SARDAR PATEL UNIVERSITY
B. Sc. (BOTANY) Sem. : VI Paper Code: US06CBOT22 (T)
ANATOMY OF ANGIOSPERMS
Total Credit: 4 (Four Lectures per week)
(Total Marks 100, Internal-30 marks, External 70-marks)
Syllabus with effect from: June 2020

2. The Tissue systems:

Classification of tissues; Simple and complex tissues (no phylogeny); cytodifferentiation of tracheary elements and sieve elements; Pits and plasmodesmata; Wall ingrowths and transfer cells, adcrustation and incrustation, Ergastic substances.

Hydathodes, cavities, lithocysts and laticifers.

Apical meristems: Evolution of concept of organization of shoot apex (Apical cell theory, Histogen theory, Tunica Corpus theory);

Types of vascular bundles; Structure of dicot and monocot stem. Origin, development, arrangement and diversity in size and shape of leaves; Structure of dicot and monocot leaf, Kranz anatomy.

Organization of root apex (Apical cell theory, Histogen theory, Korper-Kappe theory); Quiescent centre; Root cap; Structure of dicot and monocot root; Endodermis, exodermis and origin of lateral root.

The Tissue systems : All the tissue**s** of a plant which perform the same general function, regardless of position or continuity in the body, constitute **the tissue system**. **The tissues** of a plant are organized to form three types of **tissue systems**: the dermal **tissue system**, the ground **tissue system**, and the vascular **tissue system**.

Classification of tissues; Simple and complex tissues (no phylogeny);

There are three types of **tissue systems**: dermal, vascular, and ground. Dermal **tissue** is composed of epidermis and periderm. Vascular **tissue** is composed of xylem and phloem. These tube-like structures transport water and nutrients throughout the **plant**.

Types of Simple Permanent Tissue :

(1) Parenchyma (2) Collenchyma and (3) sclerenchyma.

1. Parenchyma : Parenchyma (Fig. 534) is the most common simple tissue of the plants with relatively little specialisation. It is composed of cells which are usually isodiametric in shape with intercellular spaces.The cells have active protoplast. This tissue is universally distributed in all the plants, the softer portions like epidermis, cortex, pith, pericycle whole or part, of stems and roots, mesophyll of leaves, pulp of the fleshy fruits, embryo and endosperm of the seeds being composed of parenchyma cells.

It is called the fundamental tissue of the plant, because it really constitutes the ground substance where other tissues remain embedded. Bodies of lower plants are made of parenchyma cells. The meristematic cells are also parenchymatous in nature.

Thus parenchyma is the precursor of all other tissues. So, it is considered to be the most primitive tissue, both phylogenetically and ontogenetically.

Parenchyma occurs as homogeneous mass in many portions, but it may also be associated with other elements in complex tissues like xylem and phloem. Normally parenchyma cells are polyhedral in shape with profuse intercellular spaces.

Unspecialised cells may approach 14-sided tetrakaidecahedron in shape.In the mesophyll of the leaves they are slightly elongated. Irregular shapes as a result of folding (Fig. 534D), lobation, etc., are also not uncommon.

Parenchyma cells have usually thin cell wall made of cellulose. Primary pit fields may be present. In storage region the walls of the cells may be considerably thick due to deposition of hemicellulose, as formed in the endosperm of Phoenix (date- palm). Often thick and lignified walls are present in the parenchyma cells of xylem, particularly secondary xylem.

From the point of view of function it is a very important tissue. Due to presence of active protoplast this tissue is the seat of all essential vegetative functions like photosynthesis, storage of food matters, secretion and excretion. Parenchyma cells occurring in xylem and phloem help in the conduction of water and food matters in solution. Parenchyma with thin cellulose wall can also serve as a supporting tissue due to turgid condition of the cells, what is particularly evident in herbaceous plants.

Epidermal cells with cutinized outer walls have protective function. Parenchyma cells retain the potentialities of cell division. Secondary meristems usually originate in this type of cells. Thus they are concerned in increase in thickness and also in healing of wounds and formation of adventitious roots and buds. In some xerophytic plants they are specially adapted for storage of water.

Water-storing parenchyma cells are large with prominent vacuoles, scanty chloroplasts and thin cell wall. Mucilaginous matters are present in the cell sap which increases water-holding capacity.

The parenchymatous cells of leaves and sometimes other organs like stem contain enough chlorophyll. These cells with that all-important function photosynthesis are also called chlorenchyma.

Fairly large air cavities may be present in the parenchyma cells of aquatic plants in particular, where the volume of cavities is often greater than that of the cells. As a result they often taken up star-like or stellate or armed appearance (Fig. 534 E, F & G).

The air spaces give buoyancy to the plants in addition to normal aeration. The term aerenchyma is usually attributed to this type of parenchyma. Parenchyma with small intercellular spaces is noticed in the endosperm cells.

Specialised parenchymatous cells which produce and store tannins, oil and crystals of calcium oxalate are referred to as idioblasts. They markedly differ from normal parenchyma cells.

The term prosenchyma for the cells much longer than breadth had been used by early authors.

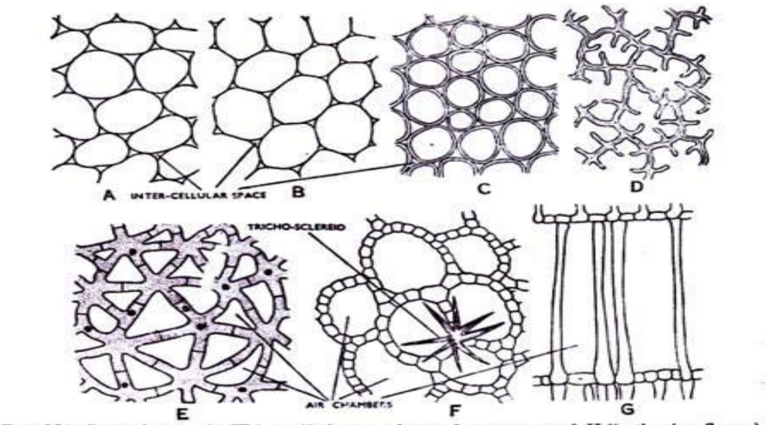

FIG. 534. Parenchyma. A. Thin-walled parenchyma from cortex of *Helianthus* (sunflower). B. Same from pith. C. Thick-walled parenchyma from pith of *Clematis* spp. D. From leaf of *Pinus*. E. Aerenchyma from petiole of *Musa* (banana). F. Same from petiole of *Nymphaea* with trichosclereid. G. Same from stem of *Jussiaea*.

2. Collenchyma : It (Fig. 535) is also a simple tissue consisting of one type of elements. The cells are somewhat elongate, occurring along the long axis of the body.
The shape of the cells is variable, the short ones being more or less like parenchyma and the longer ones resembling the fibrs, which may have, tapering ends often overlapped and interlocked like fibres.They are usually polygonal in cross-section.

The cells are living with vacuolate protoplast. Chloroplasts may also be present. Though normally collenchyma cells are narrower and longer than parenchyma, the two types of tissues very often intergrade; even transitional forms may occur.

Like parenchyma it can undergo reversible changes and retain the capacity of cell division. On account of these similarities collenchyma is considered a type of parenchyma specially adapted for supporting function.

The most distinctive character of the collenchyma cells is the cell wall which becomes unevenly thickened. There are different methods of deposition, but commonly, the thickenings are confined to the corners of the cells.

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Often the degrees of deposition may be so much pronounced that cells look circular in cross-section. On the basis of thickening of the cell wall and arrangement of cells three forms of collenchyma have been recognised.

They are: (i) Angular collenchyma (Fig. 535 A & B), the most common type, where deposition is-localised to the junctions between the cells. This typical collenchyma is a compact tissue consisting of irregularly arranged cells without intercellular spaces.

Due to continued thickening of the cell wall the lumen may look circular. A term annular collenchyma has been used by some Workers for this type which has lost the angular appearance.

(ii) Lacunate or tubular collenchyma is the second type in which intercellular spaces are present and thickenings are restricted to the walls of the regions bordering on spaces (Fig. 535C).

(iii) Plate or lamellar collenchyma consists of compactly arranged cells with vigorously thickened tangential walls (Fig. 535D). As a result the cells appear like plates or bands.

Though these are the three types of collenchyma recognised, it should be noted that sharp distinction between them hardly exists. In fact, all the three types may occur in the same strand or one type may merge with another.

The wall though considerably thickened is primary in nature. It is composed of cellulose and pectic materials with high percentage of water. In some plants cellulose-rich and pectin-rich layers alternate on the wall. In some cases the wall may undergo sclerification. Simple pits may be present both on the thin and thick portions of the wall.

Collenchyma occurs in the peripheral portions of rapidly elongating organs like young stems, petioles of leaves, floral stalks and the leaves. They are noticed most commonly as homogeneous bands beneath the epidermis, or they may occur as discontinuous patches.

In ribbed organs like the stem and petiole of Cucurbita and square stems of members of family Labiatae, collenchyma occurs as patches in the ribs and at the corners of square stems. In leaves they may be present on both sides of the veins or along the margin.

This tissue is normally absent in underground organs, though it may rarely occur in roots, particularly when they are exposed to light. It is usually absent in the monocotyledons, both stems and leaves.

Collenchyma is an effective mechanical tissue of the growing organs, where it can give considerable strength and elasticity. The closely packed cells with thick walls have the capacity of increasing in surface and in thickness when the organ is still growing. In growing organs it provides sufficient tensile strength till more effective mechanical tissues like sclerenchyma are differentiated.

Here it serves temporary supporting function and may be crushed afterwards. In herbaceous stems collenchyma usually continues to function permanently, because secondary increase in thickness is poor in these organs.

In leaves they give support occurring on both sides of the bundles or as isolated patches. Though chloroplasts may often be present, this tissue probably has no photo- synthetic function.

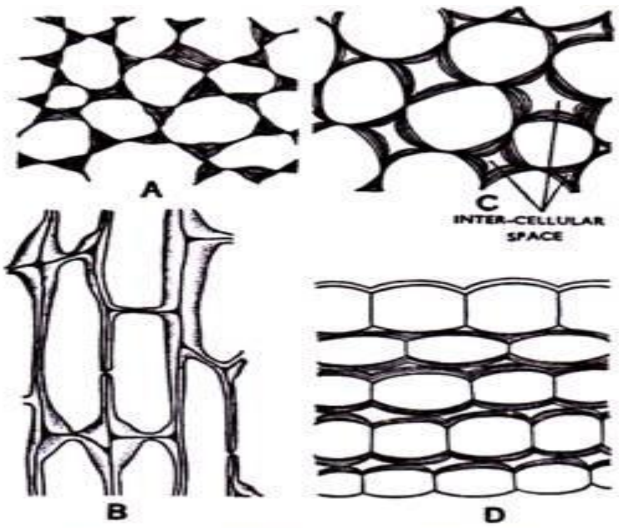

FIG. 535. Collenchyma. A. Angular (t.s.). B. Same in l.s. C. Lacunate (t.s.). D. Lamellar (t.s.).

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3. Sclerenchyma : Sclerenchyma is another simple tissue nicely adapted for mechanical function. The component cells are usually 'prosenchymatous', a term once used to designate the cells much longer than breadth.
The walls are considerably thickened, often heavily lignified with simple pits. The presence of hard elastic secondary wall with low water-content distinguishes sclerenchyma from collenchyma possessing plastic primary walls with high percentage of water.

The shape and size of the cells constituting this tissue are variable. They may be broadly placed into two groups: very much elongate cells, called sclerenchyma fibres, and short cells, isodiametric or irregular in shape, known as sclereids or sclerotic cells.

Fibres : Fibres (Fig. 536) are very much elongate sclerenchyma cells usually with pointed needle-like ends. The fibres of ramie, Boehmeria nivea of family Urticaceae may measure as much as 55 cm. in length. These are really the longest cells in the higher plants.

Though typical fibres have acute ends, blunt and even branched ends may also be noticed. At maturity these cells lose protoplast and become dead. It has been worked out that protoplast becomes multinucleate during differentiation and ultimately disappears.

Here is another anatomical feature by which sclerenchyma fibres may be distinguished from parenchyma and collenchyma. Of course some fibres may retain protoplast even up to the permanent stage. In cross-section sclerenchyma cells look angular.

The wall is usually hard, uniformly thickened and lignified. Small pits, round or slit-like in appearance, are frequently present. Often the secondary wall is so much thickened that the central lumen is almost obliterated (Fig. 536B).

Some fibres have non-lignified walls. In fact, highly thickened secondary walls of fibres of flax, Linum usitatissimum of family Linaceae are made of pure cellulose. Their walls exhibit lamellations. Some fibres may have gelatinous walls which may swell and fill up the entire lumen. They have been called gelatinous or mucilaginous fibres.

Fibres usually occur as groups or sheets along the longer axis of the body in different parts of the plants. They have peculiarly overlapped or interlocked ends (Fig. 536G). The value of sclerenchyma as the most effective mechanical tissue is due to the interlocking of the ends and considerably thickened walls. They may also occur singly as idioblasts as in the leaflets of Cycas.

The distribution of sclerenchyma in the plant members has direct relation to the strains and stresses to which they are subjected. They are abundantly present in cortex, pericycle, xylem and phloem. As regards classification of fibres a number of systems have been in use.

Often fibres are put in two groups, viz., intraxyllary fibres or wood fibres, and extraxyllary fibres, also called bast fibres. Fibres associated with xylem differ from other fibres particularly in the occurrence of bordered pits.

These fibres are put into two groups; libiriform fibres and fibre-tracheids (Fig. 536D). Libiriform fibres actually resemble other fibres, whereas fibre-tracheids are regarded as reduced tracheids due to presence of bordered pits.

These are really something intermediate between the tracheids and fibres. Some xylem and phloem fibres develop partition walls later, e.g., Vitis, which are called septate fibres (Fig. 536E).

They are living and have been found to contain starch, oils, resin and crystals and are thus thought to have storage function. Fibres occurring outside xylem-the so-called extraxyllary fibres-are often called bast fibres.

This term is misleading, because phloem is also commonly known as bast. It is possibly desirable to designate extraxyllary fibres on the basis of their topography as cortical fibres, pericyclic fibres and phloem fibres.

All these fibres are typically elongate bodies with simple pits. They commonly occur as continuous bands or isolated strands in the cortex, in the pericycle, as caps or sheaths on and around the vascular bundles and as patches in the leaves of monocotyledons in particular.

As already stated sclerenchyma is the most effective mechanical tissue of the plants. It can very successfully withstand strains and stresses like flexion, compression and longitudinal pull in cylindrical bodies and shearing stresses in leaves. The fact that some fibres, even fibre-tracheids retain protoplasts may suggest other physiological functions apart from support.

The fibres have great commercial value. Jute, hemp, flax, ramie, etc., are common sclerenchyma fibres.

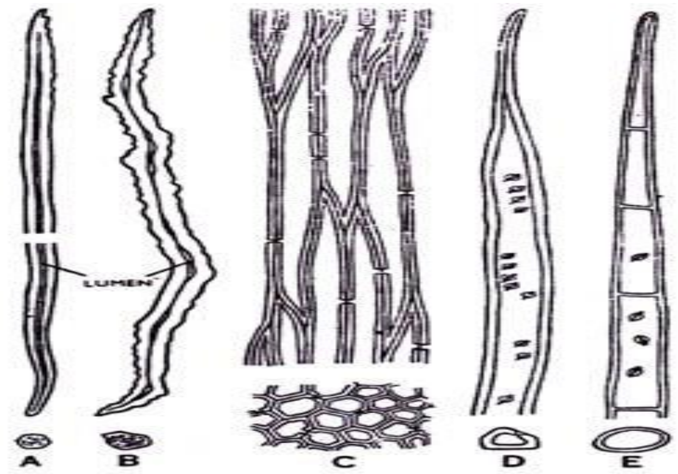


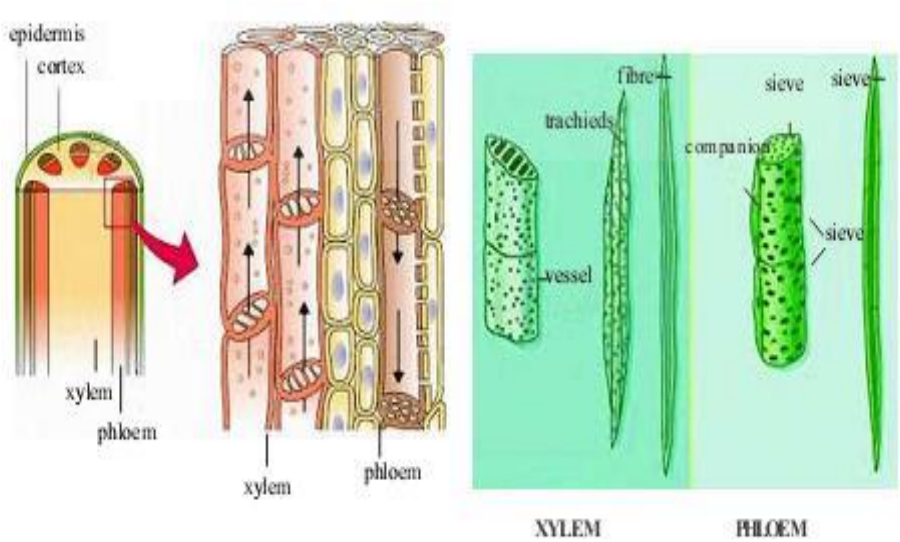
FIG. 536. Sclerenchyma fibres in longitudinal and transverse views. A & B. Fibres with highly thickened walls. C. A group of fibres showing interlocked ends and simple pitted thickerings. D. A fibre-tracheid. E. A septate fibre-tracheid.

Complex permanent tissues in plants (Structure, types and functions)

- A group of more than one type of cells having common origin and performing different but closely related functions as a unit is called complex permanent tissues.
- The cells may be living or dead.
- The important permanent tissues in vascular plants are: **Xylem** and **Phloem**
- Both of these tissues are commonly known as **vascular tissues** as they are conductive in function.

1. Xylem :

- It is the chief conducting tissue of vascular plants responsible for conduction of **water** and **inorganic solutes**.
- It consists of four components; **tracheids, vessels (tracheae), xylem fibers (wood fibers)** and **xylem parenchyma.**



Different cells of xylem and phloem

a. Tracheids:

- They are elongated tube-like dead cells (without protoplasm) having tapering ends.
- The walls are hard and lignified but not much thick and enclose a wide empty lumen.
- In the beginning, these cells possess living protoplasm but due to lignification and deposition of thickening materials in wall, they become dead at maturity.
- Tracheids possess various types of wall thickenings; **annular** (ring like), **spiral** (helical), **scalariform** (ladder like), **reticulate** (network) and **pitted**. The pits may be simple or bordered.
- The end walls are perforated by the presence of bordered pits which permit flow of water from one cell to another.

Functions :

- They conduct water and dissolved mineral elements from roots to the leaves.
- They also provide mechanical support due to the presence of hard and firm secondary walls.

b. Vessels or tracheae:

- They are long tubes consisting of a series of drum-shaped cells placed one above the other with their walls perforated or dissolved.
- Vessels are **syncytes** formed by the fusion of cells.
- Each cell appears circular, oval or sometimes polygonal with a very wide lumen which later becomes lignified and dead.
- Vessels like tracheids possess various types of thickenings like **scalariform, reticulate** and

Functions:

- They are the chief conducting tissues of vascular plants, particularly in angiosperms. They translocate water and minerals from roots to the leaves.
- They also provide mechanical support to the plants.

c. Xylem fibers or wood fibers:

- The xylem fibers develop from the same meristematic tissues as the other xylem cells.
- They have lignified secondary walls and narrow cell lumen.
- They are usually longer than the tracheids of the same plant and present both in primary as well as secondary xylem.

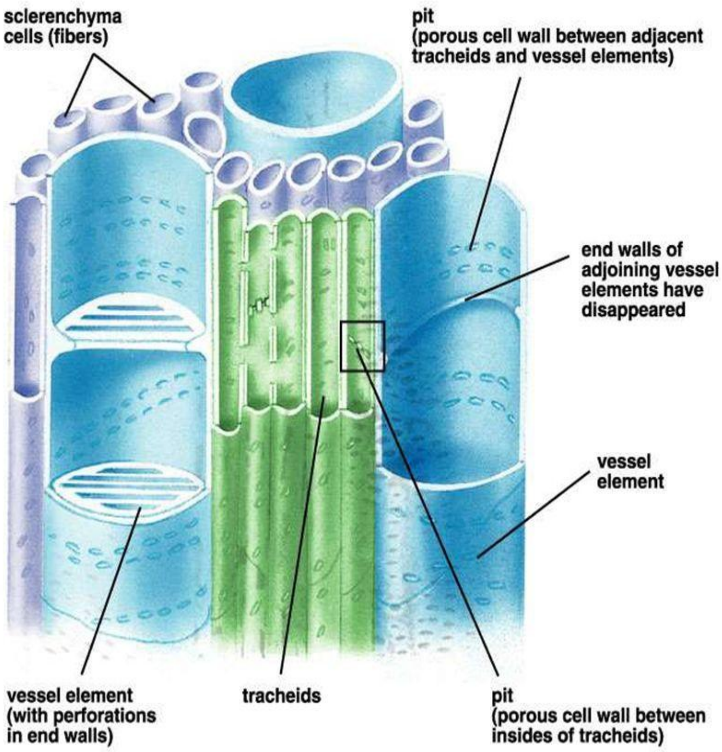
Functions : It conducts water and minerals from root to leaves and also provides mechanical support to the plant.

d. Xylem parenchyma:

- These are living parenchymatous cells present as component of the xylem, both in primary and secondary xylem.
- **Wood parenchyma** and **ray parenchyma** are two types of parenchyma present in secondary xylem.
- The wood parenchyma is formed from fusiform cambium initials whereas ray parenchyma is formed from ray initials of the cambium.
- Both of them have thin walls and living protoplasm.

Functions:

- Their main function is storage of food in the form of starch or fats.
- They also help in conduction of water and minerals.



Components of Xylem

2. Phloem:

- It is the chief food-conducting tissue of vascular plants responsible for translocation of organic solutes.
- The phloem is composed of four components; **sieve elements, companion cells, phloem parenchyma** and **phloem fibers.**
- A fifth kind of cell type, the **transfer cell** has recently been reported from the phloem.

a. Sieve elements:

- These are the main components of the phloem which are placed one above the other forming **sieve tubes**.
- They are long tubular structures which consist of living cells without nucleus, endoplasmic reticulum, mitochondria, plastids etc.
- Cytoplasm occurs in the form of thin lining enclosing a big central vacuole which is filled with albuminous substance.
- There is presence of sieve areas (group of pores present in walls) and sieve plates (the portion of cross wall with sieve areas) in sieve elements.
- The sieve plates may be simple or compound.

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- The sieve tubes are syncytes (formed by fusion of cells) and allow free diffusion of organic substances.

Functions : They help in translocation of organic solutes (prepared food) from leaves to different body parts.

b. Companion cells:

- These are living cells, each cell always associated with one sieve tube or sometimes more.
- The cell consists of thin cellulose cell wall and active protoplast with all important cellular components; nucleus, plastid, endoplasmic reticulum, ribosomes etc.
- The common wall between companion cell and sieve tube shows presence of fine pits which are traversed by **plasmodesmata**.
- They are present in angiosperms (both monocots and dicots) but are absent in pteridophytes and gymnosperms.

Functions : They assist the sieve tubes in the process of translocation of solutes.

c. Phloem parenchyma:

- They are living parenchymatous cells which are elongated with rounded ends and primary cellulose cell walls.
- They are present in most of the dicots and absent in monocots.
- Phloem ray cells are present in secondary phloem which become lignified as soon as the sieve tubes cease to function.

Functions:

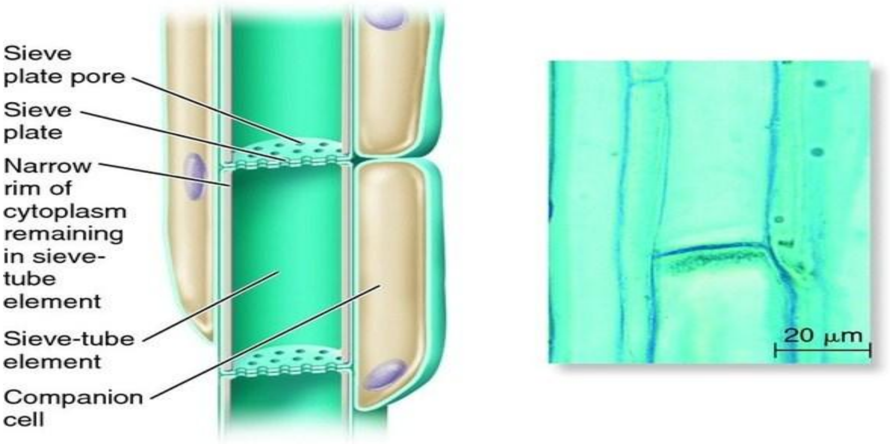
- The cells store food in the form of starch and fats. Sometimes they contain resins and tannins.
- They also help in the translocation of organic solutes.

d. Phloem fibers:

- They are non-living cells also called **bast fibers** and mostly occur in secondary phloem.
- These fibers have both cellulose and lignified thickenings.
- Secondary phloem consists of elongated lignified cells with simple pits.
- The ends of these cells may be pointed needle-like or blunt.

Functions: They provide mechanical support and give strength and

rigidity to the plant parts.



(a) Sieve-tube elements and companion cells

(b) Light micrograph of phloem stained with blue dye, showing sieve-tube elements

Components of phloem

Cytodifferentiation of tracheary elements and

Cytodifferentiation : Meaning, Primary Steps and Conclusion

In broader perspective, **quiescence** occurs due to lack of nutrition and growth factors whereas **senescence** takes place due to aging and serious DNA damages. Contrary to **quiescence**, **senescence** is a degenerative process ensuing a certain cell death.

Preliminary steps in Cytodifferentiation are reflected by a series of histological and biochemical changes in the cell. On the basis of numerous observations and publications, the proposed fate of the cultured cells during Cytodifferentiation can be divided into three steps. The callus tissue at the time of its initiation and further growth shows a mixed population of small, more rounded oval and few elongated cells with dense cytoplasm.

In ultra-structural studies of Cytodifferentiation, it is evident that a chain of intracellular degradative changes are associated with Cytodifferentiation. Auto-destruction of cellular organelles such as chloroplast, endoplasmic reticulum, dictyosomes, ribosomes and mitochondria leading to loss of entire protoplasmic mass are the main of the degradative changes.

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Cytodifferentiation

- Cytology deals with cell & differentiation is the further modification of the newly borne cells to undergo specialization to perform desired function with shape. So, during the growth and the maturation of the callus tissue or free cells in suspension culture, few dedifferentiated cells undergo cytoquiesence and cytosenesence and these twin phenomenon are mainly associated with the differentiation of vascular tissues in general and tracheary elements & sieve tubes in particular. This whole developmental process is called Cytodifferenciation.

What are??????

- **TRACHEARY ELEMENTS**
- Tracheary elements(TEs) –cells in the xylem being highly specialized for transporting water and solutes of the plant. TEs undergoes a very well-defined process of differentiation that involves specification, enlargement, patterned cell wall deposition, programmed cell death(apoptosis) and the cell wall removal.Tracheids found in xylem of all vascular plants but vessel elements only in angiosperms
- **SIEVE ELEMENTS**:
- Especially in phloem, a highly organized tissue that transports organic compounds during photosynthesis. It looses most of the cellular components such as nucleus, cytoskeleton, ribosome, tonoplast and contain structural phloem specific proteins-P proteins along with mitochondria, ER, sieve elements plastids

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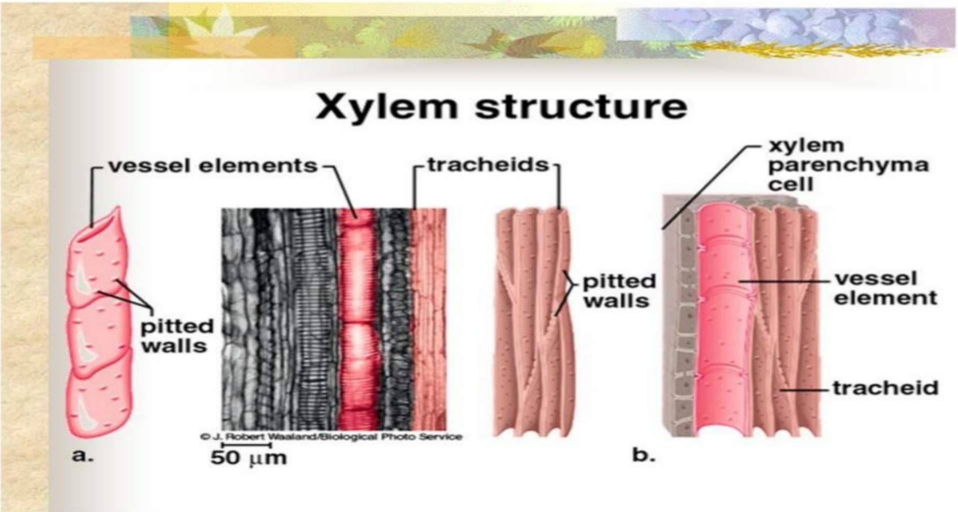
- Tracheary elements are water conducting tissues called as xylem and sieve elements are food conducting tissues called phloem. Tracheary elements , both tracheids and vessels, are highly specialized cells. These cells are devoid of protoplast when mature. These non-living cells are elongated with lignified walls. The main difference between tracheids and vessel is that vessels have perforation at the end plates which make them a tube like long structure while tracheids do not have end plates. So, the perforation of the end walls make the difference between the two along with their position & function.

Images



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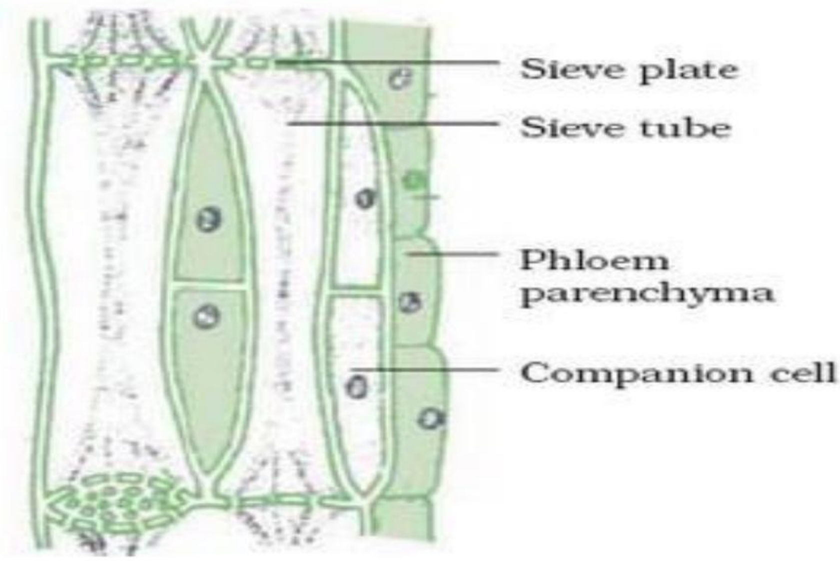
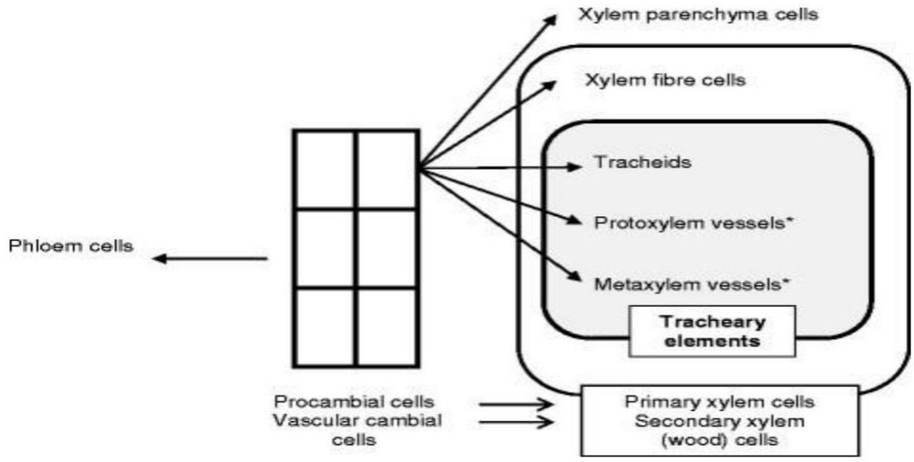


Need of cytodifferentiation



Steps for Cytodifferentiation

- Cells after division do not experience the same fate like new born babies do not undergo same destination. It depends on the intrinsic as well as extrinsic signals mediated from elsewhere. Amongst a group of cells within free suspension culture, a few cells become morpho-genetically competent for cytodifferentiation which can not be identified at the early stage in advance. It occurs either spontaneously or under the stimulus of specific nutritional or hormonal exposure. So, it is not conditioned by a single regular event.
- Primary steps are reflected by a series of histological & biochemical changes in the cell-the test tube individual. It can be differentiated into three steps-

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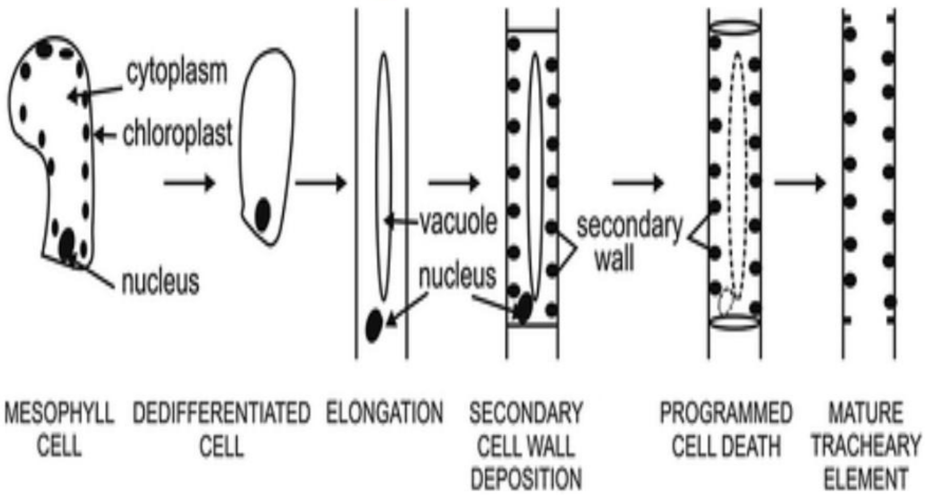
- Due to repeated mitotic growth, a few cells become more elongate with thick wall and the calli are friable. By further increase the subculture member, callus tissue shows maximum xylogenesis with tracheary elements having a continuous spiral deposition of secondary wall materials. Actually, the initiation of xylogenesis takes place from mitotically blocked and elongated cells. A chain of intracellular degradative changes are associated with cytodifferentiation.Autodestruction of cellular organelles such as Chloroplast, ER, dictyosomes, ribosome and mitochondria leading to loss of entire protoplasmic mass are the main degradative changes.

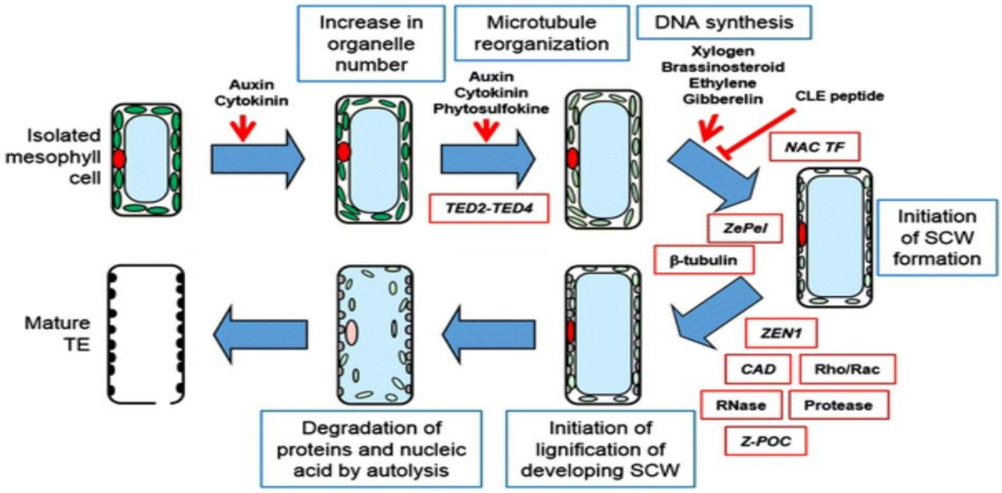
HOW?

- The separation of the cell membrane bounding organelles, the 1st step of cytoquiesence leads to cytosenesence .The auto- phagic activity within the cell in turn is closely linked with certain hydrolytic enzymes. The common one is acid phosphatage commonly present in the cell and has been detected in association with cell wall, dictyosome , plastids and the lysosomal systems associated with cell degradation. The synthesis of the acid phosphatage is indicative of autolysis of the protoplastid during cytoquiesence and cytosenesence. So, the transformation of the living cell into dead, empty tracheid during cellular differentiation and the biosynthesis of the acid phosphatase enzymes are functionally related to the autolysis of the cell contents and lignin biosynthesis for the spiral deposition of secondary wall materials for the developing trachery elements.

Steps involved



Diagrammatic View



Factors of Differentiation

- FACTORS;
- Trachery elements differentiation and secondary cell wall formation have been studied in cell cultures of coniferous gymnosperms. Several factors that influence the trachery element differentiation arte-
- The sucrose concentration of the media-the conc. of sucrose,
- Temperature-the fluctuation of temperature,
- Light-quality & quantity of life,
- The type and the concentration of the phytohormones,
- Other intrinsic factors to expedite process.

CONCLUSION

- Thus, Cytodifferentiation mainly emphasises on vascular differentiation , tracheary element differentiation etc.The plants cells in general and zygote in particular is totipotent in nature having the capability of giving rise to all type of cells and tissues in due course in order to have the stability of the plants. But to perform the specific function, a degree of specialization is required getting the molecular signal from the cells corresponding to the different extrinsic & intrinsic factors. Not only the tracheary elements & sieve elements, this concept is highly applicable in the domain of the developmental biology.

sieve elements; In plant anatomy, there are two main types of **sieve elements** which are **sieve** cells and **sieve** tube members. **Sieve** cells are specialized cells in the phloem tissue of **flowering plants**. Companion cells and **Sieve** cells originate from meristem, which are tissues that actively divide throughout a plant's lifetime.

1. Sieve cell.
2. Sieve tube element(Sieve tube member).
3. Sieve tube.
4. Sieve areas.
5. Sieve plate.
6. Lateral sieve areas.

Pits and plasmodesmata ; Pit Pairs: Structure and Types

A pit pair is structural and directional unit constituted by two pits lying opposite to each other of contiguous cells.

Structure : The space found inside the pit is called the pit cavity or pit chamber. The separating membrane which separates the two chambers or cavities of a pit pair, is called the pit membrane, or pit aperture. The pit cavity opens internally in the lumen of the cell and is closed by the closing or pit membrane along the line of junction of two contiguous cells. A pit has two pit cavities, two pit apertures, and one pit or closing membrane.

The pit membrane is common to both pits of a pit pair and consists of two primary walls and a middle lamella or intercellular substance. Usually two types of pits are met within the cells of various plants, viz., simple pits and bordered pits. Two bordered pits make up a bordered pit pair, two simple pits form a simple pit pair.

A bordered pit and a simple pit lying opposite to each other in contiguous cells, constitute a half bordered pit pair. A pit occurs opposite an intercellular space has no complementary pit and is known as blind pit.

Fundamentally the bordered pit differentiates from a simple pit in having a secondary wall arching over the pit cavity, which constitutes the actual border and becomes narrow like a funnel towards the lumen of the cell. In the simple pit, no such arching of the secondary wall and narrowing of the pit towards the lumen of the cell occurs.

Simple pits: Simple pit pairs occur in parenchyma cells, in medullary rays, in phloem fibres, companion cells, and in tracheids of several flowering plants. In the simple pits, the pit cavity remains of the same diameter and the pit or closing membrane also remains simple and uniform in its structure.
The simple pit may be circular, oval, polygonal, elongated or somewhat irregular in its facial view. The simple pits occurring in the thin walls are shallow, whereas in thick wall the pit cavity may have the form of a canal passing from the lumen of the cell towards the closing or common pit membrane. The diffusion of protoplasm takes place through these pits.

Bordered pits: They are abundantly found in the vessels of many angiosperms and in the tracheids of many conifers. They are more complex and variable in their structure than simple pits. The overarching secondary wall which encloses a part of the pit cavity is called, the pit border, which opens outside by a small rounded mouth known as pit aperture.
The overarching rim forms a border around the aperture and thus named 'bordered pits'. The pit aperture may be of various shapes in the facial view. It may be circular, lenticular, linear or oval. In the case of relatively thick secondary walls, the border divides the cavity into two parts.

The space between the closing membrane and the pit aperture may be called the pit chamber and the canal leading from pit chamber to the lumen of the cell may be termed as pit canal. The pit canal opens in the pit chamber by an outer aperture and at the same time it opens in the lumen of the cell by an inner aperture.

The closing membrane of a bordered pit pair which consists of the parts of two primary walls and the intercellular substance or middle lamella, is somewhat thickened in its central part. This thickening is called torus which remains surrounded by a delicate margin. In many bordered pits, the closing membrane may change its position within pit cavities.

The torus may remain in central position or it may shift to the lateral position. As the torus is shifted to the lateral position the pit aperture closes, and the passage of the protoplasm may take place only by diffusion through torus.

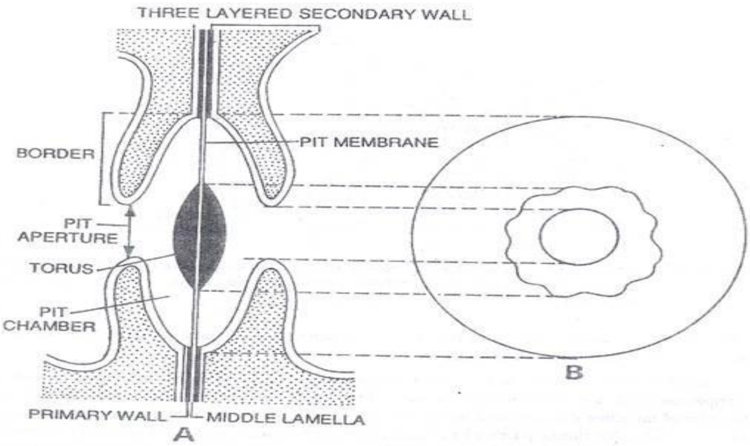


Fig. 34.13. Pits. Diagrams of bordered pit pairs. A, sectional view; B, front view. Pit membrane is made up of two primary walls and the intercellular lamella. The torus is formed by thickenings of primary wall. The front view shows that outline of torus is uneven.

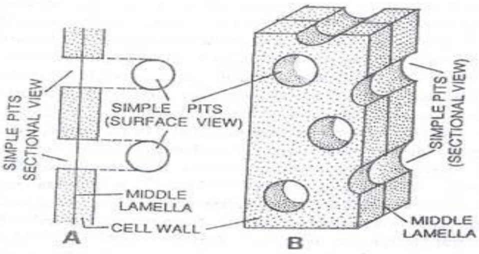


Fig. 34.14. Bordered pits. A, cell-wall with two bordered pits—sectional and surface views; B, a portion of the cell-wall with two bordered pits—sectional view (bottom) and surface view (top).

Patterns of bordered pits:

The bordered pits in vessel walls of angiosperms show three main types of arrangement: (i) scalariform, (i) opposite and (iii) alternate. If the pits are elongated or linear and make ladder-like arrangement, it is called scalariform pitting (Fig. 34.16 A). When the pits are arranged in horizontal pairs, it is called opposite pitting (Fig. 34.16 B).

If such pits are crowded, their borders assume rectangular outlines in face view. When the pits occur in diagonal rows, the arrangement is called alternate pitting (Fig. 34.16C). Generally small simple pits are arranged in clusters, and such arrangement is called sieve pitting.

Pit pairs are a characteristic feature of the xylem, as sap flows through the pits of xylem cells.

- Types of pits

Though pits are usually simple and complementary, a few more pit variations can be formed:

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- Simple pits: A pit pair in which the diameter of the pit chamber and the diameter of the pit aperture are equal.
- Bordered pits: A pit pair in which the pit chamber is over-arched by the cell wall, creating a larger pit chamber and smaller pit aperture.
- Half bordered pits: A pit pair in which a bordered pit has a complementary simple pit. Such a pit pair is called half bordered pit pair.
- Blind pits: A pit pair in which a simple pit has no complementary pit.
- Compound pits: A pit pair in which one cell wall has a large pit and the adjacent cell wall has numerous, small pits.

Plasmodesma (plural: plasmodesmata) is thin irregular cylinder of cytoplasm lined by plasmalemma, passing through fine pores in the cell walls, thus forming a connection between the cytoplasm of adjacent cells.

They are found in higher plants and fluctuate widely in abundance and distribution. They are commonly present in primary pit fields and pit membranes of young and mature living cells respectively. They may be scattered over the entire wall or occur in groups when they are concentrated on primary fields (e.g. cambium of Pinus strobus, ray cells of Sequoia sempervirens etc.).

In a meristematic cell, the number of plasmodesma ranges from 1000 to 10,000 and their distribution may not be uniform. The frequency of distribution may vary even in different walls of a single cell. Plasmodesmata, at the intercellular canal between the common walls of living cells, are encircled by plasmalemma, which is continuous with that of the adjacent cells.

At the centre of plasmodesma, there occurs a tube of membrane, termed desmotubule. The desmotubule is composed of protein sub-units and contains an axial central rod. Diameter of the lumen of plasmodesma is very narrow, 30 nm to 60 nm in diameter through which the cell organelles cannot move to the adjacent cells. The diameter of desmotubule ranges from 16 nm to 20 nm.

A space is present in between the plasmalemma and desmotubule termed cytoplasmic annulus. Sometimes plasmodesmata are branched; it is observed in the pit membranes of living fibres of Tamarix and between sieve tube and companion cell where it is branched towards the latter side. The above structure of plasmodesmata is revealed by electron microscopic study.

Plasmodesma originates during cytokinesis when cell plate is formed. It is formed at those regions of the cell plate where the endoplasmic reticulum (ER) is present and prevents the fusion of vesicles.

At this region, the cellulose microfibrils and pectic substances are not accumulated. As a result intercellular canal is formed. It is observed that the desmotubules are continuous with the ER of adjoining cells through the intercellular canals.

Therefore, it is regarded that the desmotubules are derived from ER. There are reports of the formation of plasmodesmata between mature cells, between the host cell and haustorium of parasite, between tyloses, in grafts between the cells of stalk and scion etc.

In these cases there are wall degrading enzymes and signaling devices, which perforate the common wall to form intercellular canal and align the plasmodesma situated at the adjoining cells.

Plasmodesmata exist in thick cell wall also, e.g. endosperm of the seeds of Phoenix dactylifera, Coffea arabica etc. They can be easily observed in the endosperm of seeds of Aesculns, Diospyros etc. It is best studied in plasmolysed cells where the protoplast shrinks from all the regions of cell wall, except the places where plasmodesmata occur.

Function:
(1) It helps in the short distance transport of materials;
(2) The relay of stimulus occurs through it;
(3) Viruses can pass through plasmodesmata;
(4) Plant hormones move through plasmodesma;
(5) The movement through plasmodesma is bi-directional. It is suggested that the desmotubules act as a valve and regulate the direction of flow.
(6) Small molecules and ions pass readily through plasmodesma.

Wall ingrowths and : The formation of **wall ingrowths** increases plasma membrane surface areas of **transfer cells** involved in membrane transport of nutrients in plants. Construction of these **ingrowths** provides intriguing and diverse examples of localized **wall** deposition. Papillate **wall** ingrowths are initiated as patches of disorganized cellulosic material and are compositionally similar to primary **walls**, except for a surrounding layer of callose(polysaccharide) and enhanced levels of arabinogalactan proteins at the **ingrowth** / membrane interface.

transfer cells, : Transfer cells are specialized parenchyma **cells** that have an increased surface area, due to infolding of the plasma membrane. They facilitate the **transport** of sugars from a sugar source, mainly mature leaves, to a sugar sink, often developing leaves or fruits.(Sugars move from “source” to “sink” sugars produced in sources, such as leaves, need to be delivered to growing parts of the **plant** via the phloem in a process called translocation, or movement of **sugar**. The points of **sugar** delivery, such as roots, young shoots, and developing seeds, are called **sinks**)

Adcrustation and incrustation, The thickenings present on the outer surface of the secondary walls is **adcrustation.** It participates in the special functions of

differentiated cell. The outer cell walls of the epidermis of leaves and other aerial organs the walls of cork cells replacing the epidermis of roots and stems during secondary growth, and certain walls of inner sheaths in roots and shoots are covered or impregnated by cutins and suberins in a process called adcrustation. Cutins and suberins are the complex mixture of polymeric, cross-esterified fatty acids with hydroxyl fatty acids. Cutin is a lipophilic polymer, while suberin is semi-hydrophilic. **(**is the process of the addition of any substance on a surface or substance from inside the whole substance. It means that nothing is added on the surface to make the substances thick or big, rather the growth comes from the whole body.The growth of fruits and subsequent parts is an example of adcrustation).
The **incrustation**, on the other hand, is the process by which the substances grow with the addition of new layers on the surface of the body. The cell walls of the **plants** grow by the process of **incrustation**.

Ergastic substances. **Ergastic substances** are non-protoplasmic materials found in cells. The living protoplasm of a cell is sometimes called the bioplasm and distinct from the **ergastic substances** of the cell.

The latter are usually organic or inorganic substances that are products of metabolism, and include crystals, oil drops, gums, tannins, resins and other compounds that can aid the organism in defense, maintenance of cellular structure, or just substance storage. Ergastic substances may appear in the protoplasm, in vacuoles, or in the cell wall.

Reserve Materials are those non-living inclusions which are directly concerned with the nutrition of plants, i.e.they serve as plant food matters.

They are again of three types, viz.:
(A) Carbohydrates,

(B) Nitrogenous matters, and

(C) Fats and Oils.

(A) Carbohydrates : Reserve carbohydrate of plants are the derivatives of the end products of photosynthesis. Cellulose and starch are the main ergastic substances of plant cells. Cellulose is the chief component of the cell wall, and starch occurs as a reserve material in the protoplasm.

These are composed of carbon, hydrogen and oxygen, where the latter two occur in the same proportion as in water. On heating carbohydrates get charred, leaving the black mass, carbon.

1. Sugars : Sugars are the simplest soluble carbohydrates of plants. Glucose or grape sugar ($C_6 H_{12}O_6$) is manufactured by chloroplasts in the presence of sunlight. Fructose or fruit sugar with the same formula occurs in many fruits. Sucrose or cane sugar ($C_{12}H_{22}O_{11}$) is abundantly present in sugar-canes and beets. This is our table sugar.

2. Inulin : Inulin, $(C_6H_{10}O_5)_n$, is a soluble carbohydrate present in root tubers of Dahlia and of some plants of that family. When the root tubers are steeped in alcohol or glycerine for a few days, the soluble inulin precipitates out in the form of beautiful fan- shaped crystals (Fig. 124).

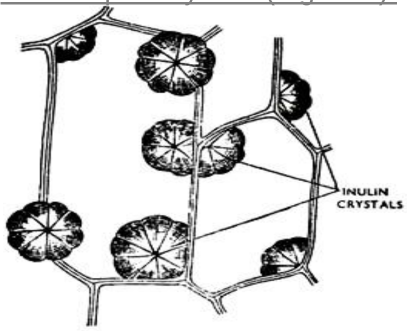


Fig. 124. Inulin crystals in the cells of root tuber of *Dahlia*.

3.Starch grains, arise almost exclusively in plastids,especially leucoplasts and amyloplasts. Starch grains are the complex plant food and are universally found in all plant groups with the exception of fungi and bacteria. Starch grains formed by the chloroplasts are called assimilatory starch, which are converted into sugar soon. Reserve starch grains are produced by the amyloplasts out of simple sugar.

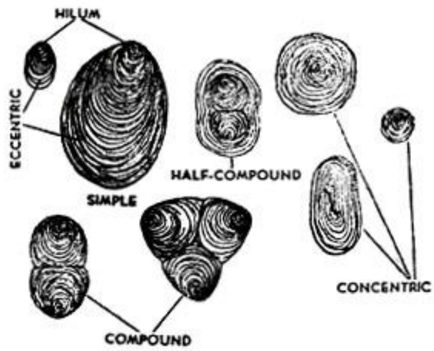


Fig. 125. Different types of starch grains.

When we speak about starch, we usually mean the reserve starch grains. They are abundantly present in the cotyledons, endosperm, roots, underground stems, etc. Starch grains are of varying shapes. Every grain has a shiny point, called the hilum, which is the centre of formation.

Around the helium starchy matters are deposited layer after layer, giving the grain a stratified appearance. The layers are known as lines of stratifications. In the starch grains of potato tuber the hilum is located at one end of the grain due to unequal deposition.

They are called eccentric grains; whereas those in the cotyledons of pea are known as concentric, as they have lines of stratifications around the hilum. Starch grains are simple, when they have one hilum with lines of stratifications.

More than one simple grain may be adpressed together to form a compound grain. An intermediate form is noticed where the grain has two hila, their own stratified lines, but they are ultimately surrounded by common lines of stratifications. Such grains are called semi-compound or half-compound.

As the plants cannot take solid food, starch grains are converted into sugar before assimilation. Starch grains have a very characteristic test, viz. they turn blue when treated with iodine solution. The formula of starch grain is $(C_6H_{10}O_5)_n$, where value of 'n' is not known.

4. Glycogen: Glycogen, $(C_6H_{10}O_5)_n$, is another insoluble carbohydrate like starch present usually in fungi. As glycogen occurs abundantly in animal bodies, it is also called animal starch.

(B) Nitrogenous Reserve Materials:

Proteins: Although proteins are the main component of living protoplasm, proteins can occur as inactive, ergastic bodies—in an amorphous or crystalline (or crystalloid) form. A well-known amorphous ergastic protein is gluten.

These are very complex chemically. They have nitrogen, usually sulphur and often phosphorus in addition to carbon, hydrogen and oxygen. They are mainly of two types, viz. complex insoluble proteids and their simple soluble forms, amino acids.

Proteids may be present in many parts of the plants. They are usually insoluble in water but dissolve readily in strong acids and alkalies. A common form of aleurone grains proteid, called aleurone grain, is found in the endosperm of castor- oil seed. Each aleurone grain is more or less round in shape which encloses a large crystalline body called crystalloid and a small rounded one celled globoid (Fig. 126).

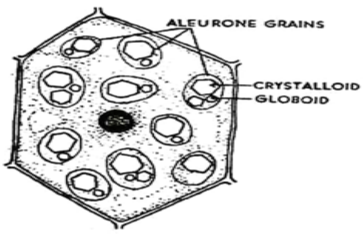


Fig. 126. Aleurone grains in a cell from endosperm of castor-oil seed.

Of the two, the crystalloid only is the nitrogenous matter, the globoid chemically being a double phosphate of calcium and magnesium. The occurrence of crystalloid and globoid is not always constant in aleurone grains.

Proteid grains are converted into simple soluble amino-acids for assimilation, and as such they travel to the different parts of the plants. That proteid grains are very complex chemically, is evident from the formula of a common proteid, known as gliadin, present in wheat. It is $C_{685}H_{1068}N_{198}O_{211}S_6$.

(C) **Fats and oils** : Fats (lipids) and oils are widely distributed in plant tissues. Substances related to fats—waxes, suberin, and cutin—occur as protective layers in or on the cell wall.

These are also important energy-giving reserve materials of plants. Like carbohydrates they are composed of carbon, hydrogen and oxygen, but the latter two do not occur in the same proportion as in water, there being more carbon and hydrogen and less oxygen. Fats, which are liquids at ordinary temperature, are called oils.

They are abundantly present in many seeds. The formula of a common vegetable fat, palmitin, is $C_{51}H_{98}O_6$. Fats are always lighter than water and leave greasy spots on paper. They are insoluble in water but dissolve in ether and chloroform.
The fat of castor-oil seed is sparingly soluble in alcohol. When treated with caustic soda or caustic potash fats saponify, i.e. they form glycerine and soap, the latter is nothing but a sodium or potassium salt of a fatty acid. Fats are formed from fatty acids and glycerine. In plants they usually occur as oils, and are extracted by pressure.

2. Secretory Materials: These are not food matters but are indirectly useful to the plants. Colouring matters or pigments like chlorophyll, xanthophyll, carotin, etc., are certainly not plant food matters, but chlorophyll, as we know, is indispensable for manufacture of food. Similarly other pigments also have positive utility.

A. Colouring Matters : The green pigment chlorophyll is certainly indispensable for manufacture of food but it itself is not a food. Other pigments are also indirectly useful for the plants.

B. Enzymes: These are the digestive agents secreted by protoplasm. They have the wonderful power of converting complex insoluble food matters into their simple soluble forms, but they themselves remain unaffected during the process. Thus enzymes are the organic catalysts. They convert starch into sugar, proteids into amino-compounds, and fats into fatty acids and glycerin.

Enzymes are specific in action, thus the enzymes responsible for the breaking down of starch into sugar have no action on proteids or fats. Enzyme re-actions are some-times reversible i.e. the enzymes having help in .converting starch into sugar are also instrumental in the formation of starch out of sugar.

3. Excretory Materials or Waste Products:
These are absolutely useless for the plants. Plants have no distinct excretory systems as animals have, but they too have devices for getting rid of waste products. There are a fairly good number of excretory products of which just a few will be discussed here.

A. Alkaloids: These are complex nitrogenous matters which occur in plants. They are bitter in taste and some of them are extremely poisonous. Alkaloids are the active principles of many herbal medicines. They are usually extracted by dissolving them in alcohol. Quinine present in the bark of Cinchona, morphine in poppy, caffeine in coffee, nicotine in tobacco are some common alkaloids.

B. Tannins: These are bitter substances present in the cell sap of many plants and also in the cell wall of dead tissues like the bark of the trees. The fruits of myrobalans (B. Hartaki, Amlaki, Bahera) contain enough of tannins. In banana, guava, mango, etc., tannins disappear with the ripening of the fruit. Tannins turn black with iron salts, and are so used for manufacture of ink. They are also used for tanning leather.

C. Latex: It is the milky fluid (often watery, as in banana) found in many plants. Latex is an emulsion of various substances in a watery matrix. It is the chief commercial source of rubber. Latex of papaw contains the enzymes—papain, which is helpful in the digestion of protein food.

D. Essential Oils: These are the volatile oils which occur in many plants. The fragrant odour of flowers like rose, jasmine, lotus, is due to presence of essential oils in special glands. These oils, unlike fixed oils, are extracted by distillation.

E. **Mineral**

Crystals: Animals eliminate excess inorganic materials; plants mostly deposit such material in their tissues. Such mineral matter is mostly salts of calcium and anhydrides of silica.

Crystals of various forms are present in the cells. They may occur singly or a large number of them may remain conglomerated together attaining peculiar shapes. Calcium oxalate crystals are abundant in the plants, particularly in the underground organs.

Solitary crystals of calcium oxalate may be rod-like, cubical, prismatic, octahedral, etc. They are common in the dry scales of onion (Fig. 127). Raphides are the crystal-bundles which look like a bunch of needles inside a sac. Sphaeraphides are beautiful crystal- aggregates which have star-like appearance. Raphides and sphaeraphides are present in Pistia (Fig. 128), arum etc.

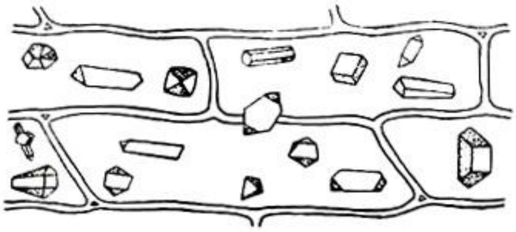


Fig. 127. Solitary crystals of calcium oxalate from dry scale of onion.

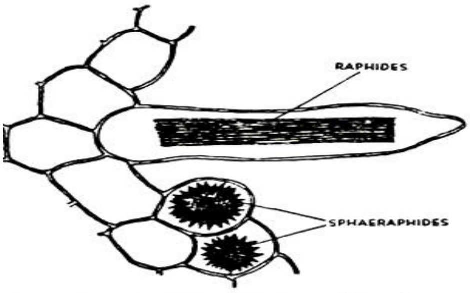
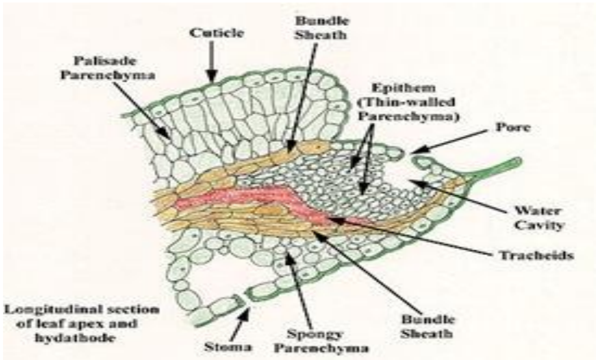


Fig. 128. Raphides and sphaeraphides in a section of the petiole of *Pistia*.

Calcium carbonate crystals are often aggregated together on the epidermis of leaves of banyan, India-rubber. Here cells of innermost layer of epidermis often enlarge to accommodate crystals of calcium carbonate deposited on a peg-like projection of the cell wall. This crystal-aggregate, called cystolith, looks like a bunch of grapes (Fig. 129). Cystoliths of irregular shape are present in the leaves of Momordica (B. Uchche).

F. Organic Acids: They are present in the cell sap of many plants, particularly the unripe fruits which taste sour. Common organic acids are tartaric acid in tamarind, oxalic acid in Oxalis, citric acid in citrus fruits (lemons).

Hydathodes,: These are structurally modified portions of leaf which are meant to send out excess amount of water in liquid form. They are are called Hydathodes or water stomata. The process of water secretion through them is called guttation. The process can be noticed early in the morning. They are present usually at the tip or margins of leaves of those plants that growing in moist places.



Each hydathodes has a mass of loosely arranged cells with large intercellular spaces called epithem. This epithem lies above a vein ending and is connected with external atmosphere through a pore in the epidermis, known as water stomata. The guard cells here are small and devoid of chloroplasts. The hydathodes are always in the open condition. The mechanism of stomata opening and closing is absent here.

Cavities, : In **plants**, the substomatal **cavity** is the **cavity** located immediately proximal to the stoma. It acts as a diffusion chamber connected with intercellular air spaces and allows rapid diffusion of carbon dioxide and other gases (such as **plant** pheromones) in and out of **plant** cells.

Three main type of cavities are:
Lysigenous cavity: This type of intercellular space arises through dissolution of entire cells, which are therefore called lysigenous intercellular spaces (lysis, loosening, Greek). These cavities of intercellular spaces store up water, gases and essential oils in them. The examples are commonly found in water plants and many monocotyledonous plants. The secretory cavities in Eucalyptus, Citrus and Gossypium are good examples.

Shizogenous Cavity: The most common intercellular spaces result from separation of cell walls from each other along more or less extended areas of their contact. In such cases, the intercellular substance dissolves partly and an intercellular space develops. Ultimately this becomes quite big in size and is known as schizogenous cavity.

The ordinary intercellular spaces and schizogenous cavities form an intercommunicating system of long intercellular canals which facilitate diffusion of gases and liquids from one part of the plant body to the other. The resin ducts in the Coniferales, and the secretory ducts in the Compositae and Umbelliferae are the typical examples. The cells lining the cavity are secretory in nature and release their product in the intercellular canal.

Shizolysigenous Cavity :This is a modified form of the shizogenous cavity when the stored space initiates. The cells of the glandular epithelial undergoes the process of autolysis and causes the enlargement of the storage cavity.

Lithocysts and Cystolith (Gr."cavity" and "stone") is a botanical term for outgrowths of the epidermal cell wall, usually of calcium carbonate, formed in a cellulose matrix in special cells called **lithocysts**, generally in the leaf of **plants**.

Cystoliths are present in certain families, including in many genera of Acanthaceae. Plants in the family Urticaceae, known as stinging nettles, also form leaf cystoliths, but only during their later flowering and seed setting stages. Other examples include Cannabis and other plants in the family Cannabaceae, which produce leaf and flower cystoliths, and *Ficus elastica*, the Indian rubber plant of the family Moraceae.

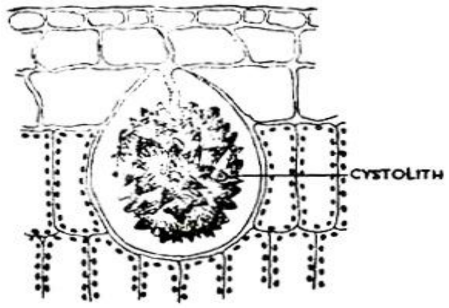


Fig. 129. Cystolith in a section of leaf of India-rubber.

Laticifers. Structure, distribution, types and function of Laticifers.

Laticifers: Laticifers are the specialised cell or row of cells that secrete the milky or watery fluid termed latex. The term encompasses the various structures like latex cell, latex vessel, latex duct, latex tube and laticiferous duct. The laticiferous duct is a tubular cavity into which latex is secreted and remains stored.

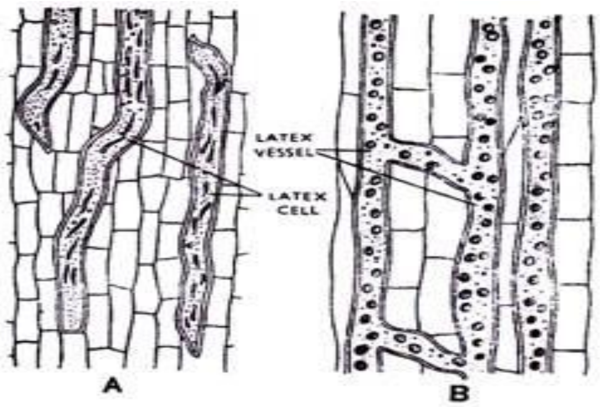


FIG. 548. Laticiferous ducts in sectional view. A. Non-articulate duct from *Euphorbia pilulifera*. B. Articulate duct from *Carica papaya* (papaw).

A **laticifer** is a type of elongated secretory cell found in the leaves and/or stems of plants that produce latex and rubber as secondary metabolites. ... **Articulated laticifers**, i.e., composed of a series of cells joined together, or. **Non-articulated laticifers**, consisting of one long coenocytic cell.

A single vegetative cell may be converted into a simple or branched latex cell. The latex ducts are also modifications of the vegetative cells into aseptated, elongated and branched structures. The latex vessel is usually an anastomosing tubular structure. It may also be simple or unbranched.

The latex vessel is formed as a result of enlargement and fusion of a group of cells. Based on origin the laticifers may be simple or compound. The simple laticifer is derived from a single cell whereas the compound laticifer originates from a longitudinal pile of cells.

The cell wall of the laticifer is non-lignified but thicker than the adjacent cells. Of course, the latex cell tip is thin-walled. The cell walls of laticifers grow in apposition and are composed of cellulose, hemicellulose and pectin.

Latex is produced within the latex vessels or cells. It is usually white and milky (e.g., Euphorbia, Asclepias, Lactuca etc.), yellow and brown (e.g., Cannabis), orange and sometimes colourless and clear (e.g., Morus, Nerium etc.). It contains many substances like sugars, proteins, alkaloids, oils, mineral salts, organic acids, terpenes, resins, rubber etc.

The latex of Euphorbia milii contains dumb-bell shaped starch grains. The latex of Carica papaya contains the proteolytic enzyme papain. The latex of Asclepias syriaca contains the enzyme pectinase. The latex of some Euphorbia species is rich in vitamin B_1.
The laticifers, where present, may remain distributed throughout the plant body or may be confined to certain tissues. Laticifers may be non-articulated and articulated. The former, which is derived from the enlargement of a single cell, has the potentiality of unlimited and rapid growth, and elongates to form a long unbranched latex tube (e.g., Vinca, Cannabis, Urtica etc.).

In some plants (e.g., Euphorbia, Nerium etc.) the non-articulated latex tubes may be branched. The non-articulated laticifers are coenocytic and multinucleate, and also termed as laticiferous cell. There is continuity of laticifers between the shoots and branches. The laticifers grow through the intercellular spaces with the help of the enzyme pectinase secreted by the growing tips of the laticifers.

The articulate laticifers or the laticiferous vessels, consist of longitudinal pile of cells. The transverse end walls of the individual cells may remain intact or partly or totally obliterated to form a continuous tube called the latex vessel. Therefore, they are of compound origin. They occur in primary or secondary phloem and in cortex.

The articulated laticifers may remain as a single chain of cells without anastomosis — articulated non-anastomosing laticifer (e.g., Convolvulus, Allium, Musa etc.). They may also form a complex anastomosing system called articulated anastomosing laticifers (e.g., Lactuca, Papaver, Carica papaya etc.). The enzyme cellulase is found in the latex of articulated laticifers suggesting that it may be involved in the lysis of common transverse walls during development.

Latex occurs in 900 genera distributed in 20 families, mostly in dicotyledons (e.g., Apocyna- ceae, Asclepiadaceae, Compositae, Euphorbiaceae, Papavaraceae etc.) and in a few families of monocotyledons (e.g., Araceae, Musaceae and Liliaceae). The different types of latex are of great economic value.

The opium, a medicinally important alkaloid, is obtained from Papaver somniferum. The most important latex is rubber whose principal source is Hevea brasiliensis. The species of Palaquium yields gutta-percha. The latex of Achras sapota yields chicle, from which chewing gum is made.

Apical meristems: Evolution of concept of organization of shoot apex (Apical cell theory, Histogen theory, Tunica Corpus theory);

Shoot apex is the growing tip of the stem. Ø It is an undifferentiated region with meristematic cells. Ø From this region the plant growth proceeds. Ø The **shoot apex** also produces lateral organs such as leaves, branches and flowers. Ø Below the **apical** meristem, different tissue zones are progressively differentiated.

Theories of Shoot Apical Meristem

Apical cell theory : Nageli in 1944 advocated this theory. According to this theory the apical meristem consists of a single apical cell (also called apical initial) and this cell is interpreted as the 'structural and functional unit of apical meristem'. The cell is very large and is shaped like an inverted pyramid.

The apical cell is tetrahedral in shape and has three or four cutting faces among which single face is directed upward and the rest points downward. The side of apical cell that is directed upward is triangular or square in shape and forms a part of the outer surface of the shoot apex (Fig. 7.7).

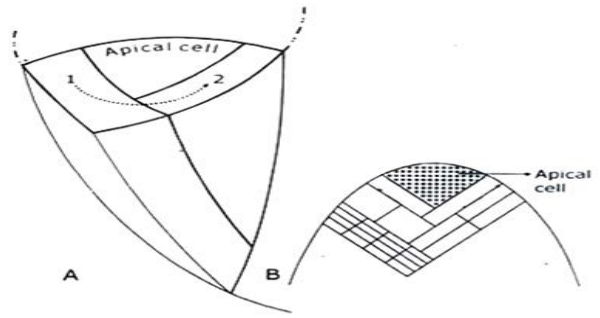


Figure 7.7

A. Diagram showing an apical cell of leptosporangiate fern and its derivatives that are formed in helical succession. The new cells are numbered as 1 & 2. B. Diagram showing a packet of cells formed by an apical cell by division and subdivision.

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The cutting faces of apical cell divide in an orderly fashion that is in helical succession. The cell divides by an asymmetric division; as a result a narrow and flat cell is formed. The next division of the apical cell is also asymmetric. This type of asymmetric division is repeated in the downwardly pointed faces of the apical cell.

As a result all cutting faces have their daughter cells. The daughter cells also divide and form large packet of cells. The packet of cells differentiates and forms different segments of shoot. So the apical cell is regarded as 'a reserve of one genetically sound cell'.

A single apical cell composing an apical meristem is present in vascular cryptogams. After the discovery of solitary apical cell in vascular cryptogams, it was supposed that such apical meristem might exist in higher plants as well.

Later extensive investigations refuted the universal occurrence of solitary apical cell in a meristem. In higher plants the apical cell theory was replaced by the concept that the different parts of a plant body have independent origin. So the apical cell theory was later superseded by histogen theory.

Histogen theory : Hanstein in 1868 put forward histogen theory (histogen means tissue builder).
According to this theory the tissues of a plant body originate from a mass of meristem where the following three (histogens) can be distinguished (Fig. 7.8):

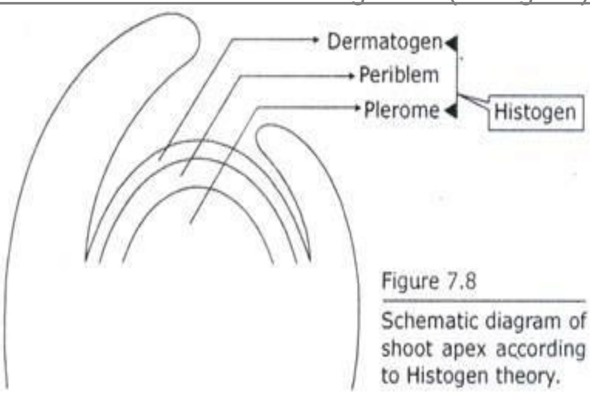

Figure 7.8
Schematic diagram of shoot apex according to Histogen theory.

(a) Dermatogen:(In Greek meaning skin). It is the outermost layer of the meristem. It gives rise to epidermises of root and stem.
(b) Periblem:(In Greek meaning clothing). This region occurs internal to dermatogen but peripheral to plerome. This histogen is destined to form cortex of root and shoot and inner tissues of leaves. It surrounds plerome.
(c) Plerome:(In Greek meaning that this fills). This region gives rise to vascular cylinder of stem and root including pith. It is the central core of stem and root and the cells composing this zone are very irregular. This region is enveloped by a variable number of mantle-like layers which are represented by dermatogen and periblem.

According to Hanstein dermatogen, periblem and plerome arise from independent initials of the apical meristem.

(i) In gymnosperm and angiosperm there exists no clear distinction between periblem and plerome.

(ii) The respective roles of the three histogens cannot be demonstrated.

The main weakness of Hanstein's concept was to assign specific destinies of histogens. The histogens — dermatogen, periblem and plerome are committal and respectfully give rise to epidermis, cortex and stele. Later this theory was superseded by tunica- corpus theory because the zones are noncommittal.

Though histogen theory is rejected it is still regarded as 'classic' due to the fact that Hanstein regarded shoot and root apex as a composite unit consisting of different groups of histogens and the histogens differed fundamentally from each other producing different tissues. It is to note that Hanstein visualized this long before when the concept of gene and DNA was established.

The present-day concept is that the different zones in the shoot apex are fundamentally same and capable of producing all tissues. It is the position in the meristem that determines the destiny of derivatives.

Tunica Corpus theory : Schmidt in 1924 postulated tunica- corpus theory on the basis of studies of shoot apices of angiosperm. This theory is concerned with planes of cell division in the apex. In contrast to apical cell theory and histogen theory tunica-corpus theory is applicable only to shoot apex and not to root. Schmidt distinguishes two tissue zones in the shoot apex and termed them as tunica and corpus.
Majority of angiosperm shoot apex exhibits tunica consisting of two layers of cells and corpus (Fig. 7.9A). Researchers designate the layers as L1, L2 and L3 to denote respectively outer layer of tunica, inner layer of tunica and corpus.

Plasmodesmata exist between the cells of tunica and corpus. It is thought that plasmodesma controls the gene expression that leads to the formation of protoderm, ground meristem and provascular tissue.

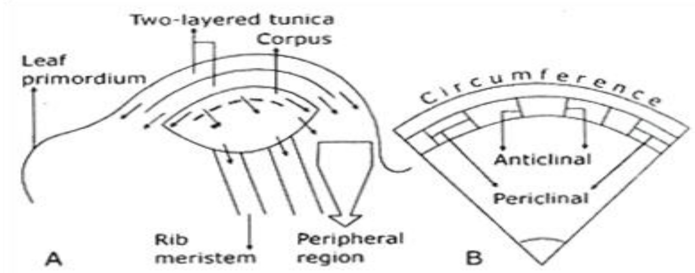

Figure 7.9

A. Diagram illustrating the tunica-corpus organization in dicotyledonous shoot apex. Arrows indicate the direction of cell formation in apical meristem. B. Schematic representation of anticlinal (= division wall perpendicular to surface) and periclinal (= division wall parallel to circumference) division.

I. Tunica: Tunica is the peripheral tissue zone of shoot apex.It consists of one or more peripheral layers of cells. Dicotyledons exhibit one to five layers of cells in tunica; two layers of cells are represented by largest number of species. Monocotyledons have one to four layers of cells in tunica; one and two layered tunica predominates in it. One single layered tunica is termed as monostratose. Many layered tunica is termed as multistratose. Xanthorrhoea media shows eighteen layered tunica.
Tunica is characterized in having anticlinal plane of cell division, i.e., the division wall is laid down perpendicular to the surface. This division reflects to the surface growth in the apex. As a result tunica grows as a sheet but not in thickness.

To increase in thickness a tunica cell will have to undergo cell division with periclinal wall, i.e. the cell wall will have to be laid down parallel to surface (Fig. 7.9B). Normally, periclinal division does not occur in tunica where anticlinal division predominates except at the point of origin of leaf primordium and axillary bud.

In multistratose tunica each layer arises from separate initials present in the shoot apex. The independence regarding origin among different layers of tunica and between tunica and corpus is strongly supported with the results of investigation by the use of periclinal chimeras.

It is the anticlinal plane of cell division that characterizes tunica.In maize, certain grasses like Agropyron repens and Chlorogalum pomeridianum (Liliaceae) etc. periclinal divisions are observed in tunica. This led anatomists to modify the ‘strictness of definition of the tunica’. One view regards that the tunica should include only those layer(s) that exhibit- anticlinal plane of division. If any inner layer(s) of tunica show periclinal division they are to be assigned to corpus.

Cytologically two zones are recognized in the tunica though all cells exhibit the same anticlinal cell division. The first zone is central apical zone and the second occurs between the central apical zone and leaf primordium.

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The central apical zone consists of one or few initial cells that are larger and contain large nuclei and vacuoles than the cells of the second zone. The cells of the second zone are small and more darkly staining than the cells of the first zone. In contrast to first zone periclinal division may occur in the second zone close to the leaf primordium in addition to anticlinal division.

The main function of tunica is to give rise epidermis. Sometimes the inner layers of tunica form cortex and vascular tissue.

II. Corpus : Corpus is the inner tissue zone of shoot apex. It consists of cells that are several cell layers deep. Tunica overarches corpus. Meristematic tissues composing this zone are larger than tunica. The initial cells of corpus occur below the tunica. They are orderly arranged in contrast to haphazardly arranged cells in the mass of corpus. So the initials of corpus are difficult to differentiate from the initials of tunica. The initials arise independently and not related to tunica. The initial cells divide periclinally and the derivatives divide to form the core of the shoot apex. In the division of derivative cells there is no definite orientation of cell wall formation, i.e. cells divide in all planes. As a result the shoot apex increases in volume. Generally corpus is destined to give rise cortex and vascular tissue.

The corpus is composed of three zones:
(a) Central mother cells —the uppermost zone of corpus.

(b) Pith-rib meristem that occurs below the central mother cell zone.

(c) Flank meristem (also called peripheral meristem) that surrounds both central mother cell zone and pith-rib meristem. The peripheral zone is shaped like a truncated hollow cone.

The component cells of tunica and corpus differ in size, shape, plane of cell division and topography. Ultrastructurally each zone is composed of cells that have characteristic architectures as is revealed by quantitative techniques.

Merits of tunica-corpus theory:
i. It deals with one thing, i.e. planes of cell division. As a result the description of meristem becomes precise.

ii. It has topographical value in the studies of development of different tissue system in plants.

iii. The destiny of derivatives of corpus is not predetermined.

iv. The derivatives of the zones are not rigid like histogen theory.

v. It explains clearly the growth pattern in the shoot apex of angiosperm.

vi. It enables to understand the development of leaves as they arise close to apex.

vii. The specific variation in the number of tunica layers may be of taxonomic significance, e.g. grasses.

Tunica-corpus organization of shoot apical meristem is observed in angiosperm only. Cryptogams and majority of gymnosperm do not exhibit tunica- corpus organization. They do not have any stable surface layer that divides only by anticlinal division. Araucaria and Ephedra have a single stable surface layer that divides only by anticlinal division.

Thus they exhibit tunica-corpus pattern. Tunica-corpus theory is noncommittal regarding the ultimate destiny of cell-lineages. In present-day concept all cells in the shoot apex with tunica-corpus organization are fundamentally same and have equal potentiality. In corpus the cells of peripheral zone and pith-rib meristem are also same as they owe their origin from central mother cell zone.

In conclusion it is to mention that tunica-corpus theory provides a flexible description of cell arrangement in the shoot apex and this is not rigid like histogen theory. It has served well in understanding the structure of shoot apical meristem and the origin and development of leaf.

The shoot apices of angiosperm exhibit cytohistological zonation in addition to tunica corpus zonation (Fig. 7.10).

Four zones are recognized namely:
(1) Tunica initials-that consist of an apical group of cells,
(2) Corpus initials-that occur below apical initials and are similar to central mother cells,
(3) A peripheral zone and
(4) A rib meristem.
Tunica initials contribute cells to central mother cell zone and to peripheral meristem. The central mother cell zone donates cells to the rib meristem and pith. The peripheral meristem is highly meristematic. Leaf primordia originate from this layer.

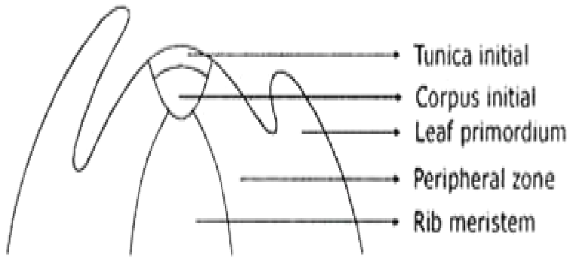

Figure 7.10

Diagram illustrating the cytohistological zonation of apical meristem.

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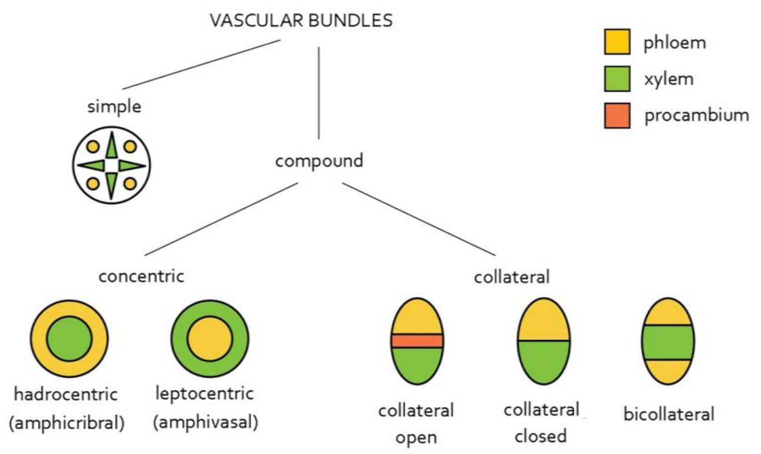
Types of vascular bundles; **Types of Vascular bundles**. (blue: Xylem, green: Phloem, white: Cambium)

- A concentric, periphloematic.
- B concentric, perixylematic.
- C radial with inner xylem, here with four xylem-poles, left closed, right open.
- D collateral closed.
- E collateral open.
- F bicollateral open.



Structure of dicot and monocot stem.

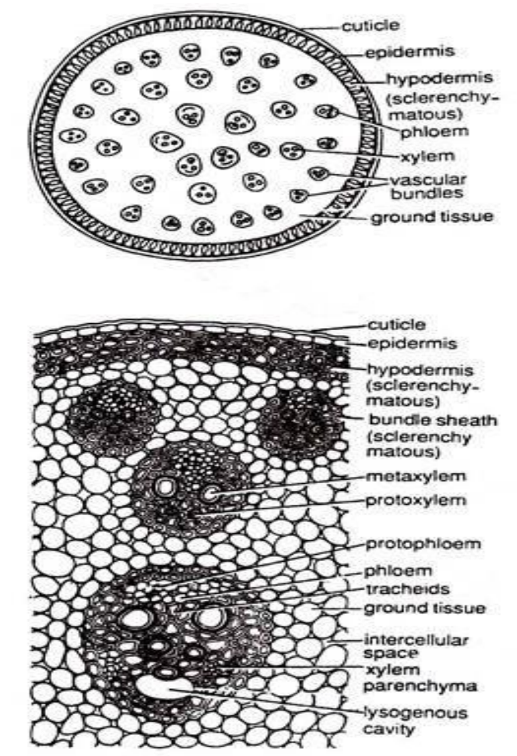


Fig. 160. Zea mays : Upper—T.S. stem (diagrammatic); Lower—T.S. stem (a part cellular).

1. Normal Monocot Stems 2. Normal Dicotyledonous Stems.

1.Normal Monocot Stems: Zea mays-Stem:

It is circular in outline with a well-defined epidermis, hypodermis, ground tissue and many scattered vascular bundles (Fig. 160).

Epidermis:

1. It is the outermost layer of stem.
2. The outer wall of cells is covered by a thick cuticle.
3. The continuity of the layer is broken by few stomata.
4. Epidermal hair are absent.

Hypodermis:
5. It is two to three cells thick, sclerenchymatous and present just below the epidermis.

6. Cells are polygonal is shape.

Ground tissue:
7. It is not differentiated into cortex, endodermis, pericycle and pith.

8. The cells are parenchymatous and extend from below the sclerenchyma up to the centre.

9. The cells are small and compactly arranged below the hypodermis but they are large, round and loosely arranged in the centre.

Vascular Bundles:
10. Vascular bundles are many and scattered in the ground tissue with no definite arrangement.

11. They are small and more in number towards the periphery than the centre of the section.

12. Each vascular bundle is conjoint, collateral, closed and endarch.

13. A well-developed sclerenchymatous sheath surrounds each vascular bundle which is more prominent at its upper and lower faces.

14. Xylem and phloem constitute the vascular bundle.

15. Xylem:
(i) Consists of vessels (protoxylem and metaxylem), tracheids and xylem parenchyma.
(ii) Vessels are in the form of 'Y'.
(iii) Metaxylem is present at the divergent ends of ' Y' in the form of two big oval vessels.
(iv) Protoxylem is present at the lower arm of' Y',consisting of two small vessels.
(v) Protoxylem is surrounded by tracheids and xylem parenchyma.
(vi) Inner protoxylem vessel and parenchyma break down and form a Water-containing cavity called lysigenous cavity.
16. Phloem:
(i) Consists of only sieve tubes and companion cells.

(ii) Phloem fibres and phloem parenchyma are absent.

(iii) The outer parts of the phloem, which is broken and disorganized, is called protophloem.

(iv) Inner phloem contains sieve tubes and companion cells, and called metaphloem.

Identification:

(a) 1. *Presence of vessels in the xylem*............**Angiosperms**

(b) 1. *Vascular bundles are conjoint, collateral and endarch.* **Stem**

(c) 1. *No differentiation of ground tissue.*

2. *Sclerenchymatous hypodermis.*

3. *Vascular bundles are closed.*

4. *Scattered vascular bundles.*

5. *Absence of secondary growth*......................**Monocot**

Special Points:

1. Scattered vascular bundles.

2. 'Y'-shaped vasels.

3. Presence of protophloem and metaphloem.

2. Normal Dicotyledonous Stems: Luffa-Stem : It is wavy in outline, usually with five ridges and five furrows, and ten vascular bundles remain arranged in two rings of five each.

Epidermis:

1. Single-layered epidermis consists of many barrel- shaped cells covered with cuticle.

2. Some of the epidermal cells protrude out as multicellular shoot hair.

Cortex:

3. It consists of collenchymatous hypodermis. chlorenchyma and an innermost layer of endodermis.

4. Collenchyma is present just below the epidermis, in the form of six to ten or more layers in the ridges and only a few layers or none in the furrows.

5. Chlorenchyma is present in the form of two to three layers in between the collenchyma and endodermis. Its cells are filled with chloroplasts.

6. Endodermis is the innermost layer of cortex. It is wavy in outline. The cells are filled with starch grains and lack casparian strips.

Pericycle:
7. It consists of four to five layers of thick- walled, lignified sclerenchymatous zone present just below the endodermis.

Ground Tissue:
8. The space between sclerenchyma and the central pith cavity is filled with many thinwalled, parenchymatous cells of ground tissue, in which the vascular bundles remain embedded.

Vascular Bundles:
9. Ten vascular bundles are arranged in two rows of five each.

10. Five vascular bundles of outer ring are present opposite the ridges whereas the remaining five of the inner ring face the furrows.

11. Vascular bundles are conjoint, bicollateral, open and endarch.

12. Each vascular bundle consists of centrally located xylem, surrounded on its outer and inner faces by strips of outer and inner cambia. Outside the outer cambium is present a patch of outer phloem, and inner to the inner cambium is present the inner phloem, thus representing the open and bicollateral condition of vascular bundles.

13. Xylem consists of wide vessels present on the outer side representing the metaxylem and narrow vessels present towards inner side representing the protoxylem. Xylem also contains certain tracheids, wood fibres and xylem parenchyma.

14. Cambium is present in the form of strips on both the sides of the xylem. It consists of thin-walled, rectangular cells arranged in radial rows.

(i) Outer cambium is flat and many-layered.

(ii) Inner combium is curved and only few-layered.

15. Phloem is situated in the form of patches of outer phloem and inner phloem. It consists of companion cells, thin-walled cells of phloem parenchyma, and well-developed sieve tubes.

Pith **:** Thin-walled parenchymatous cells of ground tissue form the pith.
Identification:
(a) 1. Presence of vessels in xylem …….Angiosperms

(b) 1. Vascular bundles are conjoint, bicollateral, open and endarch.

2. Multicellular epidermal hair ………..Stem

(c) 1. Vascular bundles are arranged in rings.

2. Presence of cambium.

3. Well-differentiated cortex and well-developed pith. ………Dicot.

Special Point : Presence of bicollateral, open, vascular bundles.

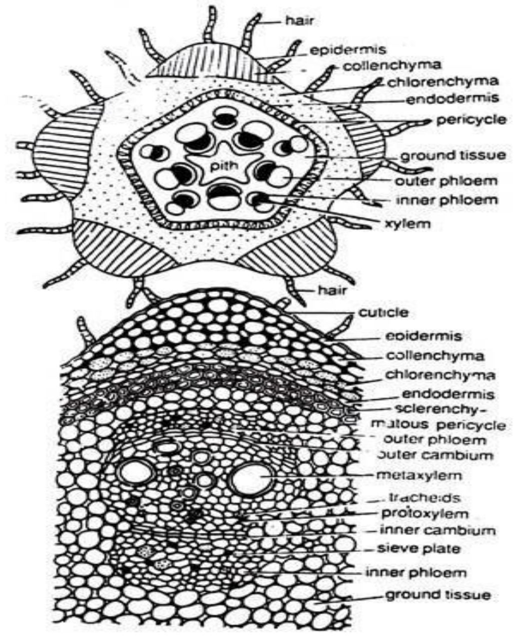


Fig. 163. Luffa : Upper—T.S. stem (diagrammatic); Lower—T.S. stem (a part cellular).

Origin, development, arrangement and diversity in size and shape of leaves;

Origin & **Development of Leaf :** Develops from **leaf** primordium from promeristem of SAM i. ... It produces a bulge called **leaf** buttress which grow laterally. **Leaf** primordium grows in length by activity of apical meristem present at tip. Further **growth** occurs by activity of apical, intercalary, adaxial & plate meristem.

Structure of dicot and monocot leaf,

1. Anatomy of Monocot Leaf :Triticum-Leaf:

Epidermis:

1. Two epidermal layers are present, one each on upper and lower surfaces.

2. Uniseriate upper and lower epidermal layers are composed of more or less oval cells.

3. Few big, motor cells or bulliform cells are present in groups here and there in the furrows of upper epidermis.

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4. Stomata, each consisting of a pore, guard cells and a stomatal chamber, are present on both the epidermal layers.

5. A thick cuticle is present on the outer walls of epidermal cells.

6. Bulliform cells help folding of leaves.

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

8. The cells are filled with many chloroplasts.

9. Many intercellular spaces are also present in this region.

10. Sub-stomatal chambers of the stomata are also situated in this region.

Vascular System:
11.Many vascular bundles are present.They are arranged in a parallel series.

12. The central vascular bundle is largest in size.

13. Vascular bundles are conjoint, collateral and closed.

14. Each vascular bundle remains surrounded by a double-layered bundle sheath.

15. Outer layer of bundle sheath consists of thin-walled cells while the inner layer is made up of thick-walled cells.

16. On the upper as well as lower surfaces of large vascular bundles are present patches of sclerenchyma which are closely associated with the epidermal layers. There is no such association between the sclerenchyma and small vascular bundles.

17. Xylem occurs towards the upper surface and phloem towards to lower surface.

18. Xylem consists of vessels and tracheids. Sometimes small amount of xylem parenchyma is also present.

19. Phloem consists of sieve tubes and companion cells.

Xerophytic Characters:
(i) Thick cuticle on epidermis.
(ii) Presence of motor cells.
(iii) Sclerenchyma patches are present.
(iv) Stomata in furrows.
Identification:
(a) 1. Presence of upper and lower epidermal layers.

2. Mesophyll is present.

3. Each vascular bundle is surrounded by bundle sheath………. Leaf

(b) 1. Many vascular bundles are arranged parallaly.
2. Absence of cambium.

3. Vascular bundles are collateral and closed.

4. Stomata on both the surfaces.

Isobilateral monocot leaf.

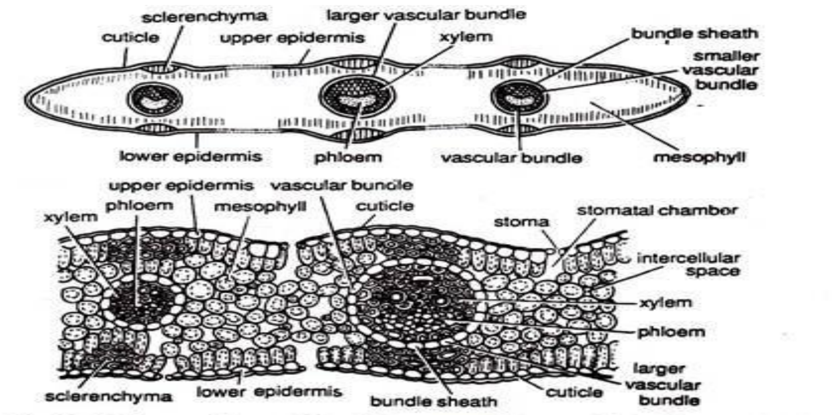

Fig. 174. Triticum : Upper, T.S. leaf (diagrammatic); Lower, T.S. leaf (a part cellular).

2. Anatomy of Dicot Leaf:Mangifera indica-Leaf:
Epidermis:
1. An epidermal layer is present on the upper as well as lower surfaces.

2. One-celled thick upper and lower epidermal layers consist of barrel-shaped, compactly arranged cells.

3. A thick cuticle is present on the outer walls of epidermal cells. Comparatively, thick cuticle is present on the upper epidermis.

4. Stomata are present only on the lower epidermis.

Mesophyll:
5. It is clearly differentiated into palisade and spongy parenchyma.

6. Palisade lies just inner to the upper epidermis. It is composed of elongated cells arranged in two layers.

7. The cells of palisade region are compactly arranged and filled with chloroplasts. At some places the cells are arranged loosely and leave small and big intercellular spaces.

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8. Palisade cells are arranged at a plane at right angle to the upper epidermis, and the chloroplasts in them are arranged along their radial walls.

9. Parenchymatous cells are present above and below the large vascular bundles. These cells interrupt the palisade layers and are said to be the extensions of the bundle sheath.

10. Spongy parenchyma region is present just below the palisade and extends upto the lower epidermis.

11. The cells of spongy parenchyma are loosely arranged, filled with many chloroplasts and leave big intercellular spaces.

Vascular Region:
12. Many large and small vascular bundles are present.

13. Vascular bundles are conjoint, collateral and closed.

14. Each vascular bundle is surrounded by a bundle sheath.

15. Bundle sheath is parenchymatous and in case of large bundles it extends upto the epidermis with the help of thin-walled parenchymatous cells.

16. The xylem is present towards the upper epidermis and consists of vessels and xylem parenchyma. Protoxylem is present towards upper epidermis while the metaxylem is present towards the lower epidermis.

17. Phloem is situated is present towards the lower epidermis and consists of sieve tubes, companion cells and phloem parenchyma.

Identification:
(a) 1. Presence of expanded portion or blade.

2. Presence of mesophyll.

3. Bundle sheath is present…………………………………. Leaf

(b) 1. Upper and lower epidermal layers are clearly distinguishable.

2. Mesophyll is clearly differentiated into palisade and spongy parenchyma.

3. Stomata only on the lower surface.

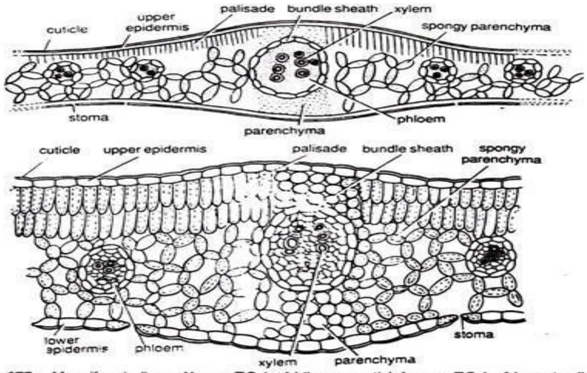

Fig. 175. Mangifera indica. Upper, T.S. leaf (diagrammatic); Lower, T.S. leaf (a part cellular).

Kranz anatomy. The bundle sheath cells are arranged in a wreath like manner. This kind of arrangement of cells is called **Kranz anatomy** (**Kranz**: wreath). In **Kranz anatomy**, the mesophyll and bundle sheath cells are connected by plasmodesmata or cytoplasmic bridges. The C_4 plants contain dimorphic chloroplasts.

Hatch-Slack (C_4) Pathway of CO_2 Fixation

The discovery of C_4 cycle in monocots such as sugarcane, maize and sorghum has indicated that these plants have solved the problem of **photorespiration.** The carbon dioxide is fixed in the mesophyll cells. The initial product being a-4 carbon compound, the process is called C_4 pathway of carbon dioxide fixation.

Hatch-Slack Pathway : Two Australian botanists Hatch and Slack (1966) discovered that there are **two types** of chloroplasts in sugarcane. One type restricted to bundle sheath cells have the normal **grana**. These chloroplasts carry on Hatch-Slack or C_4 cycle. Hence, Hatch-Slack cycle or C_4 cycle has been found in most monocots and some dicots. The plants having C_4 cycle are known as C_4 plants, and the plants C_3 (Calvin cycle) are C_3 plants.
Photorespiration occurs in C_3 plants (Calvin cycle), which leads to a 25 percent loss of the fixed CO_2. Photorespiration occurs in C_3 plants only, as the enzyme Rubisco catalysis both carboxylation and oxygenation reactions of the initial acceptor molecule that is RuBP.

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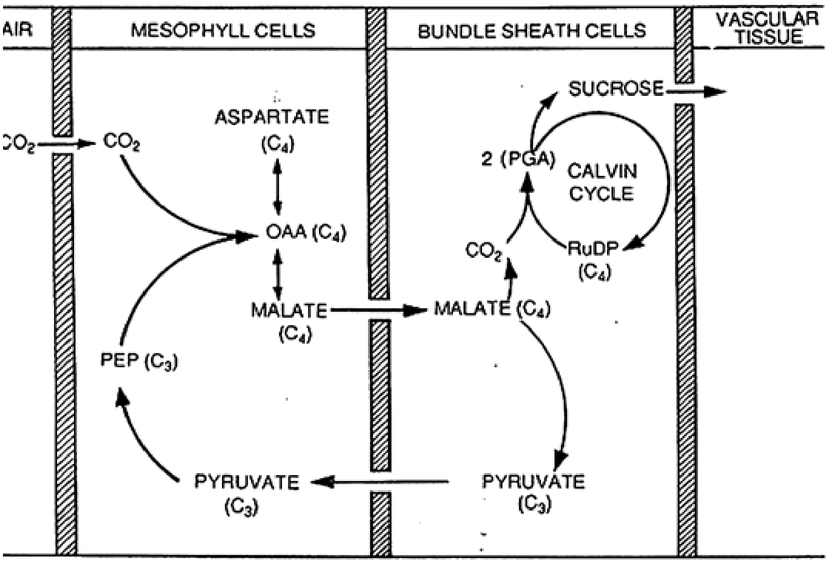

Fig. 5.11. Hatch Slack Pathway of CO_2 fixation.

In C_3 plants, photosynthesis occurs only in **mesophyll** cells. Photosynthesis has two types of reactions, i.e.,light reactions and carbon or dark reactions.

In light reactions, ATP and $NADPH_2$ are produced, and as a result of photolysis of **water O_2 is released.**

During carbon or dark reactions, CO_2 is assimilated and **carbohydrates are produced.**

As both light reactions and carbon (dark) reactions occur in mesophyll cells in C_3 plants, it becomes essential for enzyme Rubisco to catalyse both oxygenation and carboxylation reactions of RuBP, simultaneously.

However, in category of C_4 plants, nature has evolved a mechanism to avoid occurrence of photorespiration, which is thought to be a harmful process.

C_4 pathway requires the presence of **two types** of photosynthetic cells, i.e., mesophyll cells and bundle sheath cells. The bundle sheath cells are arranged in a wreath like manner. This kind of arrangement of cells is called **Kranz anatomy** (Kranz: wreath). In Kranz anatomy, the mesophyll and bundle sheath cells are connected by plasmodesmata or cytoplasmic bridges.

The C_4 plants contain **dimorphic chloroplasts**. The chloroplasts in mesophyll cells are **granal**, whereas in bundle sheath cells they are **agranal.**

The granal chloroplasts contain thylakoids which are stacked to form grana, as formed in C_3 plants. However, in agranal chloroplasts of bundle sheath cells grana are absent and thylakoids are present only as stroma lamellae.

The presence of two types of cells (granal and agranal) allows occurrence of light and carbon (dark) reactions separately in each type.

Here, release of O_2 takes place in one type, while fixation of CO_2 catalysed by Rubisco enzyme occurs in another type of cells.

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In C_4 plants (maize, sugarcane, etc.), light reactions occur in mesophyll cells, whereas CO_2 assimilation takes place in bundle sheath cells. Such arrangement of cells does not allow O_2 released in mesophyll cells to enter in bundle-sheath cells.

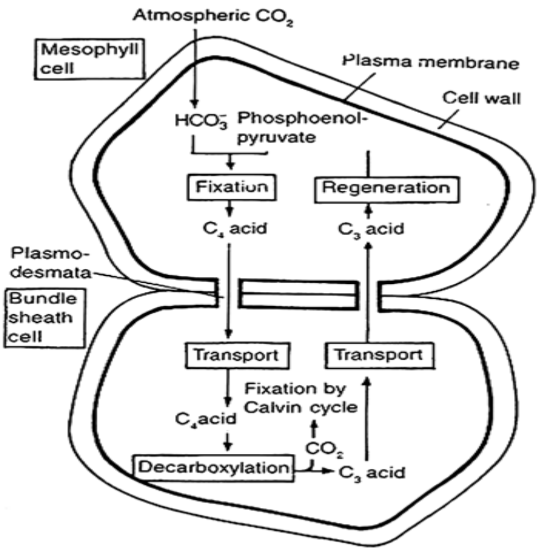

Fig. 5.12. C_4 photosynthetic carbon cycle.

Hence, Rubisco enzyme, which is present only in bundle-sheath cells, does not come into contact with O_2, and thus, oxygenation of RuBP is completely avoided.
In C_4 plants, a CO_2 concentrating mechanism is present which helps in reducing the occurrence of photorespiration (i.e., oxygenation of initial acceptor RuBP). This type of CO_2 concentrating mechanism is called C_4 pathway.
For operation of C_4 pathway, both mesophyll and bundle-sheath cells are required. The main objective of C_4 pathway is to build up high concentration of CO_2 near Rubisco enzyme in bundle- sheath cells. High concentration of CO_2 near Rubisco enhances carboxylation and reduces photorespiration.

C_4 photosynthetic Carbon Cycle:

In C_4 pathway, CO_2 from the atmosphere enters through stomata into the mesophyll cells and combines with phosphoenol pyruvate (3-carbon compound). This reaction is catalysed by an enzyme known as phosphoenol pyruvate carboxylase, i.e., PEPCase. With the result, a C_4 acid, oxaloacetic acid (OAA) is formed.

$$CO_2 + PEP + H_2O \xrightarrow[\text{enzyme}]{\text{PEPCase}} \text{Oxaloacetic acid (OAA)} + H_3PO_4$$

The above-mentioned reaction occurs in cytosol of the mesophyll cells and is called fixation of CO_2 or carboxylation.
Since this gives rise to the **first stable** product C_4 acid, and therefore, known as C_4 pathway.
The next step of reaction is transport of oxalo acetic acid (OAA – 4 C compounds) from cytosol of mesophyll cells to chloroplasts of bundle-sheath cells, where it is decarboxylated to release fixed CO_2 and high concentration of CO_2 is generated near Rubisco.

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The other product of decarboxylation reaction is a 3-carbon compound called pyruvic acid. Now, this is transported back to mesophyll cells, where if regenerates phosphoenol pyruvate to its own for continuation of C_4 pathway.

However, the C_4 pathway is more efficient than C_3 pathway due to absence of photorespiration in C_4 plants.

Organization of root apex (Apical cell theory, Histogen theory, Korper-Kappe theory);

Root Apical Meristem in Plants

1. Apical Cell Theory : This theory was proposed by Nageli who drew the attention to the occurrence of a single apical cell or apical initial that composes the root meristem. A single apical cell is present only in vascular cryptogams, e.g. Equisetum, Adiantum and Polypodium etc. The apical initial is tetrahedral in shape and generates root cap from one side.
The other three sides donate cells to form epidermis, cortex and vascular cylinder. In other words all tissues that compose a mature root including root cap are the derivatives of a single apical cell. Apical cell theory is confined to vascular cryptogams only as the root apical meristem of flowering plants does not have a single apical cell.

2. Histogen Theory : Hanstein in 1868 advocated the theory. According to Hanstein root apical meristem consists of three cell-initiating regions called histogens (Fig. 7.22). The histogens are called dermatogen, periblem and plerome that respectfully form epidermis, cortex and vascular cylinder that are present in a mature root.

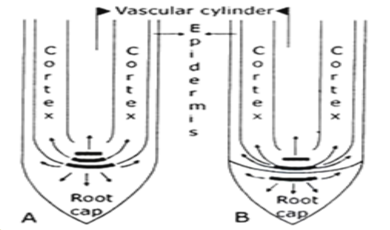

Figure 7.22
Schematic diagram of root apex based on Histogen theory. A. Root apex of *Raphanus sativa*. B. Root apex of *Zea mays* where root cap has its own histogen, i.e. Calyptrogen. Broad lines indicate histogens. Arrows indicate the direction of cell formation.

The derivatives of dermatogen vary. In Zea mays (monocot) dermatogen generates root cap only and this histogen is referred to as calyptrogen. In Brassica (dicot) dermatogen generates both protoderm and root cap and this histogen is referred to as dermatocalyptrogen.

Histogen theory explains both root and shoot apical meristem. This theory attributes specific destinies to the derivatives of the three histogens. Though histogen theory is abandoned to explain shoot apex, Eames and MacDaniels illustrated the root apical meristem on the basis of histogen concept.

3. Korper-Kappe Theory: This theory of root meristem was proposed in 1917 by Schiiepp who regarded the occurrence of two systems of cell seriation that characterize the root apex with reference to planes of cell division in its parts.

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Korper-kappe concept is also referred to as body-cap concept (Korper = body and kappe = cap) and the concept illustrates distinct type of cell wall pattern formation during cell division. The body-cap concept is illustrated below on analyzing the divisions in the derivatives of apical cell.

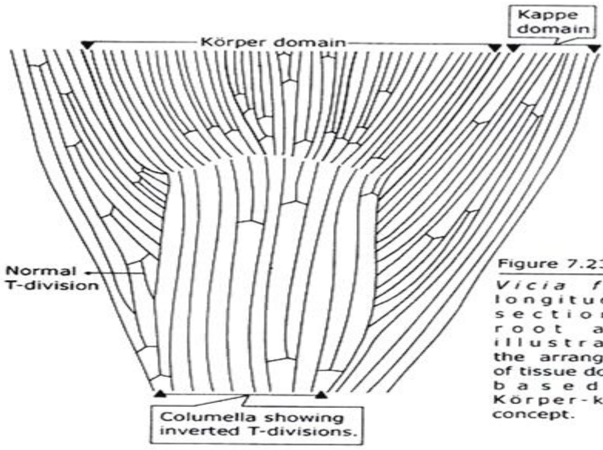

Figure 7.23 *Vicia faba*: longitudinal section of root apex illustrating the arrangement of tissue domains based on Körper-kappe concept.

The root meristem exhibits multicellular structure. It consists of conspicuous longitudinal files of cells. During growth the root changes in diameter. This happens due to cell divisions that occur in such a way that a single longitudinal file of cells becomes double files. The initial cell divides transversely. The two cells thus formed one has the capability of cell division. This cell divides longitudinally and both the daughter cells inherit the property of cell division.

The daughter cells are parallel in arrangement, share a common wall and divide by transverse partition followed by longitudinal partition in one cell. The sequences of wall formation when viewed together appear to form a configuration resembling the letter 'T' or 'Y'. Such divisions are described as T-divisions. Continuous T-divisions result in the formation of double-rowed region over a single rowed region.

It is the T-division that characterizes korper and kappe. In the kappe the initial cell first divides transversely and forms two cells. The daughter cell that faces the root apex inherits the initial function. It divides longitudinally. The two cells thus formed have the capability of cell division.

When transverse and longitudinal partition are viewed together the combined cell walls appear as 'T' that is right-way-up. When such division continues it is observed that a single rowed region is left behind over the double-rowed region. This occurs in downwardly pointed roots.

In the korper the initial cell first divides by transverse partition and forms two cells. The daughter cell that faces the base of root, i.e. away from the apex inherits the initial function.

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It divides longitudinally and the two daughter cells thus formed have the potentiality of cell division. The daughter cells divide by transverse partitions followed by longitudinal partitions. When transverse and longitudinal partitions are viewed together the cell walls form a configuration resembling an inverted 'T'.

Korper and kappe-these two zones of root are delimited by planes of cell division. The zones exhibit clear boundary when they originate from separate initials, e.g. root with calyptrogen. The zones do not exhibit sharp demarcation line when they are the derivatives of same apical cell. In root with dermatocalyptrogen the cap extends into protoderm.

The central part of root cap is the columella where the cells are arranged in longitudinal files. These cells seldom divide. When division occurs the partition walls form the configuration of an inverted 'T' that is observed in the korper. The 'T' has normal configuration in the peripheral region of root cap.

The korper-kappe theory of root apex is comparable with tunica-corpus theory of shoot apex. The body-cap concept and tunica-corpus concept both are based solely on the planes of cell division. Anticlinal division is the characteristic of tunica whereas corpus exhibits both anticlinal and periclinal division.

On the other hand the inverted 'T' – and normal 'T' pattern of cell wall formation are the characteristic of korper and kappe respectively. The boundaries between korper and kappe, and between tunica and corpus are not always sharply demarcated.

Quiescent centre; Quiescent Centre (QC) found in root-promeristem of higher plants. It is observed that in the root-promeristem of higher plants the initials divide much less frequently than other cells. This part of root-promeristem, which contains the initials of epidermis, cortex and stele and divides less frequently, is referred to as quiescent centre (QC). Quiescent centre is situated at the pole of cortex and stele and consists of four cells (e.g. Arabidopsis) or as high as 600 cells that have very low mitotic activity (Fig. 7.24).

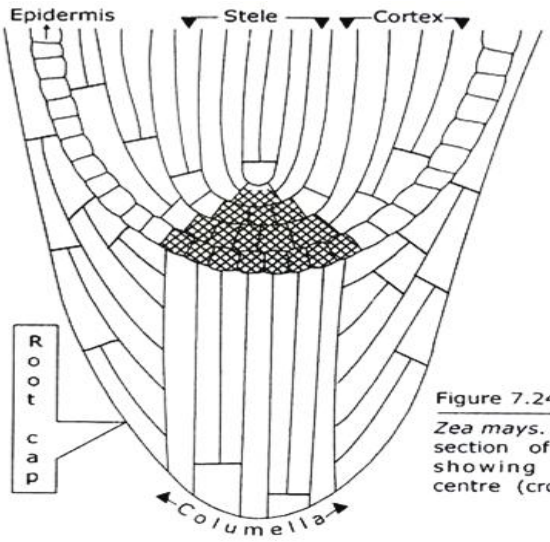

Figure 7.24
Zea mays. Longitudinal section of root apex showing quiescent centre (crosshatched).

In closed meristem QC appears more or less hemispherical whereas in open meristem it is disc-shaped. The cells composing QC exhibit smallest dictyosomes, nuclei and nucleoli. The cells also exhibit little endoplasmic reticulum and fewer mitochondria. The cells contain lower concentration of RNA, DNA and protein than other cells of root apex.

Quiescent centre is unusual in shoots, but it is universal in roots of higher plants. Though the occurrence of QC was reported in vascular cryptogams (e.g. Equisetum arvense) later investigations have established that the entire root apex of vascular cryptogams is mitotically active. Quiescent centre maintains a strict boundary in closed meristem. As a result the derivatives of QC also maintain a strict boundary in the apical zone.

Quiescent centre consists of central cells only or central cell and part of its peripheral zones. It does not include the mother cells of columella. A separate cap meristem exists and it forms root cap. In open meristem the size and position of QC change.

They fluctuate as the root ages and grow bigger. The volume and number of constituent cells of QC vary with the change of width of root. In growing roots QC is small. The columella mother cells are generated from the cells situated ahead of the central cell.

It needs special techniques to identify QC. It can be identified in autoradiograph of root sections. Supplying root with solutions of thymidine labeled with radioactive isotope hydrogen, tritium (^{3}H), the nuclei of root apical meristem can be labeled. Radioactive thymidine incorporates specifically into DNA of DNA synthesizing cells.

Function of QC:

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i. It provides a reserve block of diploid cells when the root tip is damaged at the time of pushing through the soil.

ii. It is the site of hormone synthesis.

iii. As it is the source of some growth substances, at certain concentration of hormone it inhibits cell division and growth.

iv. Quiescence is caused due to the presence of root cap and the pressure exerted by the dividing initial cells. Cells of QC maintain a long period in the presynthesis (G_1) phase of mitotic cycle and thus they may escape injury.

Root cap; Tips of roots are covered by a thimble-shaped root cap, that has its own meristem that pushes cells forward into the cap. As they move through the cap, these cells differentiate into columella cells.

Columella cells each contain 15-30 amyloplasts that sediment in response to gravity to the lower side of the cell. Besides protecting the growing root tip and its meristem, the root cap senses light and pressure exerted by soil particles.

Within a few days, columella cells differentiate into peripheral cells. The peripheral cells of the root cap and the epidermal cells of the root produce and secrete large amounts of mucigel, a slimy substance made by dictyosomes.

Mucigel is a hydrated polysaccharide containing sugars, organic acids, vitamins, enzymes, and amino acids. �

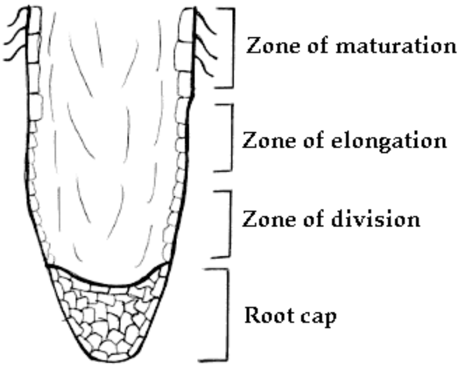
(Mucigel is a slimy substance that covers the root cap of the roots of plants. It is a highly hydrated polysaccharide, most likely a pectin, which is secreted from the outermost (epidermal) cells of the rootcap. **Mucigel** is formed in the Golgi bodies of such cells, and is secreted through the process of exocytosis).

Important functions of **mucigel: �**

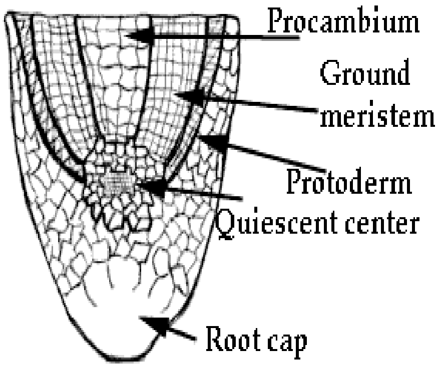
Protection-It protects roots from desiccation and contains compounds that diffuse into the soil and inhibit growth in other roots. Lubrication-It lubricates roots as they force their way between soil particles.

Water absorption-Soil particles cling to mucigel, and increase the root's contact with the soil.

These properties of mucigel help maintain the continuity between roots and soil water. Nutrient absorption-Carboxyl groups in mucigel influence ion uptake, and organic acids in mucigel make certain ions are more available to plants.Also, fatty acids, lectins, and sterols in mucigel may help establish beneficial symbioses with



soil microbes.



Quiescent center : This structure is located just behind the root cap and consists of 500-1,000 seemingly inactive cells. These cells are usually in the G1 phase of the cell cycle and divide only about once every 15-20 days.

Quiescent and meristematic cells are different in sensitivity to environmental problems such as radiation. For example, meristematic cells stop dividing when exposed to X rays while quiescent cells are unaffected by radiation and soon begin dividing to reform the meristem.

Cells in the quiescent center function as a reservoir to replace damaged cells of the meristem. Its important because it organizes the patterns of primary growth in roots.

Sub apical Region- This region of roots has traditionally been divided into three regions;

the zones of cellular division, cellular elongation, and cellular maturation. These divisions are useful for teaching but are not sharply defined. They do not always accurately define what is happening in a particular region of the root.

Zone of cellular division- Surrounding the quiescent center is a dome shaped apical meristem located 0.5-1.5 mm behind the root tip. This meristematic region is the zone of cellular division and its made of small densely cytoplasmic cells. Meristematic cells in roots divide every 12-36 hrs, in some plants, the meristem produces almost 20,000 new cells each day. �

Zone of cellular elongation- This area occurs 4-15 mm behind the root tip. Cells in this zone elongate by as much as 150-fold by filling their vacuoles with water. This zone is easily distinguished from the root cap and zone of cellular division by its long, vacuolate cells. Cellular elongation in the elongating zone shoves the root cap and apical meristem through the soil at rates as high as 4 cm per day. Cells behind the **elongating zone do not elongate. �**

Zone of cellular maturation- Differentiation is completed in this zone, which occurs 1-5 cm behind the root tip. This zone is easily distinguishable by the presence of several root hairs. Root hairs increase the absorptive surface area of the root several thousandfold and are usually less than a millimeter long. In most plants they form from asymmetric divisions of the protoderm and usually live only a few days, with old hairs farthest from the tip constantly being replaced by new ones closer to the tip. Root hairs only form in the maturing, non elongating region of the root. Because root hairs are fragile extensions of epidermal cells, they usually break off when plants are transplanted.

Structure of dicot and monocot root;

1. Anatomy of Dicotyledonous Roots.

Epiblema:

1. It is the outermost layer consisting of many thin-walled cells.

2. From some of its cells arise unicellular hair. 3. Cuticle is absent.

Cortex:

4. It is very large, parenchymatous and well- developed occupying the large part of the section.

5. In this region there are present many intercellular spaces.

6. Cortical cells are filled with starch grains.

7. In older roots, few-layered exodermis, consisting of thin-walled compact cells, is present just below the epiblema.

8. Endodermis is the ring like innermost layer of cortex made up of barrel-shaped cells.

9. Casparian strips are present in the endodermal cells.

10. Some of the endodermal cells, particularly those opposite to the protoxylem, are thin-walled and have been termed as passage cells.

Pericycle:
11. Single-layered, ring-like pericycle is present close to the endodermis on its inner side.

12. It is also a compact layer of thin-walled cells.

Vascular Bundles:
13. The vascular bundles are 2 to 6 and radial, i.e., xylem and phloem present on different radii alternating with each other.

14. Xylem and phloem patches are equal in number.

15. Xylem consists of protoxylem and metaxylem.

16. Protoxylem is exarch and consists of small annular and spiral vessels.

17. Metaxylem strands are big, present towards the centre and are made up of large reticulate and pitted vessels.

18. In some cases the metaxylem meet in the centre and thus obliterate the pith.

19. Phloem is made up of sieve tubes, companion cells and phloem parenchyma.

20. In mature roots, cambium also appears cutting the secondary structures.

21. The parenchymatous cells in between xylem and phloem strands form conjunctive tissue.

Pith : It is very small, parenchymatous and without any intercellular spaces. It gets reduced after the formation of secondary structures.
Identification:
(a) 1. Presence of vessles in the xylem. 2. Vessels have perforated end walls with scalariform and regularly arranged holes ……….Angiosperms

(b) 1. Presence of unicellular root hair. 2. Vascular bundles are radial and xylem is exarch. …Root (c) 1. Vascular bundles are 2-6. 2. Reduced pith…… Dicotyledons

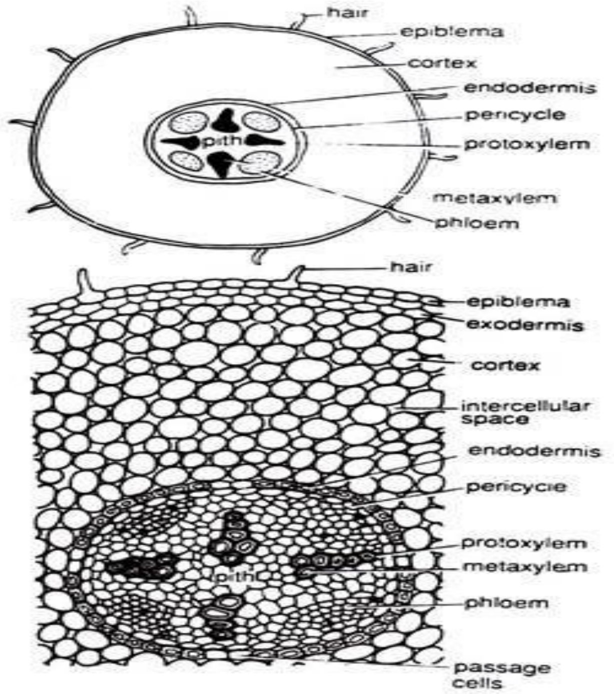


Fig. 170. Cicer. Upper, T.S. root (diagrammatic); Lower, T.S. root (a part cellular).

2.Anatomy of Monocot Root:Zea mays-Root:

Epiblema:

1. Single-layered epiblema consists of barrel- shaped or rounded cells.

2. From some cells arise unicellular hair.

Cortex:

3. It is well-developed, several cells deep and parenchymatous.

4. The cells are thin-walled, rounded in shape and leave many intercellular spaces.

5. Just below the epiblema are present 2 to 6 layers of collenchyma in old roots. This represents exodermis.

6. Remaining part of the cortex is parenchymatous.

7. Endodermis is the innermost layer of cortex. It consists of many compactly arranged, barrel- shaped cells.

8. Casparian strips are present on the radial and transverse walls of the endodermal cells.

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9. Thin-walled endodermal cells are known as passage cells. They lie opposite to protoxylem.

Pericycle : Single-layered pericycle consists of thin-walled cells and present inner to the endodermis.

Vascular Tissue:

11. It is composed of alternating strands of phloem and xylem.

12. Vascular bundles are radial, exarch and polyarch. Cambium is absent.

13. Xylem consists of vessels, tracheids and xylem parenchyma.

14. Protoxylem elements are towards the outer side, i.e., exarch, small in diameter and their walls have thickenings.

15. Metaxylem vessels face towards the centre and have larger diameter. Innermost metaxylem vessel is very large and spherical or oval.

16. Phloem consists of sieve tubes, companion cells and phloem parenchyma. It exhibits exarch condition with its protophloem towards the periphery and metaphloem towards the centre.

17. Thick-walled, sclerenchymatous conjunctive tissue is present in between the vascular bundles.

Pith : 18. It is well-developed and parenchymatous.

19. The cells are round in shape and leave many intercellular spaces.

Identification:

(a) 1. Vessels are present in the xylem. 2. Vessels have perforated end walls with Scalariform or regularly arranged holes……….. Angiosperms

(b) 1. Vascular bundles are radial. 2. Exarch protoxylem…………………………. Root

(c) 1. Vascular bundles are more than 6.

2. Absence of Cambium. 3. Well-developed pith………………. Monocot

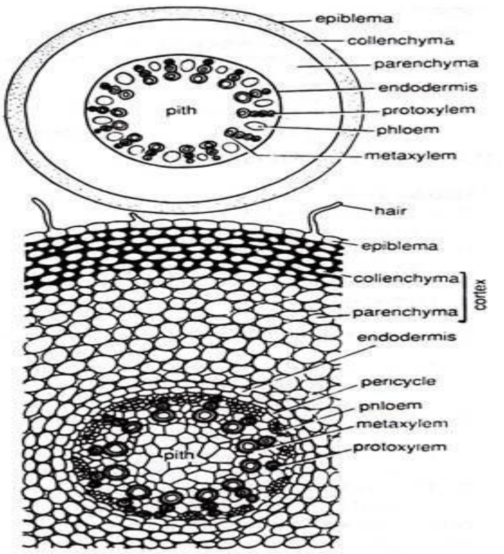

Fig. 173. Zea mays. Upper, T.S. root (diagrammatic); Lower, T.S. root (a part cellular).

Endodermis, Endodermis. single layer of cells surrounding the central stele (vascular tissue) in roots. The radial and transverse walls contain the hydrophobic Casparian band, that prevents water flow in or out of the stele through the apoplast. Also present in some stems.

- In a plant stem or root, a cylinder of cells the separates the outer cortex from the central core.
- The endodermis controls the flow of water and minerals within the plant.
- In most plants, this tissue is restricted to the roots.
- The cells are barrel-shaped and due to the accumulation of starch it is also called starch sheath
- It is in a plant stem or root, a tube of cells the separates the external cortex from the central core the endodermis controls the flow of water and minerals within the plant.
- Function: It acts as a stellar sheath and it also stores food.

The endodermal layer in a plant, almost always in the root, regulates the water and other substances that get into the plant. The **endodermis** is a single layer of cells that borders the cortex of a root. The whole system in which the **endodermis functions** allows the roots to select what gets into the vascular core.
exodermis and Definition of **exodermis**. : a layer of the outer living cortical cells of **plants** that takes over the functions of the epidermis in roots lacking secondary thickening.
The **exodermis** is thought to provide protection against water loss of the root to the soil, and also to serve as defense against microorganisms.
origin of lateral root. The **lateral roots** are endogenous in **origin** (from a deeper layer). The seat of its **origin** is cells of pericycle, usually opposite a protoxylem

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group, become meristematic and go on dividing periclinally and anticlinally. **Lateral Root** showing the Vascular Connection between it and the parent Stele.
Lateral roots are produced in a definite pattern. The youngest roots are closing (proximal) to the apex. The pattern of lateral root production is readily observed with tap root systems. The tap root can also be called the primary root while its branches are called secondary or lateral roots. The origin of lateral roots can be unraveled for species that have fibrous root systems. A clear pattern emerges with careful study. The hump penetrates into the cortex, and emerges as a lateral branch. Later, the hump differentiates into 3 regions of the root apex- dermatogen, Periblem and Plerome. Finally the lateral root comes out. The number of lateral roots corresponds

Functions of Roots :

Primary functions : are performed by the normal roots of almost all the plants, these functions include; anchorage of the plant to the substratum, absorption of water and minerals, conduction of the absorbed water and minerals to the stem.

Secondary functions : are performed by certain roots, which are specifically modified for the purpose only in some plants, such functions include; storage food, provision of additional support, absorption of atmospheric moisture, assimilation/photosynthesis, sucking food from host, reproduction, respiration, better gaseous exchange and mechanical functions like floating and balancing..