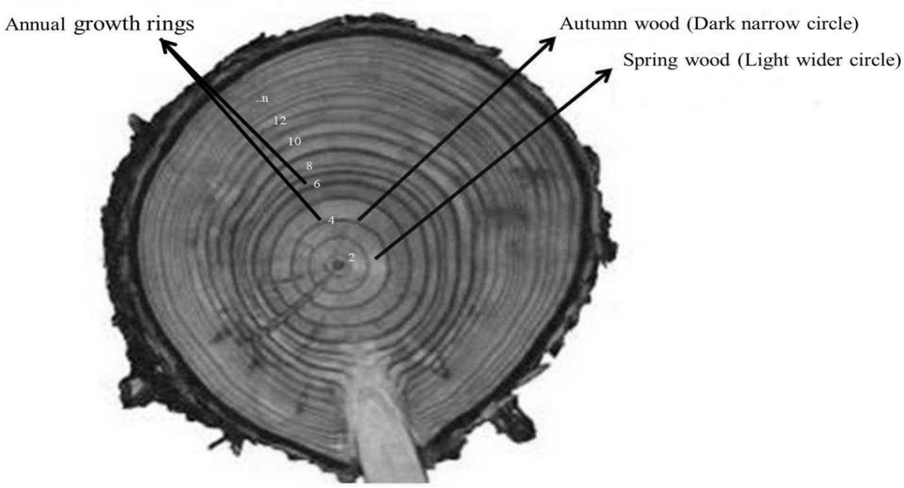

Fig. 4.1: The section of the tree trunk showing the autumn and spring wood. The numerical digits (2,4,6…n) represents the number of annual growth ring.

Growth ring/ Annual ring

The concentric circles appear in the cross sections of woody stems by the actively of cambium. These rings are refers as growth rings. The climate exerts the noticeable effects on growth rings. In climates with well-marked alternations of seasons, when water is easily available and growth is rapid (spring or wet season) the cambium produced large and thin wall xylem. On the other hand, during the unfavorable season (winter season) when the supply of water has diminished and the growth is comparatively restricted, small and thick walled cell produced. Therefore, a sharp contrast rings between the large and thin-walled cells of the spring wood followed by small and thick-walled late-season wood cells produced during the same year collectively formed an annual ring (Fig. 4.1).

Annual ring (1 year) = one large and thin wall xylem ring + one small and thick wall xylem ring

In tropical forests, where climate is consistent and growth take place throughout the year. There is usually little or no gross visible contrast appear between the annual rings, however differences exist. When rings are noticeable, they may be counted in order to obtain a reasonably accurate approximation of the age of the tree. They are also reflective (by their range of thickness) of the climatic and environmental factors that influence growth rates. The science of dendrochronology is based upon the phenomenon of variability in the thickness of annual rings. Dendroclimatology is the science of determining past climates from trees primarily from the properties of the annual tree rings (Sheppard, 2010). Using tree rings, scientists have estimated many local climates for hundreds to thousands of years previous.

Significance of growth rings

In climate

The branch of science which deals with the climatic condition of the past by using wood annual ring during different periods of time is called dendroclimatology. It is a scientific tool for synthesizing the data related to past events and its timing and also useful to determine the rate of changes in the environment (climatic) during the past years. For example adequate moisture and a long growing season result in a wide ring, while a drought year may result in a very narrow one.

In archaeology

Annual rings are also helpful in dating of ancient wooden structures. The dating of buildings with wooden structures and components is also done by dendrochronology. The dendroarchaeology is the term for the application of dendrochronology in archaeology. The dating of building via dendrochronology thus requires knowledge of the history of building technology (Sawyer and Sawyer 1993). For example: The Post Track and Sweet Track, boardwalks or timber track ways, in the Somerset levels, England, have been dated to 3838 BC and 3807 BC, respectively (Brunning, 2001). This technique is also helpful to estimate the precise age of samples, especially for those which are too recent for radiocarbon dating.

In art history

Dendrochronology plays an important role in dating of panel paintings in art historians. Besides the dating, it can provide information as to the source of the panel as well. Oak panels considered in a number of northern countries such as England, France, Germany etc. For example: A portrait of Mary, Queen of Scots in the National Portrait Gallery, London was believed to be an eighteenth century copy. However, dendrochronology revealed that the wood dated from the second half of the sixteenth century. It is now regarded as an original sixteenth-century painting by an unknown artist. (National Portrait gallery Archived, 2013).

The dendrochronology has become an important tool for dating oak panels, however not effective in dating the poplar panels because of the erratic growth rings in poplar. After 16^{th} century this technique is less often applicable because a gradual replacement of wooden panels by canvas limits its application in paintings (The Getty Conservation Institute, 2013).

4.8.2 Classification based on location

- **i. Sapwood**
- **ii. Heartwood**

Sapwood or alburnum is considered as the outermost, physiologically active, newly formed xylem elements of the woody stem or branch. This is a light coloured region of the wood having living cell associated with vessels and fibres. This part of stem actively engaged in the transportation of water and dissolved minerals between roots and the canopy of the tree and storage of food etc.

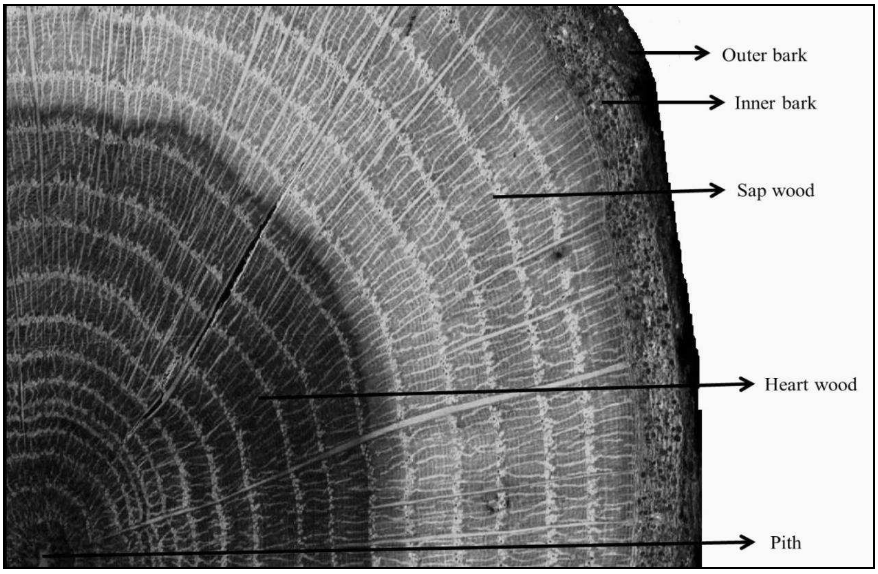

Fig.4.2: Showing the heartwood and softwood in a cross section of an old tree trunk. The lighter region considered as the sapwood and darker region as heart wood.

The middle portion of the old trees trunk which was developed earlier and contains resins, gum, tannins and other organic substances which make wood firm and durable is called heartwood or duramen (Fig. 4.2). It is the dead, inner and physiologically inactive portion however it gives mechanical support to the stem. It appear usually darker in colour due to the deposition of various chemical sustains in it. The vessels remain plugged with **tyloses**. The walls of the xylem vessels produce some balloon like outgrowths into the lumen of the vessels, are called tyloses. Usually tyloses formed in secoundry xylem but some time they can formed in the primary xylem also. Tyloses are formed by the enlargement of the pit membranes of the half-bordered pits present in between a parenchyma cell and a vessel or tracheids (Fig.4.3). The nucleus of the xylem parenchyma cells along with cytoplasm passes into this balloon like outgrowth. The wall of tyloses may remain thin and membranous or very rarely it becomes thick and even lignified. In fully developed tyloses, starch crystal, resin gums and other substances are present, but they are not found very frequently. The number of tyloses varied between few in number in a single cell or many. Tyloses undergo division in some plants and form multicellular tissue, which compactly fills the lumen as in *Robinia* and *Maclura*. Tyloses are characterstic feature of certain species, and always absent in other. In many plants the development of the tyloses takes place by means of wounding.

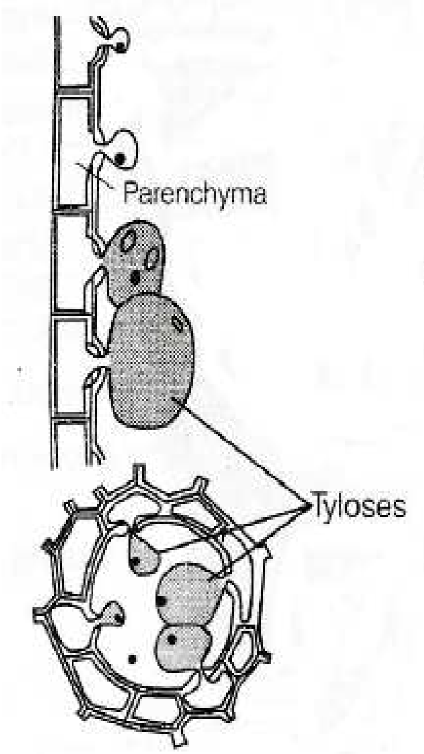

Fig. 4.3: The figure showing the balloon shaped structure called tyloses in the wood xylem tissue

In young stem of trees or young parts of the older trees, all of the wood is sapwood which gradually converted into heart wood. During this transformation, a number of changes take place. As the tree trunk became older it increases in diameter. No longer is needed for conducting sap however need for structural support. This causes noteworthy changes in the anatomy of the stem. The cells nearest the center of the trunk get aged and die which ultimately metamorphosed as heartwood. Those cells stop to transport water or store food reserves. The residues of the once living cells and additional chemical compounds (organic sustains, gum, resins, phenols, terpenes etc) deposited in the heartwood. These deposited chemical compounds not only help make heartwood more resistant to attack by insects and decay organisms but also tend to give this inner portion of the stem a distinctive darker color.

The proportion of heartwood is comparatively higher than the sapwood exceptionally in young trees or the youngest portions and branches of older trees. The percentage of heartwood to sapwood in the main stem does vary with species. For example, some trees do not have clearly differentiated heartwood (*Populus*, *Salix*, *Picea*, *Abies*etc), other possess thin sapwood (*Robinia*, *Morus*, *Taxus*), the still other possess a thick sapwood (*Acer*, *Fraxinus*, *Fagus*). In general, more vigorously growing trees tend to have wider bands of sapwood.

For the economic point of view, heartwood is more useful than sapwood. Heartwood is used as timber due its durability than the sapwood because the less of food material is available for pathogens by the absence of protoplasm and starch. The formation of resins, oils and tannis and blocking of the vessels by tyloses and gums, render the wood less susceptible to attack by the organism of decay. A natural dye haemotoxylin is obtained from the heartwood of *Haematoxylon campechianum*. Due to the absence of resin, gum and colouring substance sapwood is preferred for pulpwood and for wood to be impregnated with preservatives.

The sapwood contains the sap-conducting cells of the tree, it tends to have a relatively high moisture content. This is good for the living tree but it is not so good for the woodworker, because sapwood tends to shrink and move considerably when dried, and it is much more susceptible to decay and staining by fungi.

4.8.3 Classification based on type of plant

- **i. Hard wood**
- **ii. Soft wood**

In general, hardwood comes from a deciduous tree which loses its leaves annually. Hardwoods have a tendency of slow growth, therefore usually more dense in texture. It belongs to angiospermic (not monocots) group of plant. For example sal, Mahogany, oak, maple eucalypts, poplar, cherry, beech, blackwood etc. Hardwood has a number of vessel elements which support to transport water throughout the wood (Fig. 4.4a).

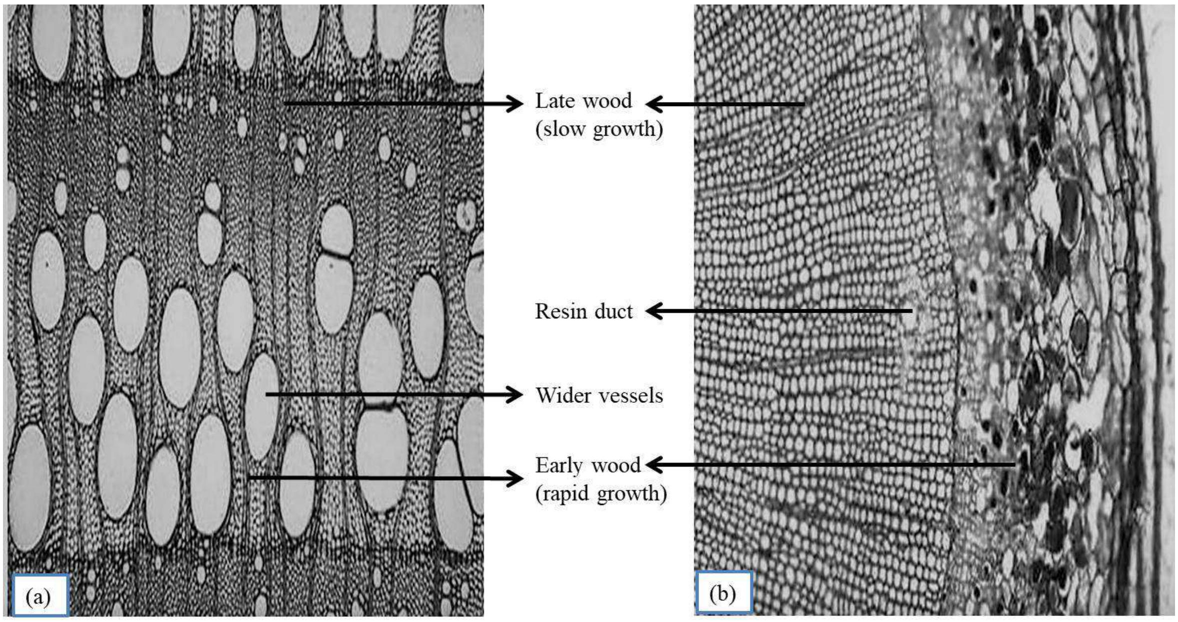

Fig. 4.4: The cross section of wood showing (a) hard wood: belongs to angiospermic group of plant having wider vessels elements and (b) soft wood: belongs to gymnosperm group of plant having not visible pores due to tracheids

Under the microscopic examine, vessel elements of the wood appear like as pores. Hardwood has narrow range of application due to its high price and slow growth rate of the tree. It is more likely to be used as quality wood products such as furniture, decks, flooring, and construction that need to last. The fire resistance rate of the wood is comparatively high.

The softwood comes from an evergreen tree and belongs to gymnosperm group. Generally it considered softer than the hardwood. For examples Deodar, pine, redwood, douglas-fir, cypresses, redwood, larch etc. In this wood medullary rays and tracheids transport water and produce sap. It has no visible pores due to tracheids while examine under the microscope (Fig.4.4b). Tracheids constitute about 90-95% of the total wood. Most of the timber products (near about 80%) come under softwood. It has a wide range of applications due to its lower cost and fast growth rate as compare to hardwood. It is basically used in building components (e.g., windows, doors), furniture, medium-density fiberboard (MDF), paper, Christmas trees etc. The fire resistance rate of the wood is poor therefore catch the fire easily.

Hardwood is not necessarily a harder material (more dense) and softwood is not necessarily a softer material (less dense). For example wood of Yew tree is considered as softwood that is relatively hard while the wood of Balsa trees, considered as a hardwood that is softer than softwoods. Both the hardwood and softwood are used as timber purpose as structural to decorative function.

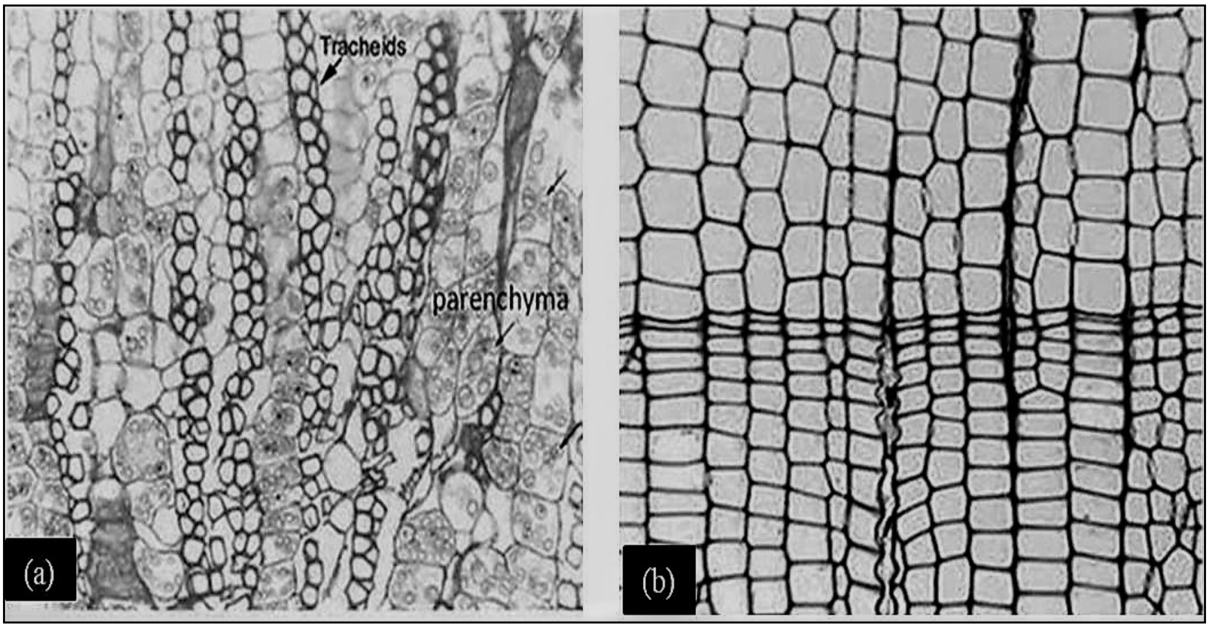

Fig. 4.5: (a) Manoxylic wood and (b)Pycnoxylic wood of the gymnospermic plant

Softwood or gymnospermic wood can be divided into two types on the basis of the xylem cells present inside them, they are classified as;

(a). Pycnoxylic wood
(b). Manoxylic wood

The gymnospermic wood having less number of xylem cells called manoxylic wood. It has non-compacted wood with large amount of parenchyma, pith cells and cortex mixed with less amount of xylem tracheid (Fig.4.5a). In this wood, the parenchyma cells are filled with the starch grain. This wood is commercially unimportant because of the quality of wood is not durable. For example: *Cycas* wood.Pycoxylic wood has large number of xylem cells in it. The cells are compacted with large amount of xylem tracheid and small amount of cortex and pith with the small amount of parenchyma (Fig.4.5b). This wood is commercially important because of the wood is comparatively more durable. For example: *Pinus* wood.

4.7 PERIDERM

In older roots and stems due to the continuous formation of secoundry tissue the epidermis gets stretched and ultimately tends to rupture and followed by the death of epidermal cells and outer tissues, and a new protective layer is developed called periderm. Structurally it consists of three parts (Fig. 4.6):

1. A meristem known as phellogenor cork cambium.
2. The layer of cells cut off by phellogenon the outer side, the phellem or cork.
3. The cells cut off by phellogen towards inner side, the phelloderm.

1. Phellogen

In contrast to the vascular cambium, the phellogen is relatively simple in structure and composed of one type of cells. The cells of phellogen appear rectangular in cross section and somewhat flattened radially. Their protoplasts are vacuolated and may contain tannins and chloroplasts.

At the time of beginning of the development of a phellogen in epidermal cells, the protoplast loses their central vacuoles and the cytoplasm increases in amount and becomes more richly granular. As soon as this initial layer develops, it divides tangentially and to a lesser extent radially, in the similar way as division takes place in true cambium. The derivative cells are normally arranged in radial rows.

Generally, several to many times as many cells are cut off toward the outside (phellem-cork cell) as toward the inside (phelloderm). Phelloderm cells are few or absent; rarely phelloderm is grater in amount than phellem.

2. Phellem (cork cells)

The cells that constitute phellem are commonly known as cork cells. They are like the phellogen cells from which they are derived. As seen in tangential section, they are polygonal and uniform in shape and often radially thin as seen in cross section of the stem. The cells of the commercial cork (*Quercus suber*) are radially elongated.

3. Phelloderm

A tissue produced inwardly by the cork cambium. The layer of tissue, often very thin, produced on the inside of the cork cambium in woody plants. It forms the secondary cortex.

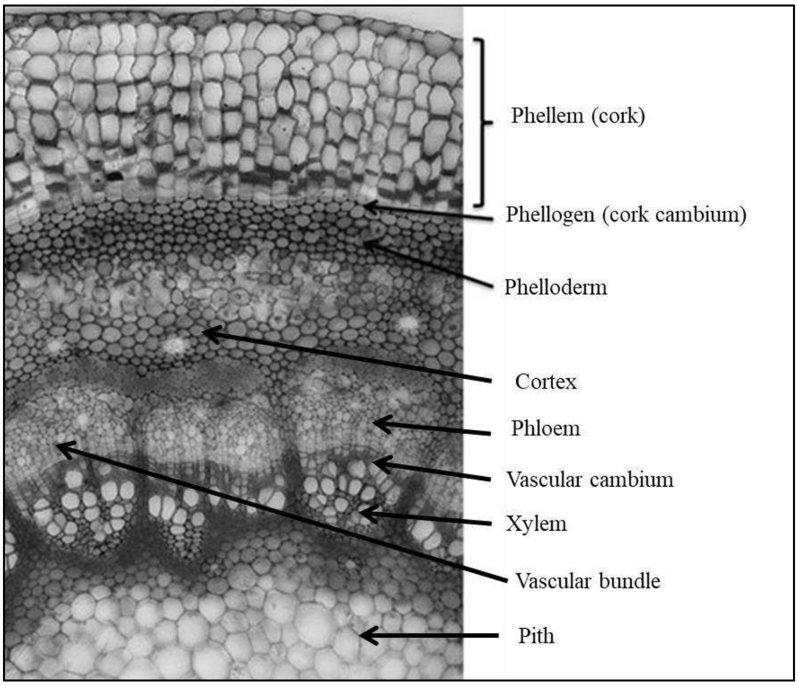

Fig. 4.6: Structural diagram of periderm. The periderm is consist of three part i.e., phellem, phellogen and phelloderm

4.8 NODAL ANATOMY

The nodal anatomy considered as one of the most significant aspect of angiosperm systematic and comparative morphology of the stem, leaf and flower. The plant shoot contains nodes and internodes which are significantly differed in their structure. This anatomical difference occurred due to the presence of vascular supply to the leaves and branches from the main vascular cylinder of the stem. The degree of differentiation between nodes and internodes influenced by the relative development of leaves attachment to the nodes. In the higher plants, each leaf which originates from the node contains vascular tissue of the leaves and connected to the stem.

Leaf trace

A vascular strand that extends between the vascular cylinder of stem and the leaf is called leaf trace or foliar trace. The number of leaf trace is independent to the shape, size, type and development of the leaf. The number of traces supplying in a leaf may vary one to many and they are constant to each family or even in a large group. In pteridophytes, usually one leaf trace is occurred while in gymnosperms the number of leaf trance may vary one to two. In angiosperms, one, three, five or many leave traces may be present however one and three are the most common phenomena. Three leaf trace perhaps the primitive number where the one is either the fusion of the original three in evolutionary development process or the reduction of the three to one by the loss of the lateral vascular bundles. Three leaf traces are the characteristic feature of families included Rosaceae, Aceraceae, Asteraceae etc while Lauraceae, Ericaceae and Lamiaceae etc possess only one leaf trace.

The leaf trace comprised both xylem and phloem elements however, the relative proportion of xylem will be more than the phloem. The proximal section (near the vascular cylinder of the stem) contain only the xylem whereas, the distil end of the leaf trace (adjacent the leaf base) contain both the elements. In the process of photosynthesis, translocation of water from the xylem to leaf lamina and prepared photosynthetic products from leaf lamina to stem is also facilitated by the leaf traces.

Leaf gap

The leaf trace considered as the extension of the vascular cylinder to the leaf even though they are not a continuous supply from the main vascular cylinder. In the vascular cylinder a minute parenchymatous patch arise just over the region of the leaf trace. This parenchymatous zone between the leaf trace and the main vascular cylinder is called leaf gap or Lacuna (Fig.4.7). The leaf gap situated just above the leaf trace. The cortical parenchyma turns out to be persistent with pith due to the existence of leaf gap during the early stage of secondary growth. Leaf gap is constant in appearance in Pteropsida and absent in Lycopsida.

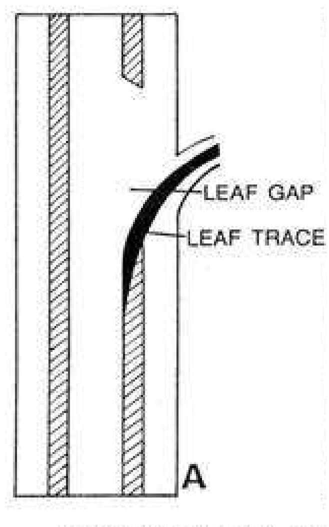

Fig. 4.7: L.S. of node through leaf trace and gap

4.9 CLASSIFICATION

The nodes can be classified according to the number of leaf gap or number of leaf traces and leaf gaps in plants.

4.9.1 *Nodal classification based on the number of leaf gaps*

Depending upon the number of leaf gaps left stele by departure of traces, nodes described as Unilacunar, Trilacunar, Pentalacunar and multilacunar. Nodal pattern often expressed in terms of number of traces and gaps for example:

Unilacunar node with a single leaf trace described as 1:1
Unilacunar node with two diverging leaf traces described as 2:1
Unilacunar node with three diverging leaf traces described as 3:1

Trilacunarnode with three leaf traces described as 3:3. Here, the first digit denotes the number of traces and the second digit is number of leaf gaps.

Unilacunar node with two leaf traces is common in Ginkophytes and other Gymnosperms and some angiosperms. Multilacunar nodes are relatively uncommon in dicotlydenous family but are present in some primitive order (Ranales) or some advanced family (Lamiales). Unilacunarnodes scattered in various groups but can distinguish an entire family that is Theaceae.

4.9.2 *Nodal classification based on the number of leaf traces and leaf gaps*

The number and arrangements of leaf trace and leaf gap varied in between different families or even different plant species. Basically four main types of nodes (Fig.4.8) recognized in dicotyledons. i.e.,

1. **Unilacunar single trace node:** The node possesses a single leaf gap and a single trace to a leaf. Ex. *Spiraea*. Unilacunar nodes are exstipulate. Unilacunar node is common in Centrospermae and in certain members of Lauraceae (*Laurus*), Myrtaceae (*Eucalyptus*) etc.

2. **Unilacunar two trace node:** The node exhibits two leaf traces associated with single leaf gap in a leaf. Ex. *Clerodendron*.

3. **Trilacunar node:** This type of node contains three leaf traces (one median and two laterals) and three leaf gaps in a leaf. Each trace is associated with single leaf gap. Ex. *Salix*, *Azadirachtaindica*. Among the three traces, the median trace is larger in size while remaining two lateral traces comparatively smaller in size. This type of node has stipules. Asteraceae (*Chrysanthemum*), Salicaceae (*Salix*), Brassicaceae (*Brassica*) etc showed the trilacunar node.

4. **Multilacunar node:** The node which contains more than three leaf traces and leaf gaps in a single leaf considered as multilacunar node. Each trace is meeting with single leaf gap.

Generally the sheathing leaf bases plants contain multilacunar node. Ex. Polygonaceae (*Rumex*) etc.

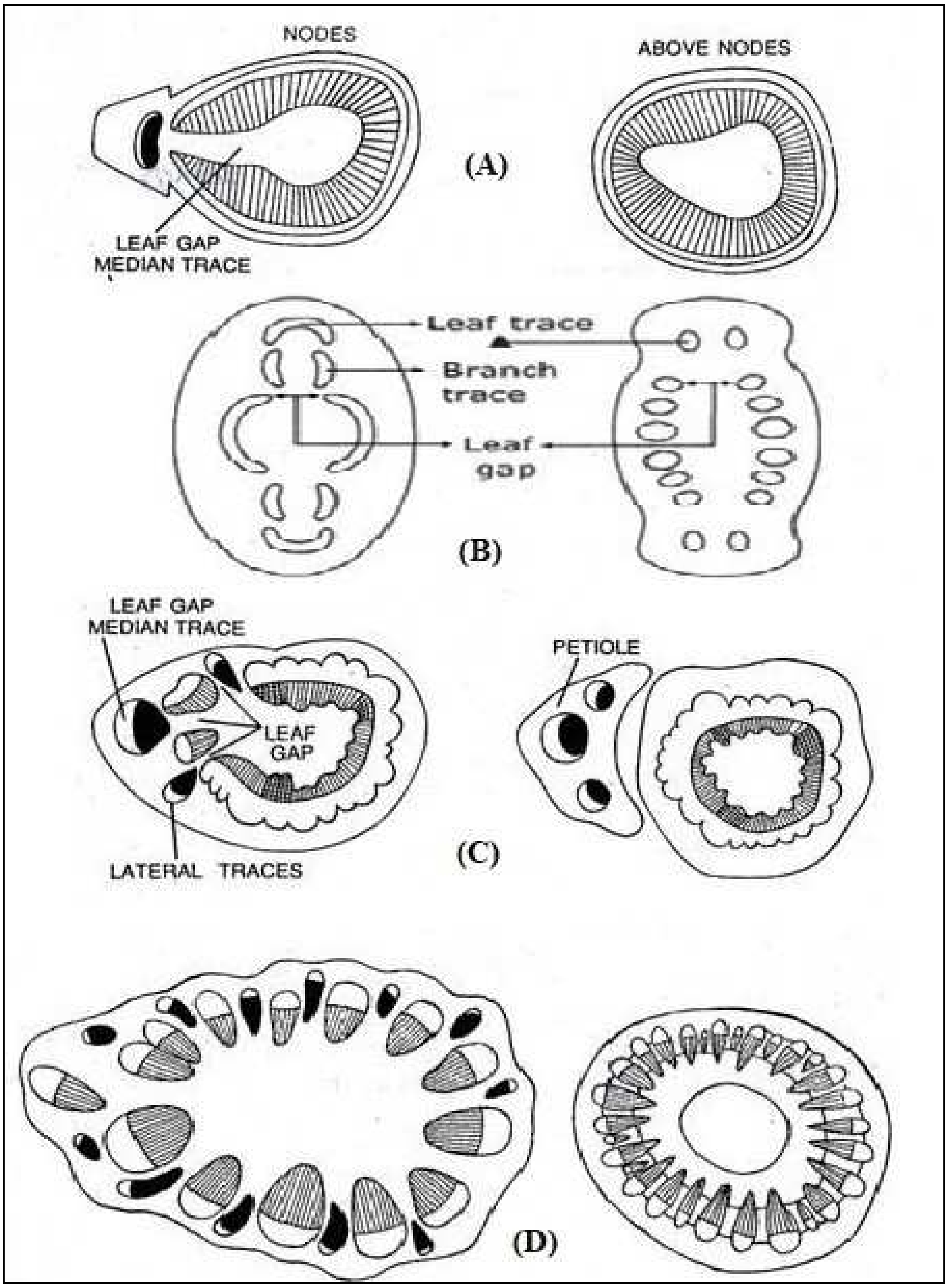

Fig.4.8: Nodal anatomy of dicotyledons (A) Spiraea (Unilacunar node): each leaf has one leaf trace and one leaf gap; (B)Clerodendron (Unilacunar two-trace node): two leaf trace with single leaf gap;(C) Salix (Trilacunar node): each leaf has three leaf traces and three leaf gaps; (D) Rumex (Multilacunar node): many leaf traces and many leaf gaps per leaf

4.10 NODAL ANATOMY OF MONOCOT STEM

In the wheat stem (monocot stem) the course of the vascular bundles through the internode and the leaf sheath is almost parallel. Near the node the leaf sheath is considerably thick and attains its maximum thickness just above its union with the stem. On the other hand, the stem has the smallest diameter above the junction with the leaf sheath. The stem is hollow in the internode and solid at the node. The sheath remains open on one side at higher levels, just near the node. Massive collenchymatous bundle caps are present in the bundles of leaf sheath. Just beneath the junction of the leaf sheath and stem the smaller of the leaf traces are prolonged in the peripheral part of the axis, and the larger leaf traces become part of the inner cylinder of strands. The inter-nodal bundles located above the leaf insertion assume, just above the node a horizontal and oblique course (Fig.4.9 C, D) and are reoriented toward a more peripheral position in the node and below it (Fig.4.9 D, E). These horizontal and oblique bundles variously branch and coalesce, and their number reduces. The large leaf traces and the bundles from the internode above the insertion of the leaf make the inner cylinder of the bundles of the next lower internode (Fig.4.9 E).

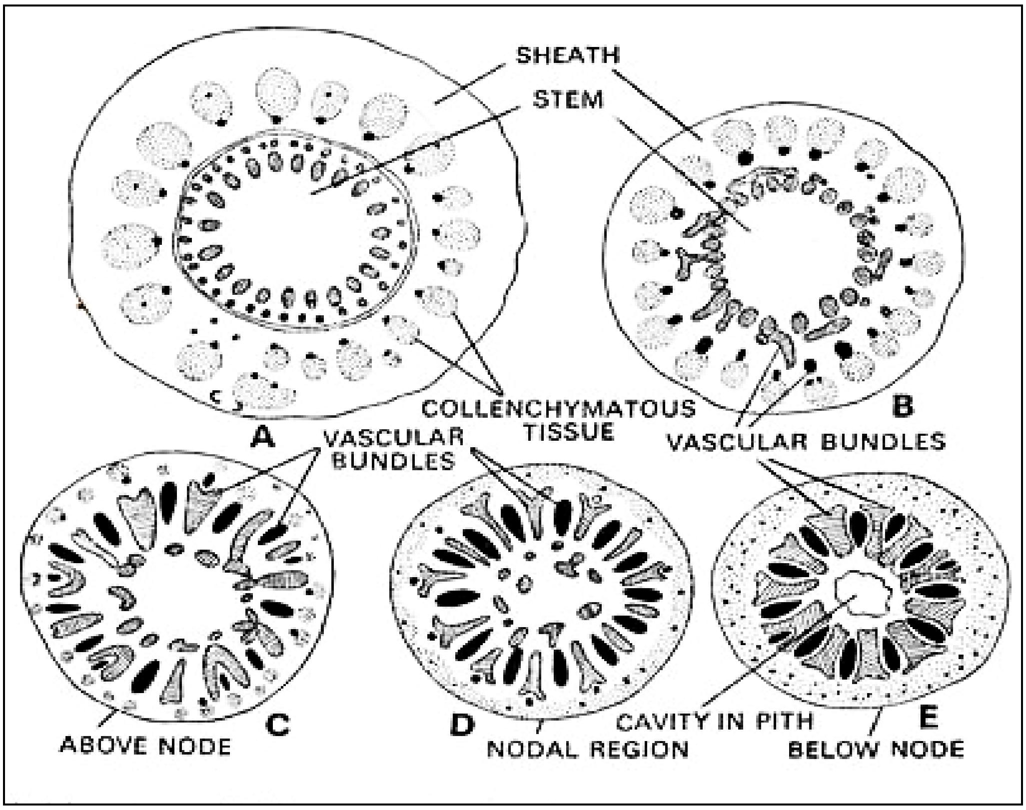

Fig. 4.9: Nodal anatomy of Triticum stem. Bundles of sheath and their traces in stem are depicted in black; vascular tissue of internodes and its continuation through node is hatched. A-E, transactions of stem at various levels. Toward node, sheath increases and stem decreases in thickness

In this cylinder approximately half of the bundles are leaf traces from the nearest leaf above and the other half of the bundles are from the internodes above the insertion of the leaf (Fig.4.9 E). The peripheral bundles are mostly leaf traces. The most conspicuous character of grass stems is the presence of transverse bundles in the nodal regions.

4.11 BRANCH TRACES AND BRANCH GAPS

The primary vascular supply to lateral branches is also derived from the vascular system of the main axes, usually in the form of two bundles, less often, one bundle. These strands are known as branch traces or ramular traces. Dicotyledons and gymnosperms commonly have two branch traces, connecting the vascular systems of the branches to the main stem. In monocotyledons the connection of the axillary shoot with the main stem consists of many strands. The branch traces are extended within the main axis and appendages are tied together by a primary vascular system. When the branch possesses two traces, these bundles unite within a short distance, forming a complete vascular cylinder. When one trace occur, this stand usually possess the cross sectional form of a horse-shoe shaped structure with the opening downward, and the vascular cylinder of the branches is formed by the closure of the opening as the branch traces passes out.

4.12 CLOSING OF LEAF GAPS

The closing of the gap may be define as a phenomenon where the development of cambium take place in the parenchyma of the leaf gap and forms the vascular tissues in continuity with those bordering the gap. The parenchymatous cells near the periphery of the leaf gap are act as cambium and after that inner portion converted (Fig.4.10 A, B). This process is slow and gradually takes place. The gap parenchyma is maintained as such within the secondary body until and cambium is differentiated throughout the entire tangential width of the gap.

Some complicated changes also take place in the leaf trace during the secondary growth. The phloem pushed in outer periphery while the primary xylem buried by the secondary tissues (Fig.4.10 C). The upper portion of the leaf trace departs outwardly and crosses the plane of the cambium. The part of the cambium which differentiates above the trace in the leaf gap developed vascular tissue between the vascular cylinder and leaf trace.

The newly developed tissues after secondary growth exerts a pressure upon the leaf trace resulted ultimately breakout of leaf trace (Fig 4.10 D).The breakout is sealed with parenchyma tissue which converted into cambium strip and joints the cambium of the lower part of the trace with that formed in the leaf gap. After cambium formation some secondary tissues, the end of the trace below the break becomes embedded in secondary xylem (Fig.4.10 E). The upper severed end is carried outward, and in time it may be thrown off, together with the cortex, by the activity of the periderm. Since the cambium within the trace itself pushes the trace phloem outward, the buried part of the trace consists of xylem only.

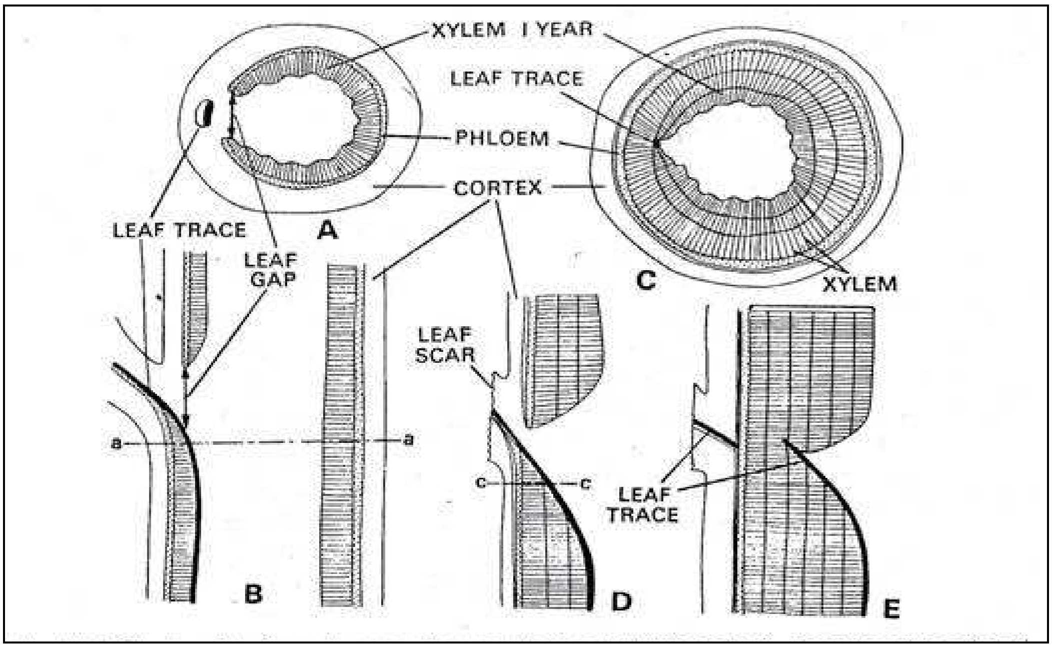

Fig.4.10: Closing of leaf gaps by the secondary growth. A and B: T.S. through nodal region of stem in first year of growth; C-E: T.S. and L.S. through stem after several years old; D and E: depict stages in closing of gaps and rupture of leaf trace

4.13 PHYLOGENY OF NODAL ANATOMY

There are varies theories are present in the phylogentic development of the nodal anatomy. The most accepted model is given by Sinnott (1914). According to this model, in the dicotyledons, trilacunar condition is most primitive whereas uni- and multi-lacunar have been derived from it. Reduction occurred either by the disappearance of the two lateral gaps with the associated two lateral traces or the two lateral traces became confluent with the median trace. In the latter case a single bundle is formed consisting of three traces. This bundle is associated with a single gap to form unilacunar node. Trilacunar condition also gave rise to multilacunar type by the formation of more new gaps and traces. The unilacunar form of node is considered as the most recent. After Sinnott, Bailey (1956), Fahn and Bailey (1957) and several studies give another model. According to them, unilacunar condition is more primitive than tri- and multi-lacunar condition. They support their model by given a strong reason i.e., many primitive groups like pteridophyta, fossil gymnosperms like Bennettitales and Cordaitales, *Ginkgo* and *Ephedra* contains unilacunar condition. Unilacunar two-trace node also seems to be primitive as it is represented by extinct Bennettitales and Cordaitalesand extant ferns, conifers, *Ephedra* and the primitive dicotyledonous genus Austrobaileya etc. Trilacunarcondition is extensive and is occurred in Asteraceae, Meliaceae, Rosaceae and Winteraceae etc. Chenopodiaceae and Degeneriaceae are presented multilacunar condition. *Lepidiumlatifolium* has unilacunar node with several leaf traces. It is regarded as more primitive than the unilacunar one-trace node.

Previously the nodal structures were described on the basis of number of leaf traces that are associated with each leaf, e.g. one-trace, two-trace, three-trace and multi-trace. Later the nodal anatomy is interpreted on the basis of leaf gaps that are associated with each leaf, e.g. unilacunar, trilacunar and multilacunar. Still later leaf gap and leaf trace —these two aspects were combined to describe a node, e.g. unilacunar-one trace, unilacunar-two trace etc. Later in the light of above facts it is now interpreted that the evolution of nodal structure proceeded in the following two sequences:

(i) Two trace unilacunar gave rise to trilacunar, which terminated in multilacunar condition;

(ii) Two-trace unilacunar, by the loss of one trace, gave rise to one trace unilacunar that formed trilacunar node by the addition of two new gaps associated with two traces.

The multilacunar condition is derived from the trilacunar type by the addition of more new traces and gaps (Fig.4.11). This evolutionary sequence may be observed in a single family namely Chenopodiaceae. The trilacunar type may also give rise to one trace unilacunar condition.

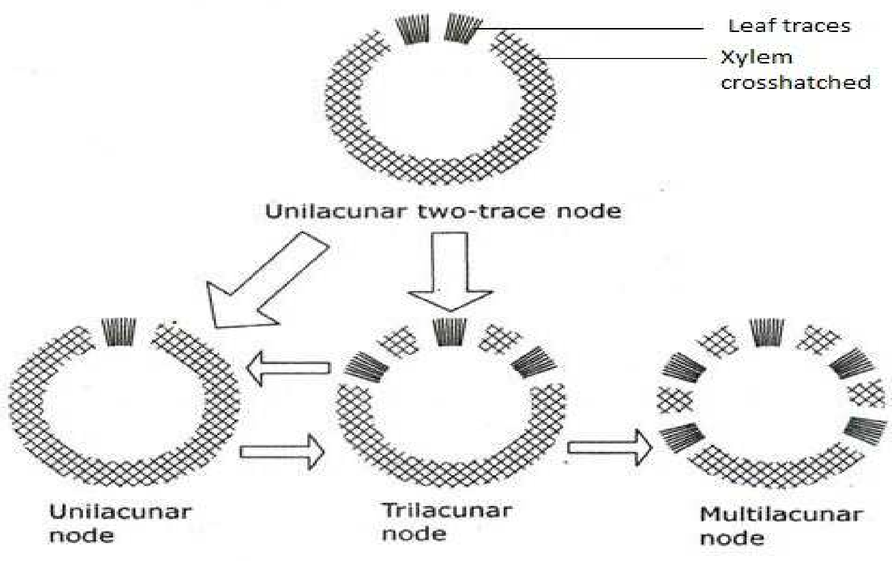

Fig.4.11: Diagram showing the probable lines of development of nodal vascularization.

4.14 SIGNIFICANCE OF NODAL ANATOMY

Nodal anatomy shows the phylogenetic primitiveness or advancements of the plant. The nodal anatomy is a good taxonomic key for systematic of plants. Due to its phylogenetic importance, nodal anatomy is concerned with the study of systematic and phylogeny of angiosperms.

4.15 SUMMARY

The wood may be possibly the most useful and multipurpose material on this earth with thousands of different commercial as well as conventional benefits. The wood contains the specific surface, physical and mechanical properties. The growth of the tree is the result of the production of new cells by tissues termed meristems. Meristems consist of cells that are undifferentiated and retain the ability to divide and produce new cells. The phases of development of wood cells are summarized as cell division, cell enlargement, cell wall thickening, lignification and death. When examine more closely, the wood can be classified according to seasons, location and type of the plants. The cambium in wood becomes more active during the spring season and forms plenty xylems vessels with wider cavities called spring wood or earlywood. The activity of cambium diminished during the winter season which gives rise to narrow xylem elements known as autumn or latewood. The portion of wood which contain more moisture, light in colour and living cell layer called sapwood. Inside the sapwood there is a dead, much darker and harder part called the heartwood. The concentric rings visualized in the cross sections of the stems by the actively of cambium. These rings refer as growth rings which tell about the age of the tree. Classification based on the type of plant, wood can also divide into two distinct kinds called hardwood and softwood, though confusingly the names don't always refer to its actual hardness or softness.

The nodal anatomy considered as one of the most significant aspect of angiosperm systematic and comparative morphology of the stem, leaf and flower. A vascular strand that extends between the vascular cylinder of stem and the leaf is called leaf trace or foliar trace. This parenchymatous zone between the leaf trace and the main vascular cylinder is called leaf gap. The nodes can be classified according to the number of leaf gap or number of leaf traces and leaf gaps in the plants. Before the discovery of unilacunar two-trace node, trilacunar node was regarded as central type from which unilacunar and multilacunar node arose. It is interpreted that unilacunar node is more advanced than trilacunar node. The closing of the gap may be define as a phenomenon where the development of cambium take place in the parenchyma of the leaf gap and forms the vascular tissues in continuity with those bordering the gap. The nodal anatomy plays a significant role in the plant taxonomy. Nodal anatomy shows the phylogenetic primitiveness or advancements of the plant. Due to its phylogenetic importance, nodal anatomy is concerned with the study of systematic and phylogeny of angiosperms.

4.16 GLOSSARY

Cambium: The layer of actively dividing cells between xylem and phloem in a vascular bundle which responsible for the secondary growth of stems and roots in higher plants.

Dendrochronology: It is the scientific method to determine the age of tree by counting the growth rings.

Gymnosperm: It is the group of plants which do not produce flowers or fruits. The naked seeds produced on the surface of scales or leaves often configured as cones.

Hard wood: It belongs to angiospermic (not monocots) group of plant have a tendency of slow growth, therefore usually more dense in texture.

Heart wood: The middle portion of the old trees trunk which developed earlier and contains resins, gum, tannins and other organic substances which make wood firm and durable.

Leaf gap: A leaf gap is a space in the stem of a plant through which the leaf grows.

Leaf trace: An extension of vascular tissue from a main stem of the plant into a nearby leaf, resulting in a leaf gap in the plant's stele**.**

Manoxylic wood: The gymnospermic wood having less number of xylem cells. It has non-compacted wood with large amount of parenchyma, pith cells and cortex mixed with less amount of xylem tracheid.

Periderm: The corky outer layer of a plant stem formed in secondary thickening or as a response to injury or infection.

Phellem: The outer protective layer of tissue of bark which is made of dead cells.

Plant anatomy: It is the general term for the study of the internal structure of the plants.

Pycnoxylic wood: Pycoxylic wood has large number of xylem cells in it. The cells are compacted with large amount of xylem tracheid and small amount of cortex and pith with the small amount of parenchyma

Sap wood: It is considered as the outermost, physiologically active, newly formed xylem elements of the woody stem or branch.

Secoundry phloem: It is a type of phloem which forms from the vascular cambium during the **secondary** growth.

Secoundry xylem: It is the type of xylem originated from the vascular cambium by the activity of secoundary growth.

Soft wood: The softwood comes from an evergreen tree and belongs to gymnosperm group. Generally it considered softer than the hardwood.

Xylem fibers: The fibers made up of dead sclerenchyma cells in between the *xylem* vessels and tracheids which chiefly provide mechanical support to the plant.

Xylem parenchyma: The short, lignified and thin walled living cells. Physiologically functioned for water conduction and storage of food.

Xylem tracheids: These are the elongated cells in the xylem of vascular plants that served the transport of water and mineral salts.

Xylem vessel: These are the long tube like structure which help in transportation of water and provide mechanical support.

4.17 SELF-ASSESSMENT QUESTIONS

4.17.1 Multiple choice questions:

1- Where the sapwood located in the stem?

(a) Below the outer bark (b) Below the inner bark

(c) Above the pith (d) Below the pith

2- What type of trees is called deciduous tree?
(a) Soft wood (b) Hard wood
(c) Spring wood (d) Autumn wood

3- Opening on the radial surface known as
(a) Pits (b) Pith
(c) Reaction wood (d) Mitochondria

4- Which of the following is an example of soft wood?
(a) Sal (b) Oak
(c) Deodar (d) Mahogany

5- Which properties of wood belong to sap wood?
(a) Medullary rays are less distinct (b) Annual rings are less distinct
(c) Dark in colour (d) Close grained

6- The age of tree by counting the annual rings are called
(a) Chronology (b) Countology
(c) Dendrology (d) Dendrochronology

7- In an old stem the major part of the wood is filled with tannin, resins, gum etc. this region is known as
(a) Sap wood (b) Soft wood
(c) Heart wood (d) Spring wood

8- Wood that entirely lacks vessels
(a) Non porous wood (b) Homoxylous wood
(c) Early woo (d) Late wood

9- Trachied percentage contribute 90-95% in
(a) Soft wood (b) Hard wood
(c) Sap wood (d) Heart wood

10- Cork cambium and vascular cambium are
(a) Part of secoundry xylem and phloem (b) Part of pericycle
(c) Lateral meristem (d) Apical meristem

4.17.2 Fill in the blanks:

1. The secondary xylem formed as a result of activity of the cambium and known as ______ .
2. The secondary xylem developed in gymnosperms and ______
3. The formation of secondary xylem is responsible for increment in ______ of tree trunk.
4. The main functions of the wood in the tree are conduction of water and ______
5. Odor depends upon ______ present in the wood.
6. The moisture content of fresh timber varies from ______
7. ______ is poor conductor of heat, electricity and sound.

8. Tracheids perform both the functions of ______ and ______
9. The activity of cambium slows down during the ______ season
10. The concentric circles appear in the cross sections of woody stems by the actively of cambium. These rings are refers as ______

4.17.3 True and false:

1. The branch of science which deals with the climatic condition of the past by using wood annual ring during different periods of time is called Dendroclimatology
2. A vascular strand that extends between the vascular cylinder of stem and the leaf is called Leaf trace or foliar trace.
3. This parenchymatous zone between the leaf trace and the main vascular cylinder is called Leaf gap or Lacuna
4. The node exhibits two leaf traces associated with single leaf gap in a leaf is called Unilacunar two trace node
5. Meristems consist of cells that are undifferentiated and retain the ability to divide and produce new cells.

4.17.1 Answer Key: 1(b); 2(b); 3(a); 4(c); 5(a); 6(d); 7(c); 8(a); 9(a); 10 (c)
4.17.2. Answer Key: 1. Wood; 2. Angiosperm; 3. Diameter; 4. Mechanical strength; 5.volatile compounds; 6. 30% to 200%, 7. Wood; 8. Support, conduction; 9. Winter; 10. Growth rings
4.17.2. Answer Key: 1. True; 2. True; 3. True; 4. True; 5. True

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4.20 TERMINAL QUESTIONS

4.20.1 Short answer type questions:

Q.1 Listed the differences between spring wood and autumn wood.
Q.2 What do you understand by tyloses?
Q.3 Explain the different components of periderm.
Q.4 Discuss the nodal anatomy of monocot stem.
Q.5 Briefly describe the term leaf gap.

4.20.2 Long answer type questions:

Q.1 What do you understand by wood? Explain the properties of the wood in a detail.
Q.2 What are growth rings? Describe their role in detail.
Q.3 What is nodal anatomy? Discuss the classification of nodes. What is the significance of nodal anatomy in the field of plant taxonomy?

UNIT-5: ANATOMY OF LEAF AND ROOT OF MONOCOTS AND DICOTS

Contents:

5.1 OBJECTIVES

In the present unit you will come to know about:

- Characteristic features of leaves and roots
- The diversity in anatomical structures of monocot and dicot leaves and root
- Difference between monocot and dicot leaves and roots.

5.2 INTRODUCTION

The leaf is a specialized organ in which the function of photosynthesis is centered. It is an appendage of the stem but it differs from it in structure. Leaf shows high level of variability morphologically as well as anatomically. They are commonly called as foliage leaves, cataphylls, hyposophylls and cotyledons. The cotyledons are the first leaves of the plant. The foliage leaves commonly do not have a storage tissue. The leaf has a flattened part called lamina and a stalk called petiole by which it is attached to the stem. Leaves have the following characteristic features:

- The leaf is a lateral dissimilar appendage of the stem.
- A leaf is always borne at the node of the stem.
- Generally, there is always an axillary bud in the axil of a leaf.
- Exogenous in origin and develops from the swollen leaf primordium of the growing apex.
- The growth of leaf is limited.
- The leaves do not possess any apical bud or a regular growing point.
- A leaf has three main parts – Leaf base, petiole and leaf lamina. In addition, it may possess two lateral outgrowths of the leaf base, called stipules.
- The leaf lamina is traversed by prominent vascular strands, called veins.

Just like leaf, root is another important organ of plant with which it absorbs water and essential nutrients from soil. The first root of a seed plant develops from the radical and is called tap root. In dicots it goes deeper in the soil and makes tap root system. In monocots these are short lived and replaced by adventitious roots. Roots have the following characteristic features:

- The root is the descending portion of the plant axis.
- It is positively geotropic.
- It is usually non-green or brown in colour.
- The root is not further differentiated into nodes and internodes.
- As per the rule, the root does not bear leaves and tree buds.
- Usually, a root cap protects the root tip.
- The root bears unicellular root hairs.

- Lateral roots arise from the root. These are endogenous in origin (arises from pericycle).

Some roots become specialized due to their function as fleshy roots of beet, carrot, raddish and in respiration in mangrove plants. Similarly the parasitic plants develop sucking roots.

5.3 ANATOMY OF LEAF OF MONOCOTS AND DICOTS

Commonly the leaves are of two types dorsiventral (dicots) and isobilateral (monocots) Fig. 5.1 A&B. The dorsiventral has distinct upper and lower surfaces and grows in horizontal direction. Most of the monocots and some dicots have isobilateral leaves. Though the leaves have lot of variability still they all have same tissue system as the root or stem. The leaves have dermal, ground and the vascular tissue system.

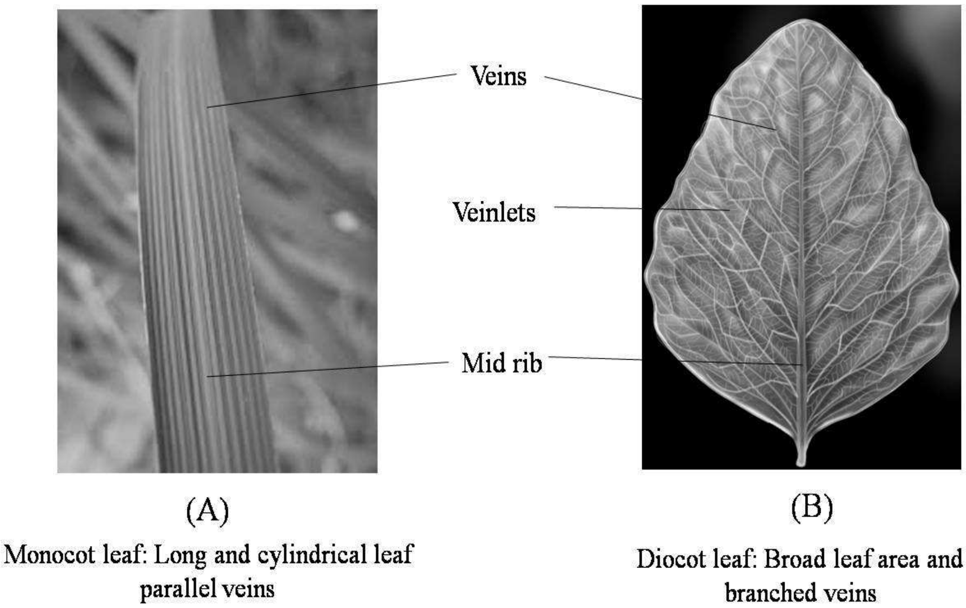

Fig. 5.1: Difference between monocot and dicot leaves

5.3.1 Monocotyledonous leaves

Majority of monocot members have isobilateral/unifacial/isolateral leaves (isos=equal, bi=two, lateris=side). Internally these are different from dorsiventral leaves. The mesophyll is made up of isodiametric cells which are all alike (Fig. 5.2). Internally it cannot be differentiated into two zones and structure is similar on both the surfaces. The stomata are present on both the epidermal layers and thus it is called as amphistomatic leaf. Anatomically monocot leaf can be differentiated into following regions:

a. **Epidermis:** The epidermis shows high variation in structure. The upper and lower epidermis is almost similar in structure. Usually epidermis is made up of thin walled compactly arranged cells. Epidermal cells are uniseriate and more or less oval in shape. The outer wall of the epidermal cells is cuticularized. A group of bigger cells called as bulliform cells or motor cells are present. In *Ammophila* these cells are restricted in the depressions and help in rolling of leaves. In water plants, e.g. *Potamogeton* the cells of both upper and lower epidermis have chloroplasts. On the basis of distribution of stomata the leaves can be differentiated into three types:

i. Epistomatic: In floating leaves stomata are present only on the upper side.

ii. Hypostomatic: the leaves are present on lower side only.

iii. Amphistomatic: the stomata are present on both the sides of leaves.

In date palm the epidermis is more than one layered. The epidermal cells may also be impregnated with wax.

b. Mesophyll tissue: The tissue of the leaf that lies between the upper and lower epidermis and between the veins is made up of thin parenchyma called as mesophyll. The mesophyll is not differentiated into palisade and spongy tissue but consists of isodiametric parenchyma cells with chloroplast and intercellular spaces continuous with outside. Bundle sheath extensions are present on one or both sides of veins which are made up of sclerenchymatous patches and continue upto the epidermis. In *Lillium* palisade like layer may be present on the upper surface of the leaf. In date palm sclerenchymatous patches are also present below the epidermis.

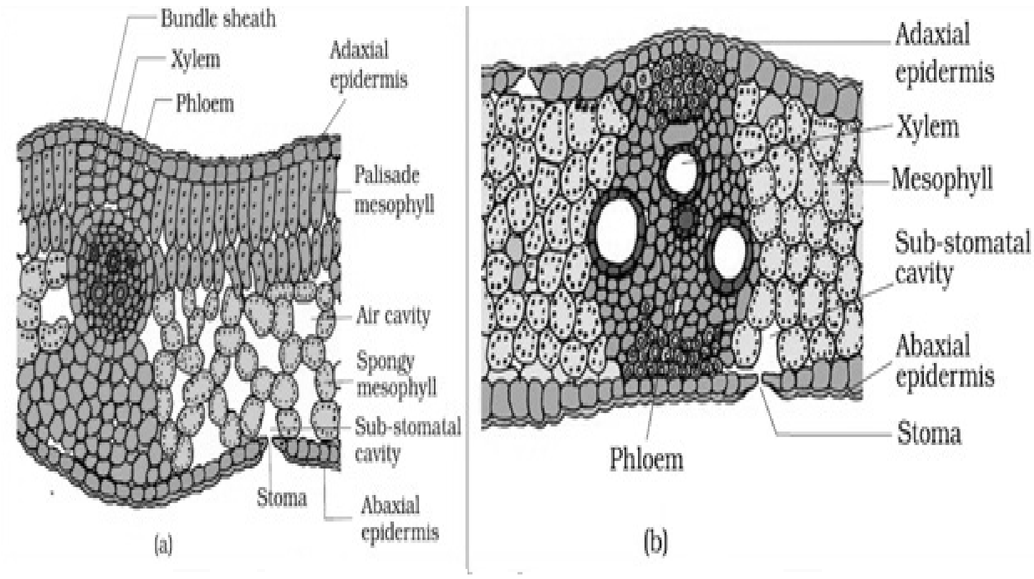

Fig. 5.2: Figure showing difference between a dicot (a) and monocot leaf (b).

c. Vascular bundles: The vascular bundles are arranged in parallel manner. The bundles are conjoint, collateral and enclosed by a bundle sheath. The xylem is towards the upper side and the phloem is on the lower side. In some cases bundle sheath is two layered of which the inner layer is sclerenchymatous. e.g. wheat. The bundle sheath cells have starch grains in them. Xylem consists of vessels and phloem of sieve tubes and companion cells. Sclerenchyma cells occur in patches on both ends of the large vascular bundles which give mechanical support to the leaf.

5.3.2 Dicotyledonous leaves

It is also called as bifacial leaf. It is differentiated into dorsal and ventral region. Anatomically a dicot leaf shows following structures (Fig. 5.2).

(A) Upper Epidermis: The leaf is covered on both surfaces by a single-layered epidermis. It is made up of single layer of cells, closely fitted and has outer thick walls. The outer wall is cutinized, covered over with a waxy substance called cutin. Due to cutin water does not pass through them and transpiration is greatly reduced. The epidermis also checks entry of pathogens into the leaf. In *Nerium* epidermis is multilayered. The chloroplast and stomata are generally not present.

(B) Mesophyll tissue: It is made up of parenchyma which is differentiated into two regions:

i. **Palisade tissue:** it is composed of one or two layers of closely arranged columnar cells. The cells are elongated and more or less cylindrical cells with their long axes perpendicular to the epidermis. The compactness of palisade parenchyma depends upon the light intensity. A large number of chloroplasts are present in each cell. The palisade parenchyma is present just below the upper epidermis and is meant for photosynthesis. It is connected with intercellular spaces to receive the proper gaseous supply. In some xerophytic plants palisade tissue may be present on both sides of the leaf. E.g. *Eucalyptus* as leaves hang vertically.

ii. **Spongy parenchyma:** It is present just below palisade tissue. They are loosely packed, thin walled cells, parenchymatous and have irregular outlines with branches extending from one cell to the other. It looks like a net and the cells have less or no chloroplast and helps in exchange of gases between the leaf and the atmosphere.

   Both spongy and palisade parenchyma contain discoid chloroplasts arranged in parallel rows in the cells. The palisade appears to be greener than spongy parenchyma

(C) Vascular bundles: The bundles are irregularly distributed in the spongy parenchyma. In mango and some other cases a midrib is present. The structure of the midrib and other bundles is similar to each other. The vascular bundles are called veins. A large number of veins arises from the midvein and form a network.

Each bundle is conjoint, collateral and closed. Xylem is present towards the upper epidermis and the phloem towards the lower. The xylem consists of annular or spiral vessels, tracheids, wood fibres and xylem parenchyma. The entire bundle is enclosed in a parenchymatous bundle sheath, which is made up of compactly arranged cells.

(**D). Midrib region**: In this region, in place of palisade, collenchyma is present above vascular bundle. On the lower side parenchyma are present.

(E). Lower Epidermis: It is similar to upper epidermis in structure. Many stomata are present in this layer. The stoma is surrounded by two guard cells. The leaves are hypostomatic. The guard cells may be present either in the level of epidermal cells or may be placed in pits. The characteristic differences between monocot and dicot leaves are given below (Table 5.1).

Table 5.1: Differences between monocot and dicot leaves

S.N.	Character	Dicot leaves	Monocot leaves
1	Venation	Reticulate venation	Parallel venation
2	Colour	The upper surface is dark green while the lower surface is light green.	The two surfaces are equally green.
3	Epidermis	The epidermal cells have sinuous lateral walls.	The epidermal cells have almost straight lateral walls.
4	Silica deposition	Normally not deposited on the epidermal cells.	Deposition occurs on the walls of epidermal cells.
5	Stomata	Stomata are absent or less abundant on the upper side. The stomata have kidney-shaped guard cells.	The stomata are equally distributed on the two sides. The stomata have dumb bell-shaped guard cells.
6	Mesophyll	Mesophyll is differentiated into two parts, upper palisade and lower spongy.	Mesophyll is undifferentiated.

5.4- MECHANICAL SUPPORT IN THE LEAF

The function of the midrib and the lateral veins are to strengthen the leaf. The important tissues giving mechanical strength to leaf are:

(a) Collenchyma: It is present in the centre in upper portion of the midrib. Wall is thick, such cells are also present just above the lower epidermis. It is made up of living cells with thick wall at the angles where cells contact with each other. This thickening increases the strength and the thin places allow rapid transfer of materials from cell to cell.

(b) Sclerenchyma: These cells or fibers are associated with vascular tissue of the leaves. They occur as bundle caps adjacent to the phloem. These are thick walled, dead and lignified. They lie exterior to thin walled phloem and gives mechanical support. They are elongated in the longitudinal direction of the midrib.

(c) Turgid parenchyma: These are turgid parenchyma cells which strengthen the midrib region.

(d) Woody Xylem: These are lignified and dead cells and their main function is conduction of water but they also give mechanical support due to their thick wall. These are lignified and dead cells.

5.5- ANATOMY OF THE PETIOLE

In petiole usually a groove is present on the upper side. There is a close similarity between petiole and stem. The ground parenchyma of both is same and collenchymas and sclerenchyma are present. The vascular bundles may be collateral (e.g. *Syringa*), bicollateral (e.g. Cucurbitaceae, Solanaceae) or concentric. The anatomy of petiole reveals following structures:

a.	**Epidermis**	**:**	The epidermis is made up of single layer of barrel shaped, elongated or radially elongated compact cells with no intercellular spaces. It is generally cuticularized.
b.	**Hypodermis**	**:**	Hypodermis is generally multilayered made up of collenchyma or sclerenchyma.
c.	**Ground tissue**	**:**	The ground tissue is made up of thin walled parenchyma cells having intercellular spaces.

The vascular bundles may be in a complete or half ring or scattered. The vascular bundles are of various sizes, largest on the lower surface and gradually smaller in size towards upper surface. The bundles are made up of xylem and phloem. The xylem is always found towards upper side and phloem towards lower side. Generally the central largest bundle is surrounded by single layered endodermis followed by multilayered pericycle.

5.6- ANATOMY OF PHYLLODE

The phyllode is a modification of petiole in which it becomes flattened like leaf and it shows xerophytic characters anatomically. It is generally isobilateral. Anatomically it shows following structures:

a.	**Epidermis**	**:**	It is single layered covered with cuticle. Sunken stomata are present and below it is present substomatal chamber for gaseous exchange
b.	**Palisade and parenchyma**	**:**	Palisade parenchyma is one or two layered and helps in photosynthesis, intercellular spaces are present.
c.	**Vascular system**	**:**	These are present in a ring. The central and marginal bundles are large in size with well developed sclrenechyma around them (characteristic of phyllode). The margins have radially elongated epidermal cells.

In Gymnosperms special tissue surrounds the vascular bundles called as transfusion tissue, it brings vascular bundles near to the mesophyll. The tissue is of two types living parenchyma with non lignified walls and thin walled but lignified tracheids with bordered pits. Near xylem the transfusion tracheids are elongated while they become short when away. Near phloem they have cells similar to the albuminous cells having dense cytoplasm and prominent nuclei.

The parenchyma is more near endodermis and trachieds near bundles. The bundles get separated from transfusion tissue by sclerenchyma. This tissue is supposed to have originated from centripetal xylem or it is a transformed parenchyma outside bundles.

5.7 ANATOMY OF ROOT OF MONOCOTYLEDONS AND DICOTYLEDONS

The internal organization of the root, though variable in different plants, is simpler than stem as it does not have nodes and internodes and lateral appendages. Root is a leafless structure and in both monocotyledons and dicotyledons it's internal structure shows a clear differentiation of the three systems of tissue system-epidermal, ground and vascular tissue system.

5.7.1 Monocotydenous root

The monocot root has the following anatomical structures (Fig. 5.3a):

(a) **Epiblema/ Epidermis**: It is outermost layer is made up of thin walled cells with unicellular root hairs. The root hairs are tubular extensions of the epidermal cells in those places where xylem tissue is mature. They increase the absorption for minerals and water. As root grows the root hairs on older portions die and new hairs continues to grow in relatively young parts of the root. But in plants like *Eupatorium purpureum* they are persistent. The root hairs are usually absent in aerial roots and present in terrestrial roots.

Though any epidermal cell may initiate root hair but sometimes some cells get morphologically distinct from other cells called as trichoblasts. In aquatic plants the root hairs develop straight but in land plants they may take different shape depending upon their contact with soil particles. Epidermis is usually uniseriate but in aerial roots of some Orchids and epiphytes it is multiseriate called as velamen. The velamen is a special tissue present outside the epiblema having few layers of thin-walled, compactly arranged, elongated and dead cells.

Velamen is supposed to have many functions like absorption of water from the atmosphere, mechanical tissue for protection and also check loss of water from cortex. They get filled with air in dry and with water in rainy season. It also has dense spiral thickenings called pneumatodes for gaseous exchange.

(b) **Cortex**: Inner to the epiblema there is present a large band of parenchyma with intercellular spaces. These cells often contain starch grains and leucoplast. In old roots of *Zea mays* suberized cells single or multilayered are usually present known as exodermis. It is protective in function. Starch grains are abundantly present in cells and sclerenchyma cells are commonly found. Chloroplasts are usually absent from cortex.

(c) **Endodermis**: It is innermost layer of cortex. Cells are barrel shaped with prominent casparian strips on radial and tangential walls. The casparian strip is part of primary cell wall. The inner walls are thickened. There are no intercellular spaces. In monocots the endodermis undergoes some wall modifications. Either only casparian strip is present or it gets covered by suberin and cellulose which makes it thick walled just opposite to protoxylem poles and are called as passage cells.

Since these passage cells are meant for diffusion they are also called as transfusion cells. This thickening usually begins in those endodermal cells which are adjacent to phloem. Various functions have been attributed to endodermis as:

i. Mechanical protective layer
ii. Inner accessory epidermis
iii. Maintaining of root pressure
iv. Air dam which prevents clogging of water conducting cells
v. Barrage which prevents leakage of nutrients from vascular tissues and
vi. Regulates inflow of water and nutrients salts

(d) **Pericycle**: It is the outer side layer of the stele lying inner to the endodermis. It has a single layer of thin walled cells parenchymatous cells. In older roots it may undergo sclerification partly or entirely. In many members of Graminae and other monocot members like *Smilax*, *Agave*, *Dracaena* and palms it may be multilayered.The pericycle may be interrupted by xylem (Graminae) or phloem (Potamogetonaceae) elements differentiation. Pericycle is derived from procambial strand and it maintains its meristematic activities.

(e) **Vascular bundles:** The vascular tissue differentiates from the procambium which consists of densely cytoplasmic cells elongated along the longitudinal plane of the root. The differentiation of vascular tissues takes place acropetally. Unlike stem the differentiation of vascular tissue is reverse to that of stem i.e. centripetally. These are radial and arranged in a ring. The xylem bundles are numerous and alternate with phloem bundles. The bundles are referred as polyarch. Depending upon the number of xylem bundles roots are called as monarch (one xylem strand), diarch (two), triarch (three) to polyarch (many bundles). The adventitious roots of Palmae and Pandanaceae have considerably large number of bundles as many as 100 or more.

In *Triticum* roots a single vessel is in centre and is separated by non-tracheary elements from the peripheral strands, in others variable number of large metaxylem vessels are arranged in circle around the pith e.g. *Zea mays*. The protoxylem vessels are narrow and have annular and spiral thickenings where as metaxylem vessels are broad and have reticulate and pitted thickenings.

In woods monocots the inner metaxylem elements may vary from two to three circles or they may be widely separated from each other e.g. *Phoenix dactylifera* or scattered throughout the centre. In Iridaceae, *Sisyrinchium* has a large central metaxylem vessel surrounded by five to seven protoxylem strands, while in Gladiolus there is only one metaxylem vessel at the base of each protxylem strand.

In some monocots like *Cordyline*, *Musa*, Pandanceae phloem strands are scattered among the trachery elements in the centre of the root. The phloem is in form of strands near the periphery of the vascular cylinder beneath the pericycle. The phloem is made up of sieve tubes, companion cells and phloem parenchyma. The phloem strands are also exarch, protophloem towards periphery and metaphloem towards the centre.

In between and around vascular bundles parenchymatous or sclerenchymatous conjunctive tissue is found. The center is occupied by large pith which may be parenchymatous or sclerenchymatous (*Canna*, *Oryza sativa*, *Avena sativa*). Xylem is exarch, i.e., protoxylem lies towards periphery and the metaxylem towards the centre. Structurally they are similar to the bundles of dicotyledons root.

(f) **Conjuctive tissue**: The small parenchyma in between the xylem and phloem bundles is the conjunctive tissue.

(g) **Pith**: It is differentiated and consists of parenchymatous cells with intercellular spaces. Sometimes as in *Sisyrinchium* the pith is completely obliterated due to development of metaxylem vessels in the centre.

5.7.2 Dicotyledons roots

The young root of a dicotyledons shows following structures (Fig. 5.3b):

(a) **Epiblema or piliferous layer:** It is formed of a single layer of thin walled cells. Some cells are enlarged outwards to form tubular and unicellular root hairs.

(b) **Cortex:** These are many layers of parenchyma with intercellular spaces. The cells contain leucoplast and starch. Sometimes it's outer layer function as exodermis on degeneration of epiblema.

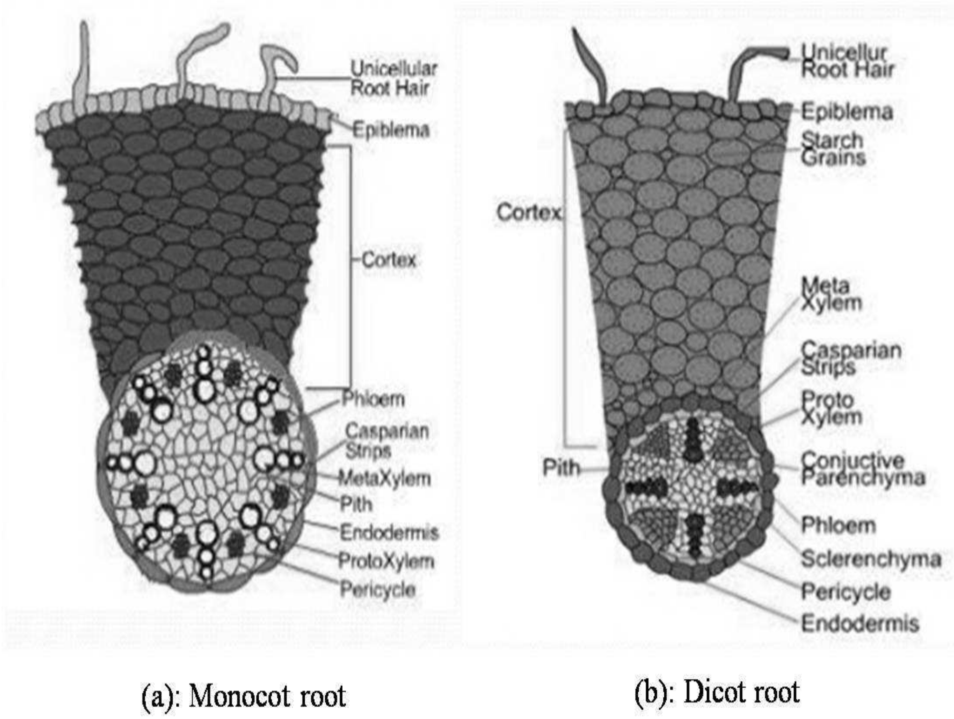

Fig. 5.3: T.S. showing differences in monocot (a) and dicot roots (b).

(c) **Endodermis:** It is the innermost layer of the cortex and forms a ring of compact, barrel shaped cells around the stele. The radial and inner walls are thickened in form of casparian strips. There are no intercellular spaces. Some cells above protoxylem are thin walled and known as passage cells.

(d) **Pericycle:** It is the outermost layer just below the endodermis. The cells are thin walled.

(e) **Conjunctive tissue:** It lies between xylem and phloem.

(f) **Vascular bundles:** these are **r**adial, the xylem and phloem alternate with each other. If bundles are 4 the root is called tetrarch, 5 then pentarch, etc. The bundles are arranged in a ring. The protoxylem is exarch and consists of annular and spiral vessels. The metaxylem has reticulate and pitted vessels. The phloem consists of sieve tissue, companion cells and phloem parenchyma. On the outer side of phloem sclerenchyma is present.

Table 5.2. Differences between Dicotyledonous and monocotyledonous roots

S.N.	**Character**	**Dicotyledonous Root**	**Monocotyledonous Root**
1.	Cortex	Cortex is comparatively narrow	Cortex is very wide.
2.	Epiblema	The epiblema, the cortex and even the endodermis are peeled off and replaced by cork.	Cork is not formed. The cortex and the endodermis persist. Only the epiblema is peeled off.
3.	Cork	Older root has a covering of cork.	Older root has a covering of exodermis.
4.	Casparian strips	Endodermis is less thickened and casparian strips are more prominent.	Casparian strips are visible only in young root. The endodermal cells later become highly thickened.
5.	Passage cells	Passage cells are generally absent in endodermis.	Thin walled passage cells generally occur in the endodermis opposite the protoxylem point.
6.	Pericycle	Pericycle produces lateral roots, cork cambium and part of the vascular cambium.	Pericycle produces lateral roots only.
7.	Xylem	2 to 6 rarely more, Xylem vessels are generally angular.	Xylem and phloem bundles are numerous and are 8 or more in number. Xylem vessels are oval or rounded.
8.	Cambium	Present and appears later as a secondary meristem	It is altogether absent
9.	Secondary growth	Secondary growth takes place with the help of vascular cambium and cork cambium.	Secondary growth is absent.
10.	Pith	Small or absent	Large and well developed

Special dicot root: The root of *Ficus* shows some special features like they don’t have root hairs.

- **Exodermis**: these are few parenchyma layers outside epiblema in young root. After secondary growth they dry up.

- **Epiblema**: Single layered and below exodermis.
- **Cortex**: many layered with chlorophyll bearing cells. Few outer cells are filled with tannin like substances.
- **Endodermis** and pericycle: like other dicot root.
- **Vascular bundles**: Xylem are 6 or more in number and alternate with phloem bundles.
- **Pith**: large, well developed and parenchymatous.
- **Secondary growth**: It is typical dicot type. Periderm is well developed.

The differences between dicot and monocot roots can be tabulated as shown in table 5.2.

Secondary structure of root: The secondary growth is observed in the roots of Gymnospems and dicotyledons. Monocotyledons mostly do not show secondary growth and remain in primary state throughout their life. However some monocots like *Dracaena* do show secondary growth. The fundamental structure of secondary structure is similar to that of stem. In roots the bundles are radial. A few parenchyma cells in the inner edges of phloem becomes meristematic and form crescent shaped strips of cambium.

These strips make secondary xylem centripetally and secondary phloem centrifugally. In the roots of herbaceous dicotyledons there is very little secondary growth. In these plants cortical layers beneath the epidermis becomes suberized and forms a thick walled exodermis. However in woods roots enormous amount of secondary tissue is formed due to extensive vascular cambium activity. In these periderm is formed due to the activity of cork cambium or phellogen. In the roots of some angiosperms like Hypericaceae, Myrtaceae, Rosaceae the periderm is made up of two types of cells suberized and non suberized alternating with each other.

5.8 DIFFERENT TYPES OF ROOTS IN PLANTS

1. **Adventitious roots:** These are the roots that arise from any part of plant other than radicle, like stem, leaf or hypocotyl. Majority of monocots and vegetatively propagating dicots have these roots. They have endogenous origin, their origin sites may vary from plant to plant

   - Cortical tissue of buds and hypocotyls e.g. *Cadamine pratensis*
   - Stem pericycle e.g. *Zea mays*
   - Ray parenchyma e.g. *Tropaeolum majus*
   - Non differentiated secondary phloem and cambium e.g *Rosa*
   - Interfascicular cambium and pericycle or the stem pith e.g. *Portulaca oleracea*
   - Parenchymatous regions in secondary xylem e.g. *Ribes nigrum*
   - Tissues of leaf margins and petioles. e.g. *Kalanchoe*, *Bryophyllum*

2. **Contractile roots**: In herbaceous dicots and many monocots the root surface shows wrinkling, and these are known as contractile roots. E.g. *Daucus*, *Medicago*, *Oxalis*, *Trifolium*

3. **Storage roots:** The storage roots are those which store food material in the form of carbohydrates. They have excessive parenchyma. Several cambial rings are formed after primary cambium ceases in function. They are first formed in pericycle and later in parenchyma tissue outside secondary phloem. E.g. *Brassica rapa*, *Raphanus sativus*, *Ipomea batatas*, *Beta vulgaris*.

4. **Aeration roots/ Pneumatophores:** In plants of swampy habitat and many halophytes like Avicennia, the roots are negative geotropic and are known as pneumatophores. The surface of these roots is covered by a thick layer of cork formed by the underlying cork cambium (phellogen). The cork has many small lenticels for gas exchange. The cortex is parenchymatous with many intercellular spaces.

5.9 SUMMARY

The leaves are of two types dorsiventral (dicots) and isobilateral (monocots). A monocot leaf has epidermis, mesophyll and vascular tissue. Epidermal cells are cuticularized, uniseriate and more or less oval in shape. The mesophyll is not differentiated into palisade and spongy tissue. The vascular bundles are arranged in parallel manner. The bundles are conjoint, collateral and enclosed by a bundle sheath. The xylem is towards the upper side and the phloem is on the lower side.

The dicotyledonous leaf is also called as bifacial leaf and it is differentiated into dorsal and ventral region. It also has epidermal, mesophyll and vascular tissues. The single-layered cutinized epidermis. The mesophyll is differentiated into spongy and palisade parenchyma. The bundles are irregularly distributed in the spongy parenchyma. The bundles are conjoint, collateral and closed. Xylem is present towards the upper epidermis and the phloem towards the lower. The tissues that give mechanical strength are collenchymas, sclerenchyma, turgid parenchyma and woody xylem.

Like leaf, petiole also has epidermis, hypodermis and ground tissue. It sometimes becomes flattened and is called phyllode. In Gymnosperms a special tissue surrounding the vascular bundles is present called as transfusion tissue.

Root is a leafless structure and in both monocotyledons and dicotyledons it’s internal structure shows a clear differentiation of the three systems of tissue system-epidermal, ground and vascular tissue system. In monocotyledons root, the outermost layer is thin walled called as epiblema or epidermis and has root hairs. The cortex has a large band of parenchyma with intercellular spaces containing starch grains and leucoplast. The endodermis is innermost layer of cortex and has barrel shaped cells with prominent casparian strips on radial and tangential walls. Passage cells or transfusion cells are also present. Endodermis and pericycle are present. The Vascular bundles are made up of xylem and phloem. Xylem is exarch, numerous and alternate with phloem bundles. The root can be monarch (one xylem strand), diarch (two), triarch (three) etc. The phloem is made up of sieve tubes, companion cells and phloem parenchyma. The phloem strands are also exarch. Conjunctive tissue is also found.

The dicotyledonous root also shows epiblema or piliferous layer, cortex, endodermis, pericycle and vascular bundles. Conjunctive tissue is also present. Vascular bundles are radial and xylem and phloem alternate with each other.

Some plants like *Ficus* have special roots. Adventitious roots are also present. Some plants like Gymnospems and dicotyledons show secondary growth in roots. Monocotyledons mostly do not show secondary growth and remain in primary state throughout their life. The roots may be Contractile, storage or aeration in nature. These shows slight variation in their anatomy.

5.10 GLOSSARY

Abaxial: Directed away from the axis.
Adxial: Directed towards the axis.
Adventitious roots: Roots that develop from any part of plant other than radical .
Bulliform cells: Group of bigger cells, restricted in the depressions and help in rolling of eaves, also called as motor cells.
Cambium: A meristem with products of divisions arranged orderly in parallel files.
Casparian strip or band: A band like wall formation within primary walls and containing lignin and suberun. Typical of endodermal cells in roots.
Centripetal development: Developing successively inwards towards centre.
Centifugal development: Developing successively outward from the centre.
Chlorenchyma: Parenchyma having chloroplasts.
Collenchymas: Supporting tissue composed of more or less elongated living cells with unevenly thickened walls.
Closed bundles: Cambium is absent between xylem and phloem
Conjuctive tissue: The small parenchyma in between the xylem and phloem bundles is the conjunctive tissue.
Conjoint: Bundle where xylem and phloem lie opposite to each other on the same radius linked with the help of cambium.
Collateral: Bundle where xylem and phloem lie opposite to each other on the same radius with phloem located towards periphery of the stem and the xylem towards center.
Cotyledons are the first leaves of the plant
Dermal tissue: Outer covering tissue of plant that is epidermis or periderm.

Diarch: Two protoxylem strands.
Endogenous: Arising from deep seted tissues as lateral root.
Exarch: Protoxylem lies towards periphery and the metaxylem towards the centre.
Ground meristem: Meristematic tissue derived from apical meristem that give rise to ground tissue. Also called as fundamental tissue.
Hyposophylls: Various types of bracts associated with flowers which may function as protective organs or to attract insects if colored.
Hypostomatic: The leaves are present on lower side only.
Intercellular space: Space among cells within a tissue.
Isobilateral/unifacial/isolateral leaves: (isos=equal, bi=two, lateris=side)
Isodiametric: Regular in form with all diameters equally long.
Lamina: The flattened part of leaf.
Lignin: an organic substance of high carbon content associated with cellulose in the wall of many cells.
Mesophyll tissue: The parenchyma tissue of leaf that lies between the upper and lower epidermis.
Open bundles: Cambium is present between xylem and phloem
Palisade tissue: it is composed of one or two layers of closely arranged columnar cells
Parenchyma: Cells with live nucleus concerned with one or more activities in plants.
Passage cells: These are thin walled cells in exodermis or endodermis having casparian strips.
Periclinal: Parallel with the circumference.
Pericycle: Part of ground tissue of the stele located between the phloem and endodermis. Present in roots and absent in stems mostly.
Phloem: Principal food conducting tissue of the vascular plant made up of sieve elements, parenchyma cells, fibres and sclereids
Sclerenchyma: Cell having thick lignified secondary walls, act as supporting cells.
Spongy parenchyma-It is present just below palisade tissue, loosely packed and made up of thin walled cells, parenchymatous cells.
Sucking roots: Also called as haustoria. These penetrate host tissues for water and nutrients.
Xylem: Principal water conducting tissue, may also act as supporting tissue.

5.11 SELF-ASSESSMENT QUESTIONS

5.11.1. Multiple choice questions:

1. In a vertical section of dorsiventral leaf
   (a) Mesophyll is undifferentiated
   (b) Mesophyll is differentiated into palisade and spongy parenchyma.
   (c) Palisade is present but no spongy parenchyma
   (d) Spongy parenchyma is present but palisade absent.

2. The ground tissue of leaf is called as
   (a) Mesophyll (b) Cataphyll
   (c) Chlorophyll (d) Veins

3. Multiple epidermis is found in
   (a) Nerium leaf (b) Guard leaf
   (c) Guava leaf (d) Grass stem

4. In a vertical section of a typical dicot leaf, the phloem in the mid-vein is situated
   (a) Facing the upper epidermis (b) Facing the lower epidermis
   (c) Facing sideways (d) All around the xylem

5. Which of the following can be seen in a monocot root
   (a) Large pith (b) No or poorly developed pith
   (c) Medullary ray (d) Endarch xylem

5.11.2 True or false

1. Bulliform cells in grasses helop in rolling of leaves.
2. In dorsiventral leaf palisade tissue occurs on abaxial surface and spongy parenchyma on adaxial surface.
3. In submerged leaves stomata occur on both surfaces.
4. Mesophyll is differentiated in palisade and spongy parenchyma.
5. In leaf xylem is towards adaxial side of leaf

5.11.3 Fill in the blanks

1. A leaf is described as________when the two surfaces cannot be distinguished anatomically.
2. The tissue between upper and lower epidermis is called as _______
3. Stomata are present on lower surface only in ________
4. Roots have _________vascular bundles.
5. Some endodermal cells lying opposity to the protoxylem are known as _______

5.11.1 Answer Key: 1 (b); 2 (a); 3 (a); 4 (a); 5 (a)

5.11.2 Answer Key: 1. True; 2. False; 3. False; 4. False; 5. True

5.11.3 Answer Key: 1. Isobilateral; 2.Mesophyll; 3.hypostomatic; 4. Radial; 5. passage cells

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5.14 TERMINAL QUESTIONS

5.14.1 Short answer type questions

1. Compare the internal structure of dorsiventral with that of isobilateral leaf.
2. Write short notes on:
   (i) mesophyll (ii) casparian strip (iii) velamen
3. Write the difference between monocot and dicot root
4. Write the difference between moncot and dicot leaf
5. Write a short note on:
   (i) Phyllode (ii) Transfusion tissue (iii) type of roots in plant

5.14.2 Long answer type questions

1. Describe in detail the internal structure of a dicot leaf. Give in details about its various tissues.
2. Compare dicotyledons leaf with monocotyledons leaf with well labeled diagrams.
3. Draw well labeled diagrams of the following:
   i. T.S. of monocot leaf
   ii. T.S. dicot leaf
   iii. T.S. monocot root
   iv. T.S. dicot root
4. Give in detail well labeled diagram of a typical monocot root.
5. Compare dicotyledons root with monocotyledons root with well labeled diagrams.

UNIT- 6: ANATOMY OF STEM IN MONOCOTS AND DICOTS AND C3 AND C4 PLANT LEAVES

Contents:

6.1 OBJECTIVES

As you have seen in earlier units that both monocotyledons and dicotyledons are group of angiosperms which differ not only in anatomy but nearly every aspect of life. In this unit you will be able to know;

- Anatomy of leaf of monocotyledons and dicotyledons plants.
- How monocotyledons and dicotyledons differ in stem anatomy from each other.
- Structure of C3 and C4 plants.
- Differences between C3 and C4 plants.

6.2 INTRODUCTION

The higher plants generally divided into two groups- the angiosperms (flowering plant) and gymnosperms (non-flowering plant). The angiosperms are further sub-divided into two group i.e., dicotyledons and monocotyledons. Monocotyledons are those plant which give rise one cotyledon while dicots have two cotyledons after seed germination.

In angiosperm, the plant body is clearly divided into root, stem and leaf. The stem is the essential aerial part of the plant, which bears branches, leaves, flowers, and fruits. It is also responsible for the conduction of water, minerals nutrients, and gases within the plant. Other than these stem provides support to the plant body. The characteristic features of the stems are;

- Stem arises as a prolongation of plumule.
- The shoot system is heterogeneous and consists of stem, branch, leaves and flowers.
- The stem is negatively geotropic, hydrotropic and positively phototropic in nature.
- The stem bears nodes and internodes.
- The stem bears vegetative buds which could be terminal or axillary or lateral.
- Lateral branches of the stem are exogenous on origin.

Both the monocotyledons and dicotyledons plants bear a well developed shoot system having the same basic architecture of nodes, internodes, flowers, buds, etc on it. Many other internal similarities and differences are also found in between monocotyledons and dicotyledons stems which we will discuss in this chapter in detail.

The green plants are unique to possess the ability to fix light energy from sunlight through a process called photosynthesis. The process of photosynthesis is take place in two process i.e., light reaction and dark reaction. In the light reaction the chlorophyll pigment absorb the sunlight and synthesized energy rich chemical compound like ATP and reduced coenzymes (NADPHH+). In dark reaction these energy rich molecules are used for the synthesis of carbohydrate with CO_2. There are essentially three different types of dark reaction pathways are operated in different plants on the earth and they are named on the basis of compounds of these pathways. They are C3 plants, C4 plants and CAM plants.

In majority of plants CO_2 is fixed into a three carbon compound (C3) by the photosynthetic enzyme ribulose bisphosphate carboxylase oxygenase (Rubisco). This is normal photosynthetic process that occurs in plants. This unique enzyme Rubisco has a dual role, when the CO_2 is more in atmosphere it behaves like carboxylase and fixes atmospheric CO_2 into sugar but when oxygen is more it undergoes oxygenase activity and participates in a wasteful process known as photorespiration. In this process it loses fixed CO_2. To overcome this certain plants undergo C4 pathway. Such plants are called C4 plants. For this change these plants have undergone certain changes in anatomy and physiology.

6.3 ANATOMY OF STEM

The anatomy of the monocotyledon and dicotyledon stem is discussed here in detail. There are several differences as well as some similarities are found in between them. The characteristic features of monocotyledon and dicotyledon stems are given below;

6.3.1 Anatomy of monocotyledon stem

It is mainly composed of hard, organised, rectangular cells coated with a waxy substance known as cutin. Generally a typical monocot stem possess a well-developed epidermis, hypodermis, undifferentiated ground tissue, and numerous scattered vascular bundles. Maize, wheat, grass etc are the examples of monocot stems. The general characteristics of monocot stem are:

- Circular stem, may have depressed structures due to the presence of lateral branches.
- Have thick cuticle, single layered epidermis and epidermal hairs are absent.
- Single layered cuticularised epidermis may contain multicellular trichomes.
- Ground tissues are not differentiated into cortex and pith.
- Hypodermis is generally sclerenchymatous.
- It has no distinct endodermis and pericycle.
- Epidermis contains stomata with guard cells.
- Scattered vascular bundles are surrounded by sclerenchymatous bundle sheath cells.
- Each vascular bundle is oval, conjoint, collateral and closed.
- There is no distinction between pith and pith rays.
- Xylem is endarch, phloem is represented only by companion cells, seive tubes and little phloem fibers.
- Secoundry growth of stem is absent.

Example: *Zea mays* (maize) represent as an example of a monocot stem (Fig. 6.1). The detail description or internal structure of *Zea mays* is described in brief under the following sections.

i. **Epidermis**: It is the outermost, cuticularised, parenchymatous, single layer of cells. It is made of barrel shaped cells arranged in a layer. Epidermal stem hairs are completely absent. Epidermis basically provides protection from the mechanical, chemical, physical and biological injuries to the internal tissues.

ii. **Hypodermis:** Just below the epidermis, a layer of compactly arranged sclerenchymatous cells without intercellular spaces is present known as hypodermis. This layer provides strength to the plant.

iii. **Ground tissue**: The ground tissue is inconspicuous or undifferentiated or not well developed parenchymatous region. This region is not differentiated into cortex, endodermis, pericycle, pith and pith rays. The cells of this region are parenchymatous, compactly arranged (toward center) or loosely arranged (toward peripheral), small, and polygonal or round in shape. The scatter vascular bundles are imbedded in ground tissues. These cells contain reserve materials.

iv. **Vascular bundles**: Endodermis and pericycle are not found. The vascular bundles are scattered throughout the ground tissue. The vascular bundles are oval in shape, conjoint, collateral and closed. The vascular bundles may be categorized into two types. The large vascular bundles lie towards the center (less in number) and smaller vascular bundles towards and periphery (more in number). Sometimes the centre of the stele in many monocot plants is free from vascular bundles and is occupied by parenchyma cells, which dry up and disappear at an early stage, thus making stem hollow as in most of the grasses. Each vascular bundle surrounded by a sclerenchymatous bundle sheath which encloses xylem and phloem.

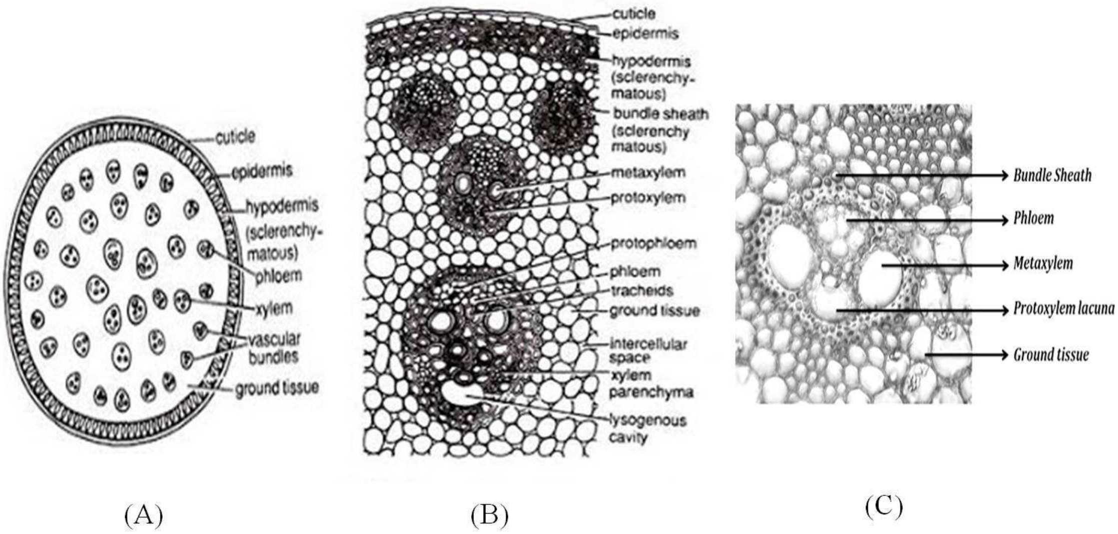

Fig. 6.1: (A): T.S. of Zea mays (diagrammatic) stem, (B): T.S. of Zea mays (cellular) stem and (C): structure of vascular bundle (magnified 400 X).

- **Xylem** consists of vessels, tracheids, xylem parenchyma and limited xylem fibres. Vessel is **Y-shaped** with larger two round pitted metaxylem vessels forming the arms and smaller annual or spiral protoxylem vessels, forming the base. The xylems are endarch with outer metaxylem and inner protoxylem.
- **Phloem** lies outside the xylem in the vascular bundle. It consists of sieve tubes, companion cells and phloem fibers, but lacks phloem parenchyma. The outer phloem is protophloem and functional metaphloem lie inner portion.

The cambium is absent, which means that monocotyledon stem usually do not have secondary growth. Pith region are not clearly distinguished in the stem. There is no distinction between pith and pith rays.

6.3.2 Anatomy of a dicotyledon stem:

A typical dicot stems represented by a well-defined epidermis having cuticle, a layer of dermis along with multicellular stem hair. The internal structure of a dicot stem mainly consists of epidermis, hypodermis, well developed cortex region, endodermis, pericycle, vascular strand, and well defined pith region. Sunflower and Cucurbita are examples of dicot stems. A typical dicot stem show the following characteristics:

- Presence of well-defined epidermis with cuticle and multicellular stem hairs.
- Well developed collenchymatous cortex is present.
- Hypodermis regularly or as discontinuous patches.
- Endodermis is distinct as the innermost layer of the cortex.
- Pericycle composed of parenchyma and sclerenchyma alternately as irregular patches.
- Vascular bundles are conjoint, collateral, endarch, and open, arranged in a ring.
- Cambium cells are present in between xylem and phloem.
- The center region of the stem is occupied by a well developed of pith, made up from thin walled parenchyma cells with distinct intercellular spaces.
- Pith rays or medullary rays are found as separator of two vascular bundles.
- Secoundry growth in stem is present.

Example: *Helianthus annus* (sun flower) represent as an example of a dicot stem (Fig. 6.2). The detail description or internal structure of *Helianthus annus* is described in brief under the following sections.

(i) Epidermis: The epidermis consists of a single layer of barreled shaped cells and is the outermost layer of the stem. It contains stomata and produces various types of trichomes. The epidermal multicellular stem hairs help in protection and heat loss. The outer cell walls are greatly thickened and heavily cutinized. The cells are compactly arranged and do not possess intercellular spaces. In transverse section the cells appear almost rectangular. It serves mainly for restricting the rate of transpiration and for protecting the underlying tissues from mechanical injury and from disease producing organisms.

(ii) Cortex: The region that lies next to the epidermis is the cortex. The cortex region is well defined and can be divided into three region;

- Hypodermis: It is the outer most layer just beneath the epidermis consists of 3-5 layers of collenchymas cells without intracellular space. It is a photosynthetic active region having deposition of cellulous with pectin. It gives the mechanical support to the plant.
- General cortex: After hypodermis a region of intercellular space with resin ducts, each surrounded by a layer of small thin walled spherical or oval cells is present called general cortex. It is made from loosely arranged parenchymatous. The cortical cells may contains chloroplast and perform photosynthesis.
- Endodermis: The innermost layer of the cortex is the endodermis, also known as the starch-sheath. It consists of a single layer of cells which surrounds the stele and contains numerous starch grains. Frequently it is most easily distinguishable from the surrounding tissue by the presence of these starch grains.

(iii) Stele: The part of the stem inside the cortex is known as the stele. The stele consists of three general regions-the pericycle, the vascular bundles and the pith.

a. **Pericycle:** The region between the vascular bundles and the cortex is known as the pericycle. It is generally composed of parenchyma and sclerenchyma cells. The sclerenchyma may occur as separate patches or as a continuous ring in the outer part of the pericycle forming a sharp line of demarcation between the stele and the cortex. The sclerenchyma cells in the pericycle are like other sclerenchyma cells in being long, thick walled dead cells which serve as strengthening material.

b. **Vascular bundles:** The vascular bundles as seen in cross section are conjoint, collateral, open and arranged in a ring (eustele). Each vascular bundle consists of three parts.

- **Xylem**: The xylem which is formed before the activity of the cambium is called primary xylem. It is composed of two parts. The xylem formed first is nearest the centre of the stem and is called protoxylem. The more peripheral part of the primary xylem is called as metaxylem. The xylem is composed of three different types of cells-tracheary cells that include tracheids and vessels, wood fibres and wood parenchyma. The diameter of vessels is usually much greater than that of tracheids. They form long tubes and constitute the principal water conducting elements of the dicotyledon stem. The tracheary cells may be divided into several types according to the method by which the walls are thickened.

Annular tracheary cells have thickening in the form of rings, while spiral tracheary cells have spiral thickenings. Pitted tracheary cells have walls which are uniformly thickened except for thin place in the form of pits. When ladder like thickenings are present, the vessel is said to be scalariform.

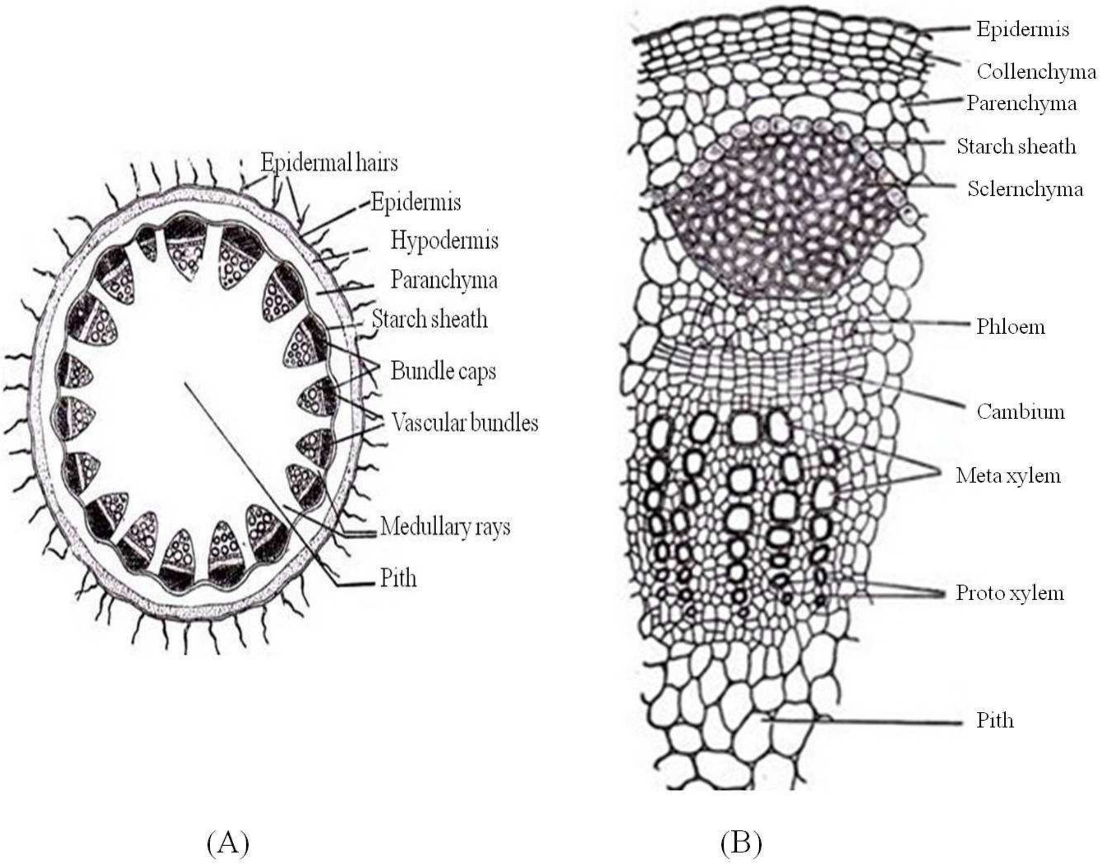

Fig. 6.2: Transverse section (T.S.) of young stem of Helianthus annus (diagramatic)

- **Phloem**: The primary phloem of the dicotyledon stems consists of three types of cells- sieve tubes, companion cells and phloem parenchyma. The sieve tube consists of thin-walled, elongated cells arranged in vertical rows. The sieve tubes serve primarily for the conduction of food material. The companion cells are small cells which are attached to the sieve tubes. Each companion cell is the sister cell of a sieve tube cell, the two being formed by the division of a mother cell.

- **Cambium**: There lies a layer of meristematic cells between the xylem and the phloem known as cambium. The cambium consists of a single layer of cells which by division gives first to xylem cells toward the centre of the stem and phloem cells toward the periphery. At first the cambium is confined to the bundles, but later the parenchyma cells of the pith rays which lie between the edges of the cambium in the bundle divide and form a layer of cambium which reaches across the pith rays and connects that in the bundles, so that the cambium becomes a continuous cylinder.

- **Pith rays**: The vascular bundles are separated from each other by radial rows of parenchyma cells known as pith rays. The pith ray cells are usually elongated in a radial direction. They serve primarily for the conduction of food and water radially in the stem and for the food storage.

c. **Pith:** In a dicotyledon stem the centre has thin-walled parenchyma cells known as the pith. The cells have distinct intercellular spaces and occupied the central portaion of the stem.

Variations in stem structure of dicot plants

The description given above is typical type of dicotlydon stem, but there may be some minor variations.

- The pith may be wide or narrow and when it disappears the stem becomes hollow.
- The vascular bundles vary considerably in number and size, while the pith rays and cortex varies in width.
- When phloem is present on the outer side of xylem it is called as collateral bundle and when it is present on both outer and inner side of xylem it is called bicollateral. E.g., *cucurbita* stem.
- In the stem of *Aristolochia,* just beneath the uniseriate layer of epidermis a few layers (2-3) of collenchyma are present. The pericycle region consists of a continuous band of sclerenchyma. Seven bundles are arranged in a ring.

The monocot and dicot plants are different kind of plants, however, they have some similarities in their stem anatomy which are listed as;

- Epidermis is usually single layered in both the plants.
- Thick layer of cuticle are present.
- Hypodermis is present in both the group of plants.
- Photosynthetic chlorenchymatous zone is present in the cortex region in both the group.
- Major portion of the groud tissue is paranchymatous.
- Xylem and phloem are organized as a vascular bundles.
- Vascular bundles are conjoint and collateral.
- Xylem and phloem composed of both proto and meta elements

Despite of having many similarities they are quite different in their anatomical characteristics. The over view of the difference between mono and dicotlydon stems are given in table 6.1.

Table 6.1: Differences between monocotlydon and dicotlydon stem

Particular	Dicotlydon	Monocotlydon
Physical state	Usually solid	Usually hollow at the centre
Hypodermis	Formed of collenchyma fibres which are often green in colour.	hypodermis is made of sclerenchyma fibres, and they are not green.
Epidermal	Epidermal hair may or may not exist.	Presence of epidermal hair.
Trichomes	Trichomes is present	Trichomes is absent.
Ground tissue	The ground tissue is differentiated as endodermis, cortex, pericycle, medullary rays, pith, etc.	The ground tissue is the same and is composed of a mass of similar cells.
Vascular bundles	The vascular bundles are formed as broken rings. They are conjoint, collateral and open.	The vascular bundles are scattered irregularly around the ground tissue. They are Conjoint, collateral and close.
	Vascular bundles are less in number and are of uniform size.	There are numerous vascular bundles of different sizes.
	The vascular bundles always remain open, due to the presence of cambium within phloem and xylem.	The vascular bundles are closed.
	The Dicot stem does not have a bundle sheath on the outside of a vascular bundle.	The monocot stem has a sclerenchymatous bundle sheath on the outside of a vascular bundle.
	Phloem parenchyma is present.	Phloem parenchyma is absent.
	Xylem vessels are of a polygonal shape and are arranged in rows or chains.	Vessels are rounded or oval and are arranged Y-shaped formation.
	Usually, vascular tissues stop functioning when they get old. New vascular tissues replace the old ones.	Vascular tissues remain the same throughout the plant’s life cycle.
Secondary growth	Dicot stem can feature secondary growth as a result of secondary vascular tissues and periderm formation.	No secondary growth is witnessed in case of monocots.
Pith	Pith is well-developed.	Pith is not as well-developed in monocots
	Pith rays are present.	Pith rays are absent.

6.4 ANATOMY OF C3 AND C4 PLANT LEAVES

The path of carbon in photosynthesis includes those reactions which incorporate carbon into more reduced or more energetic compounds. CO_2 can be fixed by three major and one minor pathway.

- The first is C3 cycle or Calvin cycle as the first product formed is a C3 compound (3 Phosophoglyceric acid, PGA).
- The second is C4 cycle as the first product is C4 compound (malate and aspartate).
- The third is known as Crassulacean acid metabolism and the minor is known as C2 cycle (C2 photorespiratory carbon oxidation cycle).
- The aquatic algae show another unique pathway known as C1 pathway.

C3 plants: C3 cycle is found in nearly all plants (nearly 85%) including wheat, rice, soybean and all tree etc. C3 plants undergo Calvin cycle to produce the final product. The first step of the Calvin cycle is the fixation of carbon dioxide by rubisco, and plants that use only this mechanism of carbon fixation are called C3 plants for the three-carbon compound (3-PGA) as the final the reaction produces.

The enzyme RuBisco (Ribulose 1, 5 bi phosphate carboxylase also called as carboxymutase) is located on the stromal surfaces of thylakoid membranes. It is synthesized in the chloroplasts itself. Besides catalyzing carboxylation of RuBP the enzyme can also oxygenase this substrate to produce phosphoglycolate, as is the case in photorespiration.

C4 plants: In 1965 H.P. Kortschak, C.E. Hartt and G.O. Burr found that malate was the first product of CO_2 fixation in sugarcane leaves. M.D. Hatch and C.R. Slack (1970) also confirmed the above observation. They worked out the entire pathway and gave C4 cycle also called as Hatch and Slack pathway. After wards it was observed in many tropical grasses and some dicots. C4 plants are common in habitats that are hot, but are less abundant in areas that are cooler. The C4 pathway is used in about 3% of all vascular plants. E.g., crabgrass, sugarcane and corn etc.

The C3 plants have normal anatomy but C4 plants have a peculiar type of leaf anatomy, called as Kranz anatomy (kranz = wreath or border) which is different from C3 plants. In Kranz anatomy the vascular bundles of leaf are bounded by large chloroplast containing bundle sheath cells having chloroplast (Fig. 6.3). The mesophyll cells also have chloroplasts as in C3 plants. These cells are thick walled, radially arranged and highly developed. This ring of bundle sheath cells is in turn surrounded by one layered mesophyll cells which are denser and compact that in C3 plants. There is a possible division of labor between chloroplasts of these two types of cells since initial fixation of CO_2 occurs in the mesophyll cells and the products are transported to bundle sheath chloroplasts where these are converted to starch and eventually translocated to a carbon sink.

Mesophyll chloroplasts are small and usually do not contain starch while bundle sheath cells chloroplasts are large with starch. Mesophyll chloroplasts have well developed grana where as bundle sheath chloroplasts have no grana or rudimentary grana. However they lack ribulose biphosphate carboxylase activity, which is present in the mesophyll chloroplasts of C3 species.

The large bundle sheath chloroplasts on the other hand, usually lack grana when mature, and they frequently accumulate much starch. These chloroplasts do have ribulose bisphosphate carboxylase activity and thus can synthesize phosphoglyceric acid from CO_2 and ribulose bisphosphate.

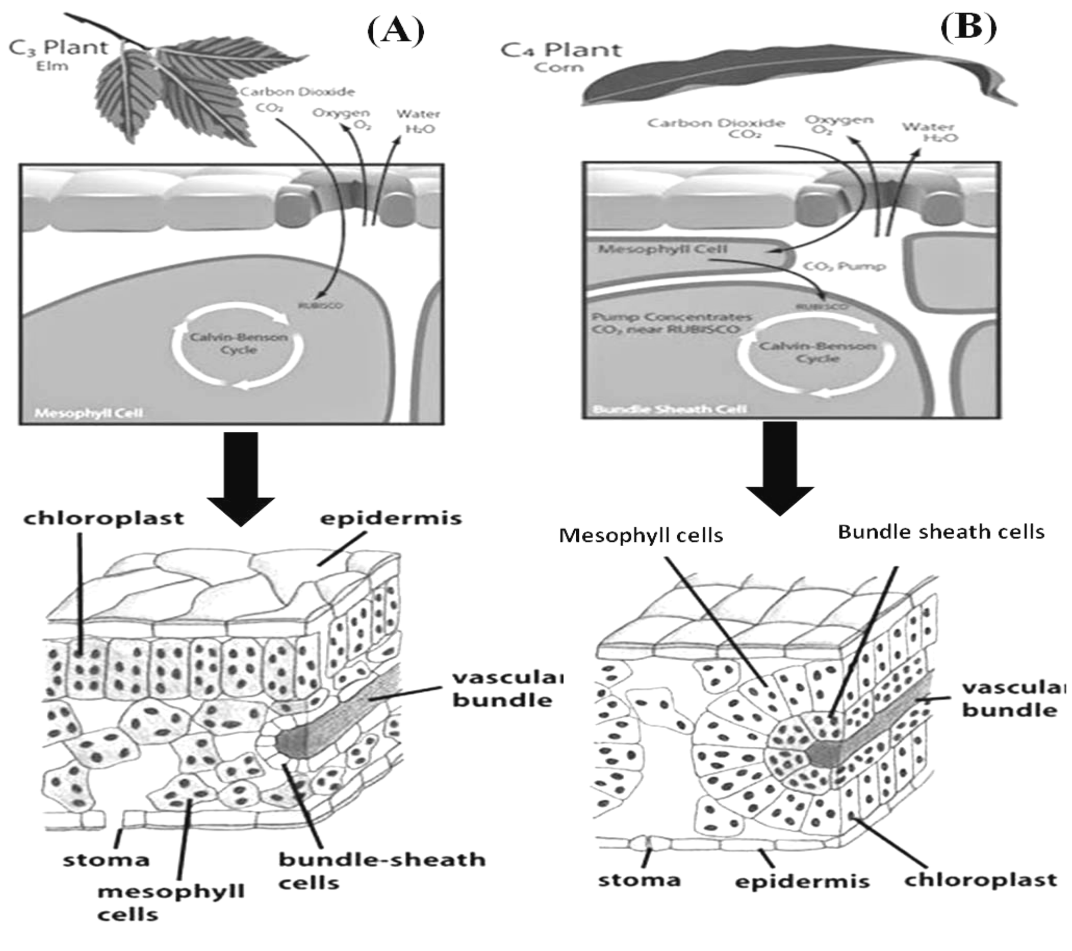

Fig. 6.3: Diagram showing difference between C3 and C4 plant leaves

In overall photosynthetic CO_2 assimilation in C4 species there is a co-operation between bundle sheath chloroplasts and mesophyll chlorplasts. Kranz anatomy is thus an adaptation which achieves a CO_2 concentration in the internal tissues which inhibits photorespiration and subsequent loss of CO_2. Furthermore less O_2 concentration is likely to be associated with relatively less PSII (photosystem II) activity of bundle sheath chloroplasts lacking well developed grana and this situation seem to minimize O_2 inhibition.

Table 6.2: Differences between C3 and C4 plants

S.N.	C3 plants	C4 plants
Example	Wheat, rye, rice, cotton, sunflower, chlorella	Maize, sugarcane, sorghum, amaranths
Plant Anatomy	Majority of plant is C3 on earth.	C4 plants are less in number.
	Leaves are simple type	Specialized Kranz anatomy.
	Perform photosynthesis when stomata are open.	Perform photosynthesis even when the stomata are closed.
	Bundle sheath cells do not contain chloroplasts.	Bundle sheath cells contain chloroplasts.
	Chloroplasts monomorphic (single type) in C3 plants.	Chloroplast dimorphic: those in the bundle sheath are large agranal and those in mesophyll are small and granal.
	Chloroplast do not contain peripheral reticulum	Chloroplast do have peripheral reticulum
Habitat	They are cool season plants commonly seen in cool and wet areas.	They are warm season plants, commonly seen in dry areas.
	The optimum temperature for photosynthesis in C3 plants is very low (18-24^{o}C)	The optimum temperature for photosynthesis in C4 plants is high (32-55^{o}C)
	Growth of C3 plant take place when the soil temperature reach 4-7^{o}C	Growth of C4 plant take place when the soil temperature reach 16-21^{o}C
Pathway	C3 cycle is evolved about 2.5 billion years ago.	C4 cycle is comparatively recent in origin, evolved about 12 million years ago.
	C3 plants uses C3 cycle or Calvin cycle for dark reaction of photosynthesis.	C4 plants uses C4 cycle or Hatch Slack pathway for dark reaction of photosynthesis.
	CO_2 fixation take place only at one place	CO_2 fixation takes place twice (one in mesophyll cells and second in bundle sheath).
	The complete steps of dark reaction take place in the mesophyll cells only.	The mesophyll cells will only do the initial steps of C4 cycle. Subsequent steps are carried out in bundle sheath cells.
	Possess only one CO_2 acceptor.	Possess two CO_2 acceptor.
	The atmospheric CO_2 acceptor is RuBP (Ribulose 1-5- biphosphate).	The first CO_2 is PEP (Phosphoenolpyyuvate).
	No secoundry acceptor is present.	The second atmospheric CO_2 acceptor is RuBP

	The CO_2 compensation point is high (about 50 ppm) in C3 plants. The CO_2 fixation is slow in C3 plants.	The CO_2 compensation point is high (2 to 5, even 0 ppm) in C4 plants. The CO_2 fixation is comparatively faster in C4 plants.
First product	The first stable product in C3 cycle is a 3 carbon compound i.e., Phosphoglyceric acid (PGA) The rate of translocation of the end product of photosynthesis is very low in C3 plants.	The first stable product in C4 cycle is a 4 carbon compound i.e., Oxaloacetic acid (OAA). The rate of translocation of the end product of photosynthesis is very fast in C4 plants.

In C4 grasses, bundle sheath cells (BS) surround the veins and these cells are then surrounded by mesophyll cells (M). The two adjacent veins are thus separated by two BS and two M cells in a V-BS-M-M-BS-V pattern where as C3 plant is typically V-BS-M-M-M-M-M-BS-V pattern.

In C4 grasses bundle sheath cells (BS) surround the veins and these cells are then surrounded by mesophyll cells (M). The two adjacent veins are thus separated by two BS and two M cells in V-BS-M-M-BS-V patterns where as C3 plant is typically V-BS-M-M-M-M-M-BS-V pattern leaves. Both the C3 and C4 plants show some similarity and dissimilarity (Table 6.2) in between them which are describe in brief.

Similarities:

- Both C3 and C4 are types of dark reaction.
- Both plants fix energy from sunlight.
- Both plants synthesize carbohydrates.
- The general equation of photosynthesis is similar in both the plants.
- Both plants require 6 molecules of CO_2 and 12 molecules of water to synthesize one molecule of glucose.
- The carbohydrate product of both C3 and C4 cycle is three carbon sugar phosphate molecules called glyceraldehyde 3 phosphate (G3P).
- Both plants require chloroplast for doing photosynthesis.
- The light reaction of photosynthesis is similar in both the plants.
- RuBP can accept CO_2 in both plants.

6.5 SUMMARY

The monocot stem is differentiated into an epidermis, a cortex and a stele. No epidermal hairs are present. Sclerenchymatous hypodermis is a usual feature. The cortex may be well developed and sharply marked off from the stele, or it may be quite narrow and inconspicuous. Endodermis is absent. The bundles are scattered throughout the stele, including the pith so that there is no distinction between pith and pith rays.

The bundles are oval shaped. The xylem is towards centre of the stele and phloem towards periphery. Cambium is absent which shows absence of secondary thickening and thee bundles are many in number.The dicot stem has three distinct regions-the epidermis, the cortex and the stele. The epidermis contains stomata and trichomes. The cell wall is thickened and heavily cutinized. The innermost layer of the cortex is the endodermis, known also as the starch-sheath.

On the innerside of the epidermis there is usually a band of collenchyma which serves as strengthening material in some plants. Rests of the cells are parenchyma which helps in conduction of water and food and also act as special storage organ of plants. Sclerenchyma, stone cells and sclereids are also present in some cases. The peripheral portion of the bundle is composed of thin walled cells called phloem.

The vascular bundles are xylem and phloem which are separated by a cambium layer. The xylem is made up of protoxylem and metaxylem. The xylem is made up of tracheary cells, that include tracheids and vessels, wood fibres and wood parenchyma. The phloem of the dicot stems consists of three types of cells-sieve tubes, companion cells and phloem parenchyma.

In plants CO_2 can be fixed by three major and one minor pathway. These pathways are named according to the first stable product formed after CO_2 fixation. The first is C3 cycle or Calvin cycle as the first product formed is a C3 compound (3 Phosophoglyceric acid, PGA) and the second is C4 cycle as the first product is malate and aspartate. The C3 plants have normal anatomy but C4 plants have a peculiar type of leaf anatomy, called as Kranz anatomy (kranz = wreath or border) which is different from C3 plants.

In Kranz anatomy the vascular bundles of leaf are bounded by large chloroplast containing bundle sheath cells. These cells are thick walled, radially arranged and highly developed. This ring of bundle sheath cells is in turn surrounded by one layer of mesophyll cells having chloroplasts which are compact and denser than in C3 leaves. Kranz anatomy is an adaptation which achieves a CO_2 concentration in the internal tissues which inhibits photorespiration and subsequent loss of CO_2.

6.6 GLOSSARY

Bundle sheath: These are photosynthetic cells arranged into a tightly packed sheath around the vein of a leaf.
C3 cycle or Calvin cycle: When the first product formed is a C3 compound (3 Phosophoglyceric acid, PGA).
C3 plants: Those plants which uses calvin cycle for dark reaction of photosynthesis. E.g. wheat, rye, cotton. These plants show C3 cycle.

C4 cycle or Hatch slack pathway: When the first product is a C4 compound (malate and aspartate).
C4 plants: Those plants which uses Hatch Slack pathway for the dark reaction of photosynthesis. E.g. maize,s ugarcane, sorghum. These plants show C4 cycle.
Collateral vascular bundle: When phloem is present on the outer side of xylem.
Collateral: It is a vascular bundle in which xylem and phloem lie on same radius, phloem on outerside and xylem towards center.
Endodermis: It is the innermost layer of the cortex, consists of barrel-shaped, elongated, compact cells, having no intercellular spaces among them.
Kranz anatomy: It is a special structure in the leaves of C4 plants where the tissue equivalent to spongythe vascular bundles of leaf are bounded by large bundle sheath cells having chloroplast and then mesophyll cells is clustered in a ring around the leaf veins outside the bundle sheath. having chloroplasts.
Metaxylem Sclereids: These are reduced form of sclerenchyma cells with highly thickened, lignified cellular walls. e.g. apple and guavas.
Metaxylem: The more peripheral part of the primary xylem and phloem lie opposite to is called as metaxylem.
Pericycle: It is the region between the vascular bundles and the cortex.
Photorespiration: A respiratory process in which plants take oxygen in the light and give out carbon di oxide.
Photosystem II: The primary function of this is hydrolysis of water and ATP synthesisstele. It is a specialized protein complex that uses light energy to driveconsists of pericycle, the transfer of electrons from water to plastoquinone, resulting in vascular bundles and the production to oxygen and the release of reduced plastoquinone into the photosynthetic membrane.
Plastoquinone: It is involved in the electron transport chain in the light dependent reactions of photosynthesis.
Protoxylem: The xylem formed first is nearest the centre of the stem and is called protoxylem.
RUBISCO: It is short name of enzyme Ribulose 1,5 biphosphate carboxylase oxygenase that catalyses the first major step of carbon fixation.

6.7 SELF-ASSESSMENT QUESTIONS

6.7.1. Multiple choice questions:

1. In a dicot stem
    (a) The vascular bundles are scattered
    (b) The vascular bundles are arranged in a ring
    (c) Xylem and phloem occur in separate bundles
    (d) Xylem is always exarch

2. In monocot stem the hypodermis is
    (a) parenchymatous (b) chlorenchymatous
    (c) collenchymatous (d) sclerenchymatous

3. Bundle sheath is present in
    (a) Dicot stem (b) Monocot roots

(c) Monocot stem (d) C4 leaf

4. Kranz anatomy is present in
   (a) C1 plants (b) C2 plants
   (c) C3 plants (d) C4 plants

6.7.1 Answers Key: 1(b); 2(d); 3(d); 4(d)

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6.10 TERMINAL QUESTIONS

6.10.1 Short answer questions:

Q.1 What is assimilatory parenchyma?

Q.2 What types of cells are present in hypodermis of herbaceous plants?

Q.3 What is starch sheath?

Q.4 Where do you find large pith cavity.

Q.5 Name any five plants showing C4 cycle

6.10.2 Long answer questions:

Q.1 Discuss how C3 and C4 plants differ in their anatomy from each other with suitable diagrams.

Q.2 Differentiate how dicot and monocot leaves differ from each other with suitable diagrams.

BLOCK-3- ANOMALOUS GROWTH

UNIT-7: ROOT-STEM TRANSITION AND SHOOT AND ROOT DEVELOPMENT

Contents:

7.1 OBJECTIVES

- By now you all have come to know about the vasculature in root and stem. In root the bundles are radial and xylem and phloem lay on different radii but in stem the xylem and phloem comes together in vascular bundles.
- In this unit you will come to know how vascular bundles change their orientation and number when they enter stem from root and also about shoot and root development.

7.2 INTRODUCTION

The root and stem together make a continuous structure called the axis of the plant. The vascular bundles are continuous throughout root and shoot. The epidermis, cortex, endodermis, pericycle and secondary vascular tissues are directly continuous in these two organs but the arrangement of vascular bundles is quite different in these organs.

In root the protoxylem develops in peripheral region and metaxylem in the centre. The orientation of xylem maturation is thus centripetal and it is called exarch. In stem protoxylem develops in the centre, thus orientation is centrifugal and the xylem is called endarch.

In root the bundles are radial while in stem they are conjoint. There is special region where these changes take place. The change of xylem position by inversion and twisting from exarch to endarch is referred to as vascular transition and the region where this change takes place is called Transition region.

This region can be very small or sometimes few centimeters long. The position of change can be in the top of radicle or base of hypocotyls, in its middle or in the upper part.

7.3 ROOT STEM TRANSITION

In plants there is a region where the transition from radial to conjoint type of bundles takes place; this is called transition region. This is also known as hypocotyl region. In this region the metaxylem rotates by 180^o around its longitudinal axis whereas protoxylem does not take part in rotation. The rotation may take place in a number of ways. Eames and MacDaneal (1947) described four types of root stem transition in plants.

1. **Type A/Mirabilis type/4-4:** In this type of root stem transition each xylem strands forks by a radial division. Each xylem strands in the root divides radially into two branches. The branches turns 180^o one to the left and other to the right and joins phloem of the respective strand. The phloem strands do not change its position as they pass directly from the root to the stem. The number of vascular bundles formed in the stem will be equal to the number of phloem strands in the roots. This type of root-stem transition occurs in *Mirabilis, Fumaria* and *Dipsacus.*

2. **Type B/Cucurbita type/4-8:** In this type both xylem and phloem strand divide in two strands. The xylem turns through 180^o and joins one phloem strand each. Thus the number of bundles increases to double in stem as compared to roots. It is found in *Cucurbita*, *Acer*, *Phaseolus* and *Tropaeolum*.

3. **Type C/Lathyrus type/4-4:** In this type phloem gets forked. The xylem rotates by 180^o. The phloem halves moves laterally to take position and fuses with adjacent phloem and xylem. Thus the number of bundles remains unchanged. E.g. *Lathyrus*, *Medicago* and *Phoneix*.

4. **Type D/Anemarrhena Type/4-2:** This type is rare. Half of the xylem gets forked. Both divided and undivided bundles gets inverted. The divided xylem moves laterally and fuses with undivided xylem. This xylem complex fuses with the phloem. Thus the number of bundles becomes half in shoot as compared to root. E.g. *Anemarrhena* and some monocotyledons. All the four types of transitions have been shown in Fig. 7.1.

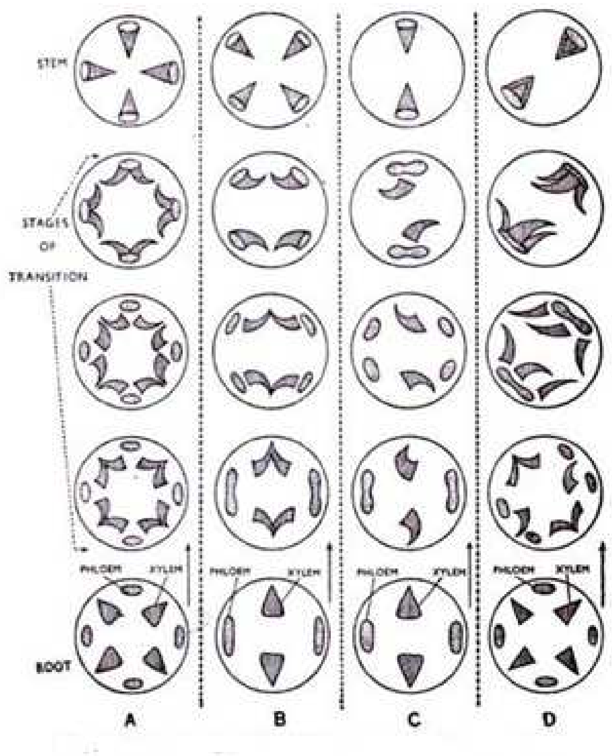

Fig.7.1. Root-Stem transition: Type A, Type B, Type C, Type D

In monocotyledons this situation is very complicated and different from dicotyledons as there is only a single cotyledon. These bundles of the roots fuse with that of the cotyledon and even with the leaf bundle. The transition region is very small in monocots.

Scheirer and Hilson (1973) found a special type of transition in *Helianthus annuus*. In this the bundles becomes 6 from 4. Bisalputra (1961) found in Chenopodiaceae that the vascular connection is between root and cotyledon and not between root and stem.

Thus various types of patterns are found due to differences in phyllotaxy (Sporne, 1974). In many cases there is another region which is known as mesocotyl. The mesocotyl is formed by the fusion of hypocotyl with the neck of the cotyledon. This position of cotyledonary bundle is very different. It is found in cortex. E.g., *Carex*. In other cases it is found deep in pericycle. E.g. *Juncus*. In some other plants it is found within the stele of hypocotyl. E.g., *Panicum*. In extreme cases it is not differentiated from hypocotyl stele. It merges with the stele of hypocotyls. E.g., *Zea mays*.

7.4 SHOOT DEVELOPMENT

The part of the axis of the plant which is usually ascending and aerial in nature and bears leaves and reproductive structures is known as stem. The stem together with leaves constitutes shoot. The stem bears nodes and internodes. The shoot development in various plant groups has already been discussed in SAM (Shoot apical meristem) unit. Here we discuss the three important theories that explain the development of shoot in breif.

7.4.1 Apical cell theory

This theory was proposed by Hofmeister in 1857 and supported by Nageli (1878). According to this theory there is a single pyramidial cell in the shoot apex of vascular plants. This cell takes part in shoot formation and its development. Apical cell theory is found appropriate in case of some algae, bryophytes and pteridophytes but this theory is not applicable for gymnosperms and angiosperms as these plants possess many cells instead of a single apical cell (Fig. 7.2).

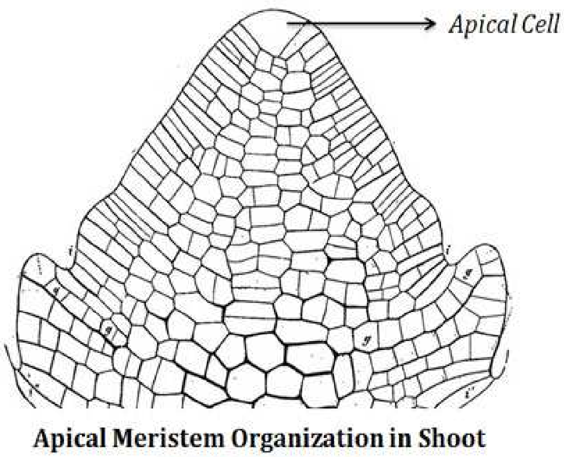

Fig 7.2 Apical meristem organization in shoot

7.4.2 Tunica Corpus theory

The Tunica Corpus theory was proposed by Schmidt. According to this theory the shoot apex has two zones (Fig. 7.3).

Tunica: It consists of one or more layers of cells and undergo periclinal division ot anticlinal devision to give rise to epidermis, leaf and axillary bud primordial.

Corpus: It is the central region whis is surrounded by the layers of tunica. Corpus cells devide irregularly in almost all planes to gice rise to endodermis, pericycle, cortex, xylem, phloem and pith.

The Tunica corpus theory is rather descriptive and does not predict the relationship berween the apical zonation and the formation of respective tissues. However this theory explains the formation of epidermis from the outer layer of tunica.

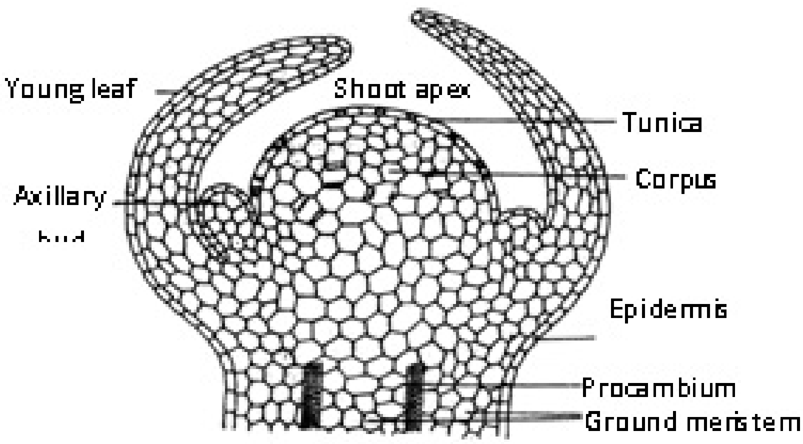

Fig. 7.3 L. S. vegetative shoot apex showing Tunica corpus region

7.4.3 Histogen Theory

This theory was given by Hanstein in 1870. According to this theory the shoot apex comprises of three distinct meristematic zones. Each zone or layer consists of a group of initials which is called as Histogen. Hence the shoot apex has three histogens.

Dermatogen : this is the outermost single nerved layer and form epidermis of shoots.
Periblem: it is the middle layer composed of isodiametric cells. These cells give rise to primary cortex.
Pleroma: it is the innermost layer which gives rise to the vascular cylinder which in turn comprises of primary xylem and phloem, medullary rays and pith.

However the histogen theory was not accepted because there is total absence of clear distinction between dermatogens and periblem. These tissues (dermatogens and periblem) were supposed to be produced by particular histogen were sometimes formed by another histogen for example the dermatogens which is supposed to produce epidermis also forms the cortex which is supposed to form by Periblem.

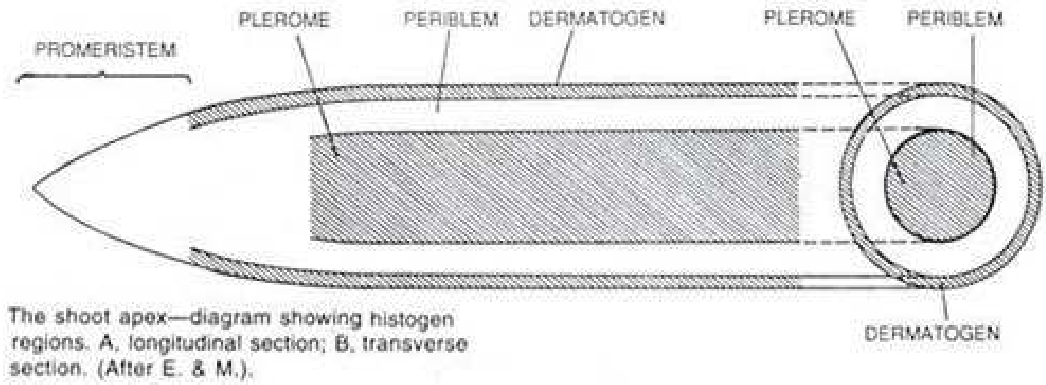

Fig. 7.4 shoot apex diagram showing histogen regions

Besides the above theories there are two more theories explaining the shoot development.

7.4.4 Mantle-Core Theory

Propham and Chan (1950) proposed this theory. This theory explains the division in peripheral tissues in shoot apical regions of some angiosperms. This theory is similar to tunica-corpus theory. This theory does not explain about the division ofcells; it only states that mantle is peripheral cellular region of the shoot apex. Mantle covers the central core region (Fig. 7.4).

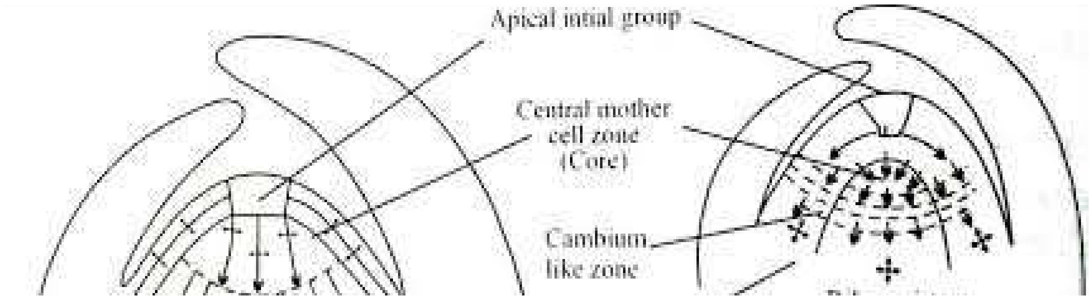

Fig. 7.5 Scheme of LS of shoot apex, according to Mantle-Core Theory (arrows indicate growth).

7.4.5 Histogen Layer Theory

Dermen (1947) proposed histogen layer theory. According to this theory, shoot apex of angiosperms is organized in three layers. Which may be called as L-I, L-II and L-III. According to this theory, epidermis of leaves and stem develop from LI; hypodermis, cortex and some

regions of the vascular bundle develop from L-II; while vascular tissues and medulla develop from L-III. This theory may be considered as a modified version of histogen theory.
The first stem meristem is organized during the development of the embryo. The embryo axis has at its upper end, one or more cotyledons and the shoot primordium, whereas at its lower end it bears root primordium covered with root cap. The embryonic shoot is found above the cotyledons. This shoot has an axis having unextended internodes and one or more leaf primordia.

This shoot (first bud) is commonly known as plumule and its stem part is called epicotyl. The hypocotyl located below the cotyledonary node, it is the transition zone between the shoot and root. It pushes the cotyledons above the ground to develop. It eventually becomes part of the plant stem. The cotyledons are the first leaves.

During seed germination the shoot meristem develops the first shoot by adding new leaves, nodes and internodes. The lateral stems normally arise by the development of new apical meristems laterally in the mother axis. Axillary buds also form shoots; these are present in the angle between leaf and stem i.e. in the leaf axil. In some plants, adventitious buds are also present which develops from the older parts of shoot and root remote from the main apices.

A lateral shoot apex is initiated on the flanks of the main apex but at some distance below the point of emergence of the youngest leaf primordium. In some species a tunica of more than one cell layer quickly forms so that the new apex appears. The differentiation starts only when the new primordium has attained considerable mass. The new apex must reach a minimal volume before it in turn can begin to form its own lateral primordia and to organize true axillary buds.

As in the main apex the formation of new primordia is associated with the annular zone, the lateral shoots also develops in the same manner. But the growth in lateral shoot is not fast in comparison to main apex, as it is absorbing much of the available nutrients. The axiallary bud grows very fast initially but as some leaf primordia are formed, the apical activity slows down. Cell division gradually stops. The bud in effect passes into a state of dormancy even though the external condition is suitable. This phenomenon is known as correlative bud inhibition.

The differentiation of the vascular system appears below the apex, in a zone of tissue which is recognized by a small area of cells. These cells make the procambium zone, by divisions at right angle to the axis and may form a complete cylinder. Further the vascular bundles, increase in thickness by more cell divisions and makes connection with the vascular systems of axillary buds. The cells differentiate to make phloem vessels, phloem parenchyma and phloem fibers toward outside and xylem vessels towards the inner side. The differentiation occurs in an upward direction so that the maturation of the vascular tissues follows at a more or less constant distance behind the apex. This is applicable for gymnosperms and ferns.

In older stems of dicots the stem increases in diameter by the activity of the cambium which makes secondary vascular tissues. When secondary thickening begins the parenchymatous cells between the vascular bundles also resume division ultimately forming a cambium cylinder. In many monocotyledons the vascular strands that pass down from each leaf primordium into the stem do not contribute to a single cylinder as the vascular bundles are scattered in the ground tissue of the stem.

7.5 ROOT DEVELOPMENT

The roots are generally divided into two categories:

i. Primary: normal roots, which originate from the embryo and usually persist throughout life and
ii. Adventitious roots: which arise secondarily from stem, leaf or other tissues and which may be either permanent or temporary.

The roots have a tendency to grow downwards or sideways rather than upwards and they do not bear leaves. They are endogenous in origin and branching. They have a relatively short zone of growth at the apex. The root apex has already been discussed in RAM (root apical meristem). Here we will discuss about the development of lateral roots. But some theries of root development are worth mentioning.

7.5.1 Apical Cell Theory:

This theory was proposed by Nageli who believed the occurrence of single apical cell or apical initial that form the root meristem. A single apical cell is present only in some alga, bryophytes and pteridophytes. The apical initial or the apical cell is tetrahedral in shape and generates root cap from one side. The rest three sides contribute cells to form epidermis, cortex and vascular cylinder. In other words all tissues that form a mature root with root cap are derived from a single apical cell. Thus the apical cell theory is confined to vascular cryptogams only as the root apical meristem of gymnosperms and angiosperms do not possess a single apical cell instead they have group of cells for root development.

7.5.2 Histogen Theory:

Hanstein (1868) developed this theory. According to him the root apical meristem consists of three cell-initiating zones known as histogens (Fig. 7.5). The histogens are named as dermatogen, periblem and plerome that form epidermis, cortex and vascular cylinder respectively which are present in a mature root. The derivatives of dermatogen vary among plants. In *Zea mays* (monocot) dermatogen generates root cap only and this histogen is referred to as calyptrogen. In *Brassica* (dicot) dermatogen generates both protoderm and root cap and this histogen is referred to as dermatocalyptrogen. Histogen theory explains both root and shoot apical meristem. Though histogen theory is not widely accepted for shoot apex development, Eames and MacDaniels explained the root apical meristem on the basis of histogen theory.

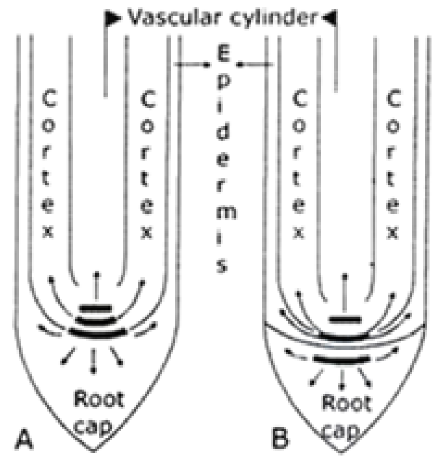

Fig 7.5 Schematic diagram of root apex based on histogen theory A. Raphanus sativa, B. Zea mays where root cap has its own histogen. Broad lines indicate histogens, arrows indicate the direction of cell formation.

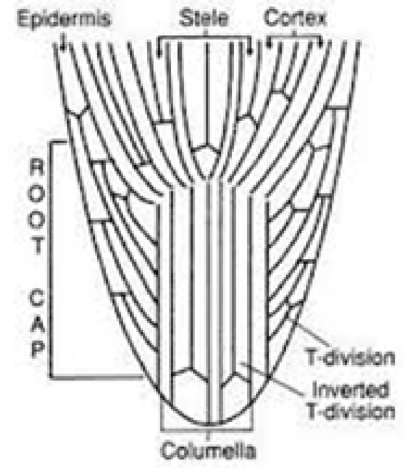

Fig. 7.6 Diagrammatic representation of root apex meristem according to Korper- Kappe theory

7.5.3 Korper-Kappe Theory:

This theory of root meristem organisation was proposed by Schuepp in 1917. Korper-kappe concept is also referred to as body-cap concept (Korper = body and kappe = cap). According to this theory, the cells of root apex are divided into two elements. The first division is of transverse type that forms two cells, out of which one divides anticlinally, this is called T division. In some of the regions of the root apex, especially in the middle area 'T' is seen upright while in rest of the regions, inverted T is seen (⊥). When 'T' is upright, it means this is directed towards the apical portion, but, when 'T' is inverted, it is directed opposite to the apical portion. Schuepp named upright 'T' as Korper or body while inverted 'T' was named as Kappy or cap. This type of division is found in the members of poaceae. This theory is considered to be equivalent to the Tunica Corpus Theory of shoot apex development (Fig. 7.6).

7.5.4 The Quiescent Centre Theory:

This concept was given by Clowes (1958). He studied root apex in *Zea mays* and suggested the presence a cellular region between the meristematic cells and root cap and named it as Quiscent Centre (QC). The cells of this centre produce cells of root. He claimed these cells as the constituent of pro-meristem. At the end, the root meristem is covered by the root cap. The cells of root cap continuously shed-off. The root apical meristem and tissue patterns are formed at the embryo stage in primary root (Fig. 7.7).

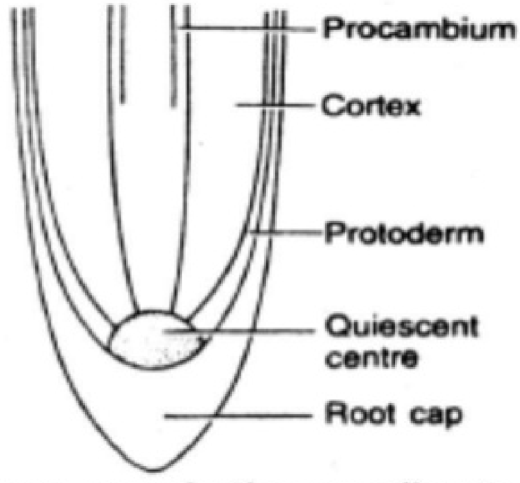

Fig. 7.7: Root apex organization according to quiescent centre theory

The cells of quiescent centre remain inactive till the peripheral cells divide but in unfavorable condition such as roots damage they start to divide. They repair the damage of primary as well as secondary roots. The division of meristematic tissues enables roots and root hair zone to grow. Root cap protects the roots from the damage under the soil. The cells of root cap are impermeable to water while meristematic cells of root apex absorb water and have capability to divide. The function of the quiescent centre may be to provide a reserve block of cells within the root.

Besides primary root development lateral roots also grow. The lateral roots are also endogenous in origin i.e. from inner tissue of mother root normally in pericycle beneath the endodermis (sometimes in endodermis also as in Pteridophytes). Usually lateral roots come out opposite to xylem in vertical rows. The number of lateral roots is equal to number of xylem strands. The pericycle cells against protoxylem become meristematic and begin to divide first tangentially and then periclinally and anticlinally making few layers of cells.

This creates pressure on endodermis which is then pushed outwards and a protrusion is formed which comes out of the cortex. This root is now differentiated into three different zones. The endodermis and some of the cortical cells form root cap. The lateral roots thus pass through cortex and epidermis and enter the soil (Fig. 7.8)

The position of lateral root primordia varies from plant to plant e.g. in diarch they originate between xylem and phloem, in triarch and tetrarch opposite to protoxylem and in polyarch opposite to protophloem as well as protoxylem.

Adventitious roots may occur on the hypocotyls of a seedling, on nodes and internodes. They may be formed in young or older tissues. They also develop endogenously. The roots that arise from stem make the main vascular system in pteridophytes, most of the monocots, in water plants, in saprophytes, in parasites and in those dicotyledons which propagate by means of rhizomes or runners.

The adventitious roots arise in the vicinity of differentiating vascular tissues of the organs from which they arise. In young organs they arise near the periphery of the vascular system. In older organs they arise deeper near vascular cambium. In young stem from interfascicular parenchyma and in older stems from vascular ray. In certain cases from cambial zone.

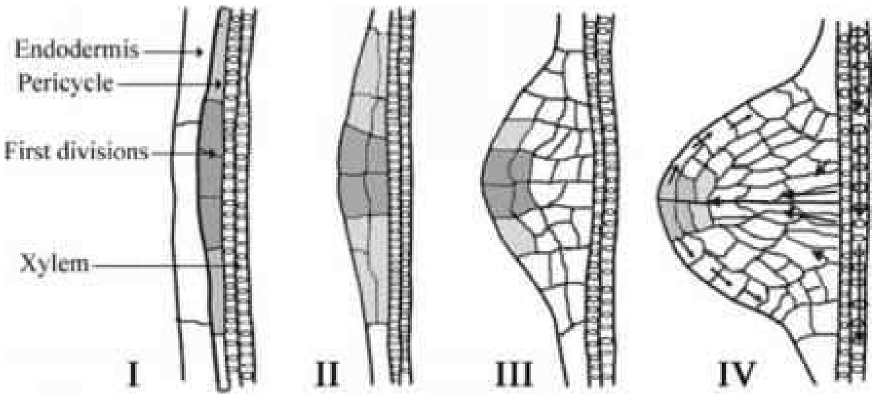

Fig.7.8: Diagram showing lateral root formation

7.6 SUMMARY

The root and stem together makes a continuous structure called as axis of the plant. The vascular bundles are continuous throughout root and shoot. The arrangement of vascular bundles is quite different in these organs. In roots the orientation of xylem is exarch while in stem it is endarch. In roots the bundles are radial while in stem they are conjoint. Transition region is that region where this change takes place. This region can be very small or sometimes few centimeters long. The transition region is very small in monocots.

The rotation may take place in a number of ways as Type A**/Mirabilis type/4-4 where e**ach xylem strand forks by a radial division and the number of bundles remains equal in root and shoot e.g., *Mirabilis, Fumaria*.

In t**ype B/Cucurbita type/4-8 both** xylem and phloem gets forked and thus the number of bundles increases to double in stem as compared to roots. In t**ype C/Lathyrus type/4-4 phloem** gets forked and the number of bundles remains unchanged. In t**ype D/Anemarrhena Type/4-2 which is found rare, only** half of the xylem gets forked and the number of bundles becomes half in shoot as compared to root.

The first stem meristem is organized during the development of the embryo. During seed germination the shoot meristem develops the first shoot by adding new leaves, nodes and internodes to the shoot system formed in the embryo. The lateral stems normally arise by the development of new apical meristems laterally in the terminal meristem of the mother axis.

The lateral roots are also endogenous in origin i.e., from inner tissue of mother root normally in pericycle beneath the endodermis (sometimes in endodermis also as in Pteridophytes). Usually lateral roots come out opposite to xylem in vertical rows. The number of lateral roots is equal to number of xylem strands. The pericycle cells against protoxylem become meristematic and begin to divide first tangentially and then periclinally and anticlinally making few layers of cells.

The adventitious roots arise in the vicinity of differentiating vascular tissues of the organs from which they arises. In young organs they arise near the periphery of the vascular system. In older organs they arise deeper near vascular cambium. In young stem from interfascicular parenchyma and in older stems from vascular ray. In certain cases from cambial zone.

7.7 GLOSSARY

Adventitious roots: These roots develop from any non root tissue and are produced both during normal development and in stress conditions.
Apical meristem: It is the growth region in plants in tips of roots, shoots and leaves. It differentiates and makes different cell types.
Axillary: in or growing from an axil, in between leaf and stem.
Cambium: it is a tissue layer that provides partially undifferentiated cells for plant growth. It is formed between xylem and phloem. It makes secondary tissues.
Collateral: Bundle where xylem and phloem lie opposite to each other on the same radius with phloem located towards periphery of the stem and the xylem towards center.
Conjoint: Bundle where xylem and phloem lie opposite to each other on the same radius linked with the help of cambium.
Cotyledons: These are the first leaves of the plant.
Endarch: Protoxylem is towards the center of the pith while metaxylem towards periphery.
Endogenous origin: Origin from deeper layers.
Epicotyl: the region of an embryo or seedling stem above the cotyledon.
Exarch: protoxylem lies towards periphery and the metaxylem towards the centre.
Hypocotyl: it is the part of the stem of an embryo plant beneath the stalks of the seed leaves or cotyledons and directly above the root.
Interfascicular: the cambium between two vascular bundles, it is a secondary meristem. During the secondary growth the interfascicular and intrafascicular cambium fuse together to make a ring of meristematic cells called as cambium.
Lateral roots: These arise horizontally from the primary root and serve to anchor the plant in soil.
Mesocotyl: it is formed by the fusion of hypocotyls with the neck of the cotyledon.
Metaxylem: it is the part of primary xylem that differentiates after the protoxylem and are larger than protoxylem.
Parenchyma: Cells with live nucleus concerned with one or more activities in plants.

Phloem: Principal food conducting tissue of the vascular plant made up of sieve elements, parenchyma cells, fibres and sclereids.
Phyllotaxy: arrangement of leaves on stem or axis.
Plumule: the rudimentary shoot or stem of an embryo plant.
Polyarch: having many protoxylem groups.
Primordia/Primordium: is an organ or tissue in its earliest recognizable stage of development.
Normal roots/Primary roots: it is an organ which forms at the root pole of the plant embryo.
Protophloem: it is the first part of the primary phloem that matures and usually smaller than metaphloem.
Protoxylem: it is the first part of the primary xylem that matures and usually smaller than metaxylem.
Radicle: the part of a plant embryo that develops into the primary root.
Stele: Central part of root or stem having tissue derived from procambium, these include vascular tissues and in some cases ground tissue and pericycle.
Transition region: the region where the change from radial to conjoint type of bundles takes place is called transition region.
Xylem: Principal water conducting tissue, may also act as supporting tissue.

7.8 SELF-ASSESSMENT QUESTION

7.8.1. Multiple choice questions

1. In root stem transition 4-8 system is found in
   (a) Type A (b) Type B
   (c) Type C (d) Type D

2. The bundles becomes half in
   (a)*Mirabilis* (b) *Cucurbita*
   (c) *Lathyrus* (d) *Anemarrhena*

3. Hypocotyl is located
   (a) Below cotyledon (b) Above cotyledon
   (c) At same level of cotyledon (d) None

7.8.2. True or False

1. The transition region is that region where change in orientation of vascular bundles takes place
2. Axillary buds arise at the tip of main axis.

7.8.3 Fill in the blanks

1. The transition region is also called as ________.
2. Type B is also known as _______and ________.

7.8.1 Answer Key: 1 (b), 2 (d), 3(a)
7.8.2. **Answer Key:** 1. True; 2. False
7.8.3. Answer Key: 1. Hypocotyl; 2. Cucurbita type and 4-8,

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7.11 TERMINAL QUESTIONS

Q.1 How does a root differ from stem in internal structure? Discuss the process of change over from root condition to stem condition.

Q.2 Write short notes on

a. Origin of lateral roots
b. Origin of stem branches
c. Transition region

UNIT-8: ANOMALOUS SECONDARY GROWTH IN MONOCOT AND DICOT STEMS AND ROOTS

Contents:

8.1 OBJECTIVES

After learning this unit you will get familiar with

- Brief recap about secondary growth
- What is anomality
- Different type of anomalous secondary growth
- Causes of this abnormality
- Detailed description of Anomalous Secondary Growth in Dicot stem
- Anomalous Secondary Growth in Monocot stem
- Anomalous Secondary Growth in roots

8.2 INTRODUCTION

Readers, till now you must have known about primary and secondary growth of plant. Primary growth results for the growth of plant and increase in length and development of lateral appendage. Secondary growth results in formation of secondary tissues from **lateral meristems** which results increases in the diameter of the stem. Secondary tissues forms bulk mass of the plant and help in protection, support and conduction of water and nutrients.

8.2.1. Secondary growth in dicot stem:

Secondary tissues are formed by two types of lateral meristems, vascular cambium and cork cambium or phellogen. Vascular cambium produces secondary vascular tissues while phellogen form periderm.

Normally in growing season vascular cambium is formed by joining fascicular or intra-fascicular and inter-fascicular cambium . Cells of vascular cambium divide periclinally both on the outer and inner sides (bipolar divisions) to form secondary permanent tissues.

The cells of vascular cambium are of two types, elongated spindle-shaped fusiform initials and shorter isodiametric ray initials (Fig. 8.1). Fusiform initials divide to form secondary phloem on the outer side and secondary xylem on the inner side (Fig.8.1B). Formation of new ray cells also occur each year. Periclinal divisions results in formation secondary tissues and while anticlinal divisions cause dilation of the cambium ring.

Secondary growth adds to the girth of the plant. It provides support to increasing weight of the aerial growth. Secondary growth produces a corky bark around the tree trunk that protects the interior from abrasion, heat, cold and infection. It adds new conducting tissues for replacing old non-functioning ones as well as for meeting increased demand for long distance transport of sap and organic nutrients.

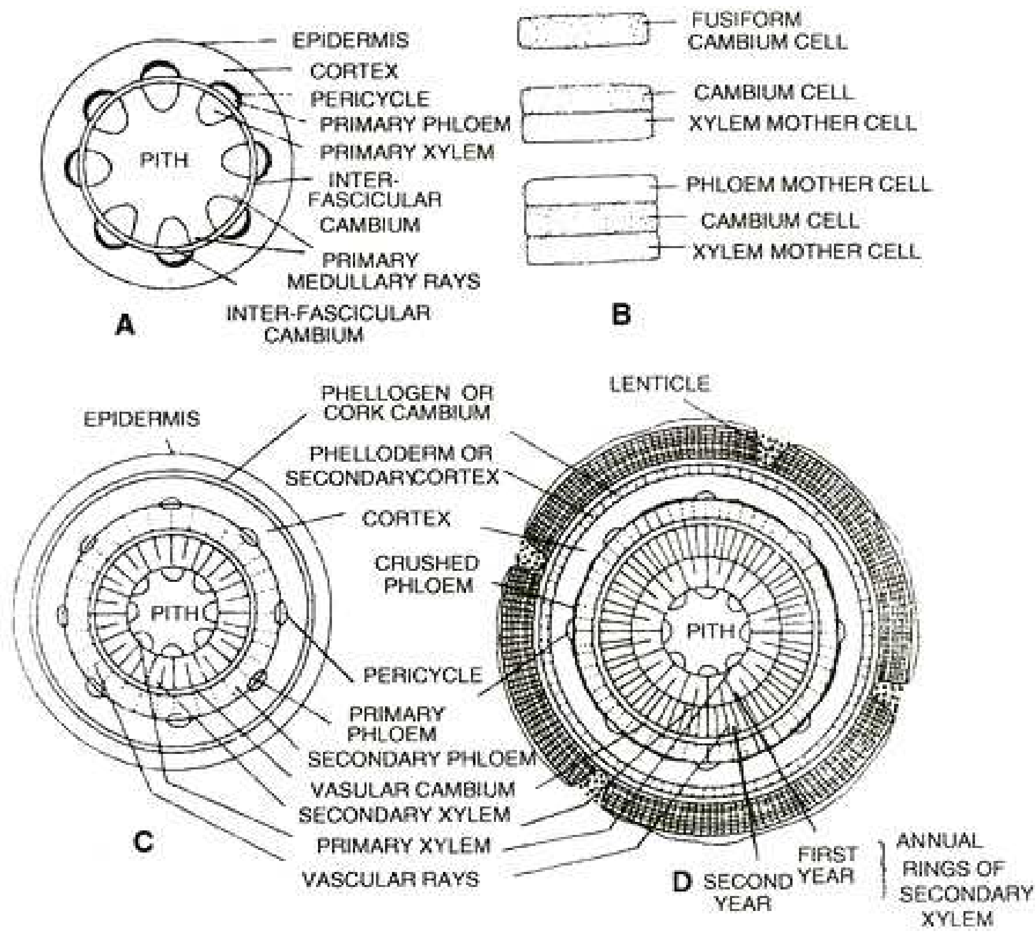

Fig. 8.1 Stages of secondary growth in dicot stem

8.2.2. Secondary growth in dicot root

The roots of some herbaceous dicotyledons and of all gymnosperms and woody dicotyledons show secondary growth in thickness. The tissues of secondary origin in the dicotyledonous roots are basically similar to those of the stem, but the way of formation is different.

In dicot roots there are limited number of radially arranged vascular bundles with exarch xylem. Pith is very little or absent. A group of parenchyma cells beneath each phloem patch become meristematic and thus form strips of cambium which divide and produce secondary xylem inside and secondary phloem outside (Fig 8.2).

The cells of the uniseriate pericycle external to each protoxylem group start dividing to form a few layers. The first-formed cambium internal to each phloem patch now extends both ways and joins with the innermost derivatives of the pericycle and finally a continuous wavy ring of cambium is formed. The cambial cells produce much more xylem at a higher rate than phloem and thus the wavy cambium cylinder ultimately becomes circular.

Due to continued secondary growth the primary xylem is pushed towards the centre and the primary phloem is pushed towards the periphery. Finally, the centrally located exarch primary xylems are fused to give a star-like appearance in transverse section. The strands of secondary vascular tissues remain collaterally arranged like those of the stem.

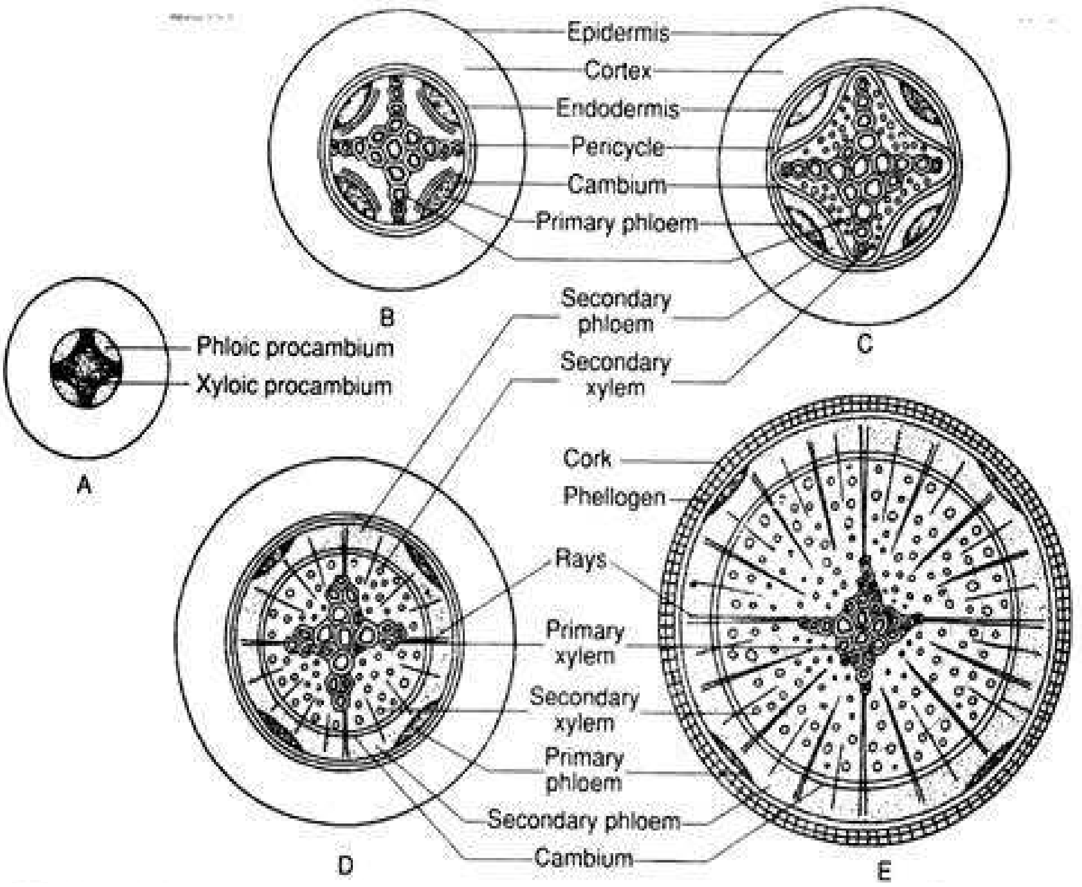

Fig. 8.2 Stages of secondary growth in dicot root

The sieve elements of the primary phloem often get crushed. The cambial cells originating from the pericycle against protoxylem groups function as ray initials and produce broad bands of vascular rays which are also called medullary rays. These rays running between xylem and phloem through the cambium are characteristic of the roots (Fig.8.2).

To cope up with the pressure generated by the secondary growth, the periderm is formed in the outer region. Phellogen arises outside the pericycle. It produces cork cells on the outer side and some phelloderm inside. The pressure due to secondary growth ruptures the endodermis and cortex, which are ultimately sloughed-off. Lenticels may occur as transversely elongated rough areas.

8.3 CAUSES OF ANOMALOUS STRUCTURES

Anomalous secondary growth is the result of deviation in the cambial activity from the normal. The term anomalous simply serves to assemble growth patterns that appears to be less common (Esau, 1965).This type of growth is more common than is known at present because the tropical flora in which it is frequently found has not been adequately studied anatomically (Obaton 1960). In normal conditions, in most of the dicot stems the vascular bundles are arranged in a ring whereas in monocots they are scattered in the ground tissue. The division of lateral meristem i.e. vascular cambium increases the thickness of the stem. The division of the cambium results in formation of secondary xylem towards inner side and secondary phloem towards outer side or periphery. The cambium remains functional/ active throughout the life of the plant and hence is referred as normal secondary growth. This occurs in most of the dicot stems. In some dicots and monocots the structures appear different from normal. Cambium shows variation in its activity. The other terms used to describe such condition is referred as cambial variants, anomalous (less common) growth or aberrant secondary growth.

Haberlandt (1914) on physiological grounds classified anomalous secondary growth into-adaptive and non-adaptive anomaly.

- Adaptive anomaly includes lianas which are woody climbers of tropics.
- Non-adaptive anomaly includes anomaly of *Rumex, Boerhaavia, Bougainviella, Mirabilis, Chenopodium, etc.*

However in a number of plants abnormal conditions are met with Abnormality is due to the two causes:

1. In some the primary structure itself is abnormal.
2. The primary structure is normal but secondary growth is abnormal

8.4 DIVERSITY OF ANOMALITY IN PLANTS

The anomalous structures found in the primary body are defined as primary anomalous structures, which occur in both monocotyledons and dicotyledonous stem and may persist throughout the life of the plant.The arrangements of tissues exhibited by the majority of the plants are considered as normal, variations from which found in minority are considered as anomalous. The various abnormality are as follows:

Presence of medullary bundle: In some dicotyledonous stem in addition to the normal ring of bundle, extra vascular bundles may be found in the pith, which are referred to as medullary bundles. In *Acanthus* (Acanthaceae) collateral and inversely oriented medullary bundles occur. In *Achyranthes aspara* (Amaranthaceae) two medullary bundles at internode and in *Cyathula prostata* four medullary bundles are observed.

Presence of cortical bundles: In dicotyledonous stem the vascular bundles remain encircled by the endodermis to form the stele. But in some dicotyledonous stems accessory vascular bundles occur in the cortex in addition to stellar bundles. They remain scattered in the cortex and are referred to as cortical bundles. In most of the species the cortical bundles are the leaf trace bun-dles. In *Campanula pyramidalis* (Campanulaceae), *Crepis, Senecio, Vernonia* (Compositae), *Momordica* (Cucurbitaceae),

Plumbago europaea (Plumbaginaceae). In *Nyctanthes arbortristis* (Oleaceae) four inversely oriented cortical vascular bundles occur with xylem outside and phloem inside.

Occurrence of atactostele in dicotyledonous stem: Normally vascular bundles in the dicotyledonous stem are arranged more or less in a ring. In *Thalictrum* (Ranunculaceae), *Podophyllum peltatum* (Podophyllaceae), *P. somniferum* (Papaveraceae), *Bougainvillea* (Nyctaginaceae), *Piper betle and Peperomia langsdorfii* (Piperaceae), Nymphaea (Nymphaeaceae) etc. the vascular bundles remain irregularly scattered throughout the ground tissue.

Occurrence of arranged vascular bundles in monocotyledonous stem: Vascular bundles are scattered in the ground tissue in monocot stems the. But in *Coix, Triticum, Ory*za (Poaceae), *Tamus communis* (Dioscoriaceae) etc. the vascular bundles are more or less arranged in one or two rings.

Occurrence of internal bundles: Besides normal ring of bundles presence of extra vascular bundles above the medullary bundles . They are referred as internal bundles..e.*g..Rumex crispus, R. orientalis* etc.

Occurrence of internal phloem or intraxylary (perimedullary, medullary) phloem: The phloem that occurs at the periphery of the pith in the form of a continuous cylinder or strands is referred to as intraxylary phloem or internal phloem or medullary phloem. e.g. *Wrightia, Vinca.*

Anomalous Secondary Growth in Monocots and storage roots: It is abnormal type of secondary growth that occurs in some arborescent monocots (*e.g., Dracaena*, *Yucca*, *Agave*) and storage roots (*e.g.*, *Beet*, *Sweet Potato*).

8.5 ANOMALOUS STRUCTURE IN DICOT STEMS

Cambium shows variation in its activity giving rise to conditions which are rather typical. As the variants are of quite regular occurrence in certain plants, anatomists have discouraged the use of the term anomalous secondary growth. Instead cambial variant has been recommended for usage.. Anamolous secondary growth is the result of cambial activity that deviates from normal type. This may be due to:

1. Those in which cambium of normal type is present and persists but by peculiarity and irregularity in its activity give rise to unusual arrangements of secondary xylem and phloem.
2. cambium which itself is abnormally situated and so give rise to abnormal arrangement of the tissue.
3. Formation of accessory and additional cambia (Cutter 1971).

8.5.1 Normal Cambium with Abnormal Activity

In many woody climbers or lianas abnormal activity of normal cambium result in formation of anomalous structure.

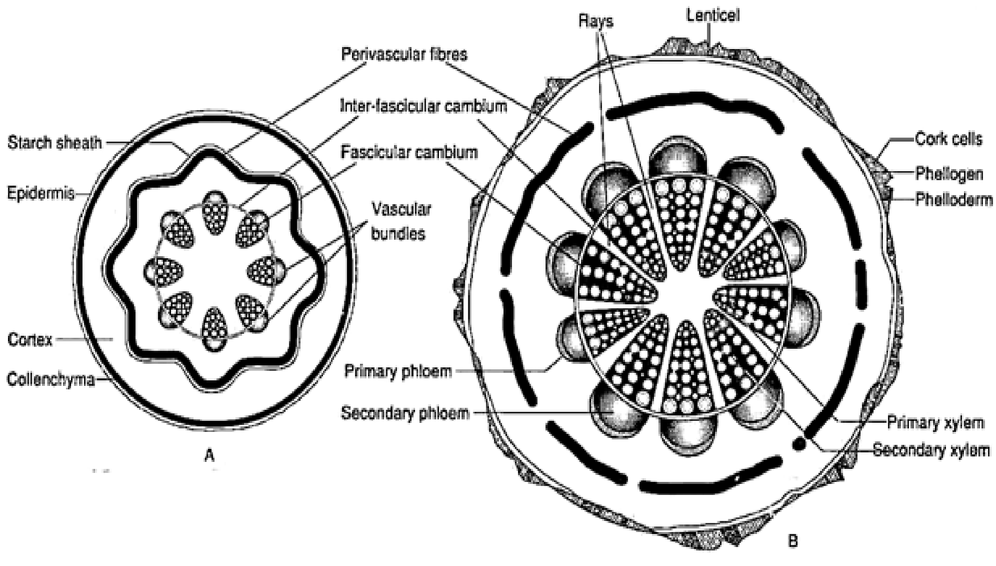

Fig. 8.3. T.S Aristolocia stem A. One Year old B. Two year old

In *Vitis* (Vitaceae), *Clematis* (Rannunculceae), *Aristolochia* (Aristolochiaceae, Fig 8.3), *Tinospora* (Menispermaceae) etc. a normal cambium ring is formed by the union of fascicular and inter-fascicular cambia. But, during function, the fascicular cambium produces secondary xylem and phloem as usual on the inner and outer sides, respectively, within individual vascular bundles, whereas the inter-fascicular cambia produce only ray-like parenchyma cells on both sides. As a result, broad and enormously elongated medullary rays and fluted vascular cylinder is formed.

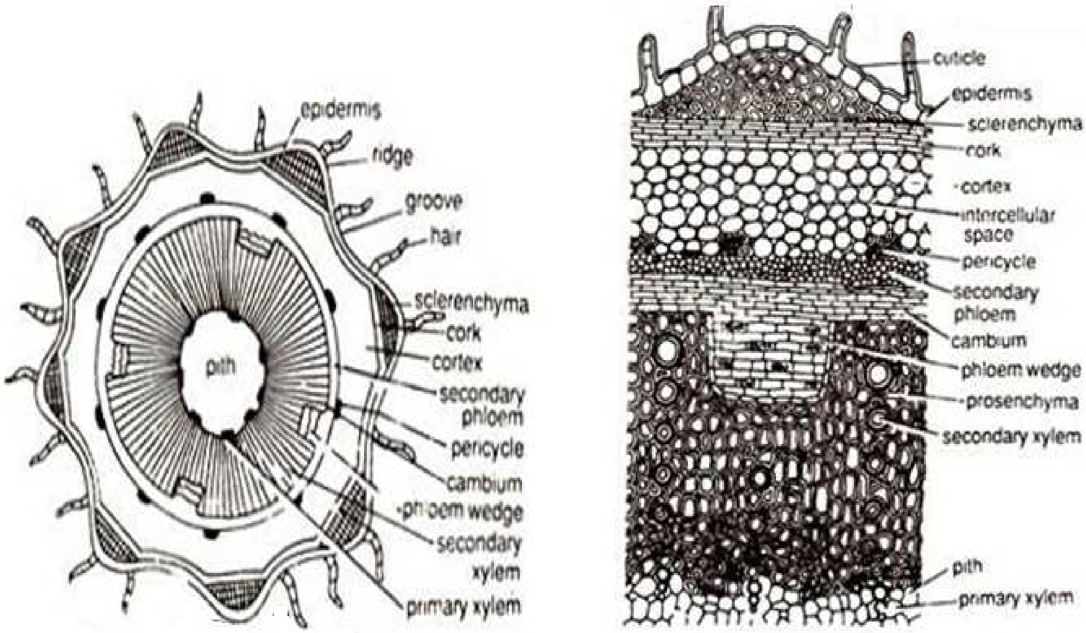

Fig. 8.4: T.S. Bignonia stem: diagrammatic and cellular

In *Bignonia* and other members of family *Bignoniaceae,* the cambium is normal in position and activity for some time, but immediately it cuts off different proportions of xylem and phloem at four alternating points arranged in form of a cross. In one set of alternating points the cambium produces less amount of secondary xylem and much amount of secondary phloem and vice versa in other set of alternating points (Fig. 8.4).

Cambium is single layered, present in between xylem and phloem and bent towards inner side along the furrows of secondary phloem. As a result the woody cylinder appears to have four longitudinal grooves alternating with four ridges. The ridges are wider than the grooves. The cambium breaks up into a number of strips. The wider ones remain on the top of the ridges while the narrower ones remain at the bases of the grooves.

This is a kind of adaptive anomaly. *Bignonia* is a woody climber (liana) and so its stem is twining and thus is inextensible as it hangs freely and has to bear its own weight. The stem is also flexible as it has to withstand high velocity of wind and again subject to radial compression due to unequal growth in thickness for twining purpose

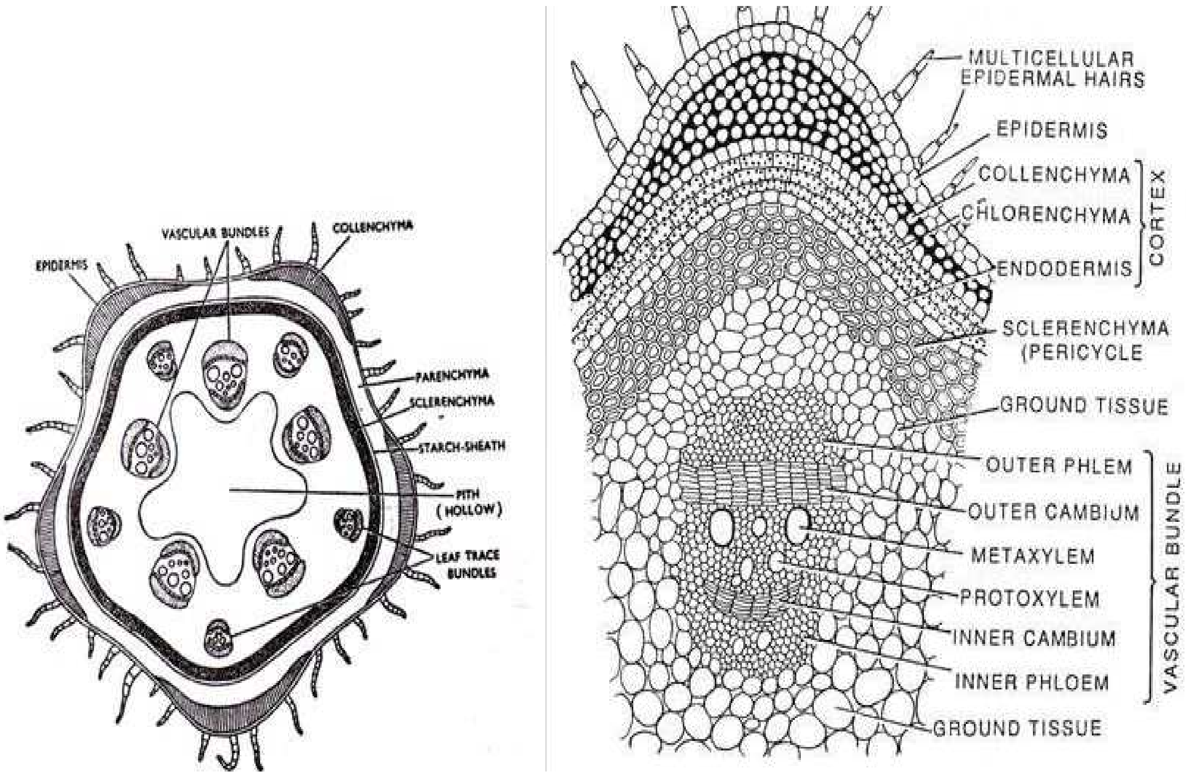

Fig. 8.5: T.S. Cucurbita stem: diagrammatic and cellular

In *Cucurbita* stem there are ten vascular bundles arranged in two rings of five each (Fig. 8.5). This normal cambium behaves abnormally as it cuts off secondary xylem and phloem in vascular bundle region only, resulting in the increased size of the bundle. The cambium forms vascular tissues only in the region of vascular bundle. The outer cambium of both inner and outer bundles becomes active along with the parenchymatous cells of the ground tissue and the combine to form a more or less wavy ring of cambium. Each vascular bundle is conjoint, open and bicollateral having an outer and inner cambium. The stem of Cucurbita ten vascular bundles arranged in two rings of five each.

8.5.2. Cambium Abnormal in Position but Normal in Activity

Serjania is a woody climber of the family Sapindaceae exhibiting several discrete vascular cylinders (Fig. 8.6) each of which has its own cambium and pith and is encircled by an endo-dermis. Thus a polystelic appearance is observed from the very beginning, as if, several stems are fused together.

During secondary growth each cylinder of primary vascular bundles becomes notched at certain points and thus folds and ridges are formed. The ridges are constricted-off from the cylinder and the thickness by means of a ring of cambium present in the separated bundles behave as independent cylinders. Each bundle ring undergoes secondary growth in them.These cambia, though unusual in position, normally give rise to internal xylem and external phloem. sclerenchymatous cylinder occurs encircling the vascular cylinders. It is again notched and wavy in outline with less amount of tissue at the notches.

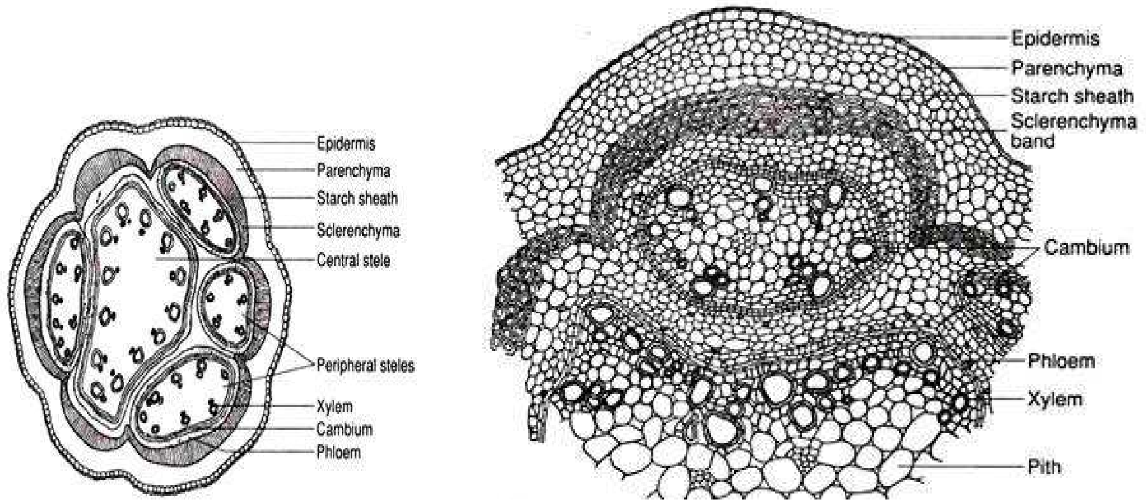

Fig.8.6: T.S. Serjania Stem: diagrammatic and cellular

Serjania and other members of the family instead of single solid woody cylinder, the stele is broken into many parts even in the procambial stage (Fig. 8.6). These modifications make the stem compatible with twining habit. The vascular cylinders remain encircled by soft parenchymatous tissue, which helps to make the stem tough, inextensible but flexible. So, this peculiarity is obviously adaptive in nature.

8.5.3. Anomaly due to formation of accessory cambium

In the families Nyctaginaceae, Amaranthaceae, Chenopodiaccae, etc., different types of anomaly is observed. The collateral and open vascular bundles normally appear either in a ring or they remain. Irregularly scattered in the ground tissues called medullary bundles. Cambial activity in the primarybundl es commences but soon ceases. This is followed by the formation a secondary accessory cambium encircling the primary bundles. This cambium cuts off secondary bundles inside, which remain embedded in a nonvascular tissue, known as conjunctive tissue consisting of either thin-walled parenchyma or thick-walled lignified elongated cells. The cambium produces very little tissue on the outer side. The secondary bundles may be irregularly scattered or may remain arranged in concentric rings. Some examples are as follows:

1. Formation of rings of vascular bundles included in the parenchyma . e.g. *Boerhaavia,*
2. Abnormal secondary growth due to Cortical bundles
3. Formation of rings of vascular bundles embedded in conjunctive tissues.
4. Interxylary or included phloem

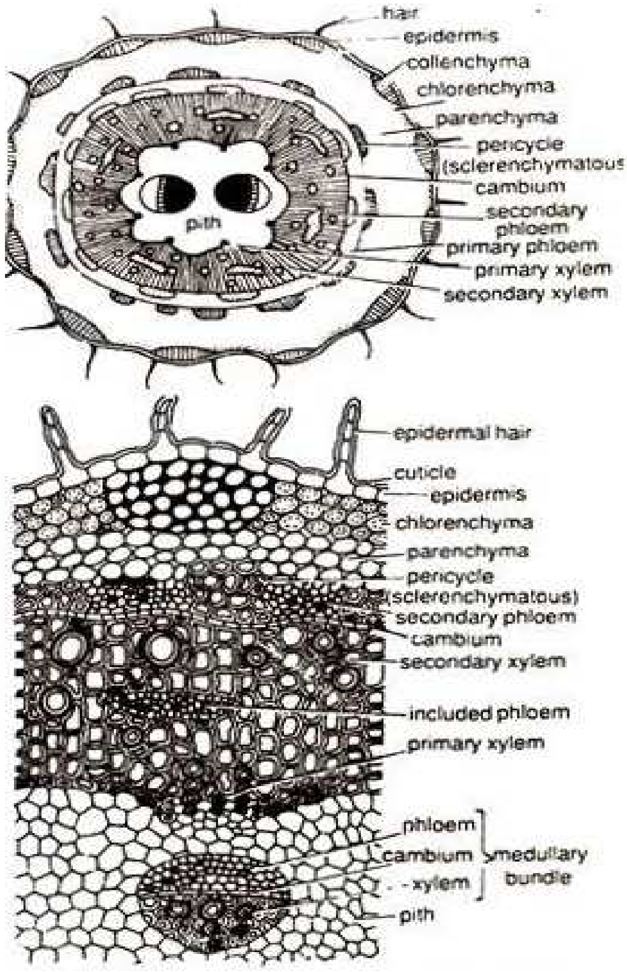

Fig. 8.7: T.S..Achyranthus Stem

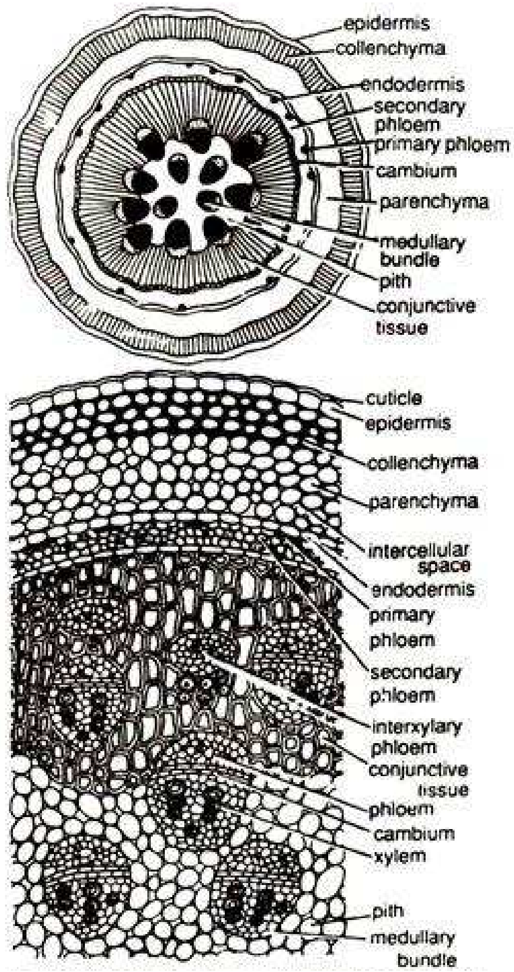

Fig 8.8: T.S.Chenopodiums Stem

8.5.3.1 Abnormal secondary growth due to Medullary bundles

In Achyranthes (Family – Amaranthaceae) stem anomalous growth in thickening takes place by the development of the successive rings of the collateral bundles from one ring of secondary meristematic tissue in the pericyclic region (Fig. 8.7). The secondary arch of rings or secondary meristematic tissue in the pericycle gives rise to collateral vascular bundles successively. The conjunctive tissue between bundles may be consisted of parenchyma in some species and in others of lignified or unlignified parenchyma. Secondary vascular bundles and conjunctive tissue are present without any sharp limits. So phloem of the secondary vascular bundles appears in the form of patches. This phloem is the included phloem. Medullary bundles are leaf traces.

Secondary growth in ***Chenopodium*** **(Family-Chenopodiaceae)** is abnormal and takes place by the formation of extrastelar cambium in the pericycle (Fig. 8.8). The first ring of the cambium is a continuous ring. It first produces a small amount of thin walled ground tissue which pushes the primary vascular bundles towards centre which now appear as medullary bundles. This cambium later on produces secondary vascular bundles and conjunctive tissue which is thick walled. Such cambial rings are produced in the pericycle successively, and the ring external to the phloem burries the latter in the conjunctive tissue. This phloem gives the appearance of included phloem or interxylary phloem.

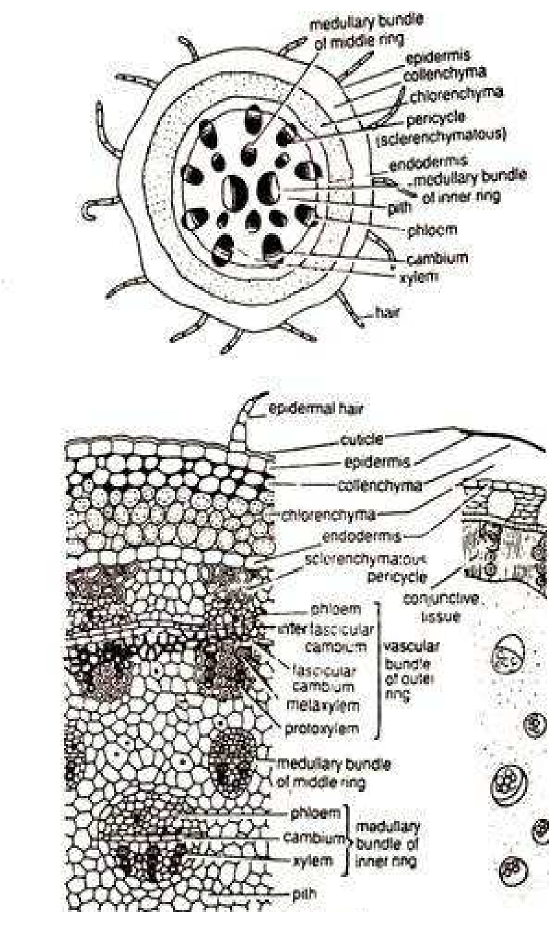

Fig 8.9: T.S.Boerhaavia Stem

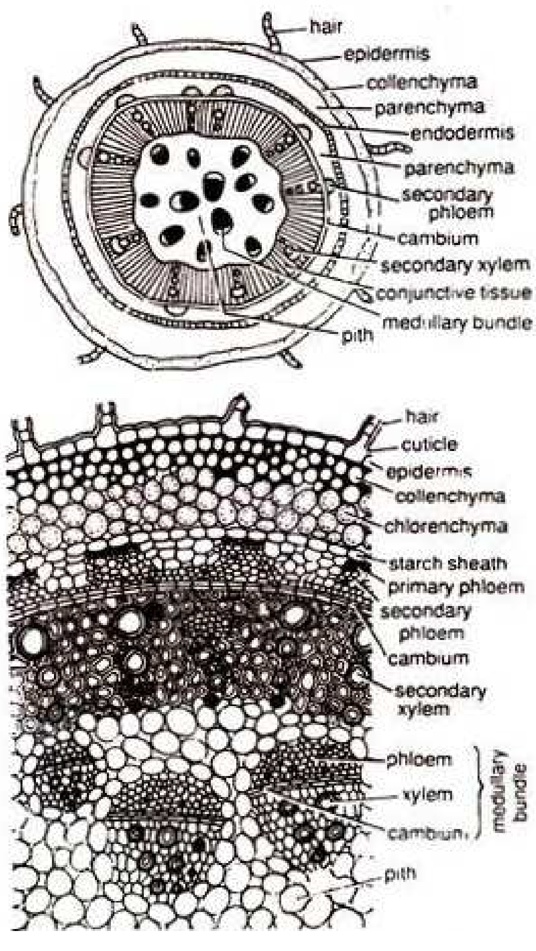

Fig 8.10: T.S. Mirabiliss Stem

In Young stem of ***Boerhaavia*** **(family) Nyctaginaceae** three rings of vascular bundles occur. The central one is having two big sized vascular bundles forming first ring of vascular bundle known as medullary vascular bundles (Fig. 8.9). Surrounding the medullary a ring of 6 to 20 normal sized vascular bundles forming the second ring of vascular. Outside of it a third ring of vascular bundles containing 15 to 20 vascular bundles.

At the time of secondary growth the cambium of first and second ring of vascular bundles remain active and show a very little activity within the vascular bundles only. The cambium of the third ring of vascular bundle remain active and by the development of inter-fascicular cambium completes the cambium ring. Now this normal cambium ring shows abnormal activity. In the regions of vascular bundles the cambium forms xylem towards innerside and rest of places it cuts sclerenchyma, while towards outerside it forms simple parenchyma only for a short period and then cambium begins to cut the phloem on the outer side just above the xylem which alternates with the sclerenchyma and in this way the previously formed parenchyma gets pushed up and the cambium ceases its activity. After some time the formation of cambium takes place from the parenchyma. Interfascicular cambium also soon becomes active and cuts internally the row of cells which become thick walled and lignified and are known as conjunctive tissue.

In **Mirabilis (Family – Nyctaginaceae;** Fig 8.10**)** many medullary bundles are scattered in the pith which are 'leaf traces'.

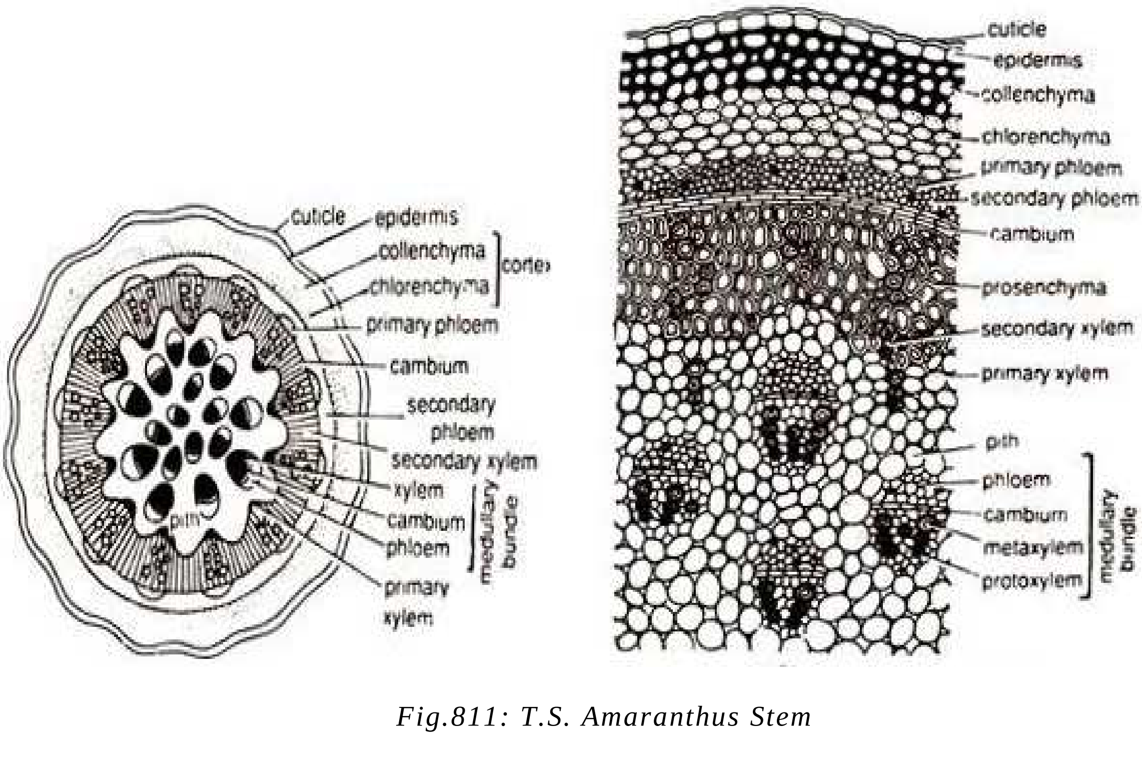

Fig.811: T.S. Amaranthus Stem

Anomalous secondary growth occurs in the form of succession of rings of vascular bundles. De Bary (1884) was of the opinion that a de novo, extrastelar cambium ring arises in the pericycle but according to Maheshwari (1930) separate strips of interfascicular cambium develop in the medullary rays between the outer rings of normal bundles. It forms a complete cambium ring by joining with the strips of fascicular cambium.

In Amaranthus – Stem (Family – Amaranthaceae): Many scattered medullary bundles are present in the pith (Fig. 8.11).

Each medullary bundle is conjoint, collateral and endarch, with the cambium either feebly developed and functionless or absent. In the pericycle region the outer primary bundles become meristematic and develop few layered cambium. This cambium cuts collateral vascular bundles towards inner side consisting of secondary phloem and secondary xylem. Cambium also cuts many layered parenchymatous conjunctive tissue which becomes lignified and thick walled. This vascular bundle lies completely embedded in conjunctive tissue.

8.5.3.2 Abnormal secondary growth due to cortical bundles

Cortical bundles have been reported in some families such as Casuarinaceae (*Casuarina*), Umbelliferae (*Eryngium*), Papilionaccae (*Latkyrus marytimus*). Mclastomaccac, Rutaccae, etc

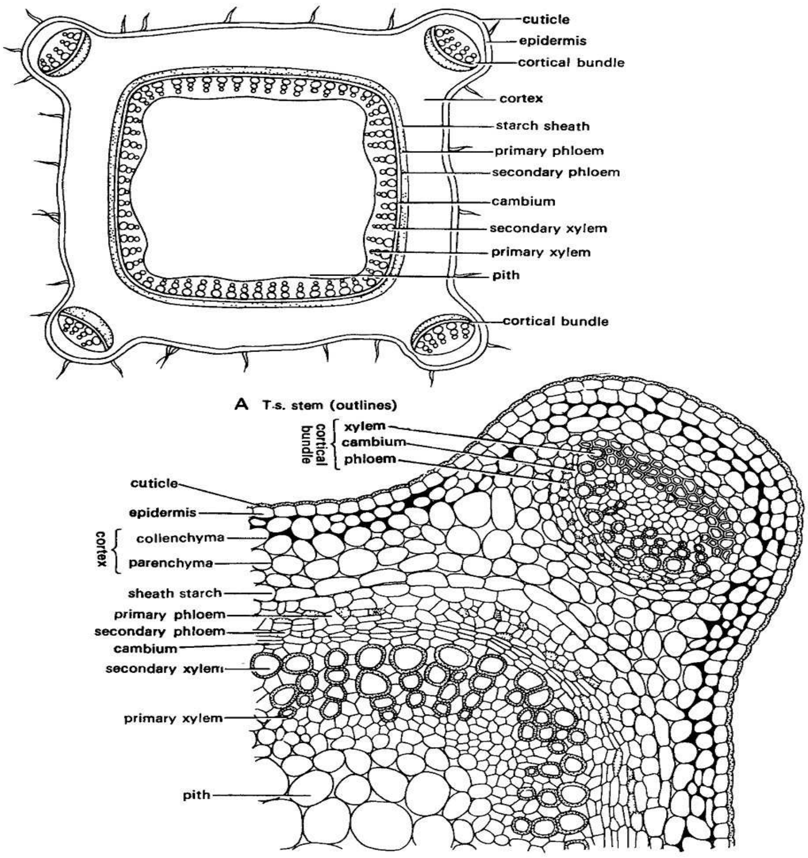

Fig.8.12. T.S Nyctanthes Stem A. Diagramatic B. A part cellular

In **Nyctanthes Stem: (Family – Oleaceae**) Four vascular bundles are present in the cortex, situated one each in each protruded bulge. Each conical bundle faces its pointed xylem end towards outer side, i.e., epidermis, and is conjoint, collateral, open and exarch.These bundles may show secondary growth at maturity (Fig. 8.12).

Abnormality in *Nyctanthes* is the presence of cortical bundles, which are inversely oriented, 4 in number and never directly connected with the main axial ring of the vascular cylinder. These are leaf trace bundles. Four vascular bundles are present in the cortex, situated one each in each protruded bulge. Each conical bundle faces its pointed xylem end towards outer side, i.e., epidermis, and is conjoint, collateral, open and exarch.. These bundles may show secondary growth at maturity.

8.5.3.3. Formation of rings of vascular bundles embedded in conjunctive tissues

In *Bougainvillea*, *Boerhaavia*, *etc.* the vascular bundles appear to be embedded in a mass of conjunctive tissue. In **Bougainvillea** stem (Fig. 8.13) cells of the secondary parenchyma are fusiform, more or less radially arranged and usually develop lignified, thickened walls.

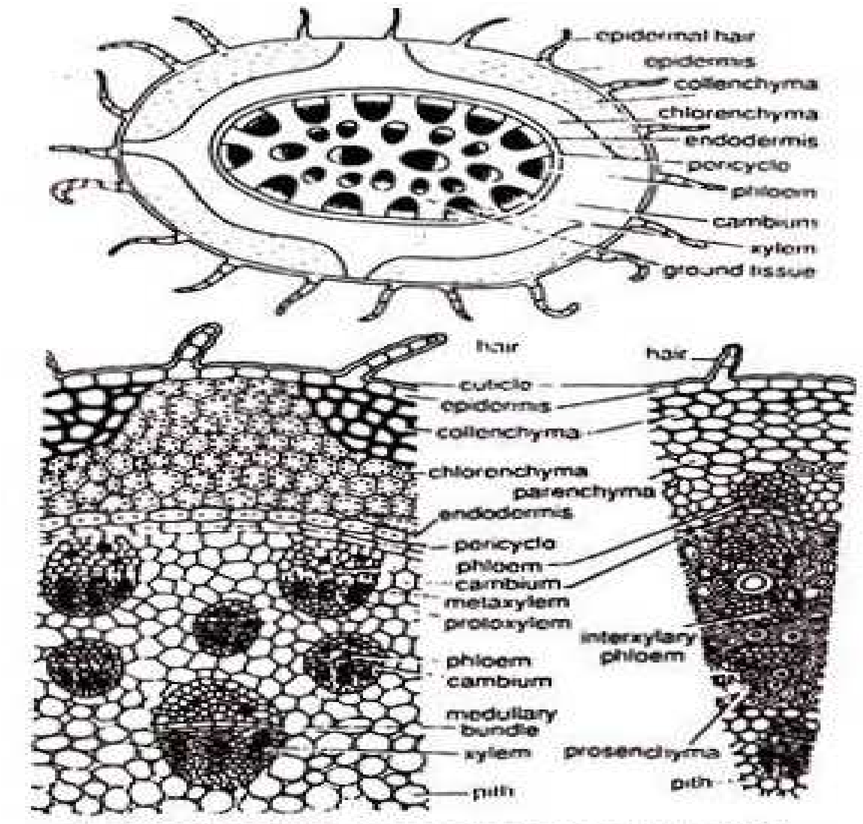

Fig 8.13 *Bougainvillea stem T.S: Diagramatic (upper) Young stem (lower left) and Old stem lower (right)*

The cambial ring cuts off secondary xylem alternating with secondary parenchyma on the inner side and secondary phloem above secondary xylem. The first cambial rings are extra-stelar in origin and arise from the pericycle, followed by successive rings of cambia. Successive rings of cambia are formed which behave in a manner similar to the first ring, as a result, concentric layers of vascular bundles are formed embedded in conjunctive tissue.

8.5.3.4. Interxylary or included phloem

In some plants due to the irregular activity of the cambium at certain places, the secondary phloem is formed towards inner side instead of secondary xylem. Other adjacent cambium cells are normally producing secondary xylem towards inner side. After some time the cambium resumes its normal activity and thus forms many patches of secondary phloem in the secondary xylem. These are called **interxylary phloem or included phloem** patches.

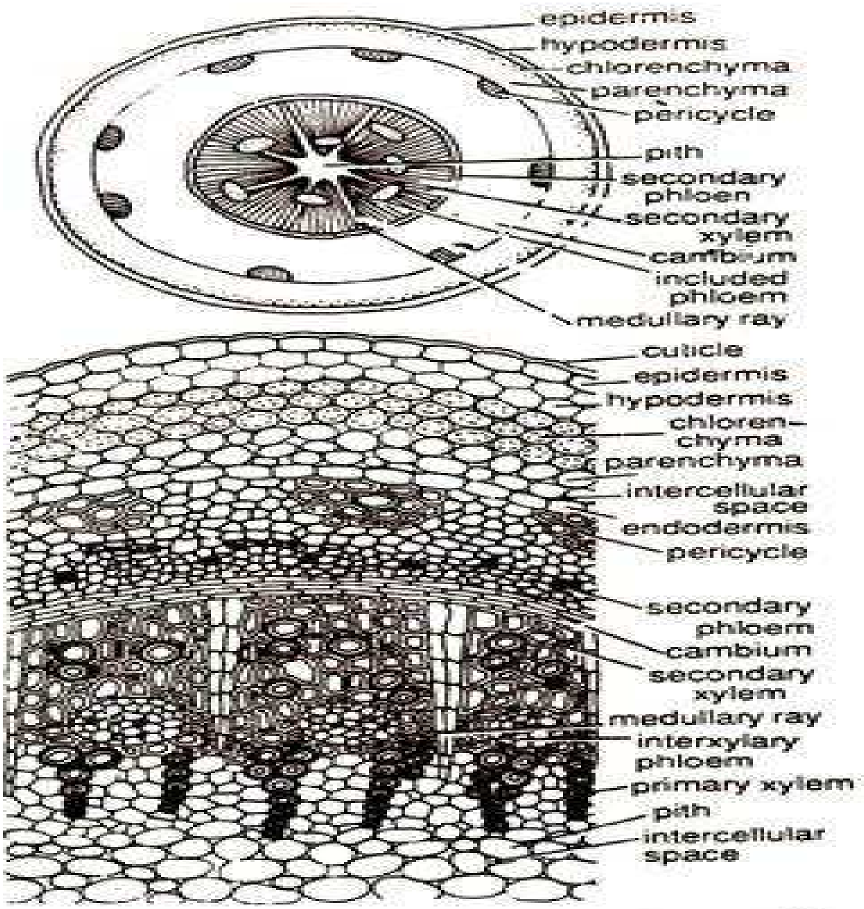

Fig. 8.14: T .S. Salvadora stem

In stem of **Salvadora** (Family – Salvadorace) included phloem develops due to the irregular activity of cambium. Some cambium cells which are normally responsible for the formation of secondary xylem form secondary phloem (Fig. 8.14). Other adjacent cambium cells keep on normally producing secondary xylem. After sometime the same abnormally behaving cambium cells start to behave normally, and thus many islands of phloem are formed.

8.6. SECONDARY GROWTH IN MONOCOTS

Most monocotyledons consist entirely of primary tissues. The usual vascular cambium is absent from this group and so there is no normal secondary growth. However, in some monocots, the thickening and elongation of stem occurs through primary thickening meristem, diffuse secondary thickening and secondary thickening meristem.

8.6.1. Analomus secondary growth in monocots

Abnormal secondary growth also occurs in some arborescent monocots (e.g., *Dracaena*, *Yucca*, *Agave*) and storage roots (e.g., *Beet*, *Sweet Potato*). In arborescent monocot stems, a secondary cambium grows in hypodermal region. The latter forms conjunctive tissue and patches of meristematic cells. The meristematic patches grow into secondary vascular bundles. In storage roots (e.g., Beet), accessory cambial rings appear on the outside of endodermis. They produce less secondary xylem but more secondary phloem. The secondary phloem contains abundant storage parenchyma.

8.6.1.1. Primary thickening meristem

This meristem is observed in palms, in the rhizomes of *Musa* and in the bulbs of *Allium cepa* etc. In these plants, the shoot apex is not large and produces only a small part of the primary body. A considerable thickening occurs below the shoot apical meristem. This is due to the intensive cell division of primary thickening meristem.

This meristem lies below the young leaf bases and originates by periclinal division of the cells situated below the region of attachment of young leaf primordia. The meristem appears as a flat zone in longitudinal section of the developing embryo. The zone gradually assumes a concave form in the mature young plant.

The meristem consists of several layer of cells which are rectangular, elongated and oriented parallel to the surface of shoot apex. The derivatives of meristem are the ground parenchyma cells. Sometimes localized mitotic activity within this meristem forms procambial strands, which run horizontal to the surface. These procambial strands gradually mature into vascular bundles.

8.6.1.2. Diffuse secondary thickening

In palm stem such as *Roystonea*, *Actinophloeus*, etc. the ground parenchyma cells close to and distant from the shoot apex , expand along with proportional increase of the intercellular spaces, thus causing diffuse secondary growth. Sometimes these ground parenchyma and the procambium cells, destined to produce the outer fibres of bundle sheath, divide, expand and thus contribute to the diameter of stem. The diffuse secondary thickening occurs after the completion of expansion and elongation caused by primary thickening meristem.

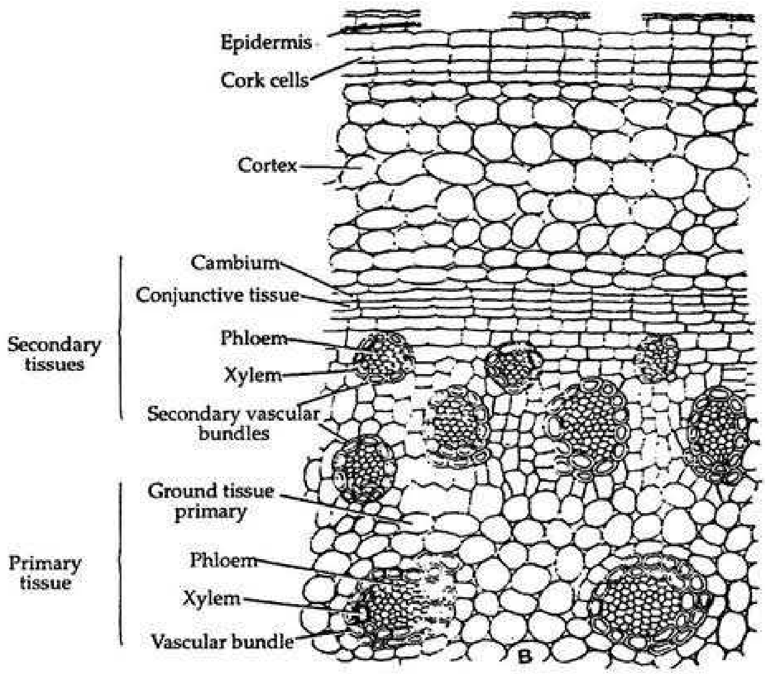

Fig 8.15. T .S. Dracaena stem

8.6.1.3. Secondary thickening meristem

Secondary thickening meristem occurs in a number of monocotyledonous species such as *Xanthorrhoea, Dracaena* (Fig. 8.15), *Cordyline*, *Aloe*, *Yucca*, *Kingia*, *Dioscorea* etc. This meristem is a type of vascular cambium, which originates in the parenchyma cells present on the peripheral sides of the entire mass of primary vascular bundles.This region may be the inner layer of cortex or pericycle. Though this lateral meristem is distant from the stem apex, in seedling stages it develops in continuity to the primary thickening meristem but in mature plants these two meristems are found to be discontinuous.

The secondary thickening meristem consists of several tiers of cells that may be of different shapes, such as fusiform, rectangular, polygonal or only with one end tapered. This cambium divides tangentially, some of the peripheral derivatives divide repeatedly and the others form secondary cortex. These parenchyma cells usually remain thin walled and sometimes may contain crystals.

The bundles are either collateral (*Kingia*) or amphivasal (*Dracaena, Aloe*). Some localized region of the tiers of cambium is involved in the formation of a single bundle. The conjunctive tissues with embedded secondary vascular bundles show radial arrangement in contrast to primary strands, which are irregularly arranged.

8.7 ANATOMICAL STRUCTURE OF STORAGE ROOTS

The underground roots may become very much thickened and serve as organs for the storage of food. Such is the case in sweet potatoes, radishes, turnips, carrots and dahlias. In such roots the food may be stored largely in the cortex or xylem region or in both. In food is stored largely in the xylem and phloem and cortex are relatively narrow. In the radish and sweet potato the xylem is also the chief region of food storage, but food is also stored outside the xylem. In the carrot there is a more even distribution between xylem and bark.

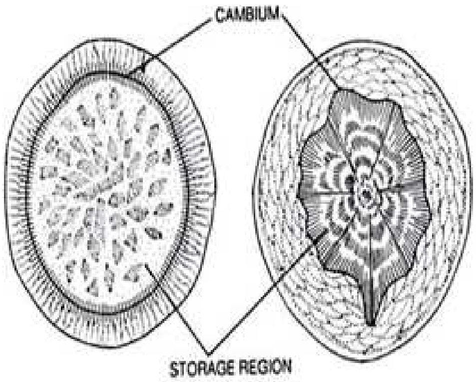

Fig 8.16: Cross section of root of Ipomoea batatas (Left) and Daucas carrota (Right)

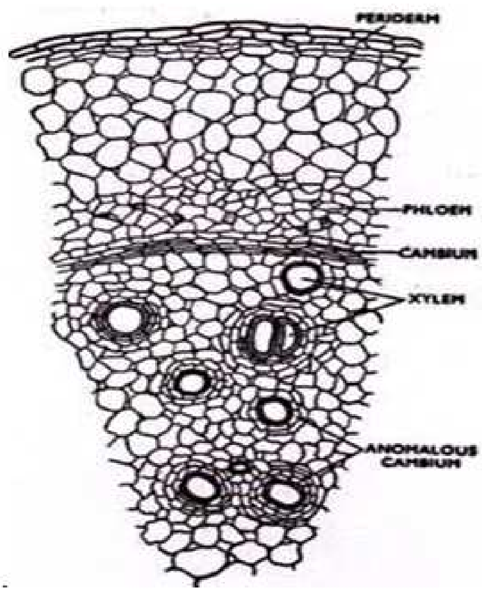

Fig 8.17 Cross section of root of Ipomoea batatas

Roots of sweet potato **(*Ipomoea Batatas)*** family Convolvulaceae show a complicated type of anomalous secondary thickening (Fig. 8.16 & 8.17). In primary state the root is pentarch or hexarch. The cortex is delimited by a single-layered distinct endodermis from the stelar region. In the normally developed but highly parenchymatous primary and secondary xylem, anomalous cambia arise around individual vessels or vessel groups and produce phloem rich in parenchyma and with some laticifers away from the vessels, and tracheary elements toward them. Massive amounts of storage parenchyma cells are developed in both the directions thus forming the tuberous roots.

Radish (*Raphanus sativus*) family Cruciferae The fleshy roots of radish show a proliferation of parenchyma in the pith and in the secondary xylem, and a differentiation of concentric vascular bundles within this parenchyma. Here, the fleshy roots show a diarch primary xylem (Fig. 8.18).

The normal cambium cuts off secondary phloem towards periphery and secondary xylem towards the centre. Several concentric vascular bundles are seen in the transverse section of the fleshy root. The concentric bundles are made of secondary cambial rings with few vascular elements in the centre.

In **Beta vulgaris, (**family Chenopodiaceae**)** there are alternate layers of xylem and phloem owing to the formation of successive cambia (Fig. 8.19). The secondary tissues of the root accumulate starch in the same kind of cells as those of the stem, that is various parenchymatous and some sclerenchymatous cells of the xylem and the phloem. In general, roots possess a higher proportion of parenchyma cells than do stems.

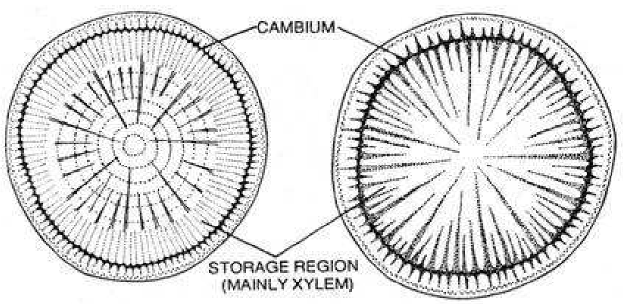

Fig 8.18: Cross section of root of Brassica rapa (Left) and Raphanus sativus (Right)

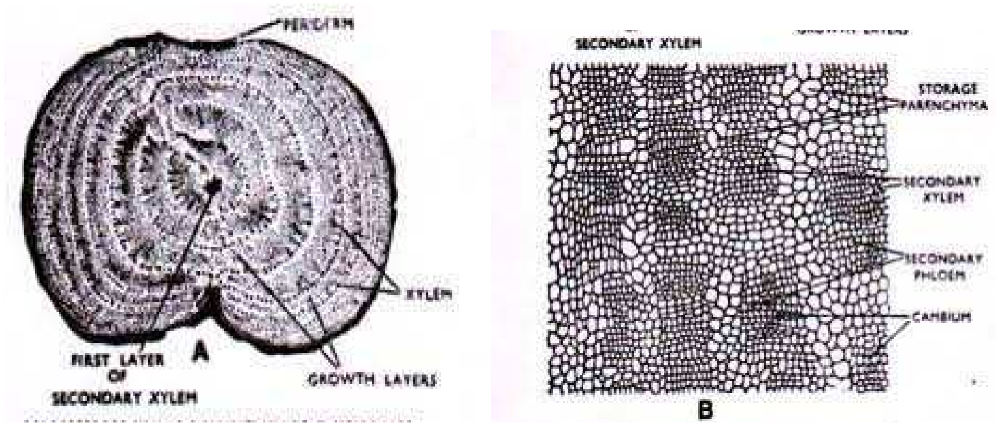

Fig 8.19: Cross section of root of Beta vulgaris (A) and A part cellular (B)

The primary cambium that gives rise to the innermost vascular ring in the beet root develops in the interstitial parenchyma except opposite the two protoxylem poles where it is derived from the pericycle. The first secondary cambium in the root and lower part of the hypocotyl arises in the phloem parenchyma, whereas in the upper part of the hypocotyl is derived from the pericycle. Later, however, a series of supernumerary cambia arise outside the normal vascular cylinder and produce several increments of vascular tissue, each consisting of a layer of parenchyma, parenchymatous xylem and parenchymatous phloem.

8.8 SUMMARY

The pattern of the secondary thickening shows deviation from the normal type in many plants. The term "Anomalous Secondary Growth" is given for this deviation or variation. The anomalous secondary growth is more common in tropical plants. Anomalous secondary thickening is NOT an anomaly or disease in plants rather it is an adaptation to suit the habit and habitat of the plant.

In dicots vascular bundles are conjoint, collateral, open and arranged in a ring. Formation of secondary tissues takes place by fascicular cambium in stele and Cork cambium in cortex. In monocots vascular bundles are conjoint, collateral, closed and are scattered in the ground tissue. Secondary growth is absent. Any deviation in the above pattern of development in Primary and secondary structure is called "Anomalous secondary growth".

There are some reasons of this anomality such as

- The normal cambium behaves peculiarly or irregularly, resulting in the abnormal arrangement of the vascular tissue.
- The normal cambium is situated in an abnormal position hence the tissue cut is placed abnormally.
- The normal cambium does not develop or if present, it is replaced by additional or accessory cambial rings.

The anomalous structures found in the primary body are defined as primary anomalous structures, which occur in both monocotyledons and dicotyledonous stem and may persist throughout the life of the plant. The arrangements of tissues exhibited by the majority of the plants are considered as normal, variations from which found in minority are considered as anomalous. The various abnormality are as follows:

- Presence of medullary vascular bundles:
- Presence of cortical vascular bundles:
- Occurrence of atactostele in dicotyledonous stem:
- Occurrence of arranged vascular bundles in monocotyledonous stem:
- Occurrence of internal bundles:
- Occurrence of internal phloem or intraxylary (perimedullary, medullary) phloem**:**

Abnormal secondary growth also occurs in some arborescent monocots (e.g., *Dracaena*, *Yucca*, *Agave*) and storage roots (e.g., *Beet*, *Sweet Potato*). In arborescent monocot stems, a secondary cambium grows in hypodermal region. The latter forms conjunctive tissue and patches of meristematic cells. The meristematic patches grow into secondary vascular bundles. In storage roots (e.g., Beet), accessory cambial rings appear on the outside of endodermis. They produce less secondary xylem but more secondary phloem. The secondary phloem contains abundant storage parenchyma.

8.9 GLOSSARY

Collenchyma: Tissue composed of cells with unevenly thickened walls.

Cork: It is the soft, light weight bark of the cork oak tree.

Graft: A plant shoot suitable for grafting; loosely, a scion, sucker, or branch

Leaf trace: A vascular bundle connecting the stele to a leaf

Monocotyledon: A flowering plant whose embryo contains one cotyledon (seed-leaf).

Parenchyma: Thin-walled cells, varying in shape, size, and function.

Phloem: The food-conducting tissue of a vascular plant.

Pith: The parenchymatous, often spongy or porous central portions of stems and branchlets.

Sclereid: A type of schlerenchyma, made up of gritty cells, often called "stone cells." Sclereids are what make a pear slightly gritty.

Schlerenchyma: Tissue composed of thick-walled cells containing lignin for strength and support.

Sieve element: Cell in the phloem tissue concerned with longitudinal conduction of food materials.

Sieve tube: A series of sieve-tube elements arranged end to end and interconnected through sieve plates.

Sapwood: It is an outer layer of wood in a tree and contains living cells

Vessel: A tube-like series of vessel elements with open ends. The walls that join the members have perforations or holes in them to allow water to pass through freely.

Vessel element: Individual cells that make up vessels.

Xylem: The water-conducting tissue of a vascular plant. Minerals are also transported through the xylem.

8.10 SELF-ASSESSMENT QUESTIONS

8.10.1 Multiple choice questions

1. When secondary growth occurs, girth of stem increase, Cambial ring increase in diameter due to

(a) Periclinal division and radial elongation of cambial cells
(b) Anticlinal division and radial elongation of cambial cells
(c) Both periclinal and anticlinal division and radial elongation of cambial cells
(d) Radial elongation of cambial cells alone

2. Interfascicular cambium is situated
(a) Between xylem and phloem (b) Between vascular bundles
(c) Outside the vascular bundles (d) Inner side of the vascular bundles

3. Secondary growth is the production of
(a) New tissue from intercalary meristem (b) New conducting cells
(c) New tissue from lateral meristem (d) New ground cells

4. *Cucurbita* stem is an exceptional dicot stem because it has
(a) Bicollateral bundles
(b) Bicollateral bundles have and several layered thick pericycle
(c) Bicollateral bundles and hollow centre
(d) Bicolateral bundles arranged in two alternate rings

5. Vascular strand having numerous scattered fibrovascular bundles is
(a) Eustele (b) Atactostale
(c) Polycyclic stele (d) Dictyostele

8.10.2 True and False

1. Cortical bundles are found in Nyctanthes.
2. Dracena has Primary thickening meristem.
3. Root of Beta vulgaris showing secondary growth and having storage in function.
4. Boerhavia show abnormal cambium showing normal activity.
5. Zimmermann categorarisd plants anatomically on the basis of their adaptive nature.

8.10.1 Answers Key: 1(b); 2(b); 3(c); 4(d); 5(b); 6(c); 7(d); 8(d); 9(d); 10(a)

8.10.2 Answer Key: 1. True; 2. True; 3. True; 4. True; 5. True

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8.12 SUGGESTED READINGS

- Anatomy of Seed pants Esau, K.1977, John Willey and Sons, Inc, New York

- An introduction to plant Anatomy Eames A.J. and L.H. Mac Daniels , Mc Graw –Hills Book Co. Inc, New York
- College Botany Vol II S.Chand Publication New Delhi
- A Text book of Botany Singh Pand eand Jain, Rastogi Publication, Merrut
- Wikipedia.org
- htttp://www.Biology

8.13 TERMINAL QUESTIONS

8.13.1 Short answer type question

Q.1 Cortical vascular bundles
Q.2 Medullary vascular bundles
Q.3 Normal behavior of abnormal cambium
Q.4 Secondary growth in dicot stem
Q.5 Cork cambium

8.13.2 Long answer type question

Q.1 Draw well labeled diagram of T.S. Nyctanthes stem.
Q.2 Write descriptive note on difffernt type of anaomality found in plants
Q.3 Comment on Primary thickening meristem
Q.4 Comment on secondary growth of storage root vegetable
Q.5 Write descriptive note on plants having interxylary phloem with their anatomical details

UNIT-9: CYTOLOGICAL AND MOLECULAR ANALYSIS OF SHOOT AND ROOT APICAL MERISTEMS (SAM & RAM)

Contents:

9.1 OBJECTIVES

After reading this unit students will come to know-

- About meristems, specifically shoot apical and root apical meristems.
- Development process in the plants.
- Difference between Shoot Apical Meristem (SAM) and Root Apical Meristem (RAM).
- About different theories about development of Shoot Apical Meristem (SAM) and Root Apical Meristem (RAM).
- The various cytological and molecular changes that take place in shoot apical meristem (SAM) and root apical meristem (RAM) will be discussed in the following unit.

9.2 INTRODUCTION

In higher plants the plant body is complex and is made up of following tissues: (i). Meristems or meristematic, (ii). Permanent and (iii). Secretory tissue. The word meristem was introduced by Nagelli in 1853. Meristos means divisible or able to divide. The meristematic tissue can be defined as a group of cells in continuous state of division or the cells retaining power of division.

The meristematic cells have the following characteristic features as:

1. The cells are isodiammetric arranged without intercellular spaces.
2. The nuclei are large and takes deep stains.
3. The cells are without vacuoles or vacuoles are very small in size.
4. The cells are devoid of stored food.
5. Plastids are absent and endoplasmic reticulum is poorly developed.
6. Meristems have capacity of perpetuation or ability to divide.

The meristems can be of various types:

1. Based on stage of development.
2. Based on origin of initiating cells.
3. Based on position in plant body.
4. Based on function.

The shoot and root apical meristem is based on position in plant body and are the apical meristems. They lie at the apex of shoot and root of vascular plants. Due to their activity the organs increases in length.

9.3 CYTOLOGICAL AND MOLECULAR ANALYSIS OF SHOOT APICAL MERISTEMS (SAM)

According to Gifford (1954), Clawes (1961) and a number of other workers “shoot apex is the meristematic region beyond youngest leaf primordium”. The form and size varies in different stage of growth. The size of shoot apex is maximum just before formation of leaf primordial. It is called maximal area phase. The size of the shoot apex is minimum just after formation of leaf primordial called as minimal area phase. The stage in between is called as mid area phase. The time lapse or period between the initiations of two successive leaves is called plastochron. It may be few hours, days, months and in certain cases in one year. Thus it is highly variable. There are various theories about shoot apex organization:

a. Apical cell theory

At the end of 19th century Hofmeister (1869) and Nagelli studied shoot apex and concluded that shoot apex is made up of single apical cell (Fig. 9.1) and hence gave apical cell theory. Nagelli on the basis of his observations on vascular cryptogams proposed it. Examples: In algae, Bryophytes and Pteridophytes this single cell is structural and functional unit.

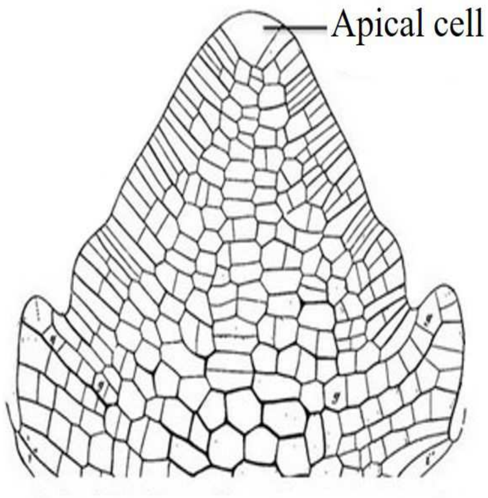

Fig. 9.1: Figure showing apical cell

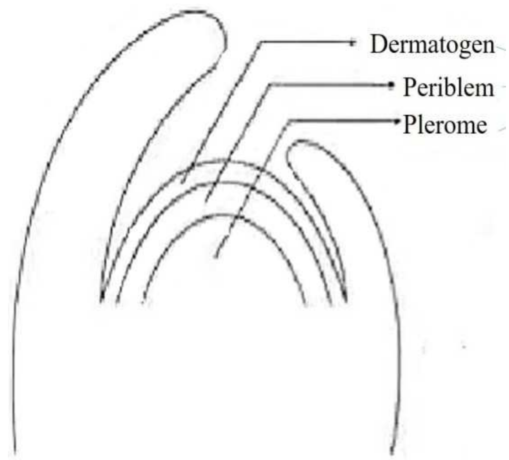

Fig. 9.2: Diagram showing histogens

Apical cell is an inverted pyramidal cell with 3 cutting faces on the proximal side and 1 cutting face on the distal side i.e. it has four sides. The distal face may or may not give rise to cells. But these three cutting faces are sufficient to give 3-dimensional structure. Their derivatives give rise to leaves. Any cell divides by anticlinal and periclinal divisions and gives rise to leaf primordial. This theory was not accepted due to water ferns, etc. In higher plant the shoot apex is complex.

After this theory a number of theories were given but it dominated till Hanstein proposed Histogen theory.

b. Histogen theory

Histogen theory was proposed by Hanstein (1879-83). According to this theory, the shoot apex of angiosperms has three distinct meristematic zones (Fig. 9.2) i.e., (i). Dermatogen, (ii). Periblem and (iii). Plerome. Each zone has its own sets of initials known as histogens. The dermatogen is the outermost histogen and its cells are arranged in parallel layers, this forms epidermis. Periblem is responsible for giving rise to cortex and procambium. Plerome is responsible for pith. Later on it was found that there is no morphological significance of these zones. The dermatogens can form epidermis and cortex. Periblem can form cortex and vascular tissue and plerome can form cortex also.

c. Tunica Corpus theory

Schmidt (1924) proposed this theory while working on lateral buds. According to this theory, the shoot apex is made up of two zones:

(i). The outer meristematic zone of parallel layered cells usually from one to four cells thick is tunica. These cells are smaller and divides anticlinally.
(ii). The inner zone is called as corpus, the cells of which are larger, irregularly arranged and divides in all directions i.e. anticlinally, periclinally and tangentially.

This theory has several benefits over histogen theory:

(i). Mechanically this hypothesis is superior. It considers the growth of surface and the mass inside.
(ii). This theory described zones and not the meristems. This theory never stated that tunica give rise to epidermis or a histogen itself. The present theory stated that tunica has got its own initials known as tunica initials and corpus has corpus initials.
(iii). There is no specific destiny assigned to tunica or corpus, therefore, there is no rigidity in the differentiation of tissue from tunica and corpus.

Majumdar (1931) while working on *Hordeum vulgare* observed that if the apex is stained with vital stains like fast green then three zones of different staining can be observed. The cells of the peripheral zone stain densely while those of rib and central zone stain lightly. If tunica represents the peripheral layer and corpus inner region, the four cytohistological zones can be differentiated into:

a. Tunica
b. Corpus: The corpus has three zones; i. Central ii. Peripheral iii. Rib zone (Fig. 9.3)

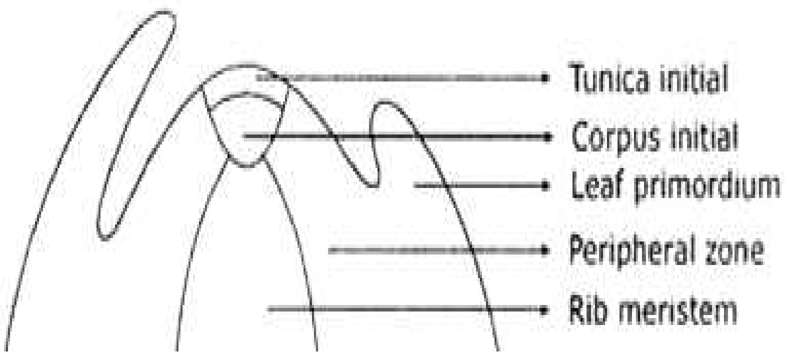

Fig. 9.3: Diagram showing the cytohistological zonation of apical meristem

Foster (1931, 1936) did sideways work in Gymnosperms. He observed that cytohistological zonation was very much clear in this case. He called one central zone as central mother cell zone whose derivatives are given in all directions i.e. the zone responsible for giving rise to derivatives on all sides especially in the cortex region.

d. Mantle core theory

It was proposed by Popham and Chan (1952). According to them shoot apex is made up of two meristematic zones mantle and core. In mantle cells divides anticlinally and sometimes periclinally. In core cells can divide in any direction. This suggestion was criticized by Gifford (1954) by saying that this concept is not far away from tunica corpus theory. But one important observation given by Popham and Chan when they were studying shoot apex of *Chrysanthemum orifolium*, they observed that shoot apex is large enough it has the tunica, corpus with peripheral and rib zone apart from this there is a zone of cells transversely stretched therefore it was called as cambium like zone. They described three major criteria associated with this:

1. A feature of larger apices- e.g in many cases like *Arabidopsis*, *Kaunferia seaposa*, where shoot apex is small, this cambium like zone is reported. In smaller apices there are not too many cells to draw attention thus many authors might have missed this cambium like zone.
2. It is prominently observed or appeared during mid to maximum phase
3. It is responsible for elongation of shoot apex. For this there is lot of controversy.

In many cases including *Calotropis*, in members of Labiatae, Verbenaceae in *Plumeria*, it has been observed. For leaf formation periclinal division are observed and periclinal division occurs at one of the flanks of this palatine (cambium like zone) thus it was concluded that it was representing differentiation of nodal region.

In *Calotropis* several such zones could be identified down in the axis, therefore, it was found that it might be representing the nodal region.

1. But is predominantly found where node differentiation is clear cut.
2. It is predominantly developed in minimal phase to mid phase. In minimal phase it is disturbed and is left and in next mid phase a differentiation of new node takes place.
3. It is not responsible for elongation of shoot apex instead it is responsible for the development of nodal region.
4. It establishes the site of leaf initiation and as it represents nodal differentiation several such zones may be observed down in the axis.

e. Anneau initials and meristeme de attente theory

The theory was proposed by Plantefol and Buvet (1952). Plantefol (1947) worked on *Papaver somniferum* and studied the pattern of phyllotaxis on basis of organization of apex and proposed that there are foliar helices. Therefore any phyllotaxis can be resolved on a few spirals (may be 1-3) or helices. All those helices end up in specific region in shoot apex, and this region is called as anneau initial. Thus anneau initial is a meristem ring which is responsible for giving rise to leaves and was suggested apart of this ring is utilized in formation of leaf and in next plastochron this ring recognizes to form a complete ring.

This concept was further supported by Budder and Buvat (1950, 52). Buvat maintained that vegetative as well as foliar activities are controlled by apex. He suggested that in the axis several meristems can be identified depending upon the activity. The shoot apex is made up of three zones. The peripheral and central zones are dividing cells and active cells and the distal cells are inactive. The three zones of shoot apex are; anneau initials, meristeme medullaire and meristeme de attente. The central zone or distal non-dividing cells are meristeme de attente and is made up of promeristeme sporogene and promeristeme receptaculaire and these two are awaiting meristems. This waiting meristem becomes active when vegetative shoot converts into flowering. The inner central zone is meristeme medullaire which divide to make pith and vascular cylinder.

Thus this concept was based upon the final structure that the shoot apex is going to give rise. This concept contributed important information and their approach are as;

1. Low mitotic activity.
2. Low cytoplasmic reactivity to different vital stains. It was shown that cytoplasm is thin and lightly stained.
3. Cells in resting state, nucleus is in interphase state, vacuolation preset and cells are of large size.

But this concept was not accepted by some scientist including Philips (1947), Gifford, Cutler (1972), Wardlaw (1968), Sahni and Steeves (1983), Awasthi et al. (1984, 86).There was also an another scientist Gregorie (1937) according to which "flower is organ suigeneris:.

The studies which went against Buvat are:

1. Presence of mitotic figures in central zone,
2. Some divisional stages,
3. Histochemical studies,
4. Cell nuclear ratio,
5. Surgical experiments,
6. DNA synthesis studies,
7. Ultrastructural studies.

All these studies have gone a long way to prove that cells in the central zone are not completely silent. Surgical experiments were done in fern *Dryopteris*, Wardlaw cut off all the peripheral region of the shoot apex and it was the central axis which was left. Thus the leaves should not be formed. But the central axis grew and also gives rise to leaves. Thus this region may not be considered as inactive region.

Sona and Ball isolated the shoot apex removed all the leaves, make a scar 1 to 2 cells deep. They found that the gap was healed up. The cell that was damages was replaced by new cell. Other set of experiment performed by them was unique. This was based on the surface growth. They separate the young leaves and put a carbon dot on shoot apex with the help of hair and saw that it moved down and radially. They concluded that there occurs surface growth in the tunica layers consequent of the divisions just below in the corpus or so called central zone.

Newmann carried out experiments or *Macrozamia* and *Lutoinus* and it was concluded that there is growth in the meristeme de aattente region during vegetative growth. Sahani and Steeves carried out DNA synthesis studies in *Helianthus* and observed that in the central zone the cell belonging to medullaire de attente could show radioactivity in ultrathin sectionS of 1 or 2 μ thick. Thus they concluded that DNA synthesis does occur in the apex in central mother cell zone or medullaire de attente zone. This radioactivity experiment could not be performed by others because of the fact that the cell cycle of these cells is long enough (20-21 days) while the synthesis phase (S1) is only a few minutes. In Ultrastructural studies it was observed that concentration of ribosomes is very low, and the endoplasmic reticulum is also sufficiently differentiated and therefore it was concluded that these cells are less activity cells and therefore equivalent to initials.

f. Neumann Concept

It was given in 1958, 1961, 1963. It was unique and was based upon the idea given by Pratt. If a cell divides it loses its entity and is replaced by two daughter cells and same concept was accepted by Newmann. This cell which continues the activity of mother cell was called as continuing meristematic residue (CMR). He explained his hypothesis on the basis of filamentous structure. As the growth proceeds this apical cell divides by transverse division into two and the apical cell has lost its entity and is replaced by two daughter cells. The upper cell will now continue to show meristematic activity and is called as CMR. In later stages the penultimate cells has also undergone divisions which are much more vigorous (4-5 times). After this the apical cell now again divides into two. He suggested that in any meristem there are two types of cells:

a. CMR: cells retaining the office
b. General meristem (GM): cells derived from apical cell and has capacity to divide.

Neumann suggested that cells of GM continue to divide rapidly in comparison to CMR. He suggested that this CMR is equivalent to initials and GM is a derived meristem. He associated it with high meristematic activity which is short lived. CMR have comparatively low meristematic activity but it is long lived activity. The GM is constituted by cells that divide at a higher rate and therefore they lose their capacity to divide quickly and finally differentiated. On the other hand CMR will divide at a lower pace but the span of activity is extremely prolonged one and therefore these CMR can be compared to initial cells.

These CMR at the time of complete succession of growth will divide very fast as GM and mature. This concept is very unique because according to it shoot apex is made up of several such filaments joined together. Therefore apical cell must come close together at a definite level. The region which is present just equivalent to CMZ is the region constituted by group of initials and these initials are very low in their mitotic division in comparison to GM constituting rib and flank zone.

Tunica is applied to those layers which divides only anticlinally. So this hypothesis of Neumann has completely shaken the concept of meristemee de attente. In vegetative phase the CMZ or central zone or meristemee de attente is constituted by initials rather than awaiting meristem. During flowering process the cells of CMR divide very rapidly because these cells are in a stage that is prior to complete cessation of growth. On the basis of these entire hypothesis people have tried to divide the distribution also.

Popham (1951) divided the organization of shoot apex into seven types, out of which 5-7 have been recognized to belong to angiosperms. Tunica and corpus having its own initials, corpus further divided into flank and rib zone. The cambial like zone was recognized by Popham and Chan. While Neumann recognized three types of shoot apex namely:

1. Monoplex: CMR is represented by single apical cell.
2. Simplex: only one CMR which give rise to tunica, corpus, rib and flank zones. E.g. Gymnospersm (Cycadales)
3. Duplex: CMR is complex and can be analyzed into 1/2/3 sets.

9.4 CYTOLOGICAL AND MOLECULAR ANALYSIS OF ROOT APICAL MERISTEMS (RAM)

Root apical meristem is very unique and is having a lot of differences from shoot apex in:

a. Being subapical.

b. Differentiated into following zones:-
   (i) meristematic region
   (ii) root hair form zone
   (iii) zone of cellular elongation
   (iv) region of lateral root formation
   (v) region of maturation

c. Apex does not have any plastochronic changes.

d. The apex does not show variable organization which may be time bound.

e. RA enters the soil thus the apical tissues are removed and are to be replaced. One assumption says that ~10,000-10,00,000 cells are damaged per day and thus high mitosis takes place.

a. Apical cell theory

It indicates that whole of root apical meristem was made up of single cell. It was proposed by Hofmeister and Nagelli. There is an inverted pyramidal cell with three cutting phases. One cutting face towards peripheral side gives rise to cap and other forms upper part. But this theory is applicable in Pteridophytes and absent in angiosperms and gymnosperms.

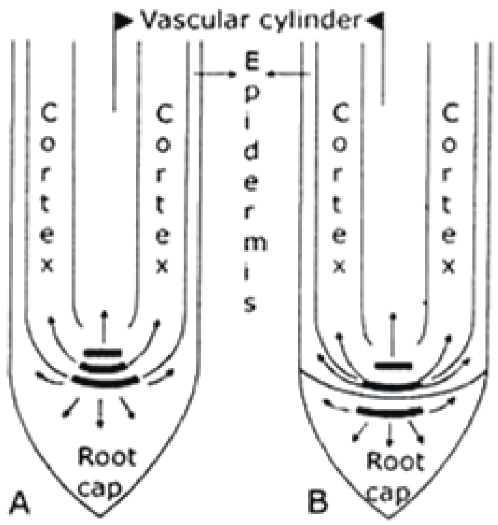

Fig. 9.4.a: Diagram of root apex based on Histogen theory. A. Root apex of Raphanus sativa. B. Root apex of Zea mays where root cap has its own histogen, i.e., Calyptrogen. Broad lines indicated histogens. Arrows indicate the direction of cell formation.

b. Hanstein histogen theory

According to this histogens, dermatogen, periblem and plerome have been postulated with a little difference (Fig. 9.4 a). In some cases outer layer of periblem was forming epidermis. Where calyptrogens gives rise to dermal tissue than it is called as calyptodermatogen. Here three layers i.e., plerome, periblem and calyptrodermatogen are present. This was proposed in late 19th century but one thing lacking in this is does not give any indication upon plane of division.

c. Korper and kappe theory

Schuepp (1970) proposed a concept of plant of division for organization of root apex which came to be known as Korper (body) kappe (cap) concept i.e., where body type divisions and cap type divisions were described. The body type divisions were described in terms of '⊥' or 'λ' and cap type in terms of 'T' or 'Y' also known as korper types of divisions and cap type of divisions, respectively. It is based upon the derivative cell (Figure 9.4.b).

Thus Hanstein theory is being proposed by Korper-kappe concept superimposed upon it. But in root apices of *Pisum*, *Fagus sylvatica* etc the apical meristem in root does have a region of meristem but it is not differentiated into histogens, therefore, this region is called as transversal meristem. According to Guttenberg (1960) there can be two types of transversal meristems:

a. A transversal meristem with differentiate called as closed type.

b. Undifferentiated meristem called as open type.

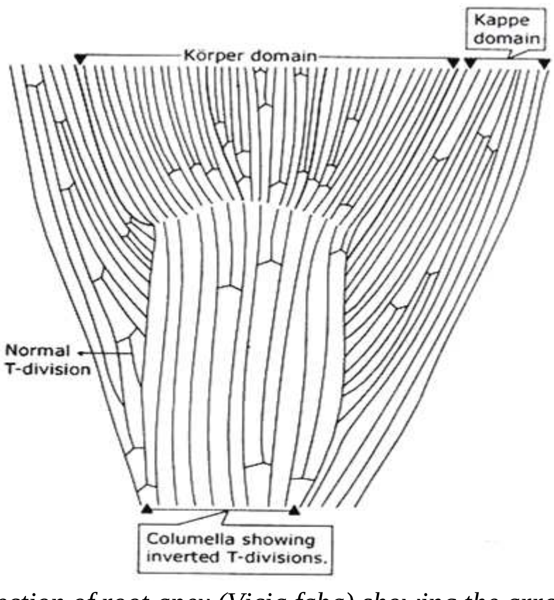

Fig. 9.4.b: Longitudinal section of root apex (Vicia faba) showing the arrangement of tissue domains based on Korpae kappe theory

It was observed that in open type (*Pisum* and *Fagus*) there is a slow transition from kappe type of divisions to Korper type of divisions i.e., cap type of divisions were more common in periphery and then the transition begins downwards. Open type is considered as advanced and closed type is primitive. Depending upon the organization one could again apply the concept of continuing meristem to designate and identify the regions where continuous, long meristematic activity at a slower rate that would constitute type transversal meristem. The second type is general meristem which will be represented by actively dividing cells but this activity is short and this is represented by cells around transversal meristem, therefore, according to organization the root apex can be classified on various types:

1. One classification is open, close type and another is by Esau, where she described *Adiantum* type having pyramidal shape with 4 cutting phases.
2. Second category was Psuedosuga type organization where there is a transversal meristem differentiated into two sectors one giving rise to initials on three sides and one sectors giving initials on two sides.
3. Third type is Allium type where there is undifferentiated transversal meristem giving rise to central ad peripheral cylinder and from the tissue to transversal meristem a columellar like tissue could be identified.

4. Other two types are:
   - *Nicotiana* type: there are three different histogens one for central, second for peripheral and third for Calyptra.
   - *Zea mays* type: one meristem giving rise to central, other to peripheral and the third giving rise to a calyptras but innermost layer of calyptras gives rise to dermis hence it is dermatocalyptrogen.

Neumann (1961) recognized following types:

a. Simplex: Can be compared to *Adiantum* type where there is only a pyramidal cell.

b. Monoplex: CMR is undifferentiated as in *Allium* type.

c. Duplex: CMR is differentiated into two or three sets of initials as in *Nicotiana* and *Zea mays*.

9.5 SUMMARY

Shoot apex is the meristematic region beyond youngest leaf primordium. The form and size varies in different stage of growth. The size of shoot apex is maximum just before formation of leaf primordial and minimum just after formation of leaf primordial called as minimal area phase. The stage in between is called as mid area phase. There are various theories about shoot apex organization:

Table 9.1. Differences between shoot apex and root apex

S.No.	Shoot apex	Root apex
1	It is terminal	It is sub terminal
2	It is dome shaped	It is cone shaped
3	Quiescent centre center is absent	Quiescent centre is present
4	Covered with young leaves	Covered with root cap
5	Leaves, branches and flowers comes out as lateral organs	No lateral organs
6	Plastochron is present	Plastochron is absent
7	Lateral organs are exogenous	Lateral roots are endogenous
8	Cells continuously divide	Quiescent cell never divide
9	It is complex structure	It is simple structure

a. **Apical cell theory:** Nagelli on the basis of his observations on vascular cryptogams proposed apical cell theory according to which shoot apex is made up of single apical cell.

b. **Histogen theory:** according to this the shoot apex of angiosperms has three distinct meristematic zones; dermatogen, periblemi and plerome. Each zone has its own sets of initials known as histogens. The dermatogen making epidermis, periblem cortex and procambium while plerome makes pith.

c. **Tunica Corpus theory:** according to Schmidt (1924) the shoot apex is made of two zones, outer tunica and inner corpus. Majumdar (1931) observed that corpus has three zones central, peripheral and rib zone.

d. **Mantle core theory:** Popham and Chan (1952) gave this theory. It was very similar to tunica corpus but they made an important observation that in *Chrysanthemum orifolium* a cambium like zone was present.

e. **Anneau initials and meristeme de attente theory:** it was proposed by Plantefol and Buvet (1952). Plantefol proposed that in apex there are foliar helices, these helices end up in specific region in shoot apex called as anneau initial. Thus anneau initial is a meristem ring which is responsible for giving rise to leaves. Buvat suggested that the shoot apex is made up of three zones, the peripheral and central zones are dividing cells and active cells. The distal cells are inactive. These three zones are called as anneau initials, meristeme medullaire and meristeme de attente. The central zone or distal non-dividing cells are meristeme de attente and is made up of promeristeme sporogene and promeristeme receptaculaire. And these two are awaiting meristems. This meristems becomes active when vegetative shoot converts into flowering. The inner central zone is meristeme medullaire which divide to make pith and vascular cylinder.

f. **Neumann concept:** This idea was given by Pratt. It was elaborated by Newmann and he suggested that in any meristem there are two types of cells:
(i). CMR (continuing meristem residue): cells retaining the cells activity.
(ii). General meristem (GM): cells derived from apical cell and has capacity to divide.

The GM have short lived meristematic activity and divides rapidly in comparison to CMR. This concept was very unique because according to it shoot apex is made up of several such filaments joined together. The Neumann hypothesis shooked the concept of meristemee de attente. In vegetative phase the CMZ or central zone or meristemee de attente is constituted by initials rather than awaiting meristem and during flowering process the cells of CMR divide very rapidly.

Neumann recognized three types of shoot apex namely monoplex, simplex and duplex.

Root apex is also an apical meristem having differences from shoot apex being subapical and having various zones in meristematic region. Unlike shoot it does not have any plastochronic changes.

a. Hofmeister and Nagelli proposed that root apex is made up of single cell and this was known as apical cell theory.

b. Hanstein proposed histogen theory according to which dermatogen, periblem and plerome are the three histogens which makes epidermis, cortex and vascular bundles respectively.

c. Schuepp proposed Korper (body) and kappe (cap) theory. According to Guttenberg (1960) there can be two types of transversal meristems, meristem with differentiation (closed type) and undifferentiated meristem (open type). It was observed that cap types of divisions were more common in periphery and than the transition begins downwards. Open type is considered as advanced and closed type primitive. The root apex can be classified on various types: One category is open, close type and another is *Adiantum* type; second was *Psuedtsuga* type, third type is *Allium* type, *Nicotiana* type and *Zeamays* type.

d. Neumann (1961) recognized following three types simplex, monoplex and duplex.

9.6 GLOSSARY

Anneau initials: that part of apex that produces the primordial of lateral organs.
Apical meristem: meristem at the apex of a root or shoot.
Continuing meristematic residue (CMR): Cells which continues the activity of mother cell. It shows meristematic activity.
Core: The cells can divide in any direction. It is considered equivalent to corpus.
Dermatogen: The young or embryonic epidermis in plants.
Duplex: CMR is complex and can be analysed into 1/2/3 sets.
General meristem: Cells derived from apical cell and having capacity to divide.
Growing point: A part of plant body at which cell division is localized, generally terminal and composed of meristematic cells.
Histogen: Tissue producing zones or layers, plerome, periblem and dermatogens.
Mantle: Meristematic zone in which cells divides anticlinally and sometimes periclinally. It is considered equivalent to tunica.
Meristem: It is a tissue in plants that consists of undifferentiated cells capable of cell division. They give rise to various tissues and organs and are responsible for growth.
Meristematic: Consisting of meristems, tissue cells of growing point.
Meristeme de attente: It is central zone of non dividing cells and is further made of promeristeme sporogene and promeristeme receptaculaire
Meristeme medullaire: The zone which divides to make pith and vascular cylinder.
Monoplex: CMR is represented by single apical cell.
Periblem: Layers of ground or fundamental tissue between dermatogen and plerome.
Phyllotaxis: the arrangement of leaves on an axis or stem.
Plastochron: It is the time interval between the two successive events during the growth of plants.
Plerome: The core or central part of an apical meristem.
Primary meristem: Ground meristem, procambium and protoderm.
Promeristem: Meristem of growing point, and primary meristem
Promeristeme sporogene: Waiting meristem which forms flower when vegetative shoot convets into flowering.
Promeristeme receptaculaire: Waiting meristem which forms stalk bearing flowers when vegetative shoot convets into flowering.
Protoderm: The outer cell layer of apical meristem, primordial epidermis of plants, superficial dermatogens.

Quiescent centre: A region in the apical meristem of a root where cell division proceeds very slowly or not at all, but the cells are capable of resuming meristematic activity if the surrounding tissue gets damaged.
Root cap: A protective cap of tissue at apex of root.
Simplex: There is only one CMR which give rise to tunica, corpus, rib and flank zones.
Tunica: Apical meristematic cell giving rise to protoderm.

9.7 SELF ASSESSMENT QUESTIONS

9.7.1. Multiple choice Questions:

1. Plerome gives rise to:
   (a) Epidermis (b) Cortex
   (c) Vascular tissue (d) Ground tissue

2. Root hairs are present in:
   (a) Meristematic zone (b) Elongation zone
   (c) Maturation zone (d) Root cap zone

3. Who proposed apical cell theory
   (a) Nageli (b) Hanstein
   (c) Clowes (d) None of the above

4. Quiescent centre cells may be stimulated for division by:
   (a) Surgery (b) Cold treatment
   (c) Radiation (d) All of the above

5. Root apex differs from shoot apex in having:
   (a) Plerome (b) Dermatogen
   (c) Periblem (d) Root cap

9.7.2. Fill in the blanks:

1. The cells of the tissue which are in state of active cell division are called as______
2. Histogen theory was given by______
3. Quiescent centre is present in_____
4. Korper Kappe theory was proposed by______
5. The origin of lateral organs in shoot apex is _______in nature.

9.7.3. True or false:

1. In shoot apex plastochron is present.
2. Quiescent centre is present in shoot apex.
3. According to Guttenberg root have open and closed type of organization.
4. The permanent tissues are derived from apical meristem.
5. Wardlaw divided shoot apex into 5 regions.

9.7.1 Answer Key: 1. (c); 2.(b); 3.(a); 4.(d); 5. (d)
9.7.2 Answer Key: 1. Meristematic cells; 2. Hanstein; 3. Root apex; 4. Schuepp; 5. Exogenous.
9.7.3 Answer Key: 1. True; 2. False; 3. True; 4. True; 5. True

9.8 REFERENCES

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9.10 TERMINAL QUESTIONS

9.10.1. Short answer type question:

Q.1 Write a short note ona pical meristem.
Q.2 What do you understand by Histogen Theory?
Q.3 Discuss the mantle core theory.
Q.4 What is quiescent centre?
Q.5 What is Korper Kappe theory?
Q.6 Explain shoot apex organization on basis of tunica corpus theory.
Q.7 Name the growth regions in the shoot apex of gymnosperms as given by Foster.

9.10.2. Long answer type question:

Q.1 Give various theories about shoot apex organization.
Q.2 Explain the organization of root apex by means of various theories.
Q.3 Which theory of shoot apex organization convinces you most? Explain it with suitable reasons.

UTTARAKHAND OPEN UNIVERSITY

Teenpani Bypass Road, Behind Transport Nagar,
Haldwani- 263139, Nainital (Uttarakhand)
Phone: 05946-261122, 261123; Fax No. 05946-264232
Website: www.uou.ac.in; e-mail: info@uou.ac.in
Toll Free No.: 1800 180 4025