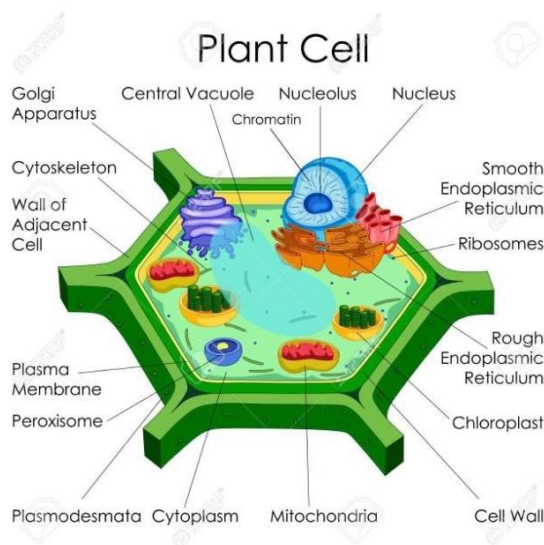# Unit - I

Cytology - Ultra structure of plant cell. Structure and functions of chloroplast, mitochondria and nucleus.

Anatomy - Simple and complex tissues; Anatomy of stem, leaf and root of dicot and monocot plants: Normal secondary growth in dicot stem.

Ultra Structureof Plant Cell

A plant cell consists of the following components:

The Cell wall is the non-living protective layer in the plant cells. Cell wall provides mechanical support and gives a definite shape to the cell. It protects plasma membrane and helps in imbibition's of water and movement of solutes towards protoplasm.

Protoplasm is the living, colourless, elastic, colloidal semi fluid substance present in the cell. Each protoplast keeps communication with neighbouring cells through small openings known as plasmodesmata. Protoplasm consists of cytoplasm and nucleus and is externally bounded by the cell membrane or plasmalemma.

Cell membrane is a thin membrane and serves as protective covering of the cell. It allows s the entry of nutrients inside and outside of the cells.

Cytoplasm is a fluid mass of protoplasm.The cytoplasm is composed of matrix which contains the membrane bound organelles and non-living inclusions like vacuoles and granules. The living cytoplasmic organelles are the site of various important metabolic activities such as photosynthesis, respiration, protein synthesis etc.

Chloroplast contain chlorophyll- the green pigment. Chloroplast in enclosed in two smooth membranes separated by a distinct periplastidial space. The interior of chloroplast is differentiated into two parts— The Stroma and the Grana.Stroma is the colourless ground substance that fills the chloroplast. It contains cholorophyll bearing double membranes lamellae that form flattened sac like structures called thylakoides collectively called Grana. Mitochondria are sausage- shaped spherical organelles present in the cytoplasm. They are also called as the powerhouse of the cell.The mitochondria are surrounded by a double walled membrane known as outer and inner membranes. The outer membrane is smooth but the inner membrane is variously folded into thin cristae. These are the sites of aerobic respiration.

The Nucleus is the most important part of the cell which regulates all metabolic and hereditary activities within the cell It is more or less spherical, lying in the cytoplasm and occupying about two-thirds of the cell space.

Golgi apparatus has three distinct components flattened sac or cisternae, vesicles and vacuoles. Golgi is mainly associated with secretory activity of the cell.

Endoplasmic reticulum (ER) is a network of interconnected and convoluted sacs that are located in the cytoplasm. Based on the presence or absence of ribosomes, ER can be of smooth or rough types. The former type lacks ribosomes, while the latter is covered with ribosomes.The function of the endoplasmic reticulum is storing and transporting structure for glycogen, proteins, steroids and other compounds.

Lysosomes are tiny membrane-bound, vesicular structure which enclose hydrolytic enzymes and perform intracellular digestion. These are also known as suicidal bags. These are found in all animal cells but only in few plant cells.

Vacuoles are sap- filled vesicles in the cytoplasm. These are surrounded by a membrane called tonoplast. In a plant cell, there can be more than one vacuole; however, the centrally located vacuole is larger than others.

Structure and Function of chloroplast

Ultrastructure of Chloroplasts:
Structurally each plastid consists of two parts:
(1) outer limiting membrane, and

(2) inner matrix or stroma.

This is a double membrane and each membrane is trilaminar and lipoproteinous and lacks chlorophyll and cytochromes. All molecular interchanges occur between the cytoplasm and chloroplast through this limiting membrane. The outer membrane is smooth and the inner membrane is much folded into the chloroplast stroma.

The inner membrane is highly selectively permeable to molecules. Each membrane is of about 40-60 A in thickness. Intervening space between the two membranes is called the periplastidial space and is 25-75 A.

In Chlamydomonas, this is continuous with endoplasm. It serves as a semipermeable membrane reticulum and as the boundary of the plastids. Their chemical structure is essentially like that of reticulum.

2. Stroma (matrix):
Plastids are filled with a watery, proteinaceous substance called the matrix or stroma. It contains about 50% of the chloroplast proteins and most of these are of the soluble type.

stacked thylakoids

external membrane

internal membrane

grana

intergrana

stroma

thylakoids space
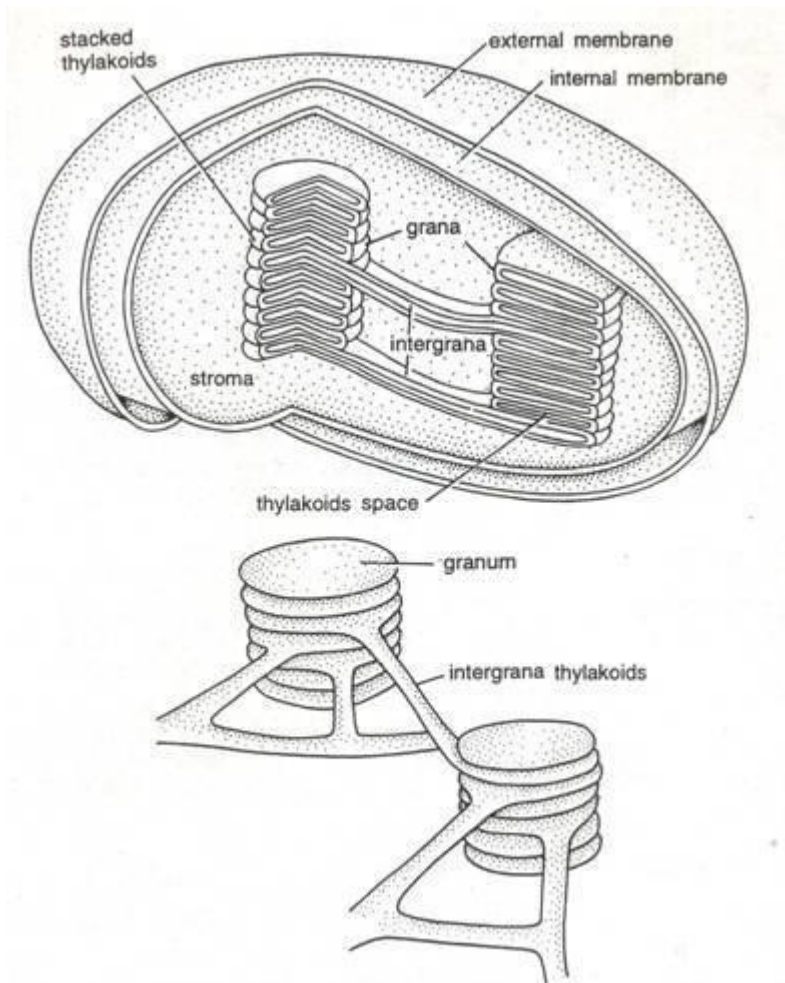
granum

intergrana thylakoids

Fig. 3. Structure of plastid.

It has ribosomes and also DNA. It also contains starch granules and osmiophilic droplets. During inactivity of the plastids the osmiophilic droplets increase, in number.

In the stroma are embedded disc-like flattened structures made of double membranes. These discs are called lamellae (thylakoids). The outer surface of the thylakoid is in contact with the stroma and its inner surface encloses an intrathylakoid space. Thylakoids may be stacked like a pile of coins, forming the grana or they may be unstacked called stroma thylakoids.

Thus, a granum consists of a series of membrane discs packed back to back, like a stack of coins. However, each disc is interconnected at an angle to all other discs in a granum by tubules called frets. By branching, a fret connects a disc to each of the other discs in turn.

Thylakoids provide a large membrane area to hold the photosynthetic pigments and enzymes. Thylakoids containing chlorophyll (photic apparatus) for photosynthesis, permit separation of the light reactions that occur there from the dark reactions in the chloroplast stroma that fix CO_2 to synthesize sugars, starch, fatty acids and some proteins.

Structure and function of Mitochondria

Mitochondria are membrane bound cell organelles, associated with cellular respiration, the source of energy, being termed as power houses of cell. Mitochondria, discovered by Benda (1898), are present in eukaryotic cells. These are bean-shaped organelles, 1 to 10 pm long and about 0.5 pm wide, occur free in the cytoplasm.

The mitochondrion is bounded by two membranes, the outer membrane and the inner membrane (Fig. 2.50). Both the outer and the inner mitochondrial membranes are about 60-70A thick. The outer membrane contains more phospholipid and cholesterol than the inner membrane.

Phosphatidylcholine is the predominant lipid of the outer membrane while the inner membrane contains most of the diphosphatidylglycerol (cardiolipin) of the mitochondrion.
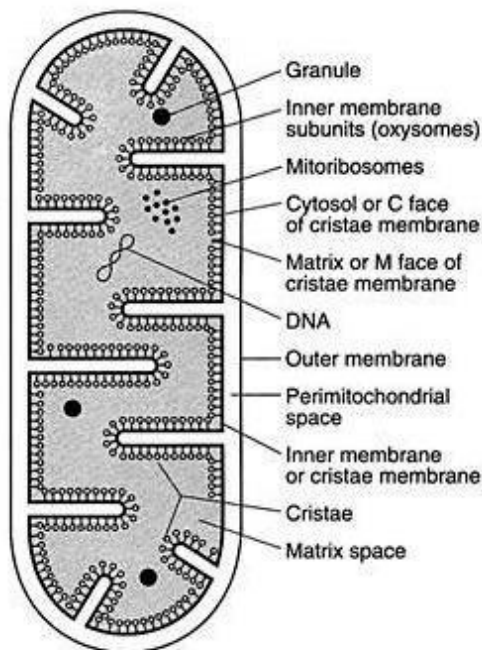

Fig. 2.50: A mitochondrion in sectional view

The space between the two membranes is called the outer chamber or inter-membrane space or peri-mitochondrial space. It is filled with a watery fluid, and is 40-70A in width. The space bounded by the inner membrane is called the inner chamber or inner membrane space.

The inner membrane space is filled with a matrix which contains dense granules, mitoribosomes (70S) and circular mitochondrial DNA and Krebs cycle enzymes. The sides of the inner membrane facing the matrix and the outer chamber are respectively called M-face and C-face.

The outer membrane is smooth while the inner membrane is thrown up into a series of folds, called cristae mitochondrial, which project into the inner chamber (Fig. 2.51 A). The cavity of the cristae is called the inter-cristae space, and is continuous with the inter- membrane space.

Associated with the inner membrane are several thousand small particles which have been called elementary particles or subunits of Fernandez-Moran, or $F_o - F_1$ complex or ATPase complex or oxysomes. Each particle consists of a base-piece, a stalk, a headpiece. The particles are spaced about 100Å intervals. The headpiece is 75-1 OOÅ in diameter, and the stalk about 50Å in length (Fig. 2.51 B).
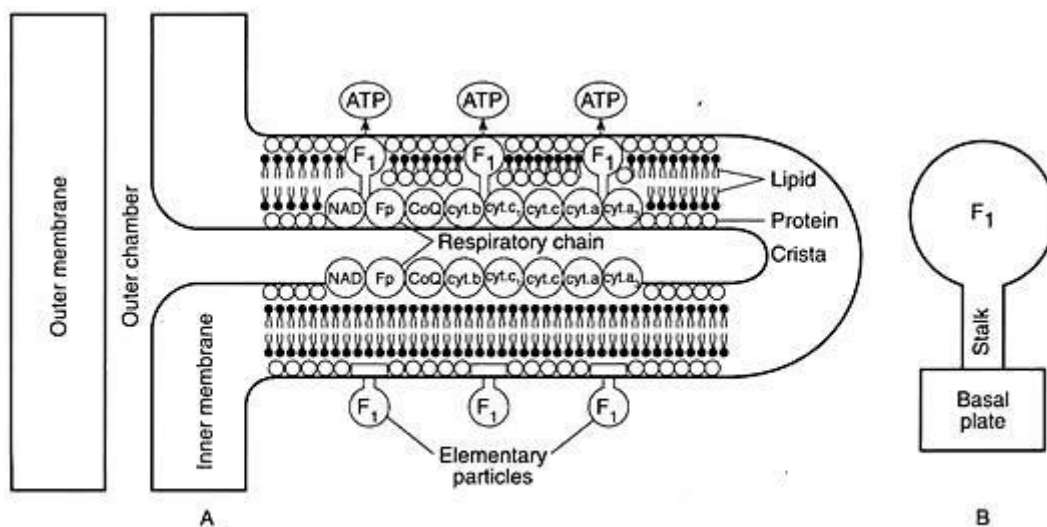

Fig. 2.51: A. Mitochondrial crista and B. Elementary particle

The respiratory chain, consists of a series of protein, located in the inner membrane of mito-chondria. Five complexes (Table 2.5) have been identified: four of them (I -IV) constitute electron transport system and the rest (V) is the ATP synthesizing system.

Structure and function of Nucleus

1. It was discovered by Robert Brown (1831).

2. It is the major part of a eukaryotic cell that contains the genetic material. Prokaryotic cells have no nucleus as such.

3. Each nucleus remains enclosed in a nuclear membrane or nuclear envelope. It is a double membrane surrounding the nucleus (Fig. 299). Each layer has a typical plasma-membrane like structure and is 4 nm to 6 nm in width.
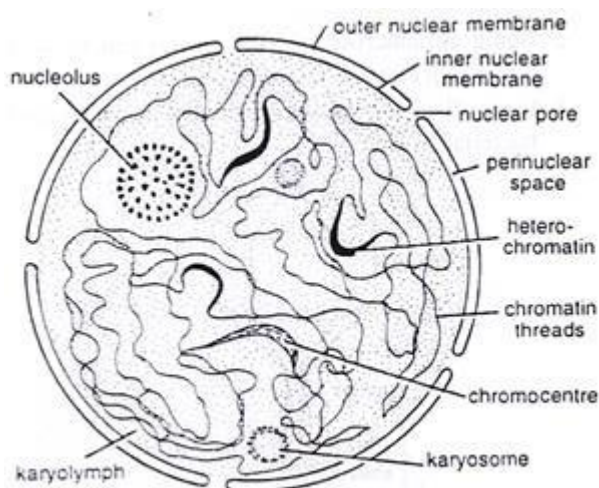

Fig. 299. Ultrastructure of a nucleus (Diagrammatic).

Electron micrographs reveal the connection between the outer nuclear membrane and the endoplasmic reticulum. A perinuclear space is present in between the membranes. At various points the two membranes fuse and form pores.

4. The interphase nucleus of eukaryotic cells contains a network of chromatin fibres, which become organised into chromosomes before cell division.

5. The substance of the nucleus apart from the chromatin is called nucleoplasm or karyoplasm. It contains complexes and enzymes necessary for DNA replication and synthesis of RNA molecules.

6. One or more nucleoli are also present in the nucleus. A nucleolus consists of proteins associated with RNA. In the electron micrographs, a nucleolus shows a central area of short fibers surrounded by a matrix of protein material with several granules embedded in the peripheral region.

7. Nucleus controls all the genetic activities of the cell. In the germ cells it carries hereditary information from generation to generations

1. Simple Permanent Tissues:

A simple permanent tissue is that tissue which is made up of similar permanent cells that carry out the same function or similar set of functions. Simple permanent tissues are of three types— parenchyma, collenchyma and sclerenchyma.

i. Parenchyma:

Parenchyma is a simple permanent living tissue which is made up of thin-walled similar isodiametric cells. It is the most abundant and common tissue of plants. Typically the cells are isodiametric (all sides equal). They may be oval, rounded or polygonal in outline.

The cell wall is made up of cellulose. Cells may be closely packed or have small intercellular spaces for exchange of gases (Fig. 6.7 B). Internally each cell encloses a large central vacuole and a peripheral cytoplasm containing nucleus. The adjacent parenchyma cells are connected with one another by plasmodesmata. They, therefore, form symplasm or living continuum.

Parenchyma is morphologically and physiologically un-specialised tissue that forms the ground tissue in the non-woody or soft areas of the stems, leaves, roots, flowers, fruits, etc. The typical parenchyma is meant for the storage of food, slow conduction of various substances and for providing turgidity to the softer parts of the plants.

It is modified variously to perform special functions:
(a) Fibre-like elongated parenchyma is called prosenchyma. It is slightly thick walled and is meant for providing rigidity and strength.

(b) Cutinised parenchymatous cells form a protective covering layer or epidermis. Epidermis is single layered. Intercellular spaces are absent. The cutin also forms a distinct layer on the outer surface of epidermal cells. It is called cuticle (Fig. 6.7 E). It reduces transpiration.

(c) The young parts of the root are covered by a layer of un-thickened and un-cutinised parenchyma cells, some of which give rise to tubular outgrowths called root hairs. It is known as piliferous layer or epiblema. This layer is specialized to absorb water and mineral salts from the soil.

(d) Xylem parenchyma is made of small and often thickened cells. It helps in the storage of food and lateral conduction of water (Fig. 6.7 D).

(e) Phloem parenchyma is formed of thin-walled elongated parenchymatous cells. It takes part both in the storage and lateral conduction of food.

(f) Parenchyma cells containing chloroplasts are collectively termed as chlorenchyma. It takes part in the manufacture of food. Chlorenchyma of leaves is called mesophyll. It is differentiated into two parts, palisade parenchyma and spongy parenchyma (Fig. 6.7 F). Cells of palisade parenchyma are columnar in shape while those of spongy parenchyma are often lobed, rounded or irregular in outline.

(g) A special parenchyma tissue is found in the aquatic plants and some land plants (e.g., petiole of Banana, Canna). It is known as aerenchyma (Fig. 6.7 G). It consists of a network of parenchyma cells which enclose very large air cavities. These air cavities store gases and make the aquatic plants light and bouyant.
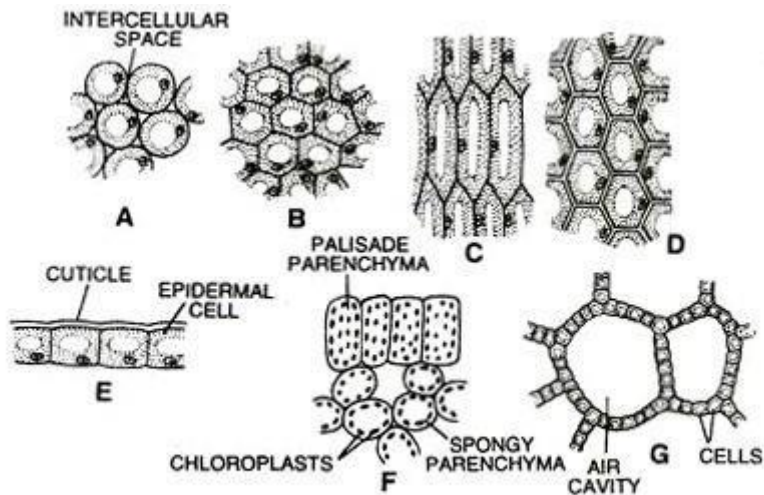
Fig. 6.7. Types of Parenchyma Cells. A–B, normal parenchyma cells; A, rounded; B, angular; C, prosenchyma; D, xylem parenchyma; E, epidermal cells; F, mesophyll; G, aerenchyma

(h) Storage parenchyma is made of large sized vacuolate cells which store water, mucilage and food, e.g., Aloe, Opuntia Potato tuber.

(i) Idioblasts are specialized non-green large-sized parenchyma cells which possess inclusions or ingredients like tannins, oils, crystals, etc.

(j) Secretory cells are specialized parenchyma cells that produce nectar, oil, etc.

Functions:
(i) Storage of food,

(ii) Providing turgidity to softer parts,

(iii) Providing rigidity to tissues when prosenchymatous.

(iv) Protection and checking water loss in the form of epidermis,

(v) Formation of water absorbing epiblema in root,

(vi) Lateral conduction in the form of xylem and phloem parenchyma

(vii) Photosynthesis in the form of chlorenchyma.

(viii) Providing buoyancy and storage of metabolic gases in the form of aerenchyma.

(ix) Secretion.

ii. Collenchyma:
(Gk. kolla— glue, enchyma— tissue):
Collenchyma is a simple permanent tissue of retractile non-lignified living cells which possess pectocellulose thickenings in specific areas of their walls. The cells appear conspicuous under the microscope due to their higher refractive index.

The cells are often elongated. They are circular, oval or angular in transverse section. Internally each cell possesses a large central vacuole and a peripheral cytoplasm. Chloroplasts are often present. Wall possesses uneven longitudinal thickenings in specific areas.

Depending upon the thickening, collenchyma is of three types:
(i) Angular Collenchyma:
The thickenings are present at the angles (angular thickenings), e.g., stem of Tagetes, stem of Tomato (Fig. 6.8 B).

(ii) Lamellate Collenchyma:
The thickenings occur on the tangential walls (plate thickenings), e.g., stem of Sunflower (Fig. 6.8 A),

(iii) Lacunate Collenchyma:
The thickenings are found on the walls bordering intercellular spaces (lacunate thickenings), e.g., Cucurbita stem (Fig. 6.8 C).
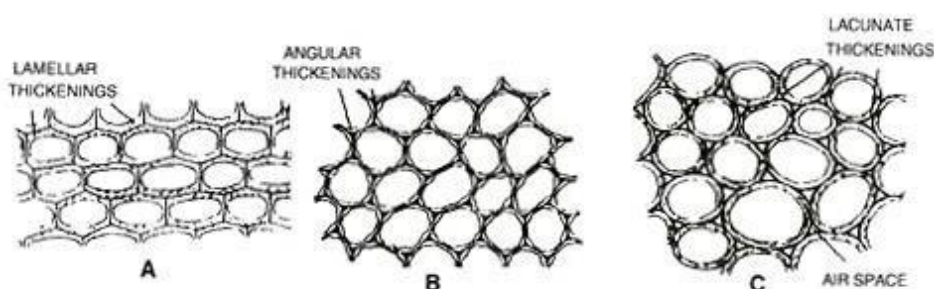

Fig. 6.8. Types of collenchyma (in T.S.). A, lamellate (plate type); B, angular; C, lacunate.

Collenchyma is found below the epidermis in the petiole, leaves and stems of herbaceous dicots, forming either continuous layers or occurring in patches, especially in the region of ridges (e.g., Gourd).

Functions:
(i) It provides mechanical strength to young dicot stems, petioles and leaves,

(ii) While providing mechanical strength, collenchyma also provides flexibility to the organs and allows their bending, e.g., Cucurbita stems,

(iii) It prevents tearing of leaves,

(iv) Collenchyma allows growth and elongation of organs,

(v) Being living, its cells store food,

(vi) Its cells often contain chloroplasts and take part in photosynthesis.

iii. Sclerenchyma:
(Gk. scleros— hard, enchyma— tissue):
Sclerenchyma is a simple supportive tissue of highly thick-walled cells with little or no protoplasm. The cell cavities are narrow. The thickening of the wall may be made up of cellulose or lignin or both. A few to numerous pits occur in the wall. Sclerenchyma is of two types, sclerenchyma fibres and sclereids.

(a) Sclerenchyma Fibres:
The sclerenchyma fibres are highly elongated (1-90 cm), narrow and spindle-shaped thick-walled cells with pointed or oblique end walls. The fibres generally occur in longitudinal bundles (Fig. 6.9A) where the pointed ends of adjacent fibres get interlocked to form a strengthening tissue.

The adjacent fibres possess simple oblique pits (un-thickened areas with common pit membranes). Bordered pits also occur in some fibres. Pits do not perform any function in the mature fibres since the latter are empty and dead.
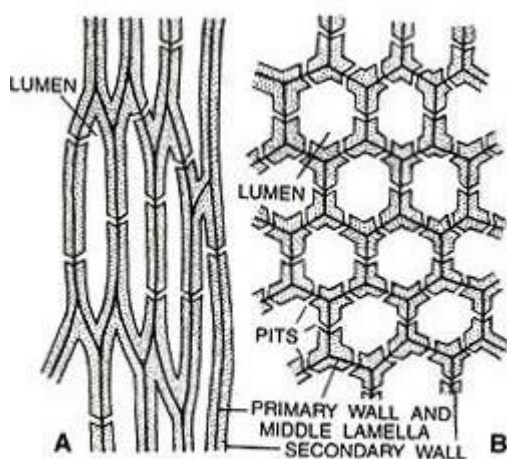
Fig. 6.9. Sclerenchyma Fibres. A, longitudinal section; B, transverse section.

Living firbes occur in Tamarix aphylla. They possess nucleated protoplasts for several years. Fibres are septate in phloem of Grape Vine. Sclerenchyma fibres constitute the major mechanical tissue of the plants because they can bear compression, pull, bending and shearing.

The fibres occur in all those parts where mechanical strength is required, viz., leaves, petioles, cortex, pericycle, phloem, xylem and around vascular bundles (e.g., monocot stem). Commercial fibres obtained from plants are usually sclerenchyma fibres, e.g., Jute, Flax, Hemp.

(b) Sclereids:

They are highly thickened dead sclerenchyma cells with very narrow cavities. Sclereids are broader as compared to the fibres being isodiametric polyhedral, spherical, oval short or cylindrical. They may also be branched.

The thick cell walls have branched or un-branched simple pits (Fig. 6.10). Being elongated, the pits of sclereids are also known as pit canals. Sclereids may occur singly or in groups. They provide stiffness to the parts in which they occur.

The important types of sclereids are as follows:
(i) Stone Cells or Brachysclereids:
Un-branched, short and isodiametric with rami-form (branched) pits, e.g., grit of Guava, Sapota, Apple and Pear.

(ii) Macro-sclereids:

Elongated and columnar or rod-like, e.g., epidermal covering of legume seeds.

(iii) Osteo-sclereids:

Bone-like or columnar with swollen ends, e.g., sub-epidermal covering of some legume seeds.

(iv) Astro-sclereids:

Branched like a star, e.g., tea leaves, petiole of Lotus.

(v) Filiform Sclereids:

Fibre-like, sparingly branched, e.g., Olea.

(vi) Tricho-sclereids:

Very elongated hair-like and regularly once branched sclereids extending into intercellular spaces.

Functions:

(i) Sclerenchyma is the chief mechanical tissue of the mature plant organs,

(ii) It allows the plant organs to tolerate bending, shearing, compression and pull caused by environmental factors like wind,

(iii) It provides rigidity to leaves and prevents their collapsing during temporary wilting,

(iv) Sclereids provide strength to seed coverings.

(v) Dehiscence of many fruits is based on differential distribution of sclerenchyma fibres, e.g., pods,

(vi) Sclereids form stony endocarp of many fruits called stone fruits, e.g., Almond, Coconut,

(vii) A number of fibres are commercially exploited, e.g., Jute (Corchorus), Flax (Linum), Hemp (Cannabis).
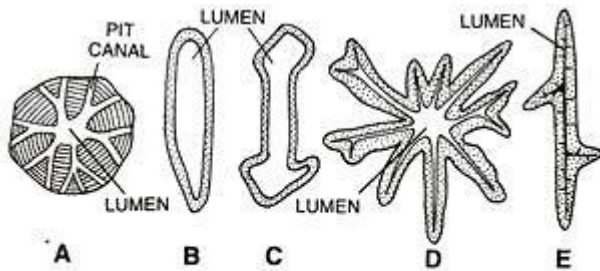
Fig. 6.10. Types of Sclereids. A, stone cell. (branchysclereid) with pit canals; B, macrosclereid; C, osteosclereid; D, astrosclereid; E, filiform sclereid.

Type # 2. Complex Permanent Tissues:

They are permanent tissues which contain more than one type of cells. All the types of cells of a complex tissue work as a unit. The common complex permanent tissues are conducting tissues, phloem and xylem.

i. Phloem:

(Gk. phlois- inner bark; Nageli, 1858):

It is a complex tissue which transports organic food inside the body of the plant. Phloem is also called bast (= bass, a vague term). It consists of four types of cells, viz., sieve tubes, companion cells, phloem parenchyma and fibres. Haberlandt (1914) uses the term leptom (e) for the conducting part of phloem.

(a) Sieve Tubes:

Sieve tubes are elongated tubular conducting channels of phloem. Each sieve tube is formed of several cells called sieve tube elements or members, sieve tube cells or sieve elements. Sieve tube members are placed end to end.

The end walls are generally bulged out. They may be transverse or oblique. They have many small pores or sieve pits. Due to the presence of sieve pits the end walls are commonly called sieve plates (Fig. 6.11 A).

In some cases the end walls of sieve elements possess more than one porous area. Such an end wall is called compound sieve plate, e.g., Grape Vine, Euphorbia royleana. The sieve plates connect the protoplasts of adjacent sieve tube members.

In non-flowering plants sieve cells remain separate. They are narrower but more elongated as compared to individual sieve tube members. The end walls are oblique. Porous areas are

less conspicuous. They are borne on the lateral walls of the elongated sieve cells. They are called sieve areas.

Internally a sieve tube member or cell has peripheral layer of cytoplasm without any nucleus (Fig. 6.11 A). The nucleus is, however, present in the young cells. The central part is occupied by a network of canals which contain fibrils of p-protein. Sieve tube takes part in the conduction of organic food.

(b) Companion Cells:
Companion cells are narrow, elongated and thin walled living cells. They lie on the sides of the sieve tubes and are closely associated with them through compound plasmodesmata. They are squarish or rectangular in a transverse section.

The cells have dense cytoplasm and a prominent nucleus. It is supposed that the nuclei of the companion cells control the activities of the sieve tube through plasmodesmata (Fig. 6.11). Companion cells also help in maintaining a proper pressure gradient in the sieve tube elements.

Sieve tube member and its adjacent companion cells are derived from the same mother cell. Death of one results in death of the other as well. Companion cells are replaced by modified parenchyma cells (albuminous cells) in non flowering plants.
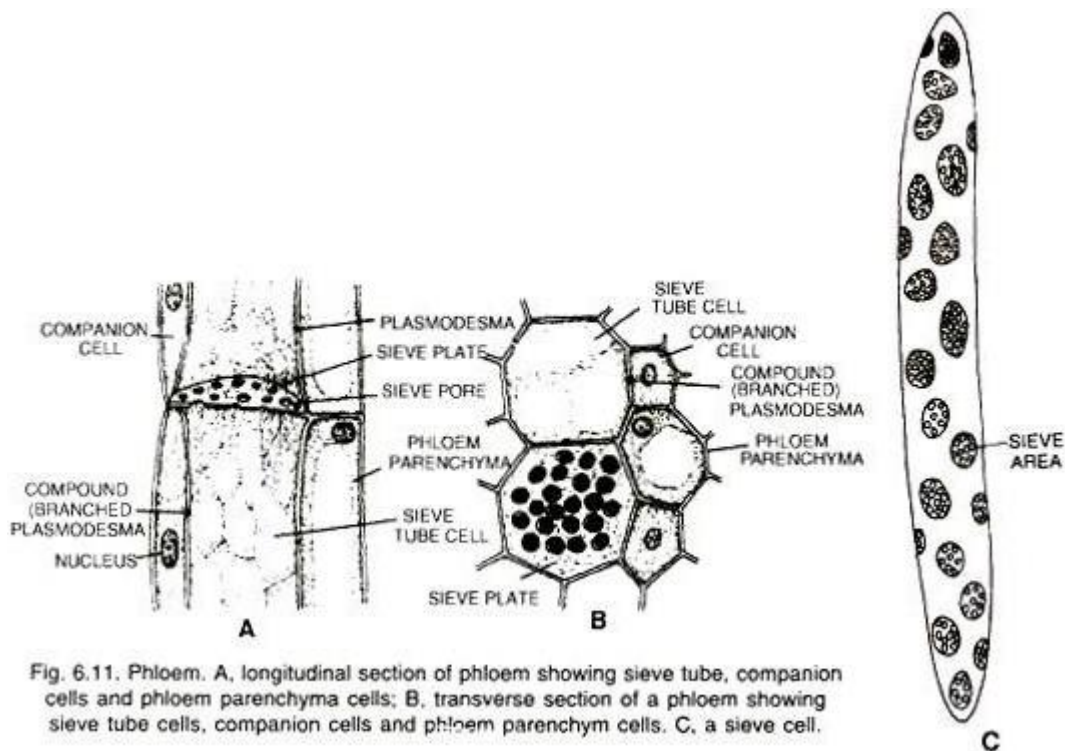
Fig. 6.11. Phloem. A, longitudinal section of phloem showing sieve tube, companion cells and phloem parenchyma cells; B, transverse section of a phloem showing sieve tube cells, companion cells and phloem parenchym cells. C, a sieve cell.

(c) Phloem Parenchyma:

They are ordinary living elongated parenchyma cells having abundant plasmodesmata. They store food, resins, latex, mucilage, etc. The cells help in slow conduction of food, especially to the sides. Phloem parenchyma is absent in most of the monocots and some herbaceous dicots.

(d) Phloem or Bast Fibres:

Sclerenchyma fibres found in the phloem are called phloem or bast fibres. They are generally absent in primary phloem but are quite common in secondary phloem where they occur more abundant in secondary phloem as compared to primary phloem.

The fibres occur in sheets or cylinders. Phloem fibres provide mechanical strength. The textile fibres of flax, (Linum usitatissimum), hemp (Cannabis) and jute (Corchorus species) are phloem fibres.

ii. Xylem:

Xylem is a complex tissue which performs the function of transport of water or sap inside the plant. Simultaneously, it also provides mechanical strength. Xylem is also known as wood. It consists of four types of cells, viz., tracheids, vessels (both tracheary elements), xylem or

wood parenchyma and xylem or wood fibres. Out of these only tracheids and vessels take part in the transport of sap.

They are hence called tracheary elements. Vessels are the main tracheary elements of angiosperms. They are absent in gymnosperms and pteriodophytes. In the last two groups, conduction of sap is carried out by tracheids. The conducting elements of the xylem have been called hadrome by Haberlandt (1914).

(a) Tracheids:

The tracheids are elongated (5-6 mm dead cells with hard lignified walls, wide lumen and narrow end walls. In outline they are circular, polygonal or polyhedral.The inner walls of tracheids have various types of thickenings for mechanical strength.

The un-thickened areas allow the rapid movement of water from one tracheid to another. Tracheids constitute 90-95% of wood in gymnosperms while in angiosperms they hardly form 5% of the wood. Depending upon the thickenings, tracheids are of the following types (Fig. 6.12).
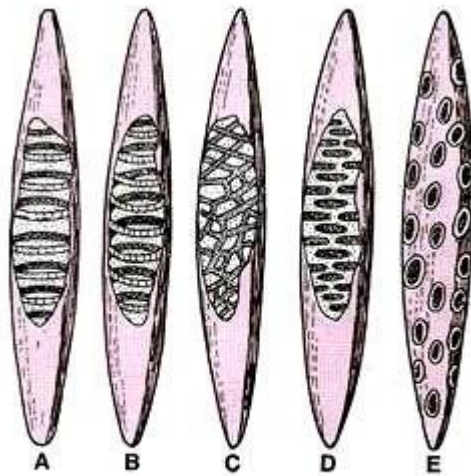

Fig. 6.12. Types of thickenings found in tracheids.
A, annular; B, spiral; C, reticulate;
D, scalariform; E, pitted.

(i) Annular:

In this type the thickening material is laid down in the form of rings.

(ii) Spiral (Helical):

The thickening is deposited like a spiral or helix. Both annular and spiral thickenings are present in the first formed tracheids because they allow considerable stretching.

(iii) Reticulate:
Thickening is present in the form of a network. It is supposed that it is formed by the presence of several spiral bands of thickenings which cross one another.

(iv) Scalariform:
Here the thickenings give a ladder like appearance because they are laid down in the form of transverse bands.

(v) Pitted:
It is the most advanced type of thickening. The pitted tracheids are uniformly thickened except for small un-thickened areas called pits. In surface view they may appear circular, oval or angular. Pits often occur in pairs, that is, exactly at the same level on two adjacent elements. The pits are of two types, simple and bordered. The simple pits have uniform width of the pit chamber or cavity.

In bordered pits the pit cavity is in the form of a flask with a narrow aperture and a wide base. The area of the primary wall and middle lamella, which is present in a pit, is called pit membrane or closing membrane.

Actually it has many submicroscopic pores for the translocation of substances. A thickening called torus is present on the pit membrane of some gymnosperms for protecting the membrane from rupturing in case of unequal pressure on its two sides.

(b) Vessels:
Vessels take part, like tracheids, in the conduction of water or sap and provide mechanical support. They are much elongated tubes (3-6 metres in Eucalyptus) which are closed at either end and are formed by the union of several short, wide and thickened cells called vessel elements or members.

The end walls of vessel elements are transverse or oblique (Fig. 6.13 B-C). They are often completely dissolved (Fig. 6.13 A). The condition is called simple perforation plate.

In a few cases the end walls remain intact and possess several pores in reticulate, scalariform or forminate forms. Such an end wall is called multiple perforation plate (Fig. 6.13 D), e.g., Liriodendron, Magnolia. Vessels help in quick movement of water in the plant.
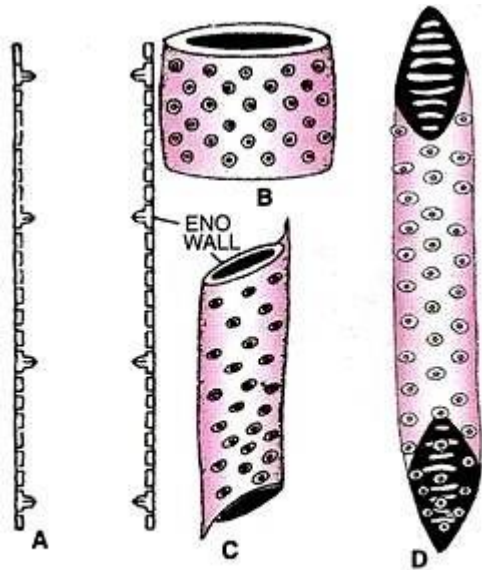

Fig. 6.13. Vessels. A, vessel in L.S. B–C, vessel elements with simple perforation plates. D, a vessel element with multiple perforation plate.

The walls of the xylem vessels are lignified. They are thickened variously— annular, spiral, reticulate, scalariform and pitted. The pitted condition is more common. In outline the vessels are rounded in monocots and angular in dicots.

Vessels are absent in gym no-sperms and pteridophytes with the exceptions of a few (e.g., Selaginella species, Gnetum). Their tracheary elements comprise tracheids only. Flowering plants possess both vessels and tracheids but the latter are comparatively fewer.

(c) Xylem or Wood Parenchyma:
It is made of generally small thin or thick walled parenchymatous cells having simple pits. The wood parenchyma stores food (starch, fat) and sometimes tannins. It helps in the lateral conduction of water or sap. Ray parenchyma cells are specialised for this.

(d) Xylem or Wood Fibres:
They are sclerenchyma fibres associated with xylem. Xylem fibres are mainly mechanical in function. They are aseptate but can be septate.

Xylem fibres are of two types:

(i) Libriform Fibres. Typical fibres with thick walls having simple pits and obliterated central lumens,

(ii) Fibre Tracheids.

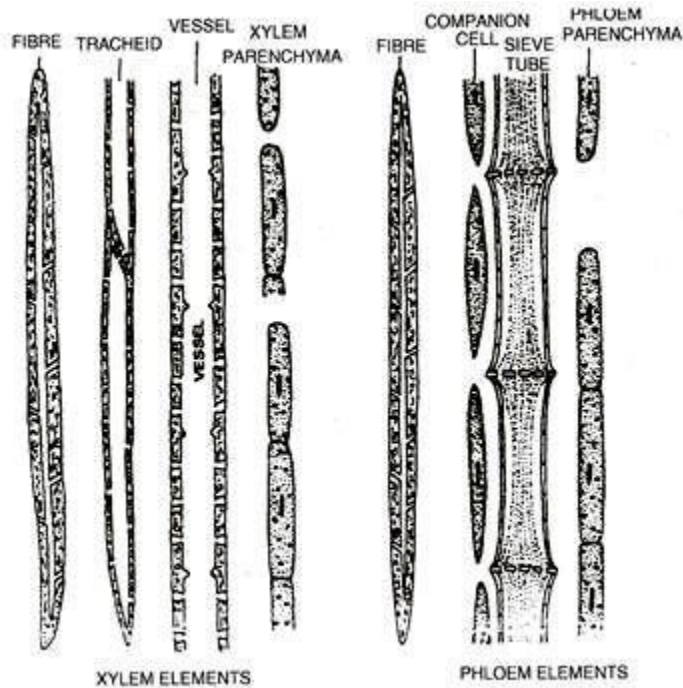Intermediate between fibres and tracheids having thin walls and pits with reduced borders.

Fig. 6.14. Xylem and phloem elements.

iii. Protoxylem and Metaxylem:

Depending upon the time of origin in relation to the growth of the plant organ, the xylem is of two types, protoxylem and metaxylem. Protoxylem (Gk. protos— first, xylem— wood) is the first formed xylem, where lignification begins before the completion of elongation.

It is made up of small tracheids and vessels which possess annular or spiral thickenings. They are capable of being stretched. The later formed xylem is described as metaxylem (Gk. meta— after, xylem— wood).

It consists of bigger tracheids and vessels which have reticulate, scalariform or pitted thickenings. Lignification occurs in them after completion of elongation. Depending upon

the position of protoxylem in relation to metaxylem, xylem can be of four types— exarch, mesarch, centrarch and endarch.

In exarch (L. ex— without, Gk. arche— beginning) type, protoxylem lies towards the outside of metaxylem. It is inner in the endarch (Gk. endon— within, arche— beginning), middle of metaxylem in the mesarch xylem (Gk. mesos— middle, arche— beginning) and centre of metaxylem in centrarch xylem.

Protophloem and Metaphloem:
Protophloem is the first formed part of phloem which develops in parts that are undergoing enlargement. It consists of narrow enucleate sieve elements which may occur singly or in groups amongst cells that often grow later into fibres. Companion cells may or may not be associated with protophloem. During elongation the protophloem elements (sieve elements) get stretched and become non-functional.

Metaphloem is part of primary phloem that differentiates in plant organs after they have stopped enlargement. The sieve elements are wider and longer. Companion cells are regularly associated. Fibres are absent but parenchyma cells may later become sclerified.
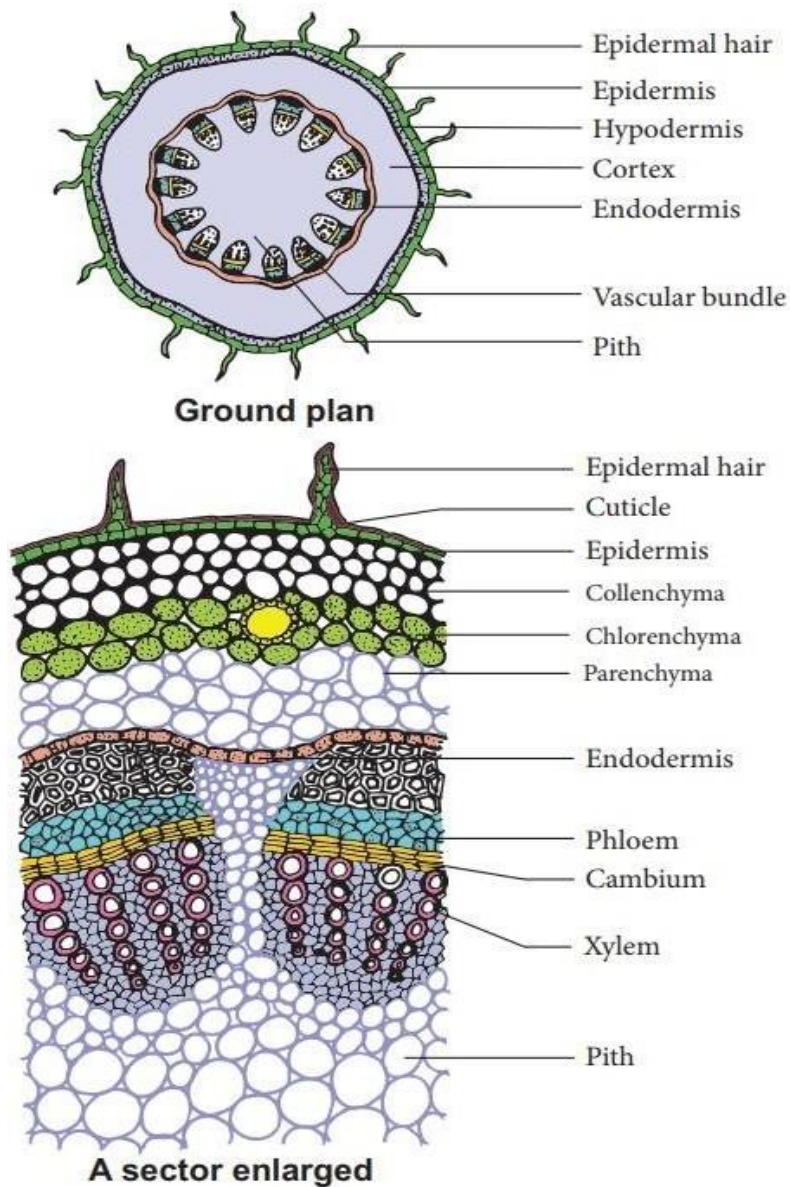
Internal structure of dicot stem

Ground plan

A sector enlarged

Figure 12.4 Transverse section of Dicot stem

Epidermis:
- It is the outermost layer and has a single layer of parenchymatous cells.
- It possesses stomata and large number of multicellular hairs (trichomes).
- The outer walls are greatly thickened and cutinized.

- The cells are compactly arranged and do not possess intercellular space.
- The epidermis has following functions:
- Minimize the rate of transpiration owing thick cuticle
- Protects the underlying tissues from mechanical injury
- Prevents the entry of harmful organisms
- Helps in the exchange of gases through stomata.

Hypodermis:
- This layer lies below the epidermis and is composed of 4 or 5 layers of collenchymatous cells.
- These cells are specially thickened at the corners against the intercellular spaces due to deposition of cellulose and pectin.
- The cells are living in nature and may contain few chloroplasts.
- It provides mechanical strength and elasticity to the peripheral portion of the stem particularly the young and growing organs.
- They perform photosynthesis and also acts as storage of food.

Cortex:
- It lies below the hypodermis.
- It consists of a few layers of thin-walled, large, rounded, or oval, living parenchymatous cells, having intercellular spaces.
- Cells of cortex may contain some chloroplasts which may function to manufacture of food materials.
- They serve for storage of food.

Endodermis:
- It is the single innermost layer of the cortex which separates the cortex from vascular bundles.
- Cells are somewhat barrel shaped and compactly arranged, having no intercellular spaces and are parenchymatous.
- Usually, the cells contain starch grains and thus the endodermis maybe termed as starch sheath.
- They serve as food reserve.
- The radial and the transverse walls are thickened due to the deposition of lignin forming casparian strips.

Pericycle:
- It lies in between the endodermis and vascular bundles.
- It is generally composed of sclerenchymatous and parenchymatous cells.
- The sclerenchyma is in the form of semilunar patches above the vascular bundles which give mechanical support to the plant parts.
- Similarly, parenchymatous pericycle is present outside the medullary rays which serves to store food.

Vascular bundles:
- These are arranged in a ring around the central pith and inner to the pericycle.
- These are conjoint, collateral, open and wedge-shaped.
- The size of the bundles varies in different species.

- Each bundle has a patch of xylem towards the center, a patch of phloem towards the periphery and a strip of cambium in between them.
- **Xylem:**
  - It lies towards the pith of vascular bundles.
  - It consists of tracheids, vessels, xylem parenchyma, xylem fibers.
  - Tracheids and vessels consists of smaller protoxylem and larger metaxylem.
  - Protoxylem is first formed that lies towards the center but metaxylem is later formed that lies towards the periphery.
  - This type of xylem is called endarch xylem. It helps in conduction of sap.
- **Phloem:**
  - It lies just below the sclerenchymatous patch of pericycle and is composed of following elements such as sieve tubes, companion cells, and phloem parenchyma.
  - It conducts the foods.
  - Cambium:
  - It lies in between xylem and phloem.
  - It consists of a narrow strip of meristematic cells having large nuclei and dense cytoplasm, called fascicular cambium.
  - It is responsible for secondary growth in thickness of the plant body.

Pith:
- It occupies the central portion of the stem.
- It is composed of thin walled parenchymatous cells which are rounded or polygonal, with or without intercellular spaces.
- Food is stored in this region.
- Medullary rays:
- These are the thin-walled, radially elongated parenchymatous cells present in between vascular bundles.
- These store food materials and help in internal translocation of water.

  - Leaves are very important vegetative organs, as they are chiefly concerned with the physiological process, photosynthesis and transpiration. Like other organs they also exhibit three tissue systems (Fig. 613).

  - Epidermal tissue system consists of the epidermal layers occurring on the adaxial (upper) and abaxial (lower) sides. Occurrence of stomata and outgrowths are distinctive features. The ground tissue system, as already reported in a preceding chapter, is known as mesophyll tissue.

  - It is often differentiated into columnar palisade parenchyma on the adaxial side and irregular or isodiametric spongy parenchyma on this differentiation in mesophyll is referred to as dorsiventral, what is very common in dicotyledons. One with

undifferentiated mesophyll, as commonly found in the monocotyledons, is known as an isobilateral leaf.

- Presence of conspicuous air spaces in the mesophyll is another marked feature. The gaseous exchange between the internal photosynthetic tissues and outside atmosphere thus becomes easy. The vascular tissue system is composed of vascular bundles which are usually collateral and closed.

- But the bundles entering the leaf occupy such a position that xylem occurs on the upper side and phloem on the lower. The vascular tissues, in fact, form the skeleton of the leaf, on which other tissues—the ground tissues, remain inserted. The petiole may continue into the midrib which bears branches and sub-branches ultimately ramifying in the leaf lamina in both reticulate and parallel type of venation.

  - The ultimate branches are very small and terminate in what are known as bundle ends. Often these ends bend into minute specialised photosynthetic areas known as vein islets or they may just extend into the mesophyll. Bundle-ends vary considerably in the leaves, but commonly it consists of a single tracheid with a single sieve element or specialised parenchyma representing xylem and phloem respectively, surrounded by a parenchymatous bundle sheath

  - In extreme cases the phloem may be absent and the veinlet may be made of a single spiral tracheid. Thus the size of the bundle depends on the position one prefers to take while making a section. Very commonly vascular bundles remain surrounded by a row of cells, which may or may not contain chloroplasts.

- This row made of parenchyma cells is referred to as bundle sheath or border parenchyma. The leaves of monocotyledons often have two bundle sheaths—outer parenchymatous one usually with chloroplasts and an inner thick-walled one without chloroplasts.

- In some dicotyledons the bundle sheath extends up to the epidermis, either on one or on both sides of the leaf, and is termed bundle sheath extensions.

- Their contact with conducting elements on one side and mesophyll on the other and often the extension up to epidermis are suggestive of positive physiological functions.

The morphology of bundle sheath was considered to be uncertain, but it is now regarded as an endodermis (Fann), where Casparian strips in -some cases have been observed.

- Often parenchyma cells of the sheath contain starch, then it may be called a 'starch sheath'. The leaves of mesophytes possess highly- thickened epidermis and patches of mechanical tissues, either as isolated patches or in association with vascular tissues, as they have to withstand shearing stresses in particular.
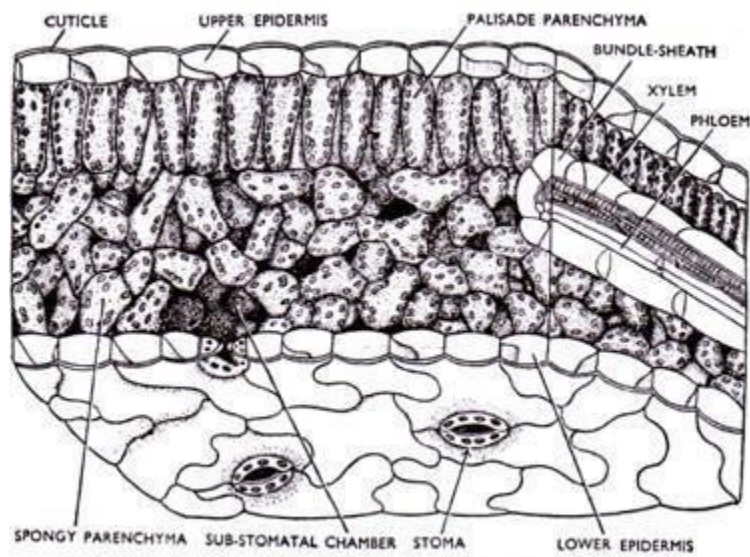
Fig. 613. Diagram of a dorsiventral leaf showing the tissues.

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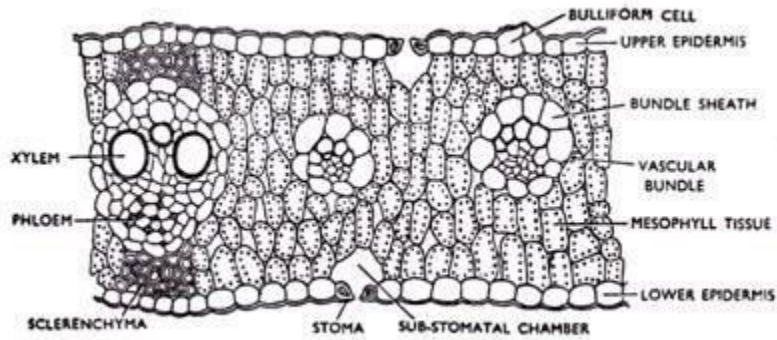-

Internal Structure of Monocot Leaf

Fig. 619. A portion of leaf of *Zea* (maize) in transverse section.

I. Epidermis:

Both upper and lower epidermal layers are uniseriate and composed of more or less oval cells with cuticularised outer walls. Upper epidermis may be easily identified due to presence of large and empty bulliform cells. Stomata occur on both the epidermal layers.

II. Mesophyll:

The mesophyll does not show differentiation into palisade and spongy cells, but is made of rather compactly-arranged isodiametric cells.

III. Vascular bundles:

The bundles are collateral and closed ones which remain arranged in parallel series. Majority of the bundles are small, but fairly large bundles occur at regular intervals. Small bundles have xylem on the upper and phloem on the lower sides surrounded by large parenchyma cells forming the bundle sheath.

The cells of the sheath contain plastids, often with starch grains. It is assumed that this layer serves as a temporary storage tissue, apart from-conducting the products of photosynthesis to the phloem. Xylem, as usual, consists of tracheary elements, and phloem of sieve tubes and companion cells.

A large vascular bundle practically resembles that of a stem. Sclerenchyma cells occur in patches on both edges of the bundles, obviously for giving mechanical strength

Internal structure of dicot root.

I. Epidermis:

It is single-layered and composed of thin- walled cells. The outer walls of epidermal cells are not cutinised. Many epidermal cells prolong to form long hairy bodies, the typical unicellular hairs of roots. Epidermis of root is also called epiblema or piliferous layer (pilus = hair; ferous—bearing).

II. Cortex:
It is quite large and extensive in roots. Cortex is made of thin-walled living parenchymatous cells with leucoplasts, which convert sugar into starch grains. The last layer of cortex is endodermis. It is of universal occurrence in roots.

Endodermis is composed of one layer of barrel-shaped cells which are closely arranged without having intercellular spaces. The endodermal cells have thickened radial walls, which are called Casparian strips, after the name of Caspary, the gentleman who first noted them.

III. Stele or Central Cylinder:
Next to endodermis there is a single-layered pericycle made up of thin-walled parenchyma cells. Pericycle is the seat of the origin of lateral roots. Vascular bundles are typically radial in roots. Xylem and phloem form separate patches and are intervened by non-conducting cells. In dicotyledonous roots the number of bundles is limited.

Xylem has protoxylem towards circumference abutting on pericycle and metaxylem towards centre. This is called exarch arrangement (of endarch arrangement of stems). Phloem with sieve tubes, etc., form patches arranged alternately with xylem. A small patch of sclerenchyma cells is present outside every group of phloem.

Conjunctive Tissue:
Thin-walled parenchymatous cells lying in between xylem and phloem groups constitute the conjunctive tissue.

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

Internal structure of Monocot stem

Epidermis:
- It is the single outermost layer composed of small, thin-walled, somewhat barrel-shaped parenchymatous cells which are tightly packed without intercellular species.
- It is externally covered with thick cuticle.
- A few stomata are present on epidermis.
- Usually trichomes or hairs are lacking.

Cortex:
- It lies below the epidermis.
- Cortex is composed of following regions:
- Hypodermis:
- It lies just below the epidermis.
- It comprises of 2-3 layers of thick-walled lignified sclerenchymatous cells, without intercellular spaces.
- It helps in mechanical support.

Ground tissue:
- It contains a continuous mass of thin-walled, round parenchymatous tissue which lies below the hypodermis.
- The intercellular spaces are present.
- Cells are rounded or polygonal in shape.
- There is no differentiation of general cortex, endodermis, pericycle, pith, and rays.
- Vascular bundles are irregularly lodged in this region.

Vascular bundles:
- Vascular bundles are irregularly scattered in the ground tissues, called atactostele.
- These are conjoint, collateral, and closed type.
- Vascular bundles occurring in the peripheral region are smaller in size and compactly arranged.
- In contrast, those occurring towards the central region are larger in size and widely placed.
- All the vascular bundles have similar structure.
- Each vascular bundle consists of xylem towards the center and phloem towards the periphery without cambium.
- It is oval in shape and surrounded by a sheath of sclerenchymatous tissue.

Xylem:
- It is V or Y shaped, bearing two large metaxylem vessels with wider cavities and pitted thickening at the lateral arms.
- Few tracheids are present in between the metaxylem vessels.
- Protoxylem vessels are only one or two, smaller, narrow cavities having annular or formed lysigenously by disintegrating by disintegration or breaking of some cells or parenchyma tissue and rarely protoxylem vessels.

- Thin-walled xylem parenchyma is present around the protoxylem vessels.

Phloem:
- It lies outside the xylem and is partly present near the metaxylem vessels.
- It is composed of sieve elements and companion cells.
- In a mature bundle, the protophloem gets crushed just below the sheath. So, the inner portion is meta-phloem.
- Sieve tubes appear polygonal in T.S. having internally situated companion cells.
- It conducts the organic food.

MONOCOT ROOT

Root h

Epibler

Cortex

Endod

Phloer

Pith

Protox

Metax

▪
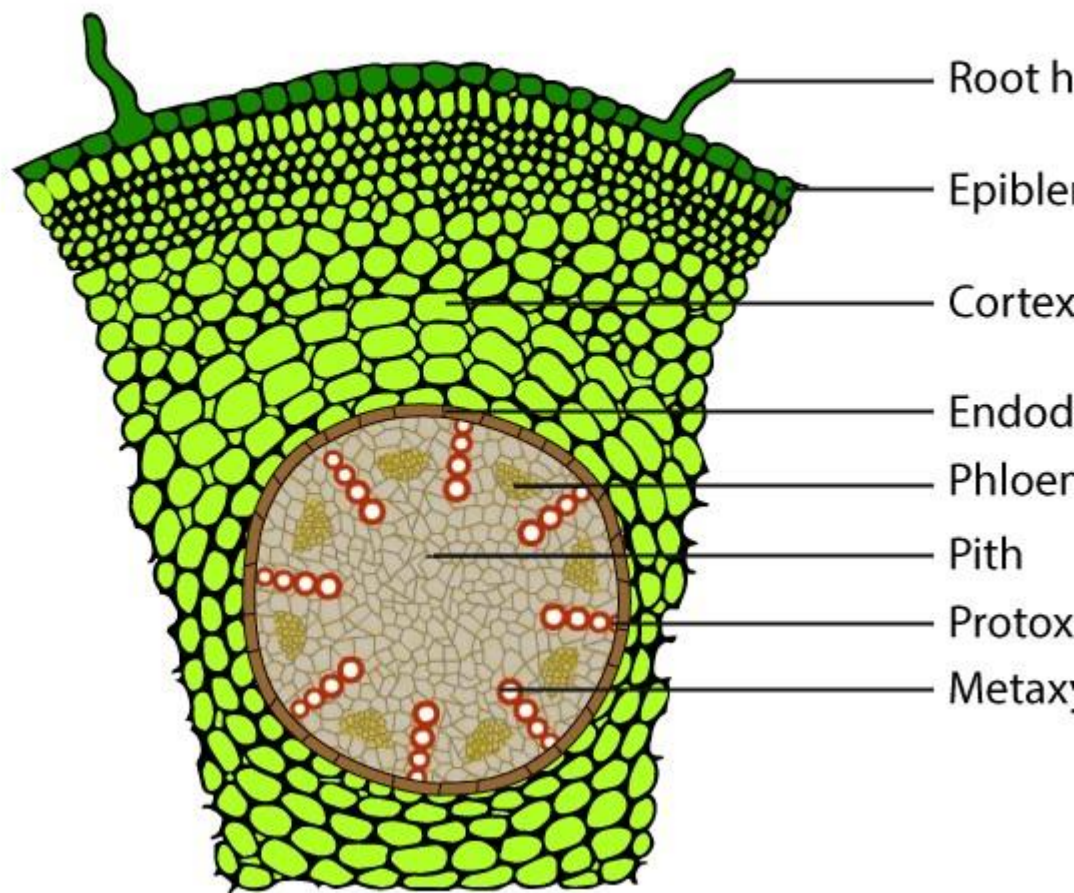
The transverse section of monocot root depicts the structures as listed below:

1.
    1.
        1. Epiblema or Epidermis
            • It is a single outermost layer with no cuticle
            • Densely arranged cells
            • Few cells may see unicellular root hair emerging
        2. Cortex
            • Found below epidermis
            • It is broad consisting of multiple layers of parenchyma cells
        3. Endodermis
            • The innermost layer of the cortex

- Barrel-shaped cells arranged in a ring-like manner
- Presence of Casparian bands

4. Pericycle
   - Found below the endodermis and is a single layer of parenchymatous cells

5. Vascular bundles
   - There are 8 or more alternating bundles of phloem and xylem known as radial bundles
   - Xylem bundles are exarch
   - Xylem bundles are oval or rounded
   - Phloem is found under the pericycle and comprises of companion cells, sieve tube, parenchyma

6. Conjunctive tissue
   - It is the xylem and phloem bundles that are distinguished from each other by the parenchyma tissue

7. Pith
   - Well developed pith is observed
   - It comprises of the parenchyma in the mid-region of the root

1.

1.
- The ground tissue consists of many scattered vascular bundles
- From the periphery to the center, the transverse section displays the structure of different tissues in a particular manner as follows:

3. Epidermis
   - An outermost, single layer
   - Thin-walled cells that are living. Presence of thick cuticle towards the outermost surface
   - The rare occurrence of stomata.
   - Lack of epidermal hair
   - Function – Protection of internal tissue

4. Hypodermis
   - Present under the epidermis
   - Consists of the thick-walled dead layer of sclerenchymatous cells. Made up of two of these three layers

5. Ground Tissue
   - Found below the hypodermis
   - Consists of thin-walled living cells, parenchymatous cells
   - Loose arrangement of cells with the presence of intercellular spaces
   - As seen in the dicotyledonous stem, there is no differentiation of cortex, pericycle and the endodermis

6. Vascular bundles
   - Several scattered vascular bundles found in the ground tissue and are closed type, collateral and conjoint
   - At the periphery, the vascular bundles are more and densely arranged when compared to the center
   - Large vascular bundles in the center compared to vascular bundles at the periphery
   - They resemble an oval shape that is girdled by sclerenchymatous bundle sheath
   - It consists of the xylem and the phloem

(a) Xylem

1.
    1.
        1.
- Y-shaped
- Metaxylem are present at the two lateral arms. Protoxylem is present at the base
- The lower protoxylem particles form a cavity known as lysogenous cavity
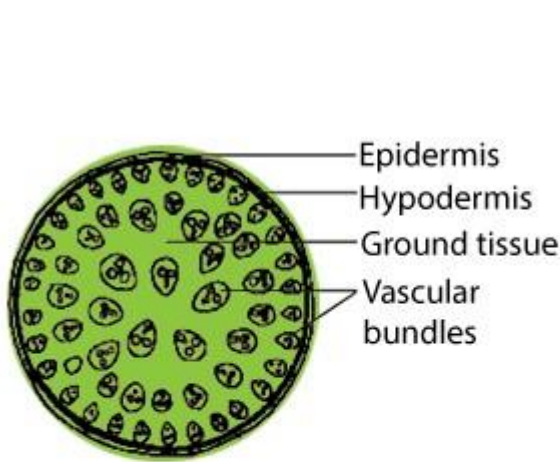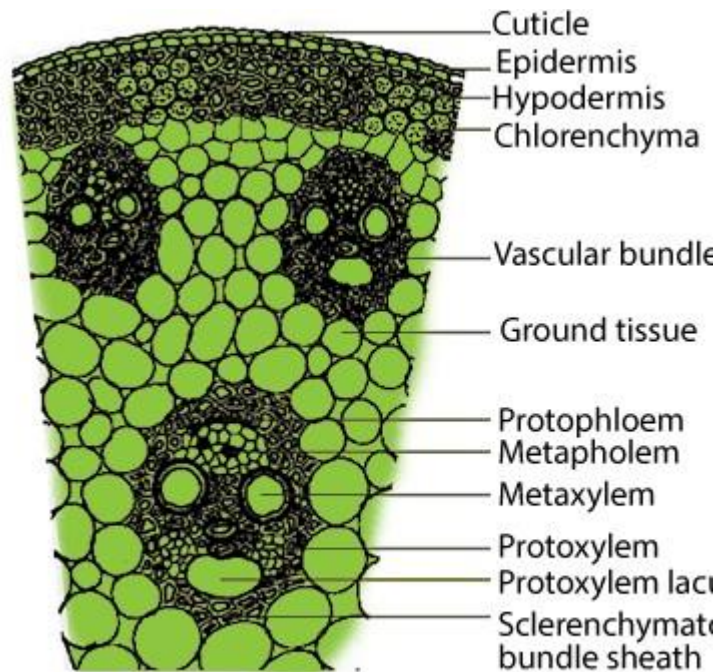- **Function:** Conducts water

(b) Phloem

1.
    1.
        1.
- Present at the periphery and consists of living cells
- It comprises of companion cells, sieve tubes, and the phloem parenchyma
- **Function** – Conducts food material

T.S of monocot stem – Maize stem

Normal Secondary growth in dicot stem

- Meristem is responsible for the development of primary plant body.
- Primary growth increases length of the plant as well as lateral appendages.
- However, secondary Grier increases thickness or girth of the plant by the formation of secondary tissues.
- There secondary tissues are formed by the two types of lateral meristem i.e. vascular cambium and cork cambium (phellogen).
- Secondary growth occurs in stem and root of dicots and gymnosperms.
- However, it is absent in stem and root of monocot and completely absent in leaf.
- A process of formation of secondary tissues due to activity of vascular cambium and cork cambium for increasing thickness or girth or diameter of plant is termed as secondary growth.
- On the basis of the activities of vascular cambium and cork cambium, the process of secondary growth can be discussed under the following headings:
    - Activity of the vascular cambium
    - Activity of the cork-cambium
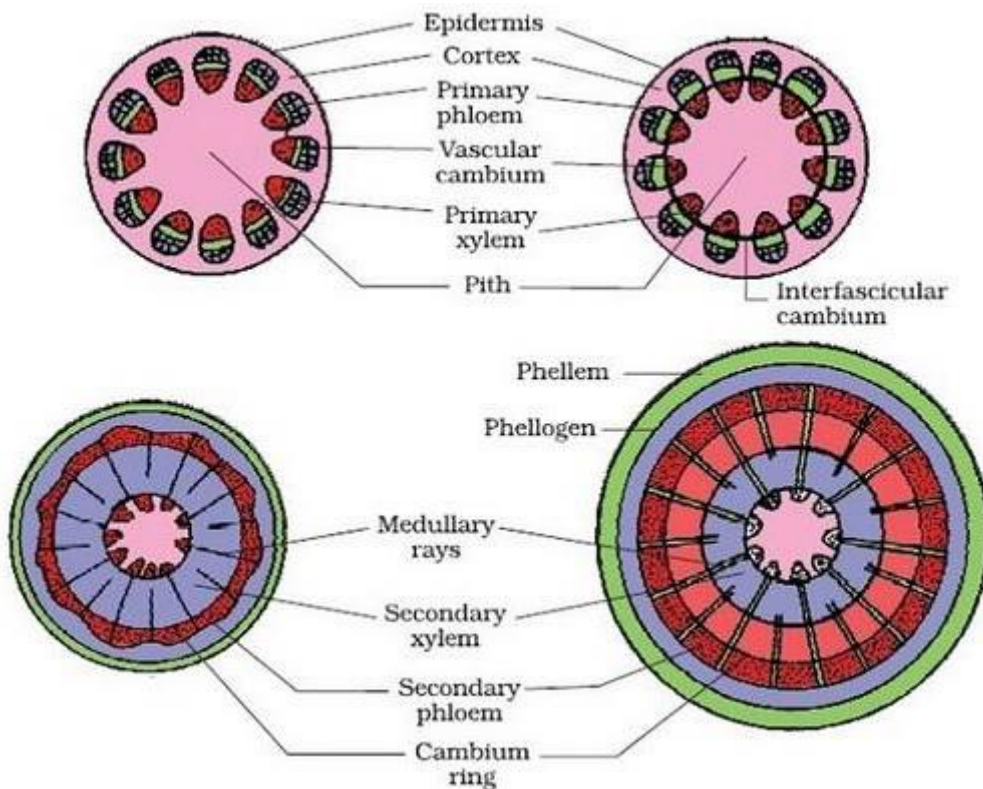
Secondary growth in stellar region due to activity of the vascular cambium

i. Formation of cambium ring:

- In vascular bundles of a dicot stem, the cambium is present in between the xylem and phloem. It is known as intrafascicular cambium.
- During secondary growth, some cells of medullary rays become active and show meristematic activity which form a strip of cambium in between vascular bundles called inter-fascicular cambium.
- Both the intra-fascicular and inter-fascicular cambium unite together to form a complete ring called the cambium ring.
- The activity of the cambium ring gives rise to secondary growth.

ii. Formation of the secondary tissues:

- The cambium ring acts as a meristem which divides.
- The cambium layer consists of a single layer of cells.
- These cells divide in a direction parallel with epidermis.
- A cambial cell divides into two daughter cells, one of which remains meristematic and other differentiates into secondary vascular tissue.
- The cell formed towards inner side develops into secondary xylem.
- Likewise, the cell formed towards outer side develops into secondary phloem.
- Normally, more secondary xylem cells are formed towards the center due to which cambium ring moves towards the periphery.
- Due to the formation of secondary xylem and secondary phloem, the primary xylem and primary phloem which were initially closed, moves towards inner and outer side respectively.
- As a result, they become separated apart.
- The layers of secondary tissues gradually added to the inner and outer side of the cambium continuously throughout the life of the plant.

iii. Formation of secondary medullary rays:

- Certain cells of the cambium instead of forming secondary xylem and phloem for some narrow bands of living parenchyma cells.
- These form two or three layers of thick radical rows of cells passing through the secondary xylem and secondary phloem and are called secondary medullary rays.
- These provide the radial conduction of food from the phloem, and water and mineral salts from the xylem.

iv. Formation of annual rings:

- The activity of cambium is affected by variations in temperature.
- In moderate climate, the cambium becomes more active in the spring and forms greater number of vessels with wider cavities, whereas in winter it becomes less active and forms narrower and smaller vessels.
- The wood formed in the spring is known as spring wood or early wood and that formed in the dry summer or cold winter is autumn wood or late wood.
- These two kinds of wood appear together as a concentric ring known as the annual ring or growth ring, as seen in transection of the stem and successive annual rings are formed year after year by the activity of the cambium.
- The growth of the successive years appears in the form of concentric or annual rings, each annual ring representing the one year's growth.

- The age of the plant thus, can be approximately determined by counting the number of annual rings.

v. Formation of heart wood and sap wood:

- In the old trees, where sufficient amount of secondary growth has taken place, the secondary wood of inner side lose the power of conduction.
- Their cells get filled with tannins, resins, gums, essential oils which makes the plant part hard and darker called the heart wood or duramen.
- The heart wood ceases the function of conducting tissue and simply provides mechanical support to the stem.
- However, the outer region of secondary wood, which consists of younger living xylem cells, remains yellow in colour called the sap wood or laburnum.
- It functions as the conducting tissue and also as the food storage tissue.

Secondary growth in extra stellar region due to activity of cork-cambium:

- The marked increase in diameter or thickness of stem brought about by the secondary thickening exerts a great pressure on the outer tissues.
- This results in the rupture of the cortex and epidermis, the outer cortical cells become meristematic and begins to divide. This is known as cork cambium or phellogen.
- The cork cambium divides to form secondary tissue on both the sides i.e. internal and external but its activity is more on the outer side than on the inner side.
- The cells formed on the outer side constitutes the phellem or cork and those on the inner side form secondary cortex or phelloderm.
- The phellogen, phellem and phelloderm together are called periderm.