SEMESTER- IV

Botany Paper VII: DSC D13: PLANT ANATOMY

Organization of Higher Plant Body

1.1: The Plant organs

1.2: Development of plant body

1.3: Internal organization

Introduction:-

Every higher plant originates from unicellular zygote, which develops into the embryo in a seed. During seed development the young embryo is differentiated into a radicle (future root) and a plumule (future shoot). This shows that the organization in case of higher plants is decided well in advance, during young embryo stage, in the process of seed formation.

The basic pattern of organization seen in all higher plants is related to the autotrophic manner of life. The autotrophic mode of life system in higher (green) plants is due to presence of chlorophyll pigments in the aerial organs exposed to sunlight. With the help of chlorophyll the higher plants can fix sunlight energy and can synthesize organic substances essential as energy supplying food molecules. For the Synthesis of organic substances, green plants require water and inorganic minerals, which are supplied by the soil system, through underground root system. The root system grows away from sunlight, in the soil. This indicates that the basic pattern of organization in higher plants, related to autotrophic mode of life, needs some organs to be exposed to the sunlight for absorption and fixation of light energy and some organs must grow in the soil for anchorage and absorption of water and minerals. The organs exposed to sunlight together form the aerial shoot system while the organs in the soil together form the root system, in most of the higher plants. The development in both these directions begins during seed germination.

During seed germination, when embryo grows and forms aerial shoot system and underground root system, some cells in the developing embryo become specialized. Such specialized cells are essential to carry out different physiological functions during growth of the embryo. The process of formation of specialized cells is called differentiation. The process of growth and the differentiation of individual cells, both are responsible for formation of different tissues, organs and the organism. This process of tissue and organ formation is called development or morphogenesis (morpho = form, genesis = origin). This morphogenesis is responsible for the development of different organs in the plant body. Therefore, both these processes, differentiation and morphogenesis (development) are responsible for proper organization of the body in higher plants, as per their genetic nature.

Sub Unit 1.1 : The Plant Organs:-

The organization of the plant body, requires development of some organs below the surface of soil, away from the light and that of some organs above the soil surface towards the light, i.e. underground system and aerial system, respectively. The development of both these systems begins with the early stages of seed germination and therefore, can be observed in seedling stage. The embryo in a germinating seed shows two distinct parts, a radicle which develops into the underground root system and the plumule which develops into aerial shoot system. The plumule bears one to many cotyledons. The portion of plumule below cotyledons, upto root boundary, is called 'hypocotyl'; and the portion of the plumule between the cotyledons and first photosynthetic leaf is called epicotyl. Both hypocotyl and epicotyl regions together form the central root-stem axis in the seedling stage.

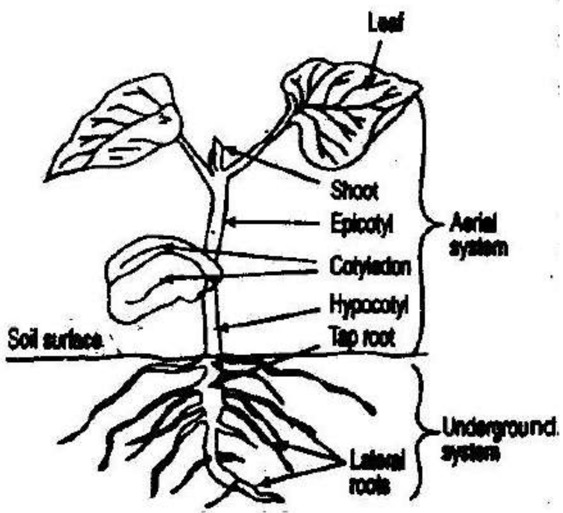


Fig. 1.1 : Development of aerial and underground systems during seedling stage.

After germination of the seed, when embryo grows and forms the adult plant, the morphological and anatomical characters develop as per the genetic nature of the plant. Due to difference in the genetic nature, the adult plant body in different species exhibits distinct variations in their size, structure and form. In all the adult plants of different species, irrespective of variations in such characters, the basic plan of organization of the plant body is the same and all of them exhibit fundamental uniformity in the organs. The body of an adult plant consists of an axis called root-stem axis. In most of the seeds of dicot plant, this axis is represented by hypocotyl region between apical meristem of root (radicle) and apical meristem of shoot (plumule). The lower part of this axis grows with the activities of apical meristem in root (radicle) region and remains in the soil in the form of root system. The upper part of the axis grows with the help of apical meristem in shoot (plumule) region and grows towards light in the form of aerial shoot system.

The root-shoot axis produces three types of appendages or laterals. Out of these, the leaves are the most important as they show presence of vascular strands in the form of branches from main vascular strand in the central axis or stem. The aerial part of the root-stem axis shows distinct nodal regions, while the underground part of the axis shows absence of nodal region. The aerial stem shows nodes and intemodes, while underground root shows absence of nodes and intemodes. The leaves are produced only from the nodal regions on the aerial part or stem and they are totally absent in the underground root system. The leaves have definite order of development and have close association with the stem in the nodal region. Due to close association with the stem, in the form of vascular connection, the leaves are considered as lateral expansion of the stem. Therefore, the adult plant body shows three main organs in the form of root, stem and leaves.

During development of plant body, the leaves carry out photosynthesis and prepare organic substances, from raw materials supplied by the underground root system and the aerial atmosphere.

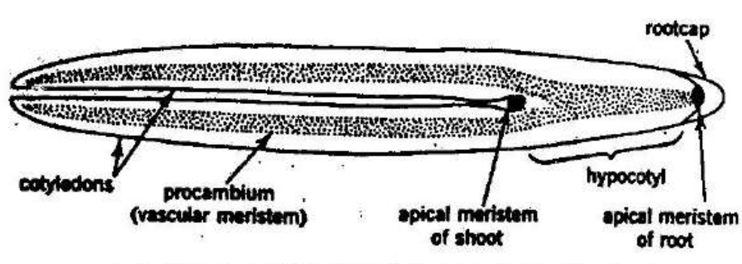


Fig. 1.2 : L.S. of dicot seed showing parts of embryo.

The organic substances from the leaves and water, minerals from the root system are translocated through the stem to various regions in the plant body. This shows that the three organs of the plant body, root, stem and leaves, are intimately related with each other for the development and formation of different structures in the plant body.

In the axils of the leaves, the axillary buds are present. These axillary buds develop either into vegetative branches or reproductive branches. These buds in the form of branches on the stem, increase the. surface area of the plant body, especially in the aerial part. Branches also develop in root system, but not from axillary buds. The root branches are endogenous and develop from interior region (the pericycle) and have connections with conducting strand in the root axis. The main root produces primary, secondary, tertiary branches, which increase the surface area of the plant body, especially of the underground system. All these branches with main root form the underground root system, while all the branches on the main stem, together form the aerial shoot system.

The flowers are the reproductive structures, develop from axillary buds and develop on the stem when the plant attains maturity. The flower is considered as modified stem with floral leaves and therefore, it is the part of aerial shoot system.

The second type of appendages are emergences. The term emergences is used for the structures which develop from external part of the stem, mainly epidermis and outer part of the stem cortex. These structures are without vascular supply and therefore, superficial in nature (e.g. Prickles).

The third type of appendages are the out-growths or projections on the surface of the organs e.g. Stem surface and leaf surface. The hairs are superficial structures on the epidermal layers and they may be unicellular or multicellular structures. The emergences and hairs have no definite pattern of development and both are without vascular supply.

The organization of the adult plant body consists of three main organs viz. root, stem and leaf. The root grows in the soil in the form of root system and carries out two important functions (a) anchorage (fixing) and (b) absorption of water and minerals. The stem in the form of main axis with or without branches carries out two functions (a) translocation of food and water to different regions and (b) production of leaves and reproductive structures. The leaf in the form of stem appendage also carries out two functions (a) Synthesis of organic substances by photosynthesis and (b) Transpiration and gaseous exchange through stomata.

Sub Unit 1.2 : Development of the Plant Body:-

Development of the plant body is a cyclic process. This cyclic process begins from the development of a seed. The seed represents quiescent or resting plant body, which is in dehydrated state capable of surviving adverse conditions in the surrounding atmosphere.

Seed develops from ovule in the ovary of a flower. During development of a seed, rudimentary plant in the form of embryo develops: An embryo consists of an axis with one or more cotyledons. At one of the ends of embryonic axis is present plumule which will form the shoot system (i.e. stem, leaves and flowers) in adult plant At the other end of the axis, the radicle is present, which will develop into root system in adult plant. The embryo in monocot shows single cotyledon, while that of dicot shows two cotyledons. Surrounding the seed, the seed-coat (testa) is present, which protects the embryo in the seed.

Under appropriate conditions the seed germinates and the embryo begins the growth and development. During initial stages, the radicle grows, enlarges and comes out by rupturing the seed coat. This is essential step, as the developing juvenile plant (embryo) requires contact with water and nutrients (in the soil) for further growth and development.

After sufficient growth of the radicle, the plumule grows. In some seeds, during the growth of the plumule first hypocotyl region elongates exhibiting epigeal germination, while in some seeds epicotyl shows excessive elongation exhibiting hypogeal germination.

Once the embryo establishes itself in the soil (in the form of a seedling) new cells and organs are produced by differentiation and development processes. The new cells are produced by the active cell divisions and enlargement of newly produced cells, in specific regions called meristems. The shoot apical meristem (SAM) located at the tip of the stem (in young plant) is a dome shaped structure surrounded by curved leaf primordia. This SAM carries out two principle functions: (1) to form primordia that give rise to lateral organs and (2) to perpetuate itself (to remain in the form of original embryonic cells) by maintaining a small population of undifferentiated dividing cells. The SAM contains a small number of dividing cells that give rise to all other tissues in primary shoot including stem, leaves, branches and flowers. With each cell division, one of the two daughter cells is left behind to elongate and differentiate, while other daughter cell remains in the meristem to undergo further cell division.

The shoot apical meristem (SAM) is generally divided into two zones, the outer zone is tunica and die central zone is corpus. The tunica may be composed of one to several layers of cells. The cells in tunica region divide in a plane perpendicular or anticlinal, to the surface of the meristem.

The tunica gives rise to the outer layers of the plant body, the epidermis. The corpus, on the other hand, divides more randomly in both anticlinal (perpendicular) and periclinal (parallel) planes, thereby giving rise to bulk of the internal tissues of the stem and leaves.

The development of the shoot axis proceeds through the combination of cell division and enlargement of the cells produced by divisions in apical meristem (SAM). The developing shoot axis shows definite nodal regions (leaf nodes) at which the leaf primordia or leaves are produced, and the intemodal regions i.e. region between two successive leaf nodes. The final length or height of the shoot axis (and that of a plant) is determined by the rate and extent to which internodes elongate. This process is genetically controlled through hormonal action.

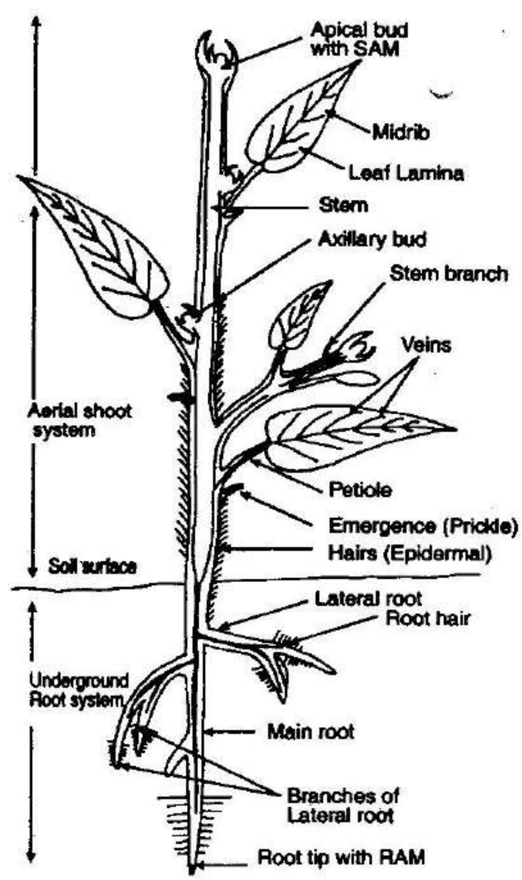


Fig. 1.3 : Plant organs with emergences and hairs.

The leaf primordia arise, as small outgrowths or protrusions on the sides or surface of the meristematic region. They develop due to increased cell divisions in both the part of apical region, the tunica and the corpus. The initiation of leaf primordia occurs in a definite orderly sequence, which is species specific. This orderly sequence determines the arrangement or phyllotaxy of leaves on the stem. The primordium grows into a leaf.

As the leaf primordium grows, a small group of meristematic cells remains trapped in the region of contact of leaf with stem. This region is called leaf axil. These meristematic cells in leaf axil give rise to axillary bud or future branch, which maintains its own apical meristem. As per the requirement during growth process, this axillary bud develops into a vegetative branch or a reproductive branch, with the activities of its meristem.

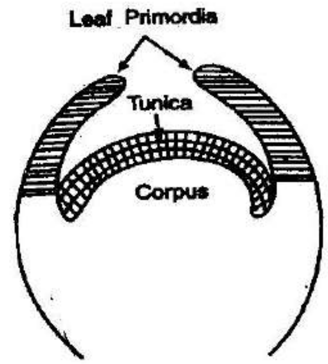


Fig. 1.4 : Two zones of SAM - Tunica, Corpus.

The cells and tissues derived from the apical meristem, together form the primary body of the plant. After some definite amount of primary growth, secondary tissues are added in the plant body due to activities of secondary meristems, such as the vascular cambium and cork cambium These secondary tissues (together with primary tissues) form the secondary plant body.

The root apical meristem (RAM) is structurally less complex than the shoot apex meristem (SAM), because RAM is not responsible for the production of branches in root system. The branches in a root system arise endogenously from pericycle region, surrounding the vascular region. The tip of the root is covered by root-cap which protects the RAM as root grows through the hard soil particles. In addition to protection, root cap secretes mucilagenous substance, called mucigel, which provides lubrication to the root-tip when it moves forward in the soil.

The root apical meristem lies immediately below the root cap. This region shows in the centre, zone of slowly dividing cells called quiescent zone. On the two sides of this region or in the peripheral region (of the quiescent zone) are present relatively fast dividing cells. The cell divisions in RAM are responsible for elongation of root, new tissues in the root system and regeneration of the rootcap. These divisions occur in the periphery (around the quiescent zone) in the zone of fast dividing cells. Differentiation of vascular tissues begins soon after the cells are produced by root apical meristem (RAM). In root system, primordia or buds of laterals (branches) originate in pericycle, a ring of meristematic cells present in the region just inside the endodermis of the primary root.

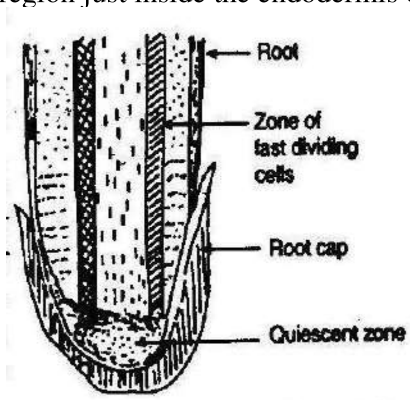


Fig. 1.5 : Two zones in root tip (RAM) region.

After some definite amount of vegetative growth, when a plant attains the stage of maturity, induction of flowering occurs, and flowers develop on the stem. The development of flowers is one of the important processes of morphogenesis. Due to this morphogenesis, vegetative growth stage is converted to reproductive growth stage. After successful pollination and fertilization, ovules in the ovary region of a flower are converted into seeds. The production of fruit with viable fertile seeds is the final "stage in the development cycle. The development cycle of the plant body ends at this stage.

The seeds represent new individuals and with their germination new development cycles in new individuals begin.

In the case of annual herbaceous plants, with the production of seeds development of the plant, as well as, life cycle both are completed. In the case of perennial plants one development cycle ends and new cycle begins every year, to maintain the continuity in the development process for many years.

Sub Unit 1.3 : Internal Organization:-

The root, stem and leaves are the three main organs of a plant body. Functionally, these three organs are intimately related. For the development in the plant body, appropriate internal organization is essential, which can maintain the intimate relations in these three organs. All the three organs are interconnected with each other through three different zones located in the root-stem axis or the central axis of the plant body. In these three zones, number of different types of cells are present in the form of tissues [Fig. 1.6 (1)]. The tissues present in the different regions of a plant body, carrying out similar physiological functions, together form a system, which is called a tissue system. The internal organization of the plant shows distinct division of labour, through different tissue systems, present in different internal regions of a plant body.

According to the position of the tissues and their basic physiological functions, three basic tissue systems are important in the internal organization of the plant body. These three tissue systems are (a) Epidermal or Dermal tissue system, (b) Ground or fundamental tissue system and (c) Conducting or Vascular tissue system. Through these three tissue systems intimate relation between three organs (root, stem and leaves) is maintained in the plant body. These three systems are present in three different zones, outer, middle and inner, in the plant body. The outer zone is called epidermal zone, middle zone is cortical zone and the inner is vascular zone.

The epidermal zone is the outermost region of the plant body, in the form of surface of all the organs, from apex of the root to the apex of the stem i.e. surface region of the entire plant body. Generally, it is represented by single layered epidermis in the primary plant body and it forms the dermal or epidermal tissue system. Main functions of this system are protection and to check the rate of transpiration. When secondary tissues are added in the stelar region, in the epidermal region also, secondary tissues develop in the form of periderm in stem and root. The periderm develops as a protective tissue (in place of epidermis) in stem and root and it represents dermal system in a plant body with secondary tissues. In leaf, the epidermal layer shows presence of stomata.

The second zone in the internal organization is called cortex or cortical zone. This zone consists of many layers of cells and it is composed of different tissues. The cortical zone represents the ground tissue or fundamental tissue system, in the internal organization of the plant body. In the stem, this region carries out different functions with the help of respective tissues. The important functions of mis region are mechanical support, photosynthesis (in herbaceous plants), storage of starch grain etc. For the mechanical support, the cortical zone in the stem shows, either living mechanical tissue collenchyma (in soft herbaceous stem) or dead mechanical tissue sclerenchyma (in hard woody stem).

For the process of photosynthesis in green herbaceous stem, life outer cortical layers show presence of chlorenchyma. For storage of starcja; the cortical zone shows presence of parenchyma and in aquatic plants the region shows aerenchyma and air spaces. In underground root system, cortical region shows only parenchyma cells. In the leaves, the ground tissue or cortical region is in the form of mesophyll region between upper and lower epidermal layers. The mesophyll region shows chlorenchyma or parenchymatous cells with chloroplastids. The last or innermost layer of the cortical zone in stem and roots of dicot plants and only in roots of monocot plants, is called endodermis. The endodermis separates cortical zone from the central vascular zone or central stelar region. In monocot stem and in all leaves, there is no distinct endodermal layer and therefore, vascular bundles are scattered in the ground tissue.

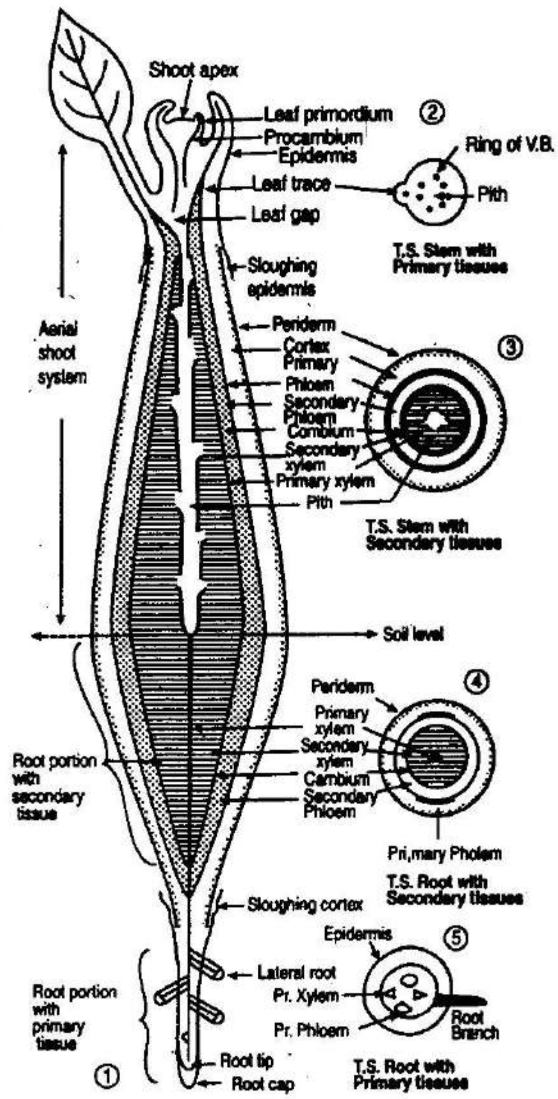
The third zone, which is present in the central part of root-stem axis and other organs is called stele or central conducting cylinder. This region shows conducting or vascular tissue system. The system shows leaf-traces and leaf gaps. The vascular cylinder is surrounded by cortex. The cortex and vascular cylinder are separated from each other by endodermis in dicot stem and all primary roots. The stelar region in primary plant body shows the vascular tissues in the form of vascular bundles. The vascular bundle consists of two types of conducting tissues, the xylem and the phloem. These vascular bundles are useful for conduction as well as mechanical support In dicot and gymnosperm stems, in the vascular bundle, between xylem and phloem patches, lateral meristem called vascular cambium is present. In monocot stems and all roots and leaves, such vascular cambium is absent. In primary roots the vascular bundle is of radial type, with xylem and phloem patches on different radii, while in primary stem and in leaves the vascular bundles are conjoint and collateral, with xylem and phloem patches close to each other on the same radius. In stem, in the centre of vascular cylinder parenchymatous pith or medulla region is present. The pith forms medullary or pith rays between vascular bundles, connecting pith with pericycle. The vascular bundles in dicot stem show definite arrangement as they are arranged in a ring while in monocot stem they are scattered. The leaves exhibit arrangement of vascular bundle as per the pattern of venation. In the region outside the vascular bundles one or more layers of parenchyma or patches of parenchyma alternating with sclerenchyma (in stem) are present, in the form of non-conducting tissue. These layers represent the region of pericycle. The pericycle lies internal to the endodermis and it represents the outermost layer of vascular region or stelar region.

In all the organs of the plant body, the epidermal, ground and vascular tissues are produced by the activities of apical meristems in shoot and root. All the tissues produced by apical meristems are called primary tissues and they are responsible for the organization in primary plant body. The organization of primary tissues is also responsible for the growth of primary plant body or primary growth in a plant. By primary growth, the length of root-stem axis increases, appendages develop and branches in root and shoot systems are produced.

According to Haberlandt's theory, primary meristem in the apical regions of the stem and root is segregated into three parts viz. protoderm, procambium and ground meristem. The protoderm develops into epidermis, the procambium part develops into primary vascular tissues and the ground meristem produces fundamental or ground tissue region.

1. L. S. showing arrangement of different tissues and organs in shoot system and root system.

2. T. S. stem with primary tissues (young stem) showing V.Bs. in a ring and leaf trace.
3. T. S. stem with secondary tissues (old stem) showing different zones of tissues and their organization in the plant body.
4. T. S. Root with secondary tissues (old root) showing different zones of tissues and their organization in the root region.
5. T. S. Root with primary tissues (young root) showing radial vascular bundle and endogenous origin of root branch



In dicot and gymnosperms, after some amount of primary growth the vascular cambium (in the central vascular cylinder) becomes active and produces secondary xylem and secondary phloem in the vascular region. After addition of some amount of secondary tissues in the vascular region, some developments occur in the sub-epidermal region.

In the peripheral region or sub-epidermal region, a new meristem (secondary meristem) called phellogen or cork cambium develops.

This phellogen produces a periderm, a new protective layer in the sub-epidermal or peripheral region. In roots, as there is no vascular cambium, meristematic patches are formed and a cambium ring develops before production of secondary tissues. The growth of the plant body due to addition of secondary tissues is called secondary growth. By secondary growth the girth or thickness of th; root-stem axis increases. The secondary growth continues for many years in perennial plants and is responsible for formation of wood in such plants.

Unit 2. Meristematic and Permanent Tissue:

2.1 Meristem:

a) Introduction, Characteristics and Classification of meristems based on position

b) Theories of structural development-

i) Apical cell theory

ii) Histogen theory

iii) Tunica Corpus theory.

2.2 Permanent tissue:

i) Simple tissue- Parenchyma, Collenchyma and Sclerenchyma

ii) Complex tissue: Xylem and Phloem

2.3 Types of Vascular bundles

Introduction:-

The tissues in a plant body can be divided into two categories : (1) Meristematic tissues and (2) Permanent tissues. For the development, the meristematic tissues are very important, because only these tissues can add new cells in the plant body. The meristematic tissues are composed of cells which are immature, not fully differentiated and possess the power of cell division. The term 'meristem' has been coined from the Greek word Meristos meaning divisible i.e. because these cells possess the power of cell division they are called meristematic.

The cells in the meristems add new cells in the region of their location and at the same time, they maintain the continuity of meristematic activity in the plant body. The cells added by the activities of meristematic cells are called derivatives. These derivative cells then gradually enlarge, change their shape and lose the power of cell division. With these changes the derivative cells develop into permanent, mature cells, with changes in their wall region and in their contents. Such changes together represent a process called differentiation. The derivatives become mature cells and the meristematic cells remain immature. The permanent mature cells are required for the development of different tissues, to carry out different functions in the plant body.

In the plant body, growth in the form of addition of new cells is restricted to certain regions are called growth regions. The important growth regions are shoot apex and root apex, and the meristems in these regions are called apical meristems. For the future development in the plant body, these meristems in the apical regions, are provided in the embryo in the seed, which, when grows develop into an adult plant. The activity of embryonic meristem, which during the course of development becomes primary meristem, remains from the beginning of the life cycle (seed germination) till the end of life cycle of a plant.

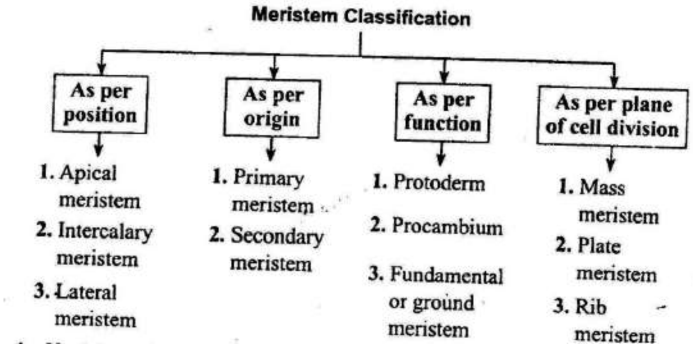
Characteristics:-

The meristematic cells differ from permanent cells in many characters. This difference in the characters is mainly because the meristematic cells are undifferentiated and immature, while permanent cells undergo differentiation and become mature. The important characters of meristematic cells are (1) The cells are thin walled, isodiametric in shape. (2) They are compactly arranged without any intercellular spaces. (3) They are with dense cytoplasm and large, prominent nucleus. (4) The cytoplasm shows very small vacuoles. (5) The plastids in the cells do not develop and remain in proplastid stage. (6) The cytoplasm shows absence of ergastic substances. (7) The cell wall is made up of cellulose and shows uniform thickness.

Classification:-

Various systems of classification of meristems in plants, have been suggested by different workers, considering different characters. The important characters of meristems, considered for the classification are (1) The position of the meristems in the plant body.

(2) The origin of the meristem in the plant body. (3) The addition of new cells in the three basic zones of the plant body by the meristems i.e. function carried out by the meristem and (4) The plane of division in meristematic cells during addition of new cells.



Meristem classification based on their position in plant body:-

On the basis of their positions in the plant body, the meristems are classified into three categories, such as (a) Apical meristems (b) Intercalary meristems and (c) Lateral meristems.

(a) Apical meristems :

These meristems are present at the tip regions or apices of the main stem, lateral branches of stem, main root and lateral branches of root, in the higher plant body. Since the position of these meristems is in the along the long axis of the plant body, due to which the height or length increases. The derivatives of the apical meristems develop into permanent tissues, which together form the primary plant body.

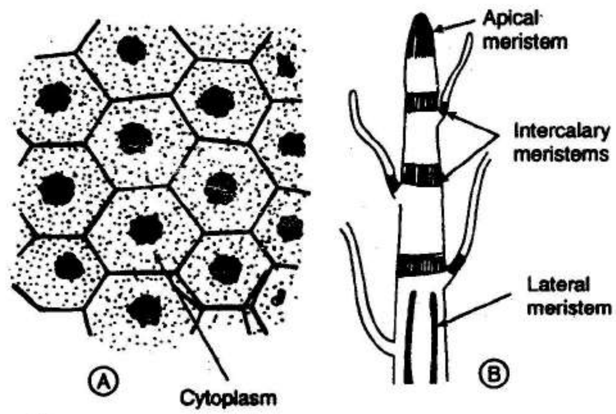


Fig. 2.1 : (A) Compactly arranged cells in meristem. (B) Three categories of meristems.

(b)Intercalary meristems :

During the growth of the long axis, some portions or patches of apical meristems get separated from the apex and remain behind in the form of intercalary (in between) patches in the permanent tissues. Due to intercalary position they are called intercalary meristems. Intercalary meristems can be observed in stem and leaf sheaths of many grasses. These meristems are internodal in position. The nodal regions consist of permanent tissues, but internodal regions in early stages of growth show presence of meristems. The meristem in internodal region is required to increase the length or height of internodal region as per genetic character of the plant body. These meristems are short lived and when their function is over, they develop into permanent tissues and merge with the surrounding region. Young leaves (needles) of *Pinus*, monocotyledonous leaves with leaf sheath, show presence of short-lived intercalary meristems at the base, till the growth of the leaves is completed.

(c) Lateral meristems:

These meristems occur laterally in the long axis, parallel to the sides of the axis in dicots and gymnosperms. From their position they are called lateral meristems. These meristems consist of cells which divide periclinally (parallel to the axis) and therefore, add the cells along the short axis and increase the diameter of the plant body. The derivatives of this meristem develop into secondary tissues and the growth in width or girth of the plant body is therefore, called secondary growth. The cambium in vascular bundles in dicot stem and phellogen or cork cambium are the examples of lateral meristems. Cambium is primary meristem and cork cambium is secondary meristem, but both are lateral in position.

Theories of structural development: The Apical Cell Theory; Histogen Theory and Tunica-corpus Theory

For the proper organization of plant body, a definite direction of structural development is essential. The higher plants exhibit complex structure and are built up of diverse types of cells, varied in shape, size, origin, and physiological functions. All such cells are primarily the derivatives of meristematic cells. The real structural development occurs when these derivatives, develop into diverse types of cells to carry out different physiological functions. During this developmental process, the derivatives gradually change their shape, enlarge, lose the power of ceil division and ultimately become mature cells with some definite anatomical and physiological characters, and become ready to carry out some definite function. This process of structural development, responsible for mature, specialized cells, is called differentiation. This differentiation is responsible for the development of different tissues, which are required for different physiological functions in the plant body. It means, the development of diverse types of cells and tissues in the plant body is the initial requirement in the process of growth in response to the basic division of labour in higher plant body.

The structural development of the derivatives added by meristems in the apical regions is the important problem in plant histology and anatomy. To explain the process of structural development, various theories have been proposed. The three important theories are (a) Apical cell theory, (b) Histogen theory and (c) Tunica-corpus theory.

(a) Apical Cell Theory:

In many lower plants, like marine algae, bryophytes and pteridophytes the growing region shows, single apical meristematic cell, instead of many celled meristem (Fig. 2.3). Due to this fact, the apical cell theory was proposed by Hofmeister (1857) and it was supported by Nageli (1878). Hofmeister believed that like lower plants, in higher plants also single apical cell is present in growing region.

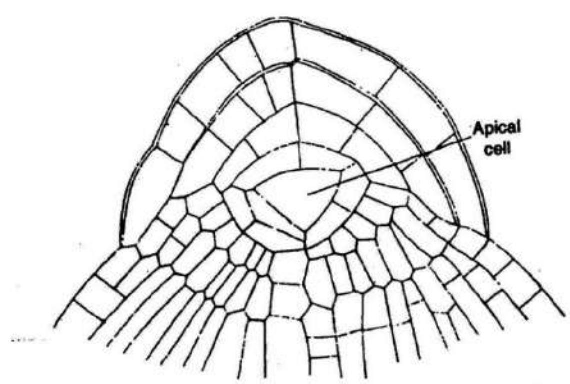


Fig. 2.3 : L.S. through apex of pteridophytic root, showing single apical cell in growing region, producing derivatives on three sides (surfaces).

But later on, in 20th century, it was confirmed that in gymnosperms and angiosperms, the growing apices of root and stem are provided with groups of initial cells instead of single apical cell. For this reason, it was accepted, that structural development by

single apical cell is possible only in lower plants and the same theory cannot be made applicable to the higher plants. The research work during 20* century clearly refused the concept of single apical cell in all plants and accepted the concept of independent origin of different organs. The apical cell theory was replaced by histogen theory.

(b) Histogen Theory:

In the 19th century, for the structural development in higher plants, Hanstein proposed Histogen theory. The theory was supported by Strasburger (1868). According to this theory the apical meristematic regions consist of a group of meristematic cells instead of single apical cell. This group of cells forms of promeristem or primordial meristem. In the apical regions of root and shoot, the meristematic region shows three distinct zones or histogens or strata, each with a small group of initials. These histogens arise from separate set of initials and exhibit separate patterns of growth and development.

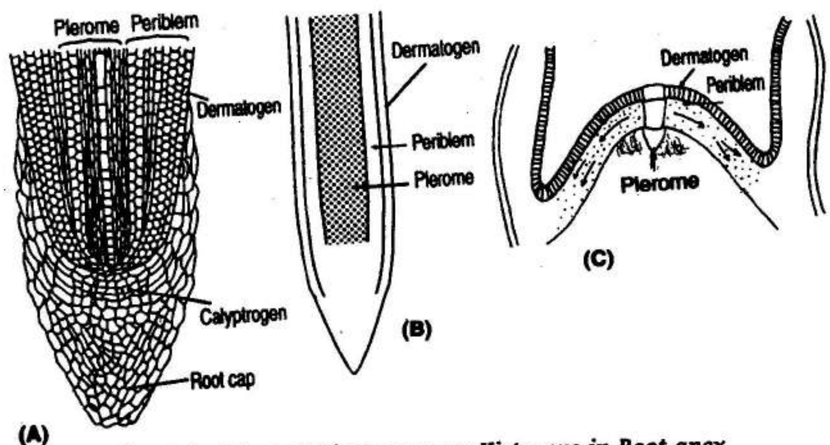


Fig. 2.4 : Three distinct zones or Histogens in Root apex (A) and (B), and Shoot apex (C). (Diagrammatic)

The three zones or histogens suggested in this theory are (i) outermost uniseriate layer-dermatogen, (ii) the central core consisting of many longitudinally arranged cells-plerome and (iii) the region between dermatogen and plerome consisting of isodiametric cells-periblem.

Dermatogen is the single outermost layer, which shows anticlinal divisions in the cells and develop into uniseriate epidermis of the stem. In the root region also it is single layered, but at the apex (tip) it merges with outermost layer of periblem and produces a special meristem called calyptrogen which produces cells of rootcap.

Periblem is the middle region, next to dermatogen, of apical meristem. It is single layered at the tip and many layered in the central part. In stem apex and root apex this region (periblem) shows similar nature and characters and develops into cortex.

Plerome is the central core region of the meristem in the root and shoot apex. This region is composed of thin walled cells. The region develops and produces the central stelar region consisting of primary vascular tissues, non-vascular tissues (regions) like pericycle, medullary rays and medulla in the central part. In this region, at some distance, just behind the tip, special cambium called procambium develops and it produces strands of cells, which become differentiated into vascular strands or vascular bundles. In dicot stem, some portion of this procambium remains undifferentiated and develops as vascular cambium in vascular bundles.

1) The important objections to histogen theory are : 1. In some plants, the apical regions do not show distinct zones or histogens.
2) The plerome may form only pith or entire central vascular cylinder or some part of cortex and the central cylinder.
3) The periblem may form the entire cortex and the outer part of central vascular cylinder or only some part of cortex.
4) The histogens in the same plant body may develop into different parts in different regions.
5) Recent research work indicates no strict relationship between development of histogens and regions in the plant body.

(c) Tunica Corpus Theory :

The apical cell theory and histogen theory were proposed for the structural development in both root and shoot apices. Schmidt (1924) on the basis of the direction of cell division in successive layers, proposed a new theory for the interpretation of structural development in shoot apex. After few years, Foster (1939-41) supported the theory. According to this theory, in the active stem apex, the meristematic apical region shows two distinct tissue zones (a) the tunica (cover) consisting of one or more peripheral layers, dividing only in anticlinal plane and forming the outer enveloping region [Fig. 2.5 (A) and (B)] and (b) the corpus, the central core in the form of mass of cells, produced by cells dividing in various planes and surrounded by the cover or tunica.

These two regions differ in structure and appearance due to difference in the rate and pattern of growth. The cells in tunica region are small and exhibit mainly anticlinal divisions (perpendicular to the surface).

Due to such divisions number of cells increases without increasing the number of layers. This pattern of growth increases the surface area. The tunica region may be one to many layered and the number remains constant as it is a genetical character.

The term tunica is used for a layer which shows only anticlinal division and never shows periclinal division. According to Guttenberg (1960), tunica region contains only two layers, the dermatogen and sub-dermatogen.

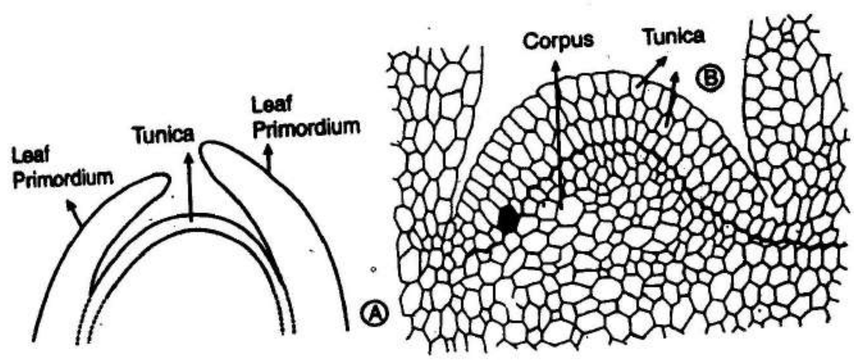


Fig. 2.5 : L.S. stem apex showing tunica and corpus regions. (A) Diagrammatic, (B) L.S. shoot apex showing three layered tunica and multicellular corpus below it.

The additional layers in the region, as inner layers of tunica, are actually the part of corpus.

The cells of corpus region are relatively large and exhibit divisions in various planes, producing mass of cells. Due to irregular, arrangement and planes of cell divisions, the whole mass of cells exhibits increase in volume, i.e. as the mass increases in size, the volume of the region also increases. The important structural difference in the development of tunica and corpus is, each layer of tunica arises from a separate group of initials, while the corpus develops from only one layer of such initials. In the tunica region, the number of layers of initials is equal to number of layers of tunica. The corpus arises from a single layer of initials, which divide first periclinally to produce a group of derivatives, which then divide in various planes and produce a mass of cells. In different species, both the regions exhibit variation in appearance, as the tunica is one layered to many layered with massive or slender corpus. This variation in appearance is mainly because of variation in the number of initials e.g. in slender seedling of grass only one or two tunica initials are present with about two corpus initials.

These observations indicate that tunica-corpus concept is of flexible nature and the theory may be treated as morphological identity with fluctuating limits, as there are no clearly demarcated limits for the two regions. The primordia of lateral organs like leaves, stem-branches and floral structures, develop from the young stem apex, the tunica-corpus theory adds to knowledge of origin and early development of these organs .

In lower vascular plants and in gymnosperms, there is no sharp distinction between tunica and corpus. In angiosperms, two sets of initials can be located, which give rise to tunica and corpus regions, indicating separate origin of tunica and corpus. In vascular plants, in general, the differentiation of zones in l the stem apex follows more or less definite patterns and each pattern is the characteristic of the group. These patterns exhibit increasing complexity from lower group to higher groups. Each pattern represents a series of specialized characters, from simple lower plant body to complex higher plant body.

In all the theories suggested for structural development of higher plant body, tunica-corpus theory has been accepted by many workers. It gives an interpretation of apical growth in the stem which has been observed in many plants. The stages in the structural development of primary plant body, from initiating cells can be understood in better way by tunica-corpus theory.

Significance of Tunica-corpus Theory :

1) The concept is flexible and explains greater plasticity in sub-epidermal layers.
2) The theory is useful to know the characters of growing shoot apex in angiosperms and for the origin and early development in lateral organs.
3) The growth pattern of structural development in shoot apex, from initiating cells explained by the theory, is accepted by many workers.
4) The position, number and behaviour of initiating cells in angiosperm shoot apex are understood in better way by tunica-corpus theory.
5) The theory explains structural development in stem in primary plant
6) body.
7) The tunica-corpus theory has topographical value in structural development.
8) Some workers (Guttenberg-1960) do not accept the concept as it does not relate the apical activity and origin of the tissue. According to some workers (Thielke 1963) in some monocot (e.g. Sachharum) tunica-corpus organization is absent.

Comparative Account of Three Theories:

1) Plants with single apical cell shows simple pattern of development (Lower vascular plants) and plants with different zones of initials, exhibit-complex pattern.

2) Higher plants exhibit different zones in apical meristems, due to difference in planes of divisions in initials, while in lower plants zonation is not distinct due to single apical cell.

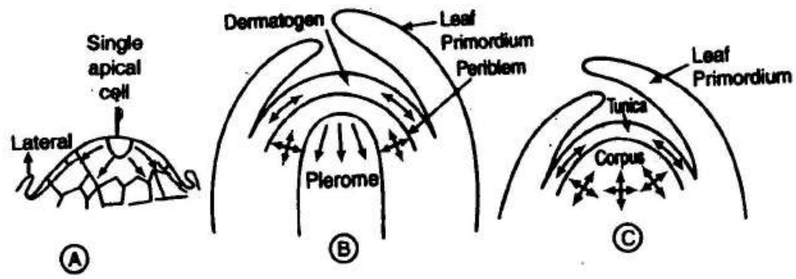


Fig. 2.6 : Planes of divisions in initials as per three theories. (A) As per Apical cell theory, (B) As per Histogen theory, (C) As per tunica corpus theory.

3) As per histogen theory as well as tunica-corpus theory, the cover region, dermatogen and tunica, show only anticlinal divisions.
4) As per Histogen theory apical meristem shows three zones, each with its own plane of division. Tunica corpus theory shows two zones, tunica with anticlinal division, corpus with anticlinal and periclinal divisions, Apical cell shows no zones.
5) All the three theories show development of laterals (leaf primordia) very close to growing apex.
6) All the three theories exhibit that the structural development in stem apex depends on the planes of divisions in the meristem.

Permanent tissue:

i) Simple tissue- Parenchyma, Collenchyma and Sclerenchyma

ii) Complex tissue: Xylem and Phloem

Permanent tissue:-

This is group of cells which have lost the capacity of division and aquired permanent size, shape and functions. It is due to different morphological, physiological and functional changes that occur during maturation of the cell. Depending upon types of cells, there are two types as simple and complex permanent tissues.

A. Simple permanent tissues:-

These are made up of only one type of cells carrying similar functions. This tissue is either living or dead. Following are the types of simple permanent tissues namely, Parenchyma, Collenchyma and Sclerenchyma.

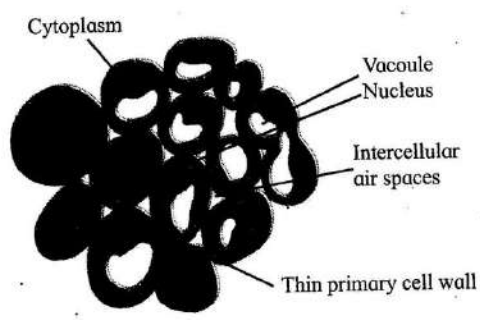
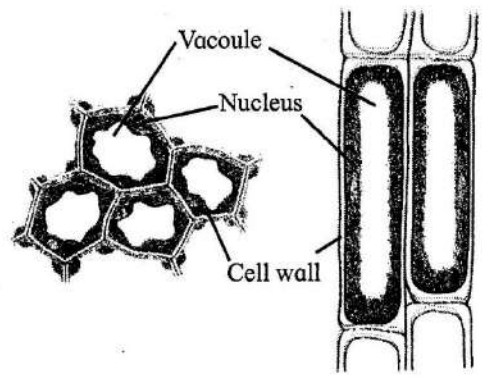


Fig. 8.3 Simple permanent tissue

I. Parenchyma : Cells in this tissue are thin walled, isodiametric, round, oval to polygonal or elongated in shape.
Cell wall is composed of cellulose. Cells are living- with prominent nucleus and cytoplasm with large vacuole. This is less specialized permanent tissue.

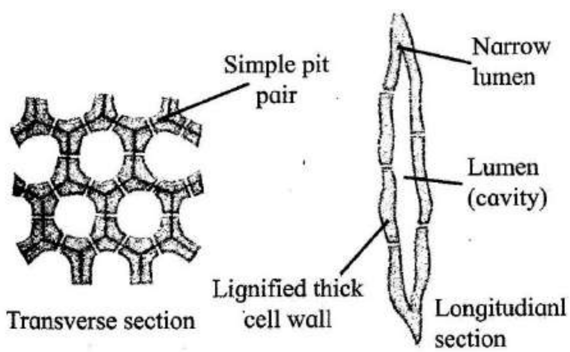
Parenchyma has distinct intercellular spaces. Sometimes, cells may show compact arrangement. The cytoplasm of adjacent cells is interconnected through plasmodesmata and thus forms a continuous tissue. These cells are distributed in all the parts of plant body viz. epidermis, cortex, pericycle, pith, mesophyll cells, endosperm, xylem and phloem. These cells store food, water, help in gaseous exchange, increase buoyancy, perform photosynthesis and different functions in plant body. Dedifferentiation in parenchyma cells develops vascular cambium and cork cambium at the time of secondary growth.

II. Collenchyma : It is a simple permanent tissue made up of living cells. The cell wall is cellulosic but shows uneven deposition of cellulose and pectin especially at corners. The walls may show presence of pits. Cells are similar like parenchyma containing cytoplasm, nucleus and vacuoles but small in size and without intercellular gaps. Thus appears to be compactly packed. The cells are either circular, oval or angular in transverse section.



Collenchyma is living mechanical tissue and serves different functions in plants. It gives mechanical strength to young stem and parts like petiole of leaf. It allows bending and pulling action in plant parts and also prevents tearing of leaf. Growth of organs and elongation are other functions. Collenchyma is usually absent in monocots and roots of dicot plant.

III. Sclerenchyma:-



It is simple permanent tissue made up of compactly arranged thick walled dead cells. The cells are living at the time of production but at maturity they become dead. As cells are devoid of cytoplasm their thickened walls are due to uniform deposition of lignin. Cells remain interconnected through several pits. It is of two types viz. fibres and sclerids.

Fibres are thread-like, elongated and narrow structures with tapering and interlocking end walls. These are mostly in bundles, pits are narrow, unbranched and oblique. They provide mechanical strength. Sclerids are usually broad, with blunt end walls. These occur singly or in loose groups and their pits are deep branched and straight. These are developed due to secondary thickening of parenchyma cells and provide stiffness only.

This tissue functions as the main mechanical tissue. It permits bending, shearing and pulling. It gives rigidity to leaves and prevents it from falling. It also gives rigidity to epicarps and seeds. Commercial fibres are also produced from sclerenchyma fibres, e.g. jute, flax, hemp.

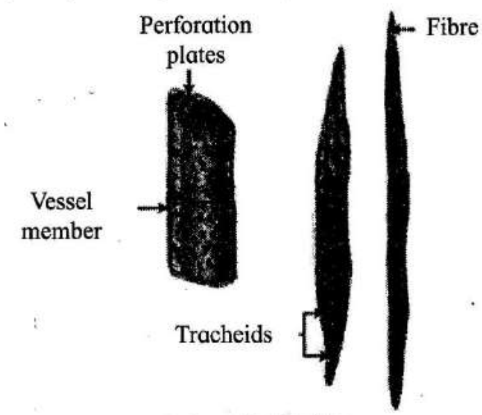
Complex tissue: Xylem and Phloem

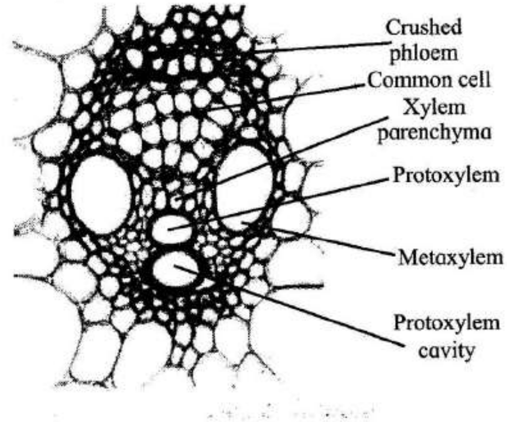
This tissue is heterogenous comprising of more than one type of cells and all function as a single unit. This tissue is involved in conducting the sap and food from source to sink area. Xylem and phloem are the complex tissues present in plants.

Xylem:-

It is a dead complex tissue. Components of xylem are tracheids, vessels, xylem parenchyma and xylem fibres.

The xylem also provides mechanical strength to the plant body. Tracheids and vessels conduct water and minerals. These are also known as hadrome. In pteridophytes and gymnosperms tracheids are conducting elements and vessels in angiosperms, Selaginella (Pteridophyte) and Gnetum (Gymnosperm) show presence of vessels.





Tracheids are elongated, tubular and dead cells. The ends are oblique and tapering. The cell walls are uniformly thickened and lignified. This provides mechanical strength. Tracheids contribute 95% of wood in Gymnosperms and 5% in Angiosperms. The different types of thickening patterns are seen on their walls such as annular (in the form of rings), spiral (in the form of spring/ helix), scalariform (ladder like), pitted is most advanced type (small circular area) which may be simple or bordered.

Vessels are longer than tracheids with perforated ends and formed by union of several vessels end to end. These are Involved in conduction of water and minerals. Their lumen is wider than tracheids and the thickening is due to lignin and similar to tracheids. In monocots, vessels are rounded where as they are angular in dicot angiosperms.

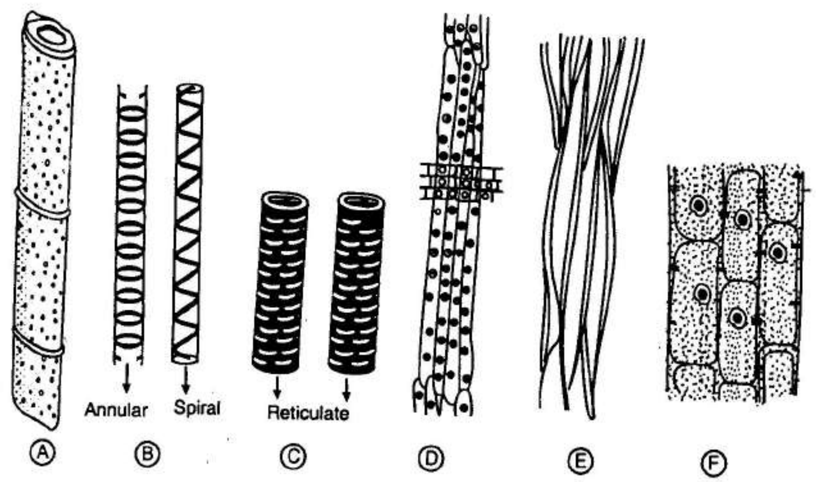


Fig. 1.11 : Four elements of xylem : (A) Vessel tube - vessel elements with pits, (B) and (C) Different types of thickenings in vessel elements. (D) Trachieds with border pits, (E) Xylem fibres, (F) Xylem parenchyma.

The first formed xylem vessels (protoxylem) are small and have either annular or spiral thickenings while latter formed have larger vessels (metaxylem) have reticulate or pitted thickenings. When protoxylem is arranged towards pith and metaxylem towards periphery it is called as endarch e.g. in stem and when the position is revert as in the roots is called as exarch.

Xylem parenchyma cells are small associated with tracheids and vessels. This is the only living tissue among this complex tissue. The function is to store food (starch) and sometimes tannins. Parenchyma are involved in lateral or radial conduction of water or sap.

Xylem fibres are sclerenchymatous cells and serve mainly mechanical support. These are called wood fibres. These are also elongated, narrow and spindle shaped. Cells are tapering at both the ends and their walls are lignified.

Phloem :-

This is a living tissue. It is also called as bast. Phloem is responsible for conduction of organic food material from source (leaf generally) to a sink (other plant parts). Phloem was named as leptome by Haberlandt as similar to xylem. On the basis of origin, it is proto (first formed) and meta (laterly formed) phloem. It is composed of sieve cells, sieve tubes, companion cells, phloem parenchyma and phloem fibres.

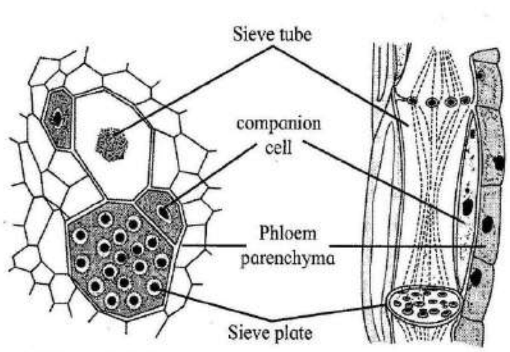
Sieve tubes are long tubular conducting channel of phloem. These are placed end to end with bulging at end walls. The sieve tube has sieve plate formed by septa with small pores. The sieve plates connect protoplast of adjacent sieve tube cells. The sieve tube cell is a living cell with a thin layer of cytoplasm but loses its nucleus at maturity. The sieve tube cell is connected to companion cell through phloem parenchyma by plasmodesmata. Sieve cells are found in lower plants like pteridophytes and gymnosperms. The cells are narrow, elongated with tapering ends and sieve area located laterally.

Companion cells are narrow elongated and living. These cells are laterally associated with sieve tube elements. Companion cells have dense cytoplasm and prominent nucleus.

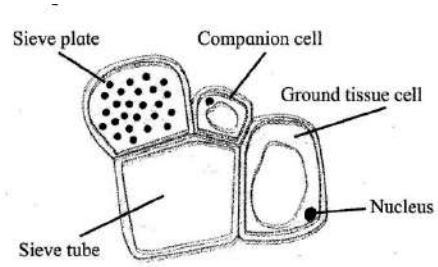
Nucleus of companion cell regulates functions of sieve tube cells through simple pits. From origin point of view, sieve tube cells and companion cell are derived from same cell. Death of the one results in death of the other type.

Phloem parenchyma cells are living, elongated found associated with sieve tube and companion cells. The chief function is to store food, latex, resins, mucilage, etc. The cells carry out lateral conduction of food material. These cells are absent in most of the monocots.

Phloem fibres are the only dead tissue among this unit. These are sclerenchymatous. Generally absent in primary phloem, but present in secondary phloem. These cells are with lignified walls and provide mechanical support. These are used in making ropes and rough clothes.



A. Phloem in T. S. B. Phloem in L. S.



Vascular Tissue - Types of Vascular Bundles

Introduction:

The tissue system derived from the cambiurn is known as vascular tissue system. It is essentiallyeensTsts of various number of strands called the 'vascular bundles'. The vascular bundles are embedded in the ground tissue to form the central cylinder. The main components of vascular bundles are xylem and phloem. The strip of meristem, the cambium may or may not be present between xylem and phloem. The arrangement of bundles is variable in different parts. Thus, the vascular bundles may be arranged regularly in a ring (e.g. Dicotyledonous stem, root and monocotyledonous root). On the contrary the vascular bundles are scattered irregularly in monocotyledonous stem.

Now, let us study the components of vascular bundle in detail.

(a) Structure of Xylem

The xylem is the main water conducting tissue in the vascular bundle of vascular plant. The xylem is usually associated with phloem. As xylem consists of more than one type of cell types and performs a definite function, it is described as complex permanent tissue. The xylem is also considered to be an important member in supporting the plant body. It carries out the main function of conduction of water and solutes from the root upto the top of the plant. The development of xylem in the plant is controlled by various factors, mainly the environmental factors.

Two types of xylem can be recognized on the basis of mode of development.

Primary xylem: It is derived from procambium during the formation of primary plant body which is developed from embryo and

Secondary xylem: It is formed from the cambium during second stage of development of plant body I e. when increase in thickness or girth (secondary growth) takes place.

Primary xylem:- It is present in vascular bundle. It is further differentiated intoprotoxylem and metaxylem.

The protoxylem is the first formed part of xylem. It consists of tracheary elements (i.e. vessels and/tracheids) which are embedded in xylem parenchyma. The protoxylem differentiates in primary plant body. It is generally subjected to stresses. It disorganizes during secondary growth.

The metaxylem is a part of primary xylem that differentiates after the protoxylem and it possesses fibres in addition to tracheids/vessels and wood parenchyma. It is initiated in still growing primary parts of plant body. After the formation of secondary xylem it becomes non-functional. But it is not destroyed.

The sieve cells show presence of sieve areas on their lateral walls. The sieve areas consists of fine pores through which cytoplasm of one cell gets linked with cytoplasm of another cell.

Sieve tubes : The sieve tubes are elongated cells placed one above the other to form a continuous pipeline like system. Sieve tubes are of living nature. The nucleus is absent in mature sieve tubes. The end walls or transverse walls of sieve tubes are oblique or transverse. These walls possess sieve areas or small pores. The cytoplasmic strand of one sieve tube extends through these pores or sieve areas to the adjoining sieve tube. These end walls are known as sieve plates as they resemble the structure of sieve having meshes. Sieve tubes are present in angiosperms.

Companion cells : These are associated with sieve tube elements. Companion cell is thin walled elongated narrow cell. It shows presence of prominent nucleus and dense cytoplasm. These cells help the function transport of organic compounds. These are present in angiosperms.

Phloem parenchyma : These are elongated parenchyma cells associated with phloem. They store reserve food for phloem.

Phloem fibres or bastfibres: These are sclerenchyma fibers occuring in the phloem tissue. Thus they may give mechanical strength to the phloem tissue.

Functions :

(1) The main function of phloem is to conduct food from leaves to other parts of the plant body.

(2) The sieve tubes carry out the function of conduction of food. (3) Companion cells and phloem parenchyma help the function of conduction.

Types of Vascular Bundles

Introduction: The green plants prepare the organic food (carbohydrates) by the important process called photosynthesis. For this, they require sunlight, water, carbon-dioxide and minerals. The vascular plants bear the roots which absorb the water and mineral salts. This absorbed water is translocated to aerial organs of the plant. This translocation is carried out in plants.by special tissue system called the vascular tissue system. This vascular tissue system consists of complex permanent tissues like xylem and phloem and they together along with other tissues form a central conducting cylinder.

If this central conducting cylinder is divided into strands, the strands are called fascicles (Latin-fascis = bundle) or vascular bundles. The spaces among the vascular strands, the interfascicular regions, are occupied by parenchymatous ground tissue.

The vascular bundles usually perform the functions like conduction of water and mineral salts, and organic food material from one region to another in different directions. These vascular bundles because of their origin and development are primary in nature in young parts e.g. in young stem the vascular tissues originate from procambium (or pro-vascular meristem) in the stem apex (i.e. apical meristem). The derivatives of the procambium develop into conducting elements or conducting strands.

The xylem and phloem elements are usually placed in a group or in a fascicle called vascular bundle. In such vascular bundle a strip of meristematic tissue (cambium) may persist in between xylem and phloem {e.g. stems of dicotyledons and gymnosperms). Such vascular bundle is considered open. But when such strip of cambium does not persist between xylem and phloem (eg. monocotyledonous stems and all roots) the vascular bundle is considered closed.

Types of Vascular Bundles

The vascular bundles show three common types of arrangement of xylem and phloem tissues viz.

a) The two complex tissues are separated from each other i.e. **radial.**
b) The two complex tissues occur on the same radius and lie side by side i.e. **conjoint and collateral**, and
c) One complex tissue remains surrounded by the other i.e. **concentric**.

These are three main types of vascular bundles. These main types can be further classified into different categories

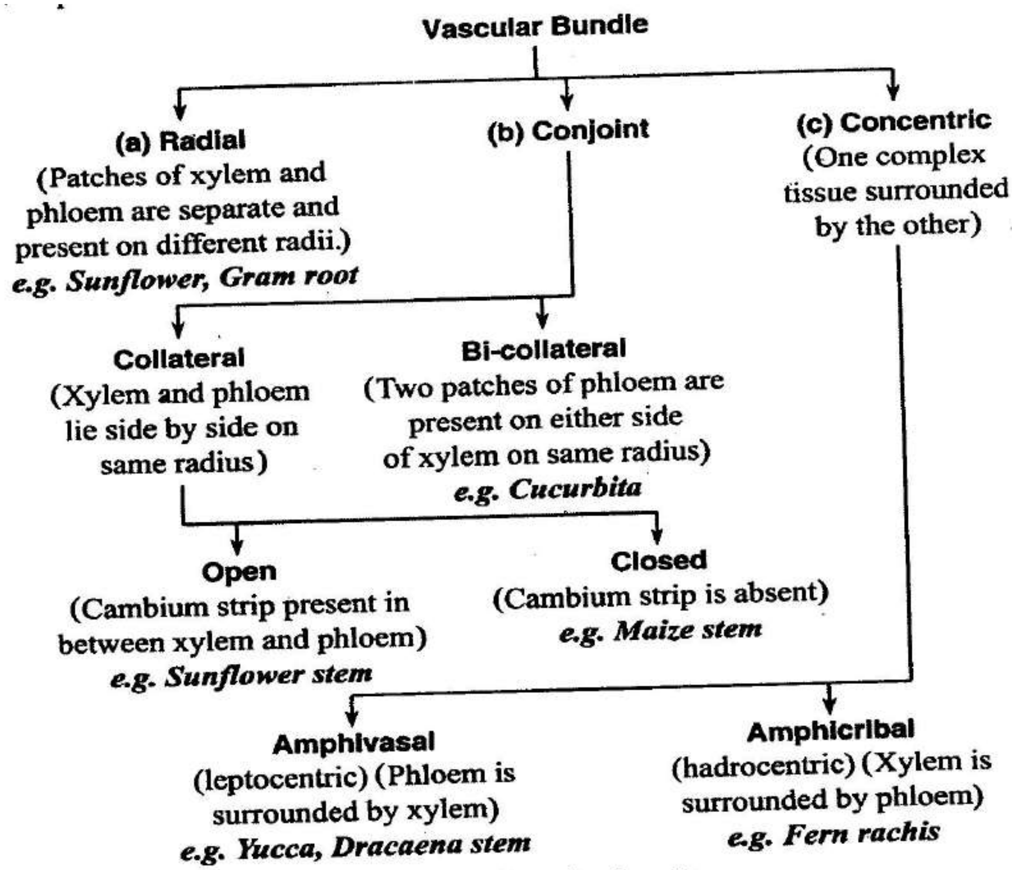


Fig. 3.16 : Vascular bundle.

(a) Radial vascular bundle :

This kind of vascular bundle is fundamentally quite different from other types. In this, the xylem and phloem occur in the form of separate patches on alternate radii. They are often separated by undifferentiated parenchymatous or sclerenchymatous conjunctive tissue. The radial vascular bundle is the characteristic of a root. The radial vascular bundle is closed type of bundle, as there is no cambium between xylem and phloem. The xylem is always exarch i.e. protoxylem is towards periphery. This vascular bundle is described as per the number of xylem patches e.g. diarch (two), triarch (three), tetrarch (four) and polyarch (many). The number of phloem patches is always equal to that of xylem patches.

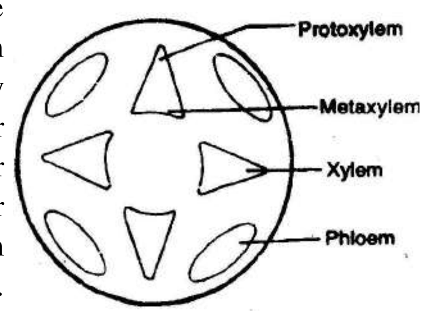


Fig. 3.17 : Radial vascular bundle (Diagrammatic)

(b) Conjoint vascular bundle: The xylem and phloem, both are present on the same radius and are grouped together to form one vascular bundle. It is known as conjoint vascular bundle. As per number of phloem patches in the bundle either collateral (one patch) or bicollateral (two patches of phloem).

(i) Conjoint collateral vascular bundle : In this type, the xylem and phloem tissues remain side by side arranged on the same radius. In stem such bundle shows that xylem is endarch {i.e. protoxylem towards the centre and metaxylem towards outside or periphery) and towards the pith i. e. internal and phloem towards outside (or periphery).

Such bundles are described as collateral. Again on the basis of presence of cambium (lateral meristem) between xylem and phloem, the collateral vascular bundle is described as open (when cambium strip present) and closed (without cambium strip). In most of the dicotyledonous stem the vascular bundles are conjoint collateral and open while in monocotyledonous stem they are conjointcollateral and closed type.

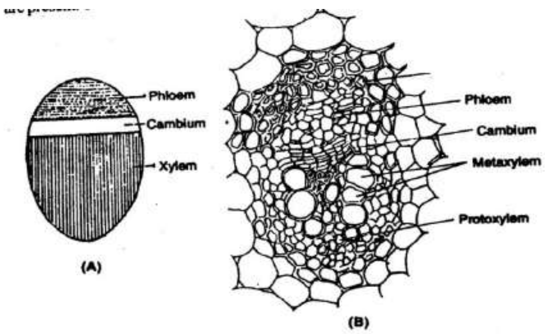


Fig. 3.18 : Conjoint collateral vascular bundle (A) open (Diagrammatic) and (B) in Sunflower stem

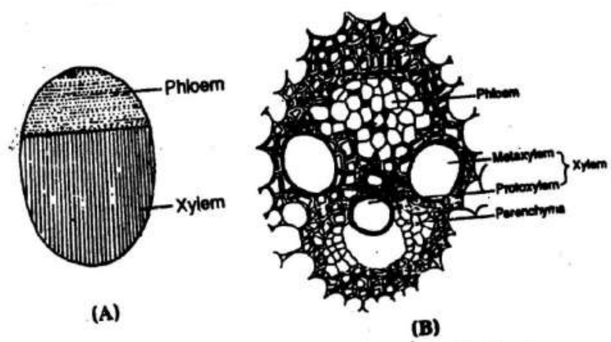


Fig. 3.19 : Conjoint collateral vascular bundle closed (A) Diagrammatic, (B) in Maize stem

(ii) Conjoint bicollateral vascular bundle:

These are collateral vascular bundles with two phloem patches on either side of the xylem patch. The phloem outside the xylem is called outer phloem and that on its inner side is called inner phloem. On both the sides, between xylem and phloem, cambium strips are present. These cambial strips are called outer cambium and inner cambium. respectively. Thus the vascular bundle possesses two phloem patches and two cambium strips are present but with single xylem patch, therefore such vascular bundle is known as bicollateral. Such bundles occur in the stems of members of natural orders (Families) Cucurbitaceae, Solanaceae, Myrtaceae, Apocynaceae etc. Such bundles are always open due to the presence of cambium strips.

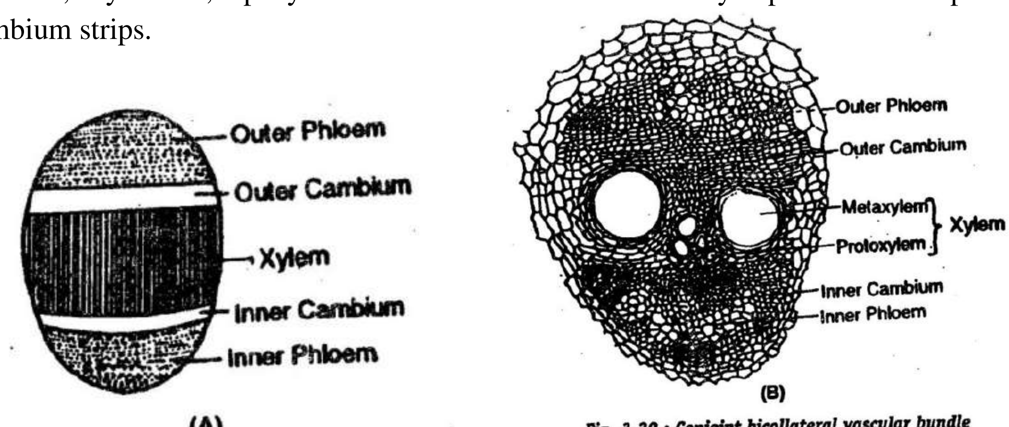


Fig. 3.20 : Conjoint bicollateral vascular bundle (A) Diagrammatic, (B) in Cucurbita stem.

(c) Concentric vascular bundle: When one type of vascular tissue (either xylem or phloem) surrounds the other, the bundles are known as concentric vascular bundles. They are further divided intortwo types viz.

(i) Amphivasal (leptocentric) bundle : In a concentric bundle when phloem is surrounded by xylem; the vascular bundle is called amphivasal or leptocentric (leptos - phloem, centric - in centre) concentric vascular bundle Examples - Stem of Dracaena, Acorns, Yucca.

(ii) Amphicribal or hadrocentric bundle : In this type the xylem is surrounded by the phloem, the bundles are known as amphicribal or hadrocentric. Examples - Ferns rachis, petiolar bundles of flowers and fruits. The concentric vascular bundles are always closed due to absence of cambium between xylem and phloem.

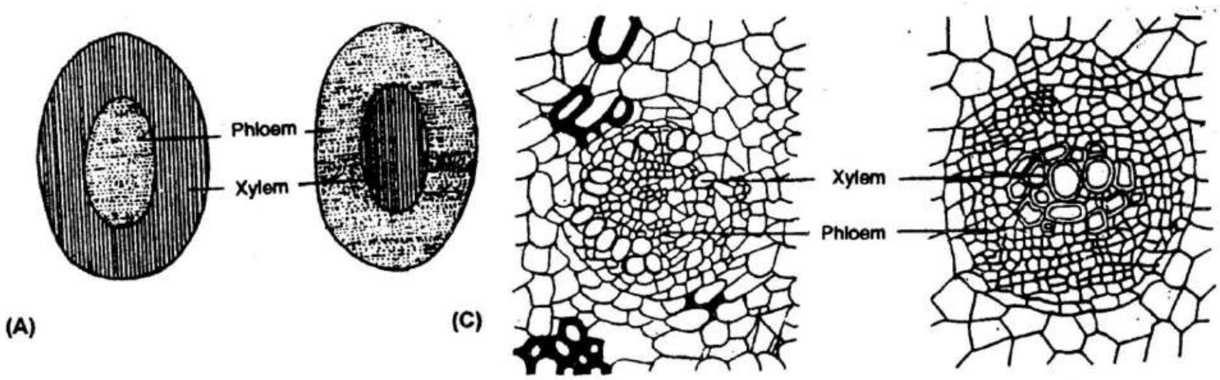


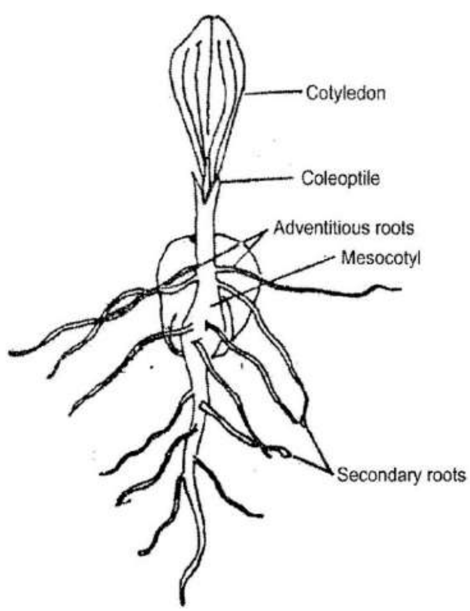
Fig. 3.21 : Concentric vascular bundle - Amphivasal - (A) Diagrammatic, (B) in Dracaena stem; Amphicribal - (C) Diagrammatic, (D) in Fern rachis

Primary and Secondary Structure of Plant Body

Primary Structure of Monocotyledon and Dicotyledon Root, Stem and Leaves

Primary Structure of Monocotyledonous Root, Stem and Leaf Example - Maize

Introduction



The adventitious root system is the characteristic of monocotyledons. The system consists of many roots developed from the base of the plumule and from lowermost nodes. Since these roots are not developed from radicle, they are adventitious. These roots persist throughout the life of the plant. Some additional roots also arise later on from the lower nodes on the aerial stem for support and are called stilt roots. General Characteristics of the monocotyledonous root are as follows.

(i) The root grows in the downward direction into the soil and spread in the upper soil layer.

(ii) They lack chlorophyll as they are not exposed to light.

(iii) They are not susceptible to influence of light.

(iv) They lack the buds.
(v) They possess a root cap over its apex.
(vi) The vascular tissues are arranged in radial manner.
(vii) Monocots possess root hairs in the region just behind its apex.

The internal anatomy of the monocotyledonous root may be studied well in the transverse section of Maize (Zeamays) underground root. The transverse section shows three tissue systems viz. epidermal, cortical and vascular in three distinct regions viz. epidermis, cortex and stele respectively.

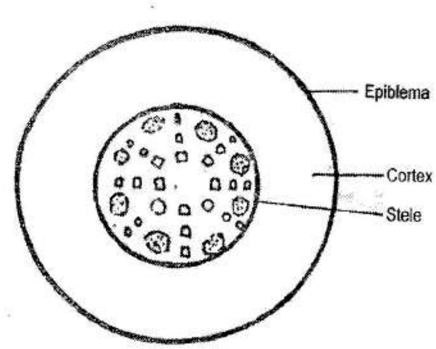


Fig. 2.2 : Maize root in transverse section (Diagrammatic)

Epidermis: It is the outermost layer of cells and is uniseriate. This layer is also called epiblema. The cells are barrel shaped, thin walled and are compactly arranged. Some of the cells give rise to unicellular hairs if the region is close to the apex.

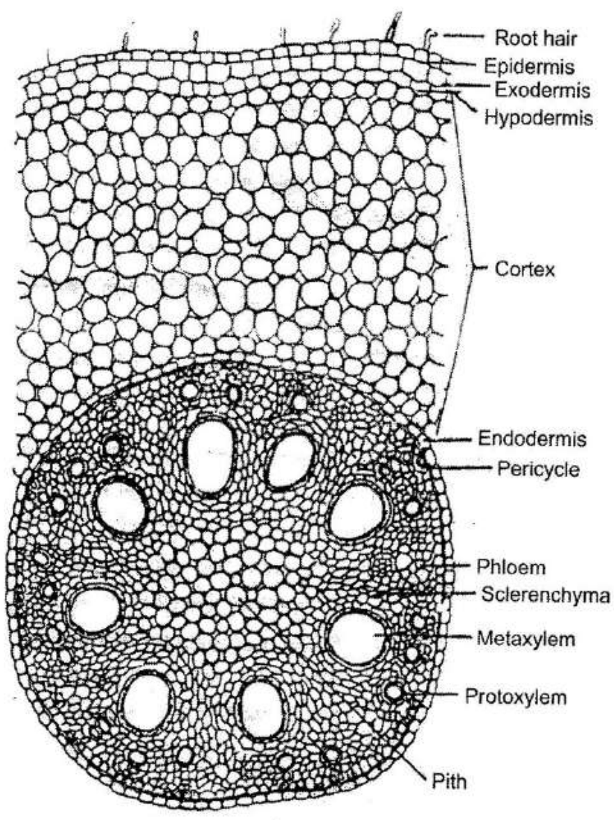


Fig. 2.3 : Maize root in transverse section (a sector) showing primary structures

Cortex : The cortex makes the major portion of the root. It is composed of many layers of thin walled parenchyma cells with many intercellular spaces. In old root when the epidermal cells become old sometimes disintegrated. Some of the outer layers of the cortex undergo some chemical changes. They get thinly suberised like young cork cells. These cells form a distinct layer below epidermis and is called exodermis. It is protective in function. Like epidermis the innermost layer of the cortex is the endodermis. It forms a definite ring around the stele. The cells of endodermis are brick or barrel shaped and are compactly arranged. Their radial and inner walls show a strip of thickenings of suberin like substance. These thickenings are called casparian strips which are impervious to water. The cells of endodermis facing to exarch protoxylem are thin walled, called passage cells as they form passage for water from cortex to xylem elements.

The layer next to the endodermis is the pericycle. It is made up of thin walled and smaller cells with abundant protoplasm. This region sometimes shows few sclerenchyma cells. The pericycle is the outermost region of the stele.

c) Stele : The vascular bundles are radial, polyarch with many xylem and phloem patches. The protoxylem in each xylem patch is facing towards the periphery hence xylem is exarch. These exarch xylem strands alternate with the phloem strands. As there are many strands of xylem, the stele is described as polyarch. Each xylem strand possesses one or two metaxylem vessels to the innerside and a few protoxylem vessels towards periphery.

The phloem consists the sieve tubes and campanion cells. In mature roots, for support, the sclerenchymatous cells develop between xylem patches and below the phloem strands. These cells form the sclerenchymatous conjunctive tissue. This is in the form of continuous ring around the pith. The central portion of the stele is known as pith. The pith is parenchymatous. The cells are with intercellular spaces. The pith cells store the starch grains.

Primary Structure of Monocotyledonous Stem Example - Maize

Introduction

The monocotyledonous stem is differentiated into distinct swollen nodes and internodes. The stem is usually cylindrical and unbranched. It terminates into an inflorescence. The space between the two nodes i.e. the internode.

The monocotyledonous stem shows following characters.

i. Monocot stem shows swollen nodes, and the internodes covered by sheathing leaf base.
ii. Stem is usually glabrous.
iii. The vascular bundles are many and are scattered in the ground tissue i.e. no definite pattern of arrangement.
iv. Vascular bundles are conjoint and collateral but are closed (as cambium is absent).
v. Each vascular bundle is enveloped by sclerenchymatous sheath.
vi. Phloem is composed of sieve tubes and companian cells only, phloem parenchyma being absent.
vii. Medullary rays are not distinguished because vascular bundles are scattered.
viii. Ground tissue is usually undifferentiated and uniform.
ix. Vascular bundles towards periphery are smaller and those lying towards the centre are larger.
x. Xylem appear 'Y' shaped i.e. metaxylem elements remain outside and protoxylem in the centre below it, and the lysigenous cavity is associated with protoxylem in mature vascular bundle.

All the characters essential to study the primary structure of a monocotyledonous stem can be observed in the transverse section passing through the internodal region of Maize stem.

The transverse section passing through the internodal region of Maize stem also shows the three tissue systems i.e. the epidermal, the fundamental and the vascular (Fig. 2.4, 2.5). In dicot stem, these tissue systems are distinct from each other, but in monocot due to absence of distinct endodermis, and due to irregularly scattered vascular bundles, fundamental and vascular tissue systems are not separated from each other. They together constitute the ground tissue without any separate intrastelar and extrastelar regions as in dicot stem.

(a) Epidermal tissue system :

Epidermis is the outermost layer of the stem. The cells are uniseriate, compactly arranged. The outer-walls of the epidermal cells show presence of thin layer of waxy cuticle.

(b) Fundamental or ground tissue system : The term cortex is used for extrastelar ground tissue when it is separated from intrastelar tissue by distinct endodermis. In Maize, such distinct endodermis is absent.Therefore the term cortex is not used. The outer few layers of ground tissue system are thick walled, generally sclerenchymatous. These layers are continuously forming a ring in the region next to epidermis, called hypodermis. The remaining region of the ground tissue internal to hypodermis shows presence of only parenchyma cells which are thin walled and are arranged with many intercellular spaces. In green young stem some of the parenchyma cells, next to hypodermis, are with chloroplastids and are green in colour. Such cells form chlorenchyma patches in the outer part of the ground tissue.

The vascular bundles remain embeded in this parenchymatous tissue. These vascular bundles are irregularly scattered in the ground tissue. The vascular bundles in the region next to hypodermis i.e. outer part of ground tissue towards periphery, are smaller in size and more crowded. Some of them show fusion of their sheaths with hypodermal layers. The vascular bundles in the central part of ground tissue are larger in size and they remain away from each other. The number of smaller vascular bundles is higher than the larger bundles. Due to irregular distribution of vascular bundles and due to absence of distinct endodermis there is no distinct stelar region in the centre. Such irregularly scattered vascular bundles, together form a type of stele, called atactostele.

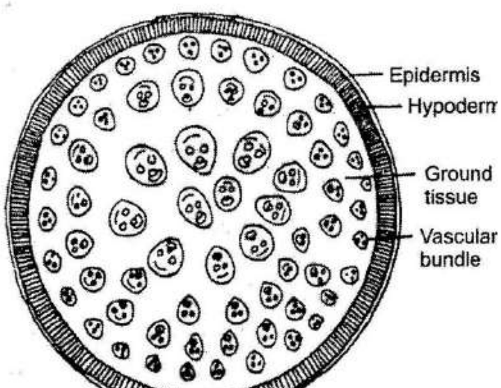


Fig. 2.4 : Maize stem - transverse section (Diagrammatic)

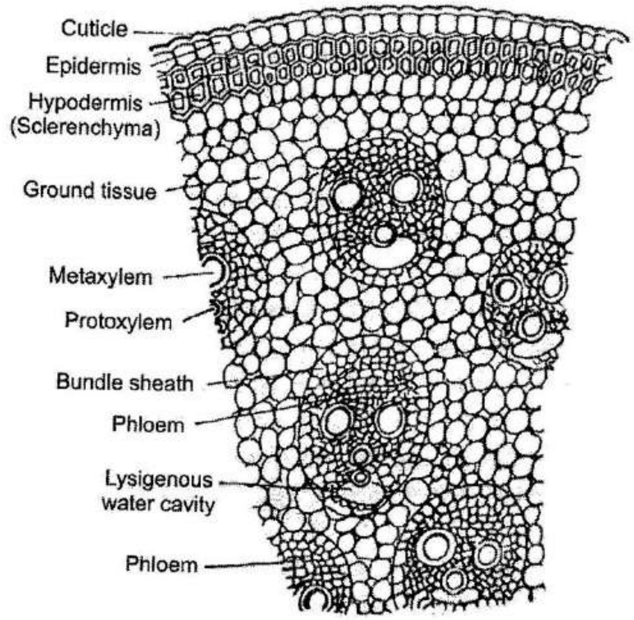


Fig. 2.5 : Maize stem - transverse section (a sector) showing primary structures

(c) The Vascular System : The vascular system consists of many vascular bundles which are scattered in the parenchymatous ground tissue. So the vascular system is in the form of atactostele. Each vascular bundle is collateral (as xylem and phloem remain side by side on the same radius) and enclosed in a sheath of sclerenchyma. The vascular bundle is closed as there is no cambium in between xylem and phloem.

The vascular bundle consists of xylem elements and phloem elements. The xylem occurs in the form of letter 'Y'. The two large metaxylem vessels are towards upper two arms and one facing below i.e. protoxylem. The metaxylem vessels are larger in size and with highly thickened walls with pitted thickenings. The protoxylem elements are smaller than the metaxylem and are with annular or spiral thickenings. They may break down forming an irregular water containing lysigenous cavity in mature bundles. Therefore many mature bundles show protoxylem cavity instead of protoxylem elements. In addition to these conducting elements, xylem shows sclerenchyma fibres and thin walled small living parenchymatous cells in the region surrounding protoxylem.

The phloem lies mostly in between the arms of 'Y'. It is relatively smaller in amount and in the form of a small patch on upper side of metaxylem. It is composed of only sieve tubes and companian cells. Here the phloem parenchyma and phloem fibres are absent. The phloem patch shows in the outer or upper region, few crushed phloem elements, which get crushed due to pressure from internal tissues. The whole vascular bundle remains surrounded by sclerenchyma sheath i. e. bundle sheath. When vascular bundle is completely surrounded by such a sheath of sclerenchyma fibers, it is called, fibrous vascular bundles and it is a characteristic of many monocot plants.

Primary Structure of Monocotyledon Leaf

Introduction

A leaf is an appendage or lateral organ borne on the node of the stem. The leaf usually possesses the same tissue systems as in the stem-as dermal, the vascular and the fundamental. The epidermis forms the outermost layer while the vascular tissue is variously distributed in the ground tissue. However, the leaf fundamentally differs from stem in details of growth and arrangement of tissues. The leaf shows limited or determinate apical growth as compared to growth of stem (due to apical meristem).

In case of large foliage leaf, the relatively large external surface, the extensive air space system, abundant chloroplasts in the ground tissue, and the close spatial relation between the vascular tissue and the ground tissues. Suggest a specialization of tissues related to photosynthesis. These characteristics favour the exposure of the chloroplast to the light and ready to get easy access of water and gases to the cells concerned with the process of photosynthesis. The foliage leaf lacks the storage tissues and absence of periderm and mainly composed of primary tissues. Due to absence of secondary growth, the leaf is restricted in its capacity to restore its tissues which are always exposed to weathering and other injurious outside environmental influences. In perennial plants new leaves are formed repeatedly and older leaves are shed. Therefore leaves are limited in their growth and longenity.

The concept of leaf is applied in case of seed plants. Into many forms of lateral appendages of the axis having variation in structure and function. This variation initiates the segregation of foliage leaf (organ) into different types such as cataphylls, hypsophylls and cotyledons or cotyledonary leaves. The cataphylls are the leaves, inserted at low levels of plant/shoot which may be known as scales occuring on buds and underground stems. These are only concernal with protection or storage or both. While hypsophylls are those inserted at high levels of plant / shoot. These are represented by the floral bracts.

The monocotyledon have usually one prophyll (pro-before, phyllon-leaf). While cotyledons are the first leaves of the plant. In Angiosperms, there are several variations of the leaf. The leaf is an expanded flattened structure called lamina. In monocotyledons, the base of a leaf is expanded into sheath.

In general the anatomical structures in monocotyledon leaf are discussed here with the help of an example - a leaf of maize considering its transverse section. The transverse section of maize leaf revealed following internal organization of tissues (Fig. 2.6).

Epidermis : The epidermis of a leaf is composed of various types of cells (Stomata cells, guard cells of the stomata, subsiding) cells, trichomes, cork cells, bulliform cells.

Epidermis occurs on upper and lower surface of a leaf. Upper surface epidermal cells are uniseriate, cells are oval with cuticularised outer walls. Upper epidermis is discontinuous where stoma is present. Below the stoma, substomatal chamber present the upper epidermis has bulliform cells and occur in groups, easily differentiated from normal adjoining cells by their larger size. The cells are hyaline. The lower epidermis is alike upper epidermis, but lacks bulliform cells.

Mesophyll : It lies between two-epidermal layers. It is many layered and composed of one type of cells. The cells are isodiametric and contaning abundant chloroplasts. The cells cannot be differentiated into palisade parenchyma and spongy parenchyma, but all cells of spongy type. These are with intercellular spaces which are continuous to the external environment through substomatal chamber and stomata.

Vascular bundle : The vascular bundles are more or less of same size except the vascular bundle of midvein which is larger in size than others. The same size vascular bundles are located at regular intervals. Each vascular bundle is collateral and closed (as cambium is absent). The xylem is facing towards upper epidermis and the phloem is facing towards lower epidermis. The patch of sclerenchyma occurs above the xylem and below the phloem. Each vascular bundle is surrounded by a ring of cells called bundle sheath of parenchyma cells. These cells are thin walled and lack chloroplasts.

Thus, monocotyledonous leaves are isobilateral due to presence of stomata on both the epidermis, and mesophyll layer is not differentiated into palisade and spongy parenchyma.

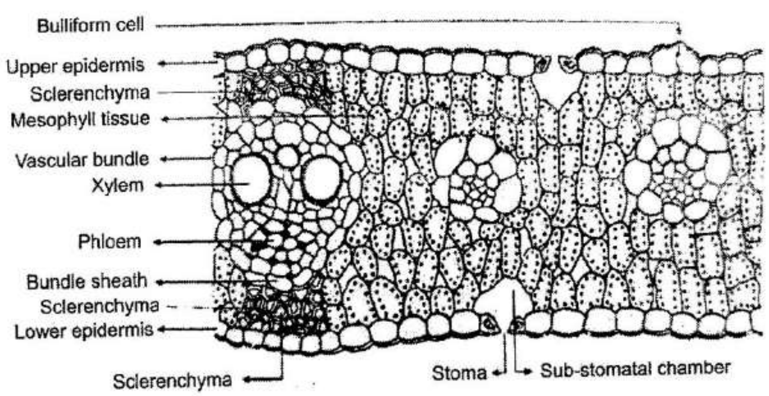


Fig. 2.6 : Transverse section of Maize leaf

The mesophyll cells with abundant chloroplast so these are photosynthetic tissues, stomata are meant for exchange of gases. Presence of sclerenchyma patches above the xylem and below the phloem are meant for mechanical strength against shearing stress.

Primary Structure of Dicotyledon Root, Stem and Leaf Primary Structure of Dicotyledonous Root Example - Sunflower

Introduction

The root is a very important part in a vascular plant. It develops from the radicle in the embryo after germination of seed. The root tip is always protected by the root cap therefore apical meristem in the root remain subterminal. During the seed germination the radicle elongates and comes out of the seed coat. In docotyledons the radicles enters the soil and grows to form the root of the plant. Such root in dicotyledons, is called primary root, which further develops into the tap root system. Such root developed from radicle in embryo usually persists throughout the life of the plant. This tap root during its further development produces lateral branches. The root is primarily concerned with fixing the plant into the soil, absorption of water and mineral nutrients from the soil.

Like stem, the apical meristem in the root tip produces the tissues called the primary tissues. The body of root made by these tissues is termed as the primary root. We also know that the root and stem form a continuous axis through vascular tissues. The internal structure of the root is comparatively simple than that of the stem. It may be due to lack of nodes and internodes, absence of buds, leaves etc. as in stem.

To understand the internal structure or anatomical details, it is necessary to know the general features of the dicotyledonous root. They are as follows.

(i) The tap root grows deep into the soil and it develops lateral branches.

(ii) They lack the chlorophyll as they remain underground and not exposed to light.

(iii) The roots are without leaves.

(iv) The root possesses a root cap over its apex to protect growing tip.

(v) The root shows endogenous origin (from pericycle) of branches.

(vi) The xylem and phloem in root lie on different radii without cambium inbetween.

(vii) The root hairs are present in young root behind the growing region.

(viii) The vascular cylinder is more compact

(ix) The xylem is exarch, and diarch or tetrarch.

(x) Cuticle is absent.

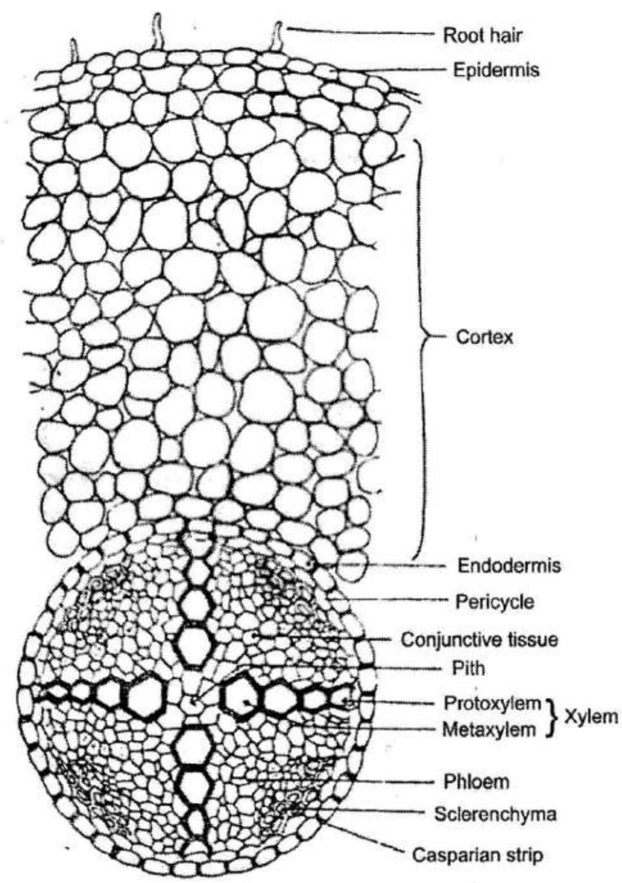


Fig. 2.7 : Sunflower : Transverse section of young root or primary root showing primary structures

The dicotyledonous roots show some variation in their structure, but in general exhibit similarities in nature and arrangement of tissues.

To know the anatomical structure of a typical dicotyledonous root, the root of Sunflower (Helianthus annuus) is selected and discussed here.

The transverse section of primary or young root of Sunflower (Fig. 2.7) shows three different regions viz. (a) Epidermis, (b) Cortex, and (C) Vascular region (Stele).

Epidermis : It is also known as epiblema or piliferous layer. It is the outermost layer consisting of single row of cells. The cells are tubular, thin walled and without stomata and cuticle. Some of the epidermal cells from their outer walls produce elongated outgrowth called root hairs. The root hairs help in the absorption of water and minerals from the soil.

Cortex : The cortex zone forms a major portion of root. It is composed of simple, thin walled, isodiametric parenchymatous cells with intercellular spaces. These cells are living and possess abundent leucoplasts. These cells are concerned with storage of food. In early stage they translocate the water and solutes from epidermis to the vascular elements. The innermost layer of the cortex in root is the endodermis. The endodermis layer is uniseriate and consists of barrel shaped compactly arranged cells. The walls of endodermis cells possess a radial thickening of lignin or suberin forming strip called casparian strip on thier radial walls. This strip is impervious to water. So there is no osmosis between the inner vascular elements and outer cortex region.

(c) Vascular region or stele : The stele in its outermost region shows a single layered pericycle. The cells of pericycle are thin walled and parenchymatous with abundant protoplasm.

The vascular bundles are radially arranged The vascular cylinder(stele) is much smaller than that of stem. The xylem and phloem elements occur in separate strands or patches on the alternate radii. The portion between these strands is filled with smaller parenchyma cells known as conjunctive tissue. The number of xylem patches is equal to the phloem patches and since it is four, the radial vascular bundle is tetrarch. In the xylem patches the protoxylem lies towards the periphery and metaxylem towards centre, therefore the xylem is exarch.

The central portion of the stele is usually occupied by large metaxylem vessels, which are placed so close to each other that they almost form a soild patch at the centre hence the stele is considered to be a protostele.

The phloem patches are composed of thin walled, compactly arranged small patches of sclerenchyma, sometimes occur above each patch of phloem in the pericycle region and protect soft tissue. Pith is parenchymatous, occupying small area in the centre or sometimes pith is obliterated due to meeting of metaxylem vessels in the centre.

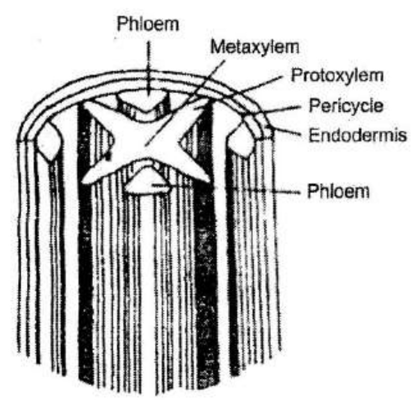


Fig. 2.8 : Sunflower : Vascular region (stele) showing radial arrangement of xylem and phloem (Diagrammatic)

Primary Structure of Dicotyledonous Stem Example-Sunflower

Introduction

The main body of the vascular plant is composed of two systems viz. root system and shoot system. The shoot system possesses the ascending and aerial axis and it bears the vegetative and reproductive structures. This axis in the shoot system is known as the stem. During the germination of seed in the development of embryo the plumule grows and forms the shoot system, radicle grows and forms the root system. In this growth of embryo the first bud is commonly called the plumule while the stem part of the plumule above the cotyledons is the epicotyl. However in some plants this embryo shoot system also includes some part of hypocotyl region. The hypocotyl (hypo - below, cotyl-cotyledon). In this case it is the initial stem unit of the plant and is situated just below the cotyledons. During germination of seed the apical meristem in the shoot axis develop into shoot system by the addition of new leaves, nodes and internodes. The shoot apex now shows distinct region of active dividing cells called apical meristem which remains throughout the life and gives rise to the stem and other parts of the shoot system. The apical meristem at stem apex divides to give rise new tissues, which become permanent and form fundamental (primary) body of the stem.

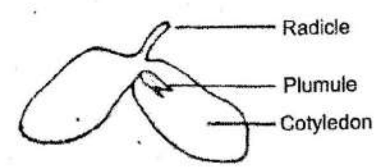


Fig. 2.10 : Germinated dicotyledonous seed showing plumule radical and cotyledons

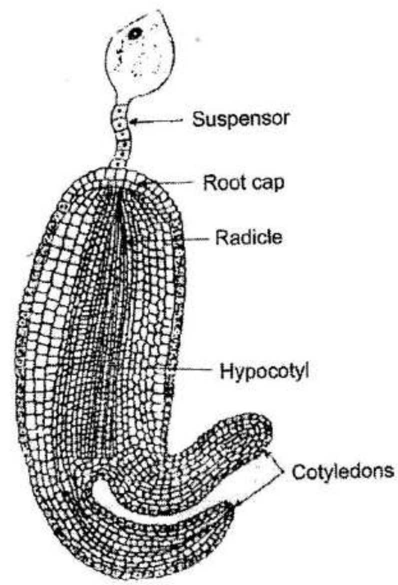


Fig. 2.9 : Dicotyledonous embryo showing development of shoot and root system

Therefore, the tissues derived from apical meristem in the stem, are called primary permanent tissues of the stem which is termed as primary body of the stem. It shows distinct nodal and internodal regions. The section passing through the internodal region of the stem shows important anatomical characters. Some of the characters are -

(i) The vascular bundles are usually few in number and arranged in a ring.
(ii) Vascular bundles are conjoint collateral or bicollateral, open and endarch, and they are uniform in size.
(iii) The vascular bundles are not surrounded by a sclerenchymatous sheath as in monocot stem.
(iv) The xylem shows proto and metaxylem elements and protoxylem is towards pith, phloem is composed of sieve tubes, campanian cells and phloem parenchyma.
(v) The medullary rays are present in between the vascular bundles.
(vi) The extrastelar ground tissue is distinguished into many layered collenchymatous hypodermis, parenchymatous cortex; endodermis and pith.

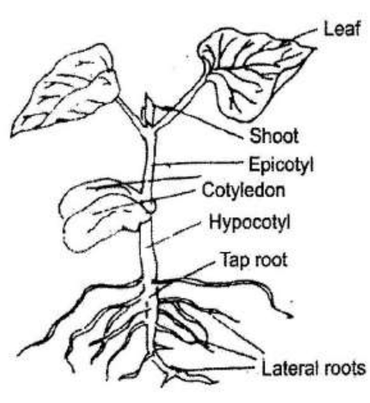


Fig. 2.11 : Dicotyledonous embryo after development showing root and shoot (primary) systems

Most of the dicotyledons show typical nature and arrangement of tissues in the stem. But some dicotyledonous plants exhibit variation in the internal structure of the stems.

Therefore, to know the typical anatomical structure of primary stem, here Sunflower (Helianthus animus, Asteraceae) From dicotyledons is selected.

The primary internal structure of young Sunflower stem is discussed the stem shows three regions namely **(a) outermost epidermis, (b) Middle-cortex, and (c) inner-vascular region (stele).**

(a) Epidermis : It is the outermost, uniseriate layer of thin walled, living cells. They are arranged end to end and are without intercellular spaces. Epidermis shows presence of epidermal hairs or trichomes (therefore
stems appear rough), which are mostly multicellular. Thus, epidermis is protective in function. The part next to the epidermis composed of the cortex region.

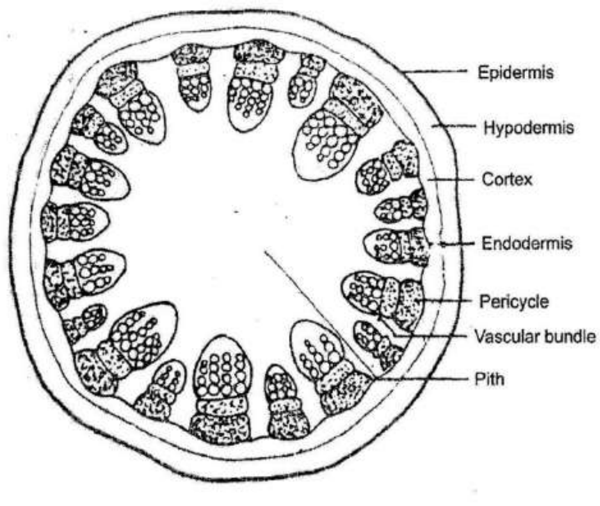
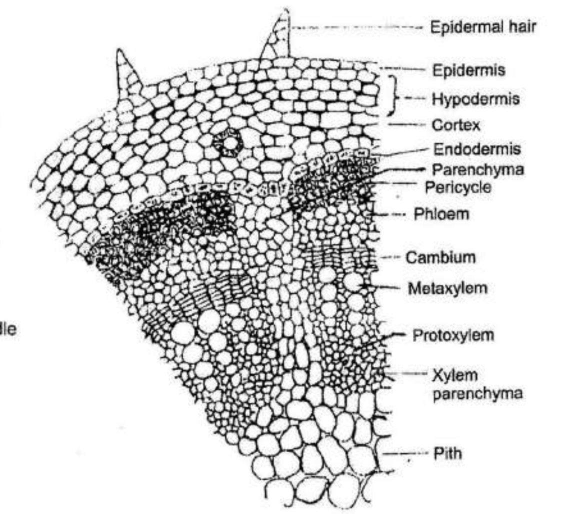


Fig. 2.12 : Sunflower : Transverse section of internodal region of young stem



!.13 : Young Sunflower stem (a sector) in transverse section showing primary structures

b) Cortex : This region possesses extra-stelar ground tissues. This may be divided into three regions, (i) The first zone just internal to the epidermis, is composed of collenchyma consisting of some 4 or 5 layers. This zone is known as hypodermis. Some patches of collenchymatous cells possess chloroplast. The collenchyma gives the mechanical support to the herbaceous young stem of this plant, (ii) The second region is composed of few layers of parenchymatous cells. They are thin walled and loosely arranged. This region show few resin ducts, each with a central hollow cavity surrounded by small densely protoplasmic epithelial cells, (iii) The last region of the cortex is made up of a layer of compactly arranged, barrel shaped parenchymatous cells called the starch sheath. As the chloroplast is present in this layer the photosynthetic product is stored in this region in the form of starch so called starch sheath in which starch grains are abundantly present. This starch sheath is the endodermis. This endodermis is the innermost layer of the cortex and delimits the cortex from the stele (vascular region).

C) Stele (vascular region) : The tissues internal to the endodermis constitute stele (eustele). The region present inside the endodermis consists the pericycle. The pericycle is the outermost layer of stelar region. It is composed of patches of parenchyma and sclerenchyma. The sclerenchymatous patches forming bundle caps, are the proper hard bast patches. The hard bast is meant for mechanical strength to the phloem (bast-phloem).

Vascular bundle

The vascular bundle is composed of xylem and phloem, both lying side by side (collateral) on the same radius (conjoint) i.e. xylem being internal and phloem external. It is typically conjoint collateral. A strip of lateral meristem is present between the xylem and phloem i.e.

fascicular cambium, so vascular bundle is open. The xylem patch shows proto and metaxylem elements. The xylem is called endarch, i.e. protoxylem towards the centre and metaxylem towards the periphery.

The protoxylem (first formed) elements are relatively smaller and metaxylem (later formed) elements are with larger cavities (vessels). In between these xylem elements parenchymatous cells are present and are known as xylem parenchyma.

The phloem is composed of thin walled living cells. The cambium in the vascular bundle is known as stelar or fascicular (fascicle-bundle) cambium, which is made up of two to three layers of fusiform (rectangular in transverse sections) cells. This cambium is responsible for growth in thickness of the stem.

The xylem conducts the water and also gives the mechanical support to the organ, while the xylem parenchyma store the food. On the other hand, phloem conducts the prepared food material and translocate from leaves to storage organs, or storage organ to the growing regions in the upward direction to the aerial parts. The phloem sclerenchyma also gives mechanical support.

Medullary rays : These are thin walled, fairly big, polygonal or radially elongated cells, present between the vascular bundles are called medullary rays.

Pith : It is the centrally situated zone having mass of parenchymatous cells with many intercellular spaces.

Primary Structure of Dicotyledon Leaf

The dicotyledonous leaf under transverse section reveals following internal tissue organization. The epidermis of dicotyledonous leaf is composed of various types of cells such as epidermal cells, composed of epidermal tissue guard cells the stomata and subsidiary cells, trichomes.

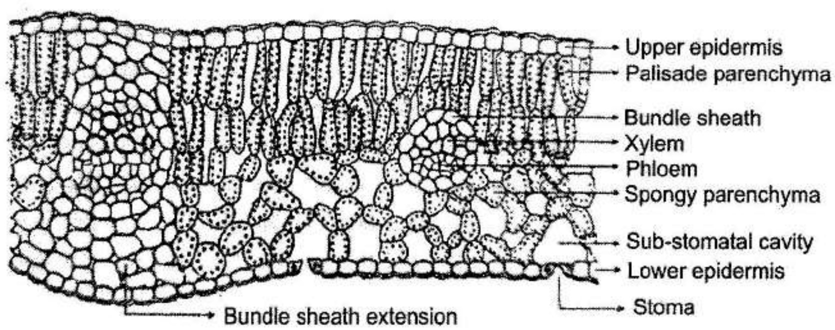


Fig. 2.14 : A part of Magnifera leaf in transverse section

Stomata are only present on lower surface of leaf (on lower epidermis). The upper and lower epidermis is single layered, but in some (e.g. Nerium) it is multilayered. The epidermis lacks chloroplasts exceptionally in certain plants abundant chloroplast is present in the epidermis cells. In aquatic plants, chloroplasts are present in epidermis than in the parenchyma beneath the epidermis. Usually epidermal cells are arranged compactly. It is continuous and lacks stomata on upper epidermis which form protection of leaf tissues against water loss. The walls of epidermis is provided with presence of cutin (e.g. mesophytic plants)

The mesophyll is the ground tissue of the leaf on closed within the epidermis. Mesophyll is a photosynthetic tissue being having chloroplasts. It is living and with intercellular spaces (lacunose), parenchymatous with chloroplasts. The mesophyll is differentiated into palisade (upper) and spongy parenchyma (lower). The palisade (elongated shape of cells) tissue is arranged in a row. The spongy parenchyma is not regular due to having intercellular spaces. There may be many layers of palisade cells with a uniform or variable length of cells. In such cases upper layer with longest size and the innermost cells are shortest. The spongy parenchyma cells are isodiametric or elongated and interconnected with lateral extensions. In xerophytic plants leaves are with relatively strongly developed palisade than mesomorphic leaves. The intercellular spaces in mesophyll tissue are schizogenous. The part of mesophyll breaks down to form space e.g. aquatic plants and plants in marshy habitat.

Vascular (tissues) bundles: The dicotyledonous leaf shows reticulate venation so that the vascular bundles are of many sizes forming network and with smaller bundles diverging from the larger vascular bundles. The vascular bundles are collateral. The xylem in the bundle occurs on adaxial surface and phloem on the abaxial surface. In some bundles are bicollateral. The veins may be larger or smaller and depending on this pattern the bundles of leaves may have primary and secondary tissues. The smaller vascular bundles are primary the xylem is with metaxylem and protoxylem elements. Usually bundle sheath is absent in dicotyledonous leaf but exceptionally bundle sheath is present in c4 plants (dicot plant - Euphorbia hirta)

For the sake of convenience anatomy of dicotyledonous leaf like Mangifera indicaL. (Fig. 2.14) is discussed here.

Epidermis : On both surfaces, single layered, thin walled, parenchymatous celled epidermis is present. The upper epidermis is continuous while lower is discontinuous and stomata are present within the layer. The upper epidermis is with cuticle on outer walls.

Mesophyll: It lies in between upper and lower epidermis. Mesophyll is differentiated into upper palisade and lower spongy parenchyma. Palisade cells lies beneath upper epidermis and are elongated columnar parenchymatous, compactly arranged consisting abundant chloroplast. The vascular bundles interapt the continuity of palisade. Spongy parenchyma lies just above the lower epidermis. It is many layered. With intercellular spaces the cells are more or less isodiametric consisting less number of chloroplast.

Vascular bundle : The vascular bundles are collateral, closed with mesarch xylem. The xylem lies towards upper epidermis while phloem towards lower epidermis. Each vascular bundles is covered with bundle sheath cells. The xylem elements like tracheids are with annular and spiral thickening and with xylem parenchyma. In phloem, sieve tubes with narrow lumen, companion cell and phloem parenchyma are present.

2.2 : Normal Secondary Growth in Dicotyledonous Root and Stem

Normal Secondary Growth in Dicot Root - In general

The normal secondary growth in dicot root follows two steps viz.

a) Formation of secondary vascular tissues.
b) Formation of secondary non-vascular tissues.

(a) Formation of secondary vascular tissues : The vascular bundles in dicot. Root are radial, that means xylem and phloem patches occur separately on alternate radii and the portion between them is filled by the conjunctive tissue. The undifferentiated parenchymatous cells of conjunctive tissue lying just above upper edges of xylem patches and just below lower margin of phloem patches become meristematic and develop into strips of cambium. Thus, the number of cambium strips coincides with the number of xylem and phloem patches (Fig. 2.15), Plate I : B). These strips of cambium grow laterally and unite with the other forming a continuous wavy ring or wavy band of the cambium. This wavy ring of cambium produces secondary xylem elements on the inner side and secondary phloem elements on the outerside.

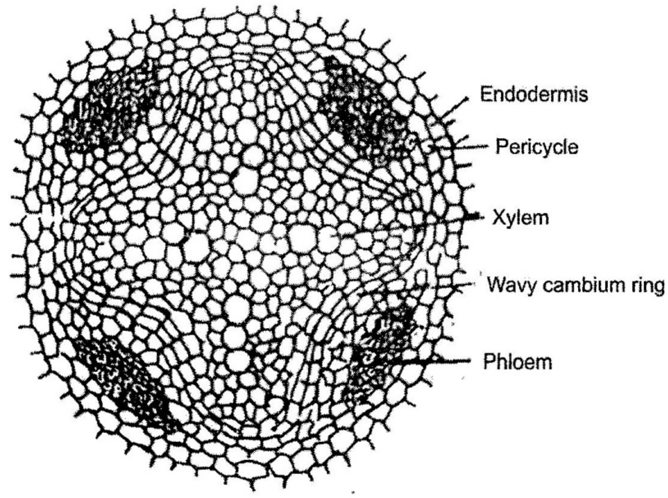
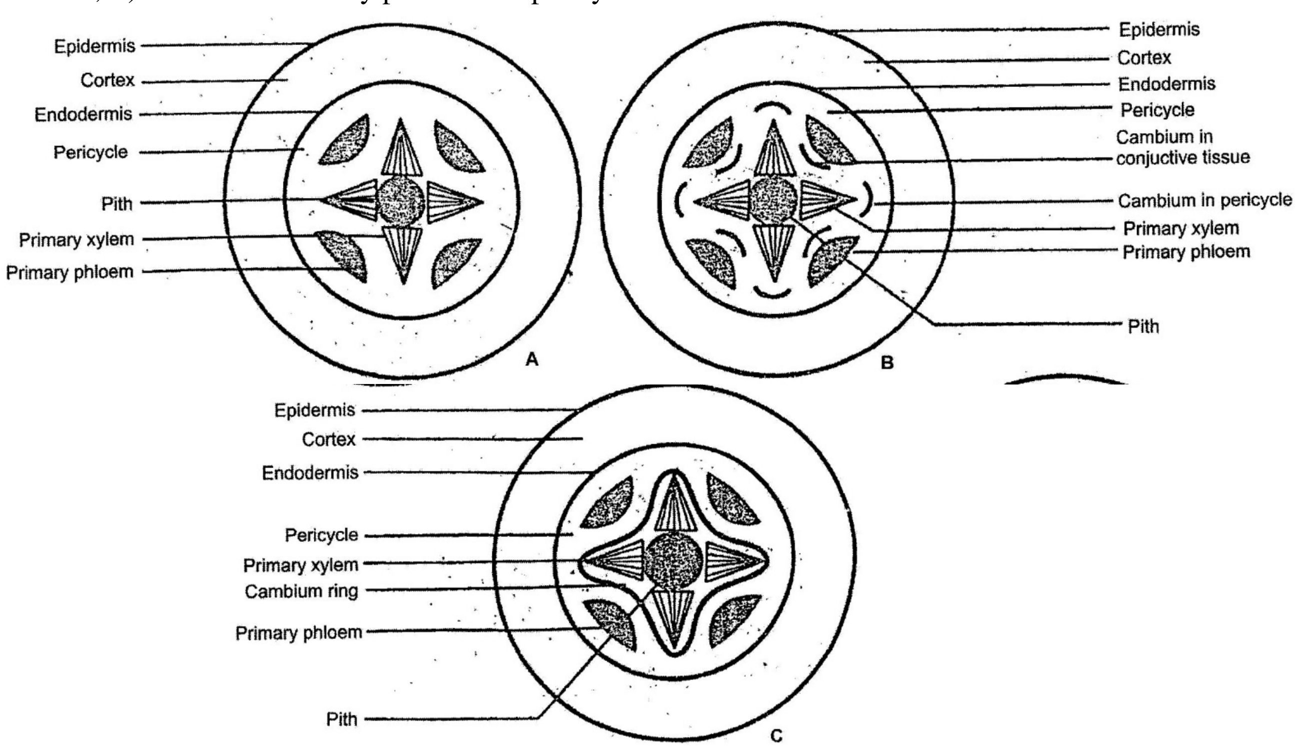


Fig. 2.15 : Normal secondary growth in dicot root in transverse section showing origin of cambium (early stage)

The wavy ring is more active in the region between the patches of xylem. Therefore this region shows vigorous secondary growth than other regions. As a result of this type of unequal growth at different places, the wavy ring of cambium becomes circular (Fig. 2.16), Plate I: D). Now whole of the cambium ring becomes normal.

It produces secondary xylem in normal way on its inner side and secondary phloem towards its outside, and growth remains equal in all the parts of the ring. The amount of secondary xylem is more than that of secondary phloem due to which xylem patches are

pushed towards the centre and fuse to form a compound mass of primary xylem with exarch protoxylem points. (Plate -1: E), the primary phloem also get crushed (Fig. 2.16 and Plate -1: D, E) between secondary phloem and pericycle.



The secondary xylem form a major portion in old dicot root, the xylem elements possesses larger and more vessels with thinner walls. The xylem parenchyma is abundant but xylem fibres are very scanty. As the more secondary xylem in added, the cambium and phloem are gradually pushed further outside. Since the roots are buried in the soil, they are not exposed to sunlight and changing conditions of temperature and other environmental factors, the annual rings are not seen in dicot root.

The secondary phloem in dicot root consists of sieve tubes, companian cells; abundant phloem parenchyma and less phloem fibres. Here the primary phloem is subjected to considerable pressure as a result they get crushed out of it existence (Plate -1, E). The medullary rays are formed from the cambial cells of pericycle exactly opposite to the protoxylem points (Plate -1: D, E). They are parenchymatous. They spread from that region through secondary xylem to the secondary phloem and become wider in the secondary phloem region so appear more or less funnel shaped.

(b) Formation of secondary non-vascular tissues.

In dicot root, there is less secondary growth as compared to that of stem, therefore the tissues outside the stele remain intact. The pericycle become meristematic and divide to form more cells to its inner and outer sides. Due to their meristematic nature they behave as cork cambium (phellogen). This cork cambium on its outside produces suberized cells which form cork (phellem) layers. This cork is impervious to water. Therefore tissues outside the cork die away due to starvation and falls off. Due to initiation of cork cambium in deeper layers like pericycle region after sufficient secondary growth when cork formation occurs, the section of old root does not show many cells in the extrastelar or cortical region. That region show development of periderm (Plate - I, E). Thus periderm shows three distinct layers viz. phellogen, phellem and phelloderm.

(B) Normal secondary growth in Sunflower root

The Sunflower root is characterised by the presence of radial vascular bundles. The primary cambium is absent in it. The normal secondary growth in root of Sunflower begins with the initiation of cambium in the stelar region. The cambium strips are developed outside each xylem bundle in pericycle region and inside each phloem bundle in conjunctive tissue region. These cambium strips are developed by the parechymatous cells of those regions (pericycle and conjunctive tissue). The strips extend laterally and meet each other and thus wavy band of cambium is formed outside the xylem bundles and inside the phloem bundles. Now this wavy cambium starts producing secondary xylem towards centre and secondary phloem towards the periphery. In the beginning the activity of cambium cells is not uniform all over the wavy band. The cambium activity is more in the region of conjunctive tissue. Now due to this uneven activity more xylem is formed in those regions and the wavy band of cambium becomes a circular ring or cylinder. Now this circular cambium ring shows uniform activity all over the ring. Usually secondary xylem is more in amount than secondary phloem. The elements of secondary xylem and secondary phloem are discussed earlier (in part 'A'). Due to formation of secondary xylem the primary xylem patches are pushed towards the centre and form a radiating core. As earlier described the medullary rays are extending from protoxylem of primary xylem towards the secondary phloem. Pith is totally obliterated (disintegrated). Primary phloem is pushed towards periphery due to formation of secondary phloem and it gets crushed due to the pressure of increasing stele. It may be seen in small (vanishing) patches outside secondary phloem.

Due to formation of secondary vascular tissues, pressure is exerted on the outer tissues like endodermis, cortex and epiblema (epidermis). Once the cambium ring is formed it remains functional throughout the life of the plant/plant part. Hence pressure from inside increases continuously. Now the endodermis and cortex cells get crashed, and epiblema tend to rupture. Now the whole pericycle becomes meristematic and forms the cork cambium or phellogen. This by tangential divisions forms cork cells or phellem to the outside and phelloderm or secondary pericycle towards inside. These three layers together form the protective tissue called periderm. This periderm protect inner tissues from dessication and mechanical injuries.

Necessity of Secondary Growth:-

Due to continuous primary growth, the length of the shoot (stem) increases, it produces more branches and leaves. Thus, the weight of the shoot increases. To bear the added weight, the stem needs more mechanical tissues. At the same time the demand for raw food is increased. To meet this, root absorb and sent more raw food. To conduct this additional raw food material, (water, mineral salts etc. from soil) stem needs more conducting tissues. Therefore the xylem is produced in the form of secondary xylem. As more food is prepared in leaves, so to conduct it secondary phloem is produced.

After secondary growth in vascular region, the secondary tissues exert pressure on the outer region, therefore epidermis is raptured. So there are chances of dessication of inner tissues, infection of microbes etc. For this purpose after the death of epidermis new protective tissue i.e. periderm is formed due to activity of cambium from non-vascular region.

Normal Secondary Growth in Dicotyledonous Stem

(A) Normal Secondary Growth in Dicot Stem-in General

Introduction

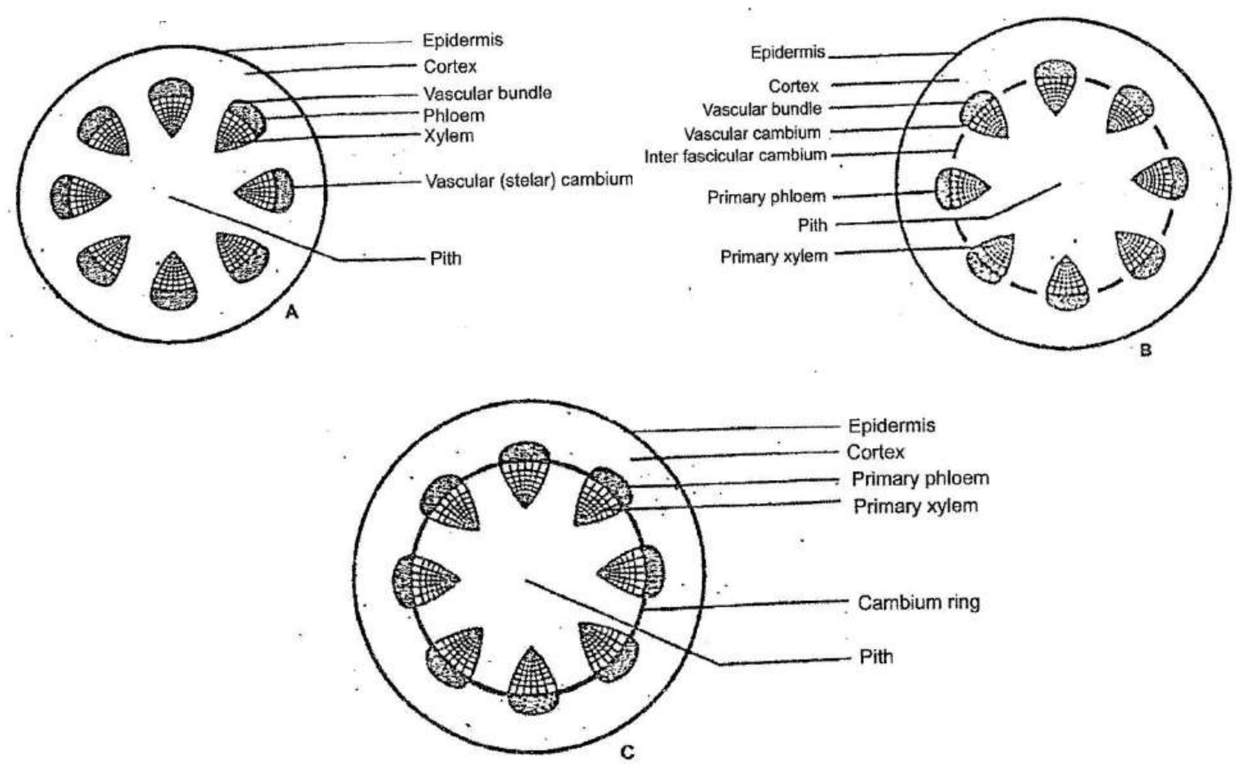
We learned in the beginning of this chapter that, the divisions in meristems results in the development of primary body of the plant. These meristems lead to formation of primary permanent tissues. In dicotyledons, the primary permanent tissues make the fundamental parts of the plant. This is responsible for growth in length or height of a plant and considered as primary growth. Further increase in thickness, which is noticed in the dicotyledons is due to formation of some new tissues by the activity of lateral meristems like vascular cambium and phellogen (cork cambium). This further growth in thickness is due to cambial activity and it is by addition of new tissues. These new tissues are called secondary tissues and growth in thickness by cambial activity is known as secondary growth. Thus, the increase in thickness, due to the addition of secondary tissues by the activity of vascular cambium and cork cambium in the stelar and extrastelar regions respectively is known as secondary growth.

The secondary tissues in the dicotyledon stem are of two types :

(a) Vascular tissues or stelar tissues developed from vascular cambium and are added in intrastelar region and (b) cork and phelloderm formed by phellogen or cork cambium, which are extrastelar tissues. Thus, in dicotyledonous stem, the secondary growth takes place in the intrastelar as well as in extrastelar regions.

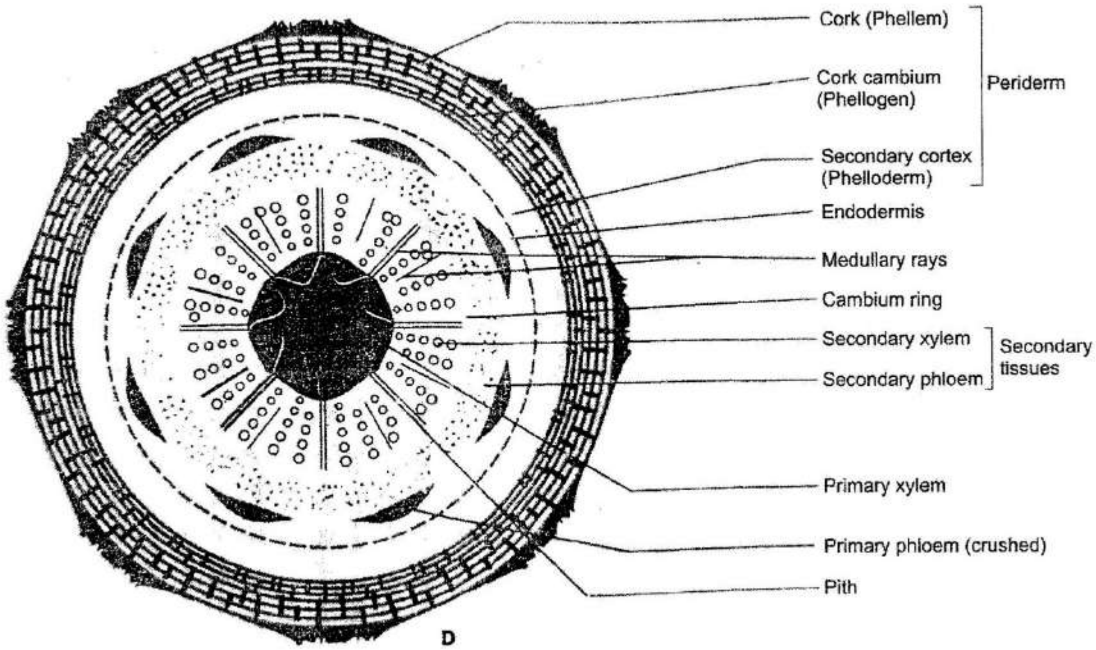
(a) Secondary Growth in Intrastelar Region (or by Vascular Tissue Formation)

The vascular bundles of dicotyledonous stem are conjoint collateral and open.



Normal secondary growth in dicotyledonous stem (Diagrammatic)

They consists a strip of meristematic tissue called vascular cambium, since it is present in between xylem and phloem in the vascular bundle. It is also called fascicular (fascicle-bundle) cambium (Plate - II, Fig. A). When the secondary growth begins in the stem, this fascicular (or intrastelar) cambium becomes active in the vascular region i.e. between primary phloem and primary xylem (here phloem and xylem as they are formed earlier in primary structures so termed primary phloem and primary xylem respectively). At first in between the two vascular bundles, there is no cambium but the cells are only parenchymatous i.e. medullary region. Now before secondary growth starts, few parenchymatous cells form this medullary region exhibit meristematic activity and develop a new cambium strips in interfascicular (inter-between, fascicles-bundles) region between two bundles. These cambium strips are called interfascicular cambium. (Plate - II, Fig. B). Further these strips grow laterally and join with cambium strips from vascular bundle (fascicular cambium) to form a entire ring of cambium (Plate - II, fig. C). Now the secondary growth begins with the activity of this cambium ring. So the formation of interfascicular cambium and complete cambium ring is the first part in secondary growth in dicot stem. This cambium ring becomes active and cut off cells towards, outer and inner side. These cells further differentiate into secondary phloem and secondary xylem respectively. The cells of the cambium ring are of two types viz. spindle shaped fusiform initials, and isodiametric ray initials. These fusiform initials produce tracheids, vessels, xylem fibres and xylem parenchyma towards inner side and sieve tube, companian cells, phloem parenchyma and phloem fibres towards outer side. These tissues lie parallel to the longitudinal axis and form vertical or longitudinal system. The ray initials give rise to ray parenchyma towards outer and inner side forming phloem and xylem rays respectively.



Normal secondary growth in dicotyledonous stem (Diagrammatic)

These forms horizontal or transverse system. Each cambium cell divides into two daughter cells, of which one remains meristematic while the other develops into a permanent tissue. When the cell differentiated, is next to xylem (towards inner side) it forms a xylem element and one next to the phloem (towards outer side) forms a phloem element. In this fashion the cambium cells divide continuously producing secondary tissues on either sides. As there is addition of secondary tissues, the cambium ring pushed more and more towards the periphery.

The secondary xylem constitute the major portion of secondary vascular tissues. It forms the bulk of the woody plant. These elements conduct water and dissolved mineral salts, as well as they give mechanical support to the vertical plant body. The secondary xylem consists xylem tracheids, scalariform and pitted vessels, xylem sclerenchyma (wood fibres) and some wood parenchyma (xylem parenchyma). The living parenchyma in this tissue stores the food.

The cambium is more active on the inner side than the outer side. So that the secondary xylem increase the bulk of the stem more rapidly and form a compact hard mass which forms the wood in plants and it occupies a major portion of the stem. The cambium forms some narrow bands of parenchyma cells running across the stem in radial direction through secondary xylem and secondary phloem, are known as secondary medullary rays. They form a conducting communication with the living cells of vascular tissues. These rays help in the exchange of gases, conduction of water and food from phloem to the cambium and to the xylem parenchyma.

The secondary phloem is formed from the cambial cells. The amount of secondary phloem is relatively less than that of secondary xylem. In most of the dicot stems the primary phloem gets crushed due to the formation of more and more secondary tissues towards its inner side and become functionless. While the secondary phloem perform all the activities for sufficiently long period. The secondary phloem cells are arranged in radial rows. The secondary phloem consists of sieve tubes, companian cells and phloem parenchyma. Sometimes phloem sclerenchyma is also formed. The companian cells are usually associated with sieve tubes.

(b) Secondary Growth in Extrastelar Region (or by Non-vascular Tissue formation)

The stem increases in diameter as a result of secondary growth. As more and more secondary tissues are added in the central stelar region by the cambium, a pressure on the outward direction develops on the parenchymatous cortical region (cortex) and epidermis. As a result of this pressure, epidermis gets ruptured (Plate - II, Fig. D). Due to ruptured epidermis, living tissues get directly exposed to the surrounding atmosphere. To protect them from infection of microbes and to check loss of water from them, there develops a zone of suberised cells called the cork in the epidermal region. The cork protects the inner tissues and perform the protective function of epidermis (Plate - II, Fig. D).

The another meristematic tissue i.e. cork cambium (phellogen) develops in the outer cortex region and behave like that of vascular cambium. It gives off new cells on the both sides. On the outer side the cork cambium produces cork or phellem in the form of suberised cells. While on the inner side, the cork cambium produces smaller parenchymatous cells producing phelloderm or secondary cortex. The cells of phellem are suberised and dead, they are impermeable to water and gases. The cork, cork cambium and secondary cortex collectively form the periderm (Plate - II, Fig. D).

(B) Normal Secondary Growth in Sunflower Stem

The Sunflower stem is characterized by the presence of conjoint, collateral, open vascular bundles. The normal secondary growth in this stem occurs by only vascular tissue formation and as mentioned earlier in part (A-a,b). The secondary growth begins with the activity of fascicular cambium, which is the primary meristem. Soon the parenchymatous cells of medullary region present between two vascular bundles, resume meristematic activity and form cambium strips called interfascicular cambium.

These interfascicular cambium strips grow laterally to join the strips of fascicular cambium and form an entire cambium rin

Now the secondary growth starts by its activity. Here cells of cambial ring divide to form two daughter cells, of which one remains as cambial cell and other develops either in xylem or phloem cells. This process repeatedly takes place and cells are further differentiated into secondary xylem and secondary phloem. The secondary xylem is produced on the inner side while secondary phloem to the outer side in cambial ring.

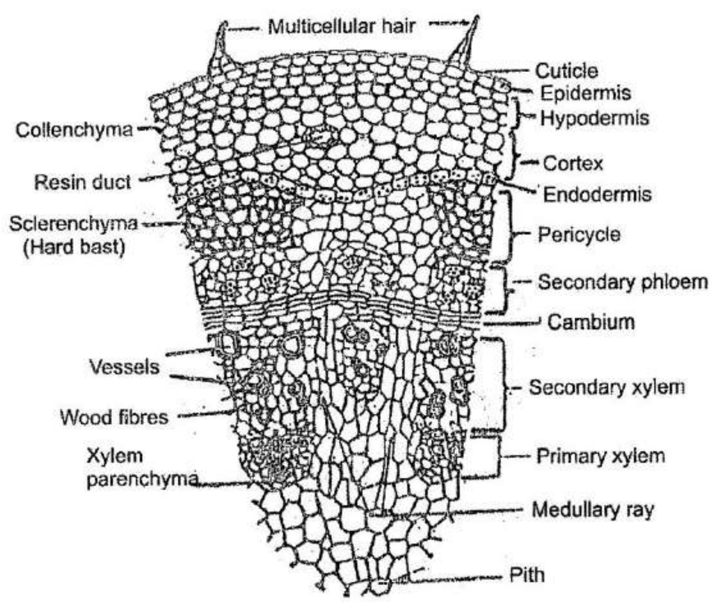


Fig. 2.17 : Normal secondary growth in Sunflower stem

This continuous activity of cambium ring and addition of secondary tissues pushes the primary xylem towards the pith and primary phloem towards the peripheral region and thus separating them from one another. In the old Sunflower stem the primary xylem is observed near the pith region but primary phloem gets crushed and therefore not observed in the section.

The cambium forms radial bands of parenchymatous cells in secondary xylem and secondaiy phloem regions. These are called secondary medullary rays. Due to formation of more secondary xylem the central pith is very much reduced.

The extrastelar secondary growth does not occur in Sunflower stem. As Sunflower is an annual herbaceous plant, only one xylem ring is formed in it. There is no initiation of cork cambium hence periderm formation does not occur. Thus the secondary growth in Sunflower stem is restricted to the stelar region only.

2.3 : Anomalous Secondary Growth in Bignonia Stem (Dicot) and Dracaena (Monocot) Stem

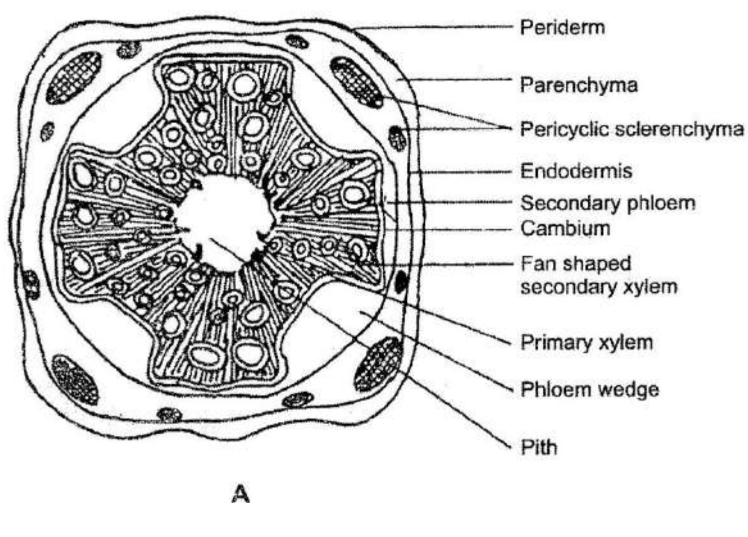
Introduction:-

In most of the dicot plants, after some amount of primary growth, the stem and root start secondary growth. During the secondary growth, vascular secondary phloem at four regions, is abnormal behaviour of the cambium ring. This abnormal activity is restricted to four diagonally or crosswise placed cambium strips. It results into the production of xylem cylinder with four ridges and furrows or fan shaped xylem cylinder in old stem.

Thus, the transverse section of Bignonia old stem shows.

i. The secondary xylem is grooved at four places due to intrusion of additional secondary phloem patches.
ii. The primary phloem gets crushed and primary xylem is pushed in the pith region.
iii. The secondary phloem form a ring and at four diagonal places, it intrudes into secondary xylem cylinder.
iv. The cambium ring separates xylem and phloem and is depressed in the region of secondary phloem patches.
v. Secondary xylem is fan shaped due to intrusion at four regions of secondary phloem.
vi. After addition of sufficient amount of secondary xylem and secondary phloem (in the stelar region), the development of periderm takes place in the epidermal region. Due to formation of many layers of periderm, the outline of the section becomes more or less circular, instead of original quadrangular.

The anomalous secondary growth in the stem of Bignonia is an adaptation required by the plant. Bignonia being the climber, the stem is relatively weak and it requires some support for climbing. When the stem moves towards the light with the help of some support it grows around the support.



A

When the stem grows around the support, its inner side gets compressed and outer side gets stretched while growing or coiling around the solid support. If only hard tissues like secondary xylem remains in the central part of the stem, during compression and stretching, the stem would break or crack. To avoid the breaking or cracking of the stem, it requires some soft tissues in the central region.

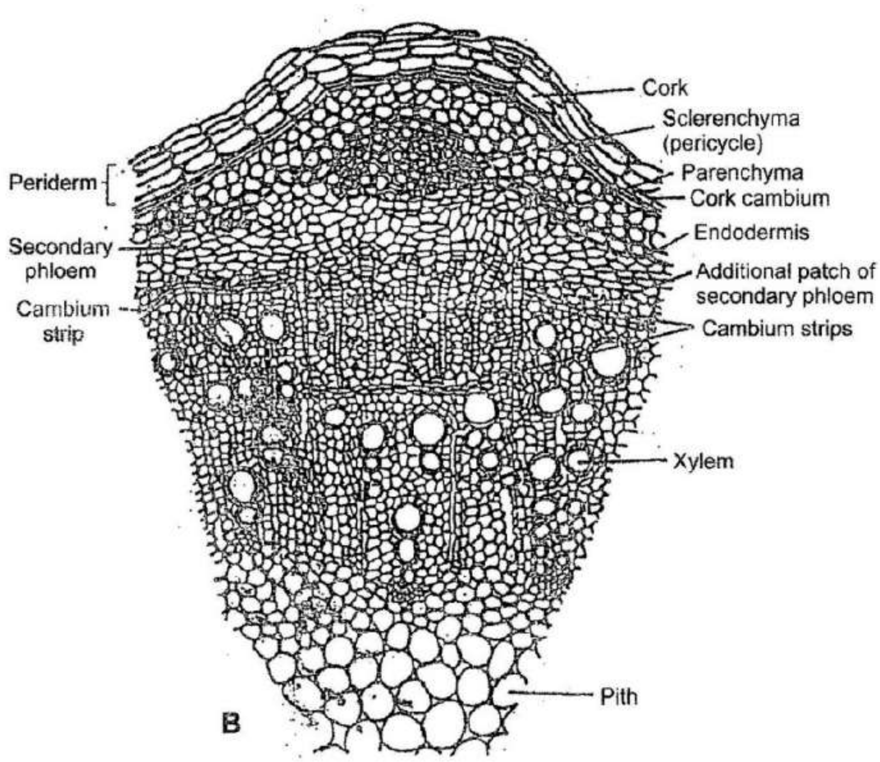


Fig. 2.18 : Anomalous secondary growth in *Bignonia* :
(A) Diagrammatic (B) Sector enlarged showing cellular details

These soft tissues are provided in the form of additional secondary phloem patches in the secondary xylem cylinder.So four secondary phloem patches intrude secondary xylem cylinder, due to abnormal behaviour of cambium and helps the plant in climbing.

Therefore, there is a direct relation between anomalous secondary growth and climbing habit of the plant. Hence, this anomalous secondary growth in Bignonia stem is described as adaptive anomalous secondary growth.

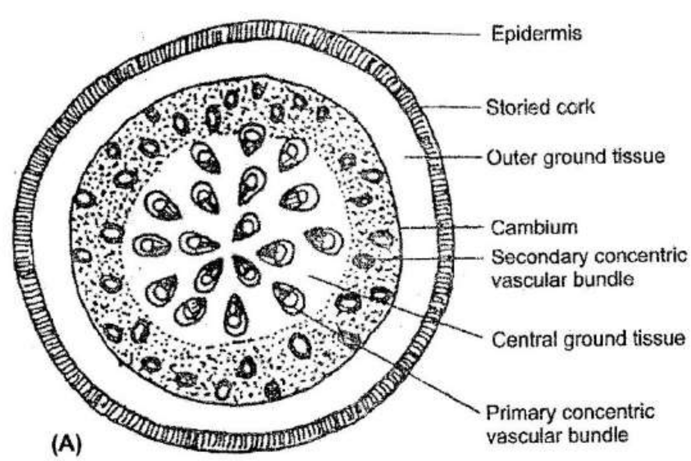
Anomalous Secondary Growth in Dracaena Stem (Monocotyledons):-

Dracaena is a monocot plant and it belongs to natural order Liliaceae. In monocot stem the vascular bundles are of closed type, so they are without vascular cambium. Because of such vascular bundles under normal conditions there is no secondary growth in monocot stem. The tall, large monocot plants like Palms, Bamboo, develop only through primary growth in them. But in some of the monocot plants of Liliaceae {e.g. Yucca, Aloe, Dracaena, Cordyline, Sanservieria etc.) after some amount of primary growth, secondary growth starts to increase the thickness of the stem. During such secondary growth, secondary vascular bundles are produced, without forming, thick continuous secondary xylem cylinder. Because of this reason, in such monocot plants even after secondary growth, there is no wood formation i.e. wood of commercial importance is not produced by these plants. Since the normal behaviour of monocot stem is to exhibit total absence of secondary growth, when any monocot stem shows secondary growth it is to be considered as abnormal or anomalous secondary growth. So secondary growth in Dracaena stem is to be described as anomalous secondary growth.

The stem of Dracaena, before secondary growth begins, shows concentric leptocentric vascular bundles, scattered in the parenchymatous ground tissue. Though vascular bundles are scattered they are restricted to the central part of the ground tissue, leaving outer ground tissue region without any concentric vascular bundle. Since concentric vascular bundles are closed and secondary growth requires cambium, before the actual secondary growth starts some changes occur in the parenchyma cells in the region of ground tissue, just outside the region occupied by the primary concentric vascular bundles. These parenchyma cells regain the power of cell division and become meristematic. All such meristematic cells in the region together form a complete cambium ring, in the outer ground tissue surrounding the vascular bundle region. After the formation of such cambium ring secondary growth begins and secondary tissues are produced.

The active cambium cells can be easily differentiated from the surrounding parenchyma cells by their rectangular shape. When secondary growth begins, the cambium cells produce secondary elements only on the inner side. The cells produced on the inner side by the cambium ring are of three types, namely secondary xylem, secondary phloem and parenchyma. Out of these, secondary xylem and secondary phloem are added in the form of secondary concentric vascular bundles. The parenchyma cells either remain thin walled or become thick walled and lignified. Since this parenchyma is produced radially along with secondary vascular bundles on the inner side by the cambium ring, during early stages of secondary growth, the secondary vascular bundles remain embedded in the thin or thick walled parenchyma cells. The parenchyma cells in which the secondary vascular bundles remain embedded, together constitute the conjunctive tissue. Because of radial arrangement, the conjunctive tissue can be easily differentiated from vascular elements and ground tissue. The secondary vascular bundles are also concentric leptocentric, like primary vascular bundles. These differ from primary vascular bundles in two characters viz. (i) They are relatively smaller in size and (ii) They are with relatively small amount of phloem and in them protoxylem elements are absent. The secondary xylem consists of only tracheids and xylem parenchyma, while phloem in secondary vascular bundle consists of short sieve tubes, companion cells and phloem parenchyma. After addition of some tissues on the inner side, the cambium ring produces few parenchyma cells on the outer side. These parenchyma cells remain thin walled and they are generally smaller than the ground tissue parenchyma cells.

In Dracaena stem, after addition of sufficient amount of secondary tissues in the central region, when epidermal layer ruptures because of outward pressure, a typical periderm develops. In this periderm development, there is no formation of phellogen (or cork cambium). This protective tissue develops by repeated periclinal divisions (parallel to long



(A)

axis) in the parenchyma cells which present in the layer just below the epidermis. By such divisions these parenchyma cells produce thin walled cells on outer sides, which remain arranged in tiers or stories.

These thin, walled cells later on undergo suberisation and form cork cells. Such cork, which develops without development of phellogen, is called storied cork. So Dracaena stem, after secondary growth show presence of storied cork instead of normal periderm.

The secondary growth in Dracaena is considered abnormal or anomalous for the following reasons :

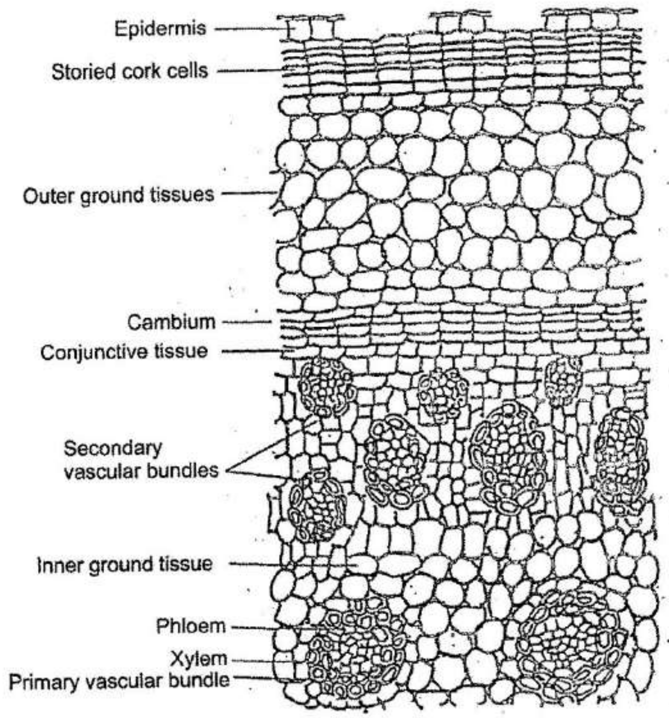


Fig. 2.19 : Anomalous secondary growth in *Dracaeana* stem (A) Diagrammatic (B) Sector enlarged showing cellular details

(1) In monocot stem, there is no secondary growth, but Dracaena though it is monocot shows secondary growth. (2) In normal secondary growth, as in dicot, cambium produces secondary xylem on the inner side and secondary phloem on the outer side. In Dracaena both secondary xylem and secondary phloem, are produced only on inner side. (3) The cambium, during normal secondary growth produces only two types of secondary tissues viz. secondary xylem and secondary phloem. In Dracaena, the cambium produces three types of secondary tissues viz. xylem, phloem and conjunctive tissue.

The anomalous secondary growth in Dracaena, which increases the thickness of the stem, is of non-adaptive type. It neither have any relation with the habit of the plant, nor it is for any special physiological function. Therefore the anomalous secondary growth in Dracaena is considered as non-adaptive anomalous secondary growth.

2.4 : Periderm and Lenticel

(A) Periderm {e.g, Tinospora **stem)**

Introduction

In plants when secondary growth is absent, the cuticle and epidermis can give sufficient protection to inner tissues while in old stems when the secondary growth takes place, secondary tissues are added in the central region. This addition of cells exerts pressure on the outward direction due to which epidermis is ruptured. The ruptured epidermis camiot give sufficient protection to inner tissues so new protective tissue called periderm, is developed in that region. Thus periderm is secondary in origin and it replaces the epidermis when destroyed.

Tinospora is an extensive climber with corky grooved stem. The vascular bundles in stem are conjoint collateral and open. The secondary growth takes place in vascular region and it is as discussed in part VII, A. in this chapter. In addition to secondary growth by cambium in vascular region, the cells of non-vascular region develops the periderm. The structure of periderm in Tinospora is described here.

Structure of Periderm

The periderm consists of three parts viz. (a) phellogen or cork, (b) phellem or cork and (c) phelloderm.

(a) Phellogen or cork cambium : It is lateral meristem produced in the cortex region. It is uniseriate layer arising from some of the living cells of cortex and behave meristematically. These cells are rectangular, radially flattened and compactly arranged due to absence of intercellular spaces (Fig. 2.20). They divide tangentially to produce new tissues to its outer and inner sides. Actually earlier formed phellogen (cork cambium) is not everlasting and therefore it is replaced by another layer of cork cambium. Hence the second phellogen may arise in the inner region of cortex and the third phellogen in pericycle and as well as in the phloem and secondary phloem. The cork cambium cuts off the new cells towards its outer side and these cells are known as phellem and the layer of cells towards inner side of phellem is called phelloderm.

(b) Phellem or cork : The periderm originates at the superficial region of the stem that may not be adequate to withstand the pressure from outside (i.e. environment). In such condition the additional layers of phellem are formed in the cortex or in deep in the stem and when the phellogen develops in the deeper region (like in pericycle and phloem). It produces more phellem or cork cells on outer side and outer living cells get crushed and become dead. Thus, all these dead cells togetherly known as cork (Fig. 2.21). This cork is always a part of the bark which later on peeled off and new bark is again formed.

(c) Phelloderm or secondary cortex: This is the third layer of periderm composed of loosely arranged living cells with non suberised walls. Chloroplast may also be present in these cells and perform the photosynthesis and storage of starch. The region is also known as secondary cortex.

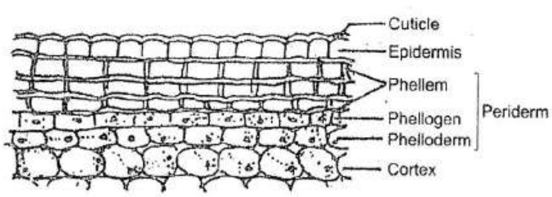


Fig. 2.20 : Structure of periderm in early stage

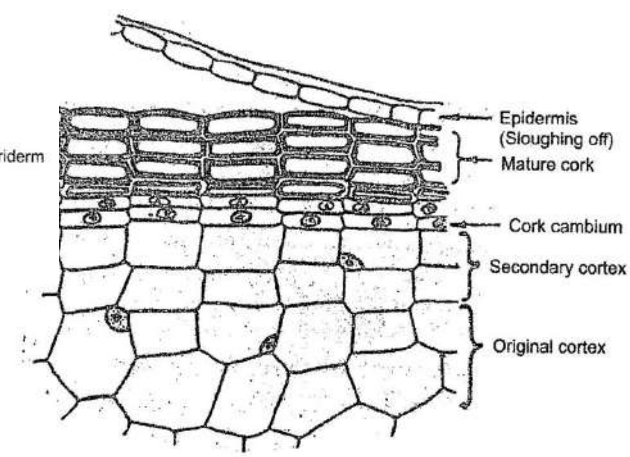


Fig. 2.21 : Structure of periderm in later stage

So, after the addition of secondary tissues in the central part of the stem when epidermis get ruptured, for the protection of inner living cells, a new protective tissue is formed. This tissue consists of outer phellem or cork, middle phellogen or cork cambium and inner phelloderm or secondary cortex. These three tissues together form the protective layer called periderm.

(B) Lenticel in Tinospora

In herbaceous dicotyledonous stems, the epidermis is with stomata for exchange of gases. But when secondary growth has taken place and the cork layers have been developed around the stem. The gaseous exchange through stomata becomes difficult as the epidermis gets ruptured and peeled off. For the activities of the living cells inside, the gaseous exchange is essential and for it the small areas of loosely arranged cells are produced in the periderm region on the stem. These openings in the periderm region are called lenticels.

The lenticels are usually slightly raised above the periderm. They are usually formed just below the stomata existed before the beginning of secondary growth. Lenticels are formed by the phellogen. At these places, the phellogen or cork cambium cells divide in different planes to form a mass of loosely arranged, rounded and unsuberised cells. These loose cells are called complementary cells. The complementary cells have abundant intercellular spaces. Due to mass of these cells and adjoining tissue of phellogen, which divides tangentially (tangential cells are observed below the complementary cells) and pressure is exerted on the epidermis in the outward direction. Because of this pressure, epidermis gets ruptured and the layer is pushed in the outward direction. It results in the formation of passage surrounded by areas of ruptured epidermis and the mass of complementary cells are exposed to the surrounding atmosphere. Altogether it produces spherical or oval openings on the surface of stem. These are lenticels. Such raised areas can be observed on the stem by hand lens. Through these regions the gaseous exchange takes place.

The complementary cells form a diaphragms of dense tissue layer called closing layers. These protect the inner living cells as well as help in the exchange of gases.

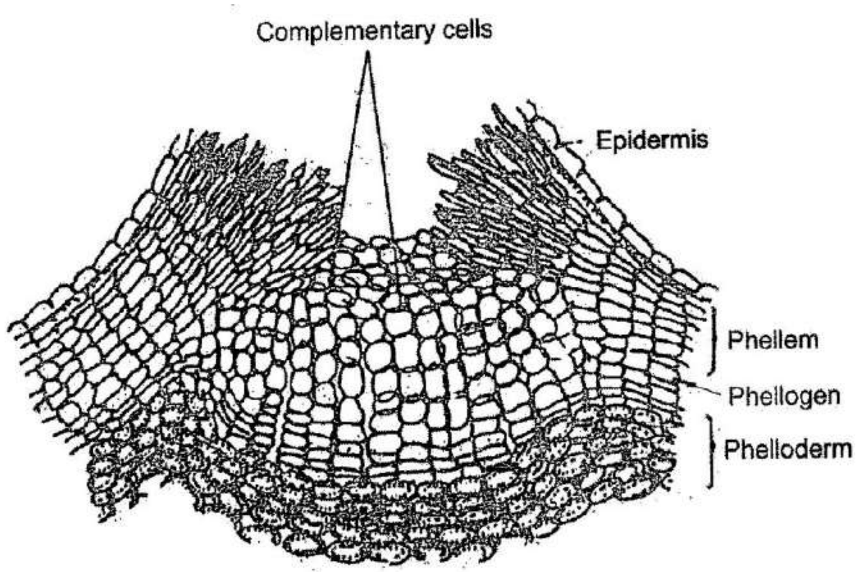


Fig. 2.22 : Structure of lenticel