04

Plant form and function

Structure, Growth and Development of Plants

The main focus of this unit is on structure, growth and development of vascular plants.

Plants consist of a root system and a shoot system and roots and shoots grow at their tips, which are with meristematic properties and called as apices, buds or meristems.

Types of plant tissues, structure- function relationship

A Tissue is a group of one or more cell types which carries out specialized function(s).

Meristems, locations and role in plant growth

Plants have undifferentiated tissues called meristems, consisting of cells which constantly divide under suitable conditions and produce new cells. Some of these cells then elongate and differentiate to produce new tissues of the plant body and others remain as meristems. Meristems may have dormant periods. Due to the action of meristem new cells are added. Subsequently these cells get differentiated and therefore plant growth occurs by making new plant tissues.

Characteristics of meristematic cells

All cells in the meristems have common characteristics. They;

- are living cells
- are isodiametric (roughly spherical)
- are structurally and functionally undifferentiated
- have a central nucleus
- have a dense cytoplasm
- have ability to multiply

In meristem there are three overlapping zones of cells consisting of cells at successive stages of

- cell division
- cell elongation and
- differentiation

There are three types of meristems. They are;

1. apical meristems
2. lateral meristems
3. intercalary meristems

Apical meristems

These meristems are located at root tips and shoot tips. They add new cells that enable increase in length. This process is known as primary growth.

Lateral meristems

Vascular cambium and cork cambium are lateral meristems. They are found in woody plants and involve in the secondary growth in increasing circumference of roots and stems. The vascular cambium produces secondary xylem and secondary phloem. The cork cambium produces thick and tough periderm, replacing epidermis.

Intercalary meristems

Some monocots such as grasses show meristematic activity at the bases of stems and leaves (nodes). These are known as intercalary meristems. They allow rapid regrowth in damaged leaves.

Primary growth of roots

Elongation of root due to the activity of primary meristems located on root apex is called primary growth of the root.

During the growth three processes take place.

i. Cell division - due to mitotic division.
ii. Cell elongation
iii. Cell maturation - due to differentiation.

These stages are found in three overlapping regions starting from meristems.

The zone of cell division includes the root apical meristem and its derivatives. In this region, new cells are produced to both sides. Cells produced outward to the apical meristem are differentiated to form root cap which prevents damaging the root apical meristem from friction when grows through soil.

Cells produced inward to the meristem undergo elongation, in the zone of cell elongation. Root cells elongate, sometimes to more than ten times their original length. Hence the root is pushed forward through soil.

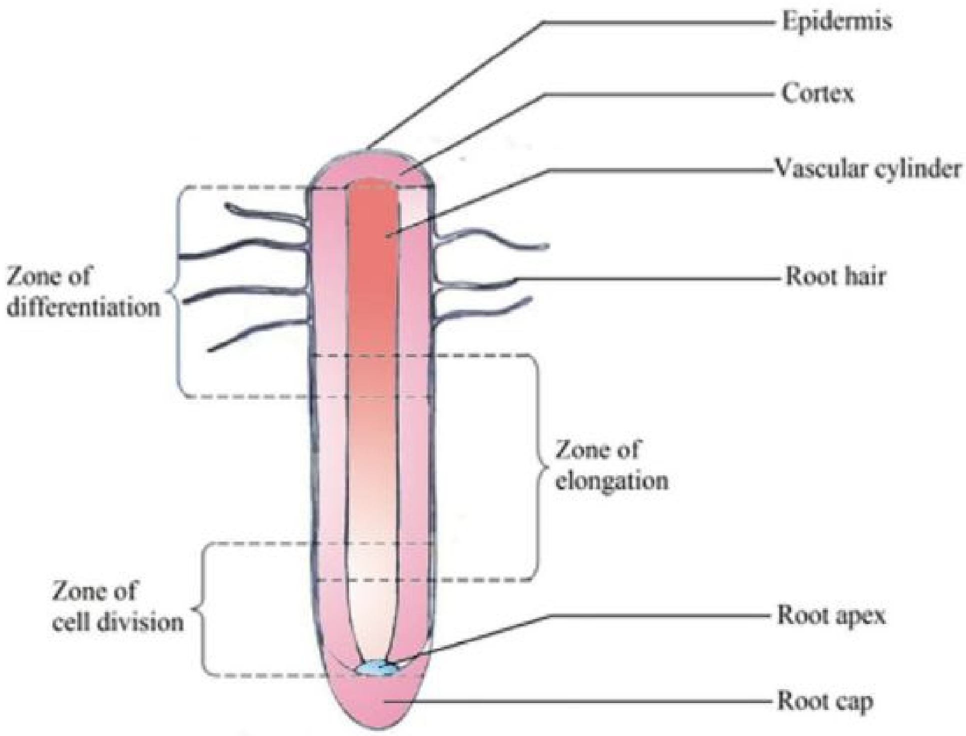


Fig. 4.1 The different zones of the root (zone of differentation , Zone of elonjation and zone of cell divisions

In the zone of maturation, the cells begin specializing in structure and function where cells complete their differentiation and become functionally mature. Primary structure of the root is formed as a result of primary growth.

Primary growth of the shoot:

Elongation of shoot is due to the activity of primary meristem located in shoot apex, and is called primary growth of the shoot.

A shoot apical meristem is a dome-shaped mass of dividing cells located at the shoot tip.

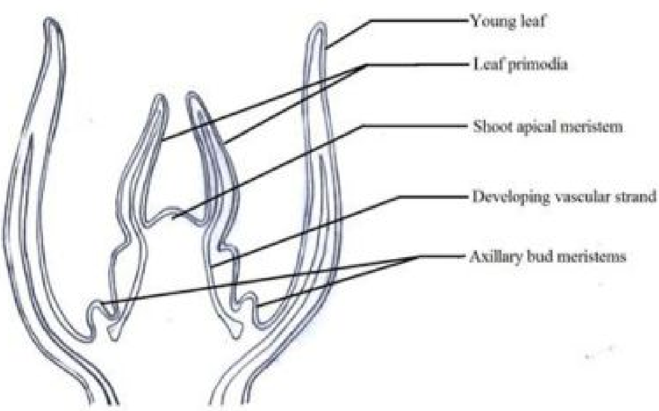


fig 4.2 . The Ls of the Shoot

Leaves develop from leaf primordia, finger-like projections along the sides of the apical meristems. Normally these primordia cover the shoot apical meristem.

Shoot apical meristem produces new cells only towards the stem, due to mitosis. After cell elongation, cell differentiation takes place.

Then the primary tissues of the stem are formed due to cell differentiation. Therefore, the height of the stem is increased due to primary growth.

Table 4.1 Differences between shoot apex and root apex

Shoot apex	Root apex
Found at tips of shoot	Found at the tip of the root
Protected by leaf primordial	Protected by root cap
Produces new cells only inwards	Produce new cells both sides outwards and inwards

Plant tissue systems

The new cells originating from the meristems are differentiated to perform specialized functions and form a plant tissue system. During differentiation process, they undergo changes in cytoplasm, organelles and cell wall. Therefore, several types of plant cells can be recognized according to their structure and function.

A tissue consists of group of one or more cell types which carries out specialized function(s).

Vascular plants have three main tissue systems. They are;

1. dermal tissue systems
2. ground tissue systems
3. vascular tissue systems

Dermal tissue system

This is the outer protective covering of plants.

e.g. Epidermis

- Protective layer in the stems and roots of the primary plant body and leaves
- Tightly packed single cell layer
- Normally covered by a cuticle which is a waxy epidermal coating in aerial parts
- Specialized cells such as guard cells, trichomes and root hairs are also found in epidermis

Functions of epidermis:

- Defense against physical damage and pathogens
- Cuticle helps to prevent water loss

- Root hairs involve in absorption of water and mineral ions
- Guard cells help gaseous exchange
- Trichomes (epidermal outgrowths such as hairs and glands) ;
  - o hair like trichomes reduce water loss, shiny hairs reflect excess light
  - o Some trichomes secrete chemicals involved in defense against insects/ pathogens/ herbivores,

Epidermis in older regions of stems and roots is replaced by a protective layer called periderm after the secondary growth

Ground tissue system

Ground tissue fills the gap between dermal tissue and vascular tissue, mainly consists of cortex (outer to vascular tissue) and pith (inner to vascular tissue). The ground tissue includes cells specialized for functions such as storage, photosynthesis, support and short distance transport.

Three main types of cells are present in ground tissue. They are;

1. parenchyma cells
2. collenchyma cells
3. sclerenchyma cells

Parenchyma cells

- Living even at functional maturity
- Mature cells have primary cell walls which are relatively thin, flexible and most of the cells lack secondary walls
- They have a large central vacuole

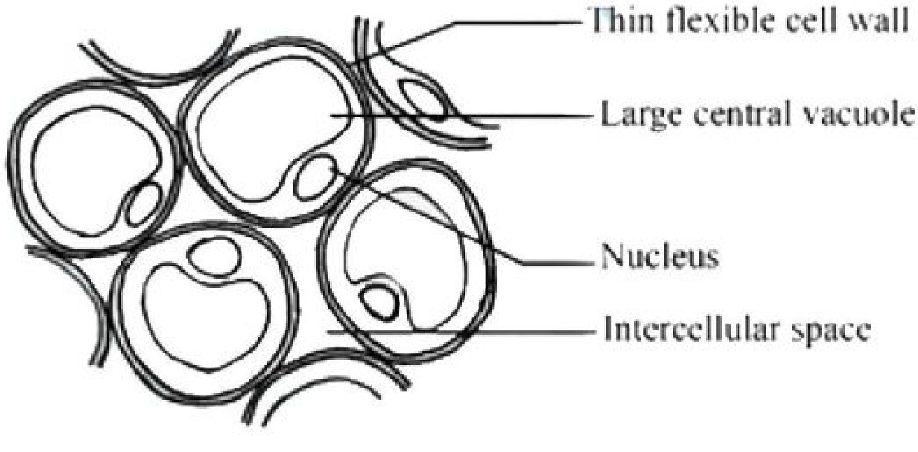


Fig 4.3 Diagram of General Parenchyma cells

Functions

- Perform most of the metabolic functions of the plants.

  e.g. synthesis of various organic products

- Storage-

  e.g. some cells in root and stems contain plastids (leucoplasts) which store starch.

- Most of the parenchyma cells retain the ability to divide and differentiate under suitable conditions. This ability is important in wound repair. These abilities also make it possible to multiply and differentiate cells even from a single parenchyma cell in tissue culture practices.

Collenchyma cells

- They are generally elongated
- They have thicker primary walls than parenchyma cells
- Their walls are unevenly thickened
- Young stems and petioles often have strands of collenchyma cells just below the epidermis
- Even at functional maturity they are living, flexible and elongating with stems and leaves they support

Functions

- Give mechanical support to leaves and stems without restraining growth

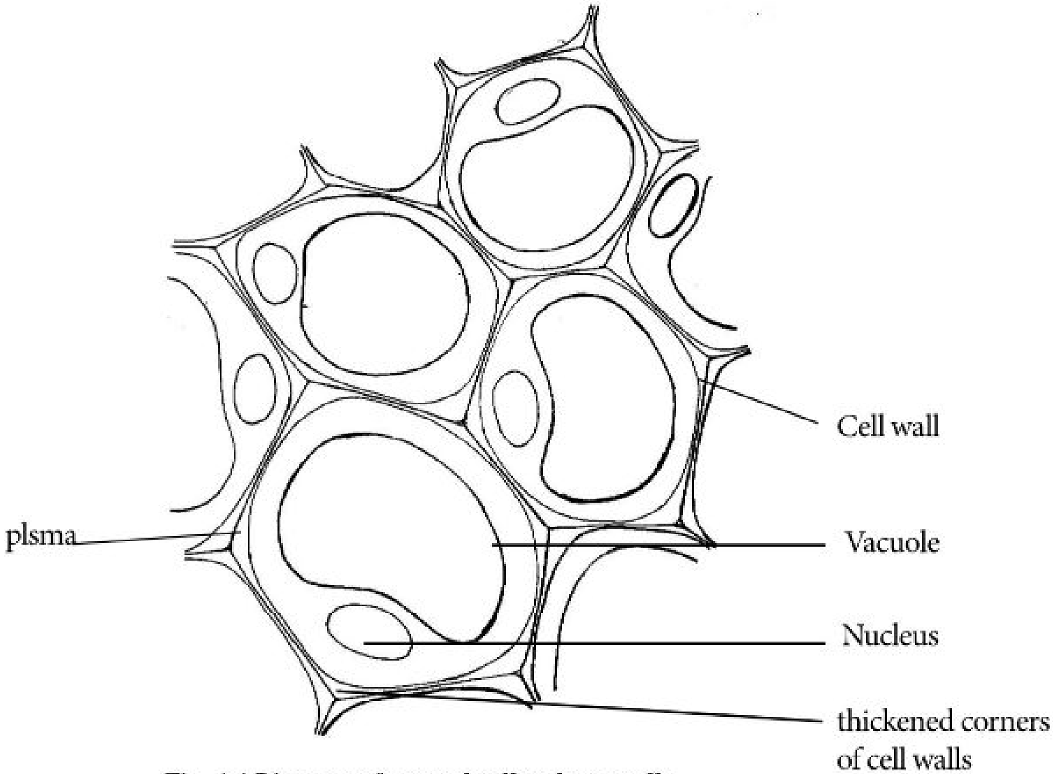


Fig 4.4 Diagram of general collenchyma cells

Sclerenchyma cells

- Secondary cell walls are produced after cell elongation
- They have secondary cell walls thickened by large amount of lignin
- They are dead cells at maturity

There are two types of sclerenchyma cells;

1. sclereids
2. fibers

Sclereids are shorter and wider than fibers and irregular in shape. They have very thick lignified secondary cell walls. They are found in places where growth has stopped e.g. nut shells, seed coats and flesh of coarse fruit.

Fibers are usually grouped in strands. They are long, slender and tapered. Used commercially to obtain fibers. e.g: coconut husk fiber, hemp fibers

Functions

Sclereids and fibers are specialized to provide support and strength.

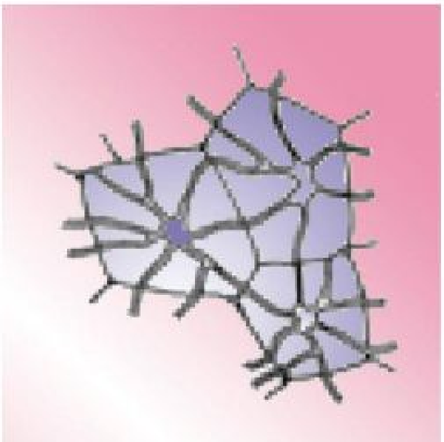


Fig 4.5 : Diagram of T.s of sclereids

Vascular tissues- Xylem and phloem

Xylem tissue

- It consists of vessel elements, tracheids, fibers and parenchyma cells in angiosperms and some of the gymnosperms.
- Vessel elements and tracheids mainly conduct water.
- They are dead at functional maturity.
- Fibers give mechanical strength.
- Parenchyma functions in storage and in radial transportation.

Vessel elements

- In all angiosperms and some gymnosperms, contain vessel elements
- They are cylindrical and long.
- They are wider, shorter and have thinner walls than tracheids
- Secondary walls are thickened by lignin
- They provide support to prevent collapse under tension of water transport
- Perforation plates are present at end walls of vessel elements. Other walls are interrupted by pits
- They form xylem vessel by aligning end to end with perforation plates
- Water flows freely through perforation plates

Tracheids

- Found in all vascular plants
- Long, thin cells with tapering ends
- Secondary walls are thickened with lignin and often interrupted by pits
- Water moves from end to end through pits
- Thickening by lignin provides support to prevent collapse under water transport

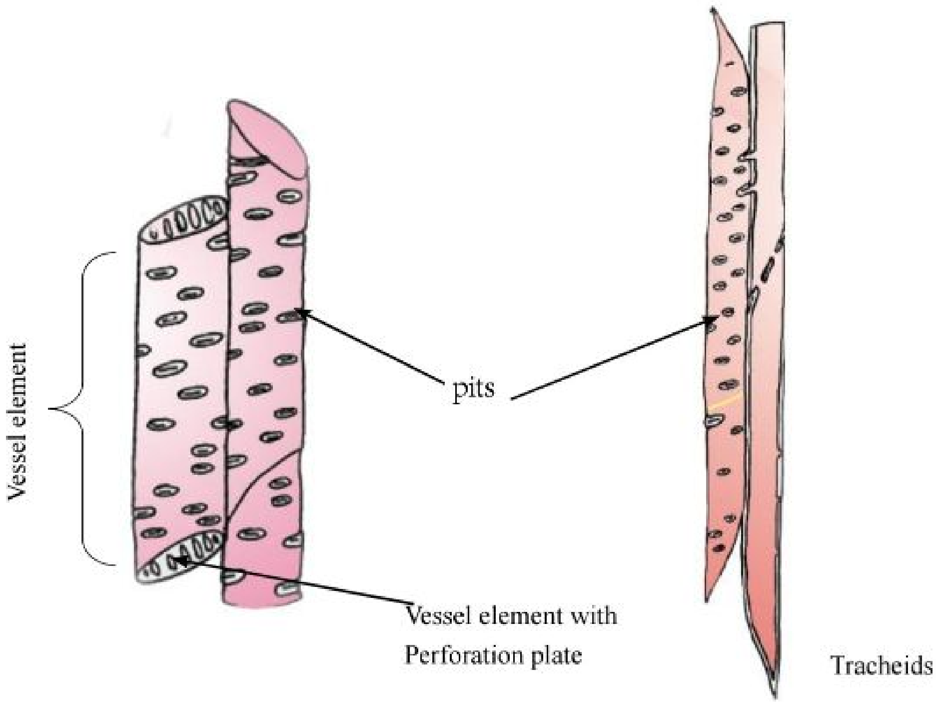


Fig 4.6 Diagram of L.S of vessel elemetmt amd tracheids

Phloem tissue

- It consist of sieve tube elements, companion cells, parenchyma cells and fibers in angiosperms
- Except fibers other phloem cells are living cells
- In seedless vascular plants and gymnosperms sieve tube elements and companion cells are absent. Instead of sieve tube elements, long narrow cells called sieve cells are present in these plants.

Sieve tube elements

- Sieve tube elements lack nucleus, ribosomes, a distinct vacuole, and cytoskeletal elements-
- cytoplasm reduced into a thin peripheral layer.
- Absence of these allow passing of nutrients more freely
- Chains of sieve tube elements are aligned to form sieve tubes
- The end walls between sieve tube elements contain porous plate called sieve plate.
- Sieve plate allows movement of fluid from one sieve element to the next.

Companion cells

- They are non-conducting cells.
- Found alongside in each sieve tube element and connects with sieve tube element by numerous plasmodesmata
- Nucleus and ribosomes of these cells also serve to adjacent sieve tube element
- Some companion cells in leaves help in phloem loading and in other organs unloading

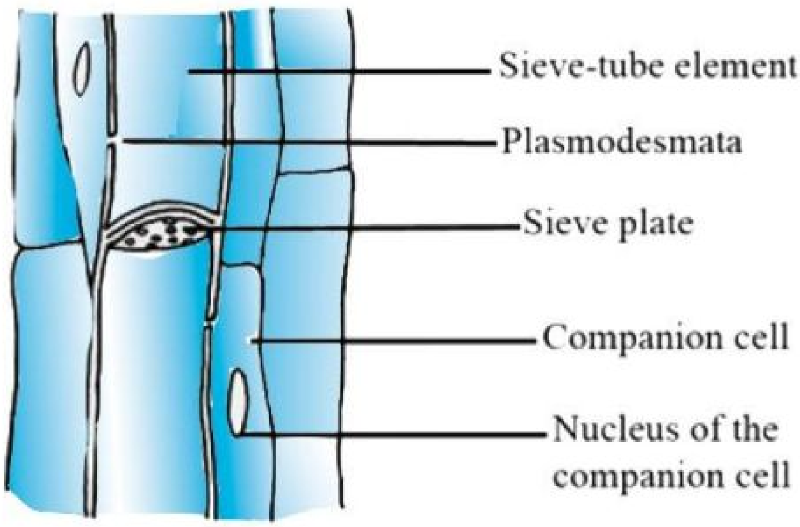


Fig -4.7 Longitiudinal view of sieve tube elements and companion cells

Growth and development process of a plant

Plant growth

Growth involves irreversible increase of dry mass associated with the development of an organism. Often it is associated with increase of cell number as a result of producing more cells from the meristem accompanied by cell elongation.

Plants continue growth throughout the life known as indeterminate growth.

Primary structure root

Apart of the distribution pattern of xylem and phloem tissue structures of both monocot and dicot roots are more or less similar.

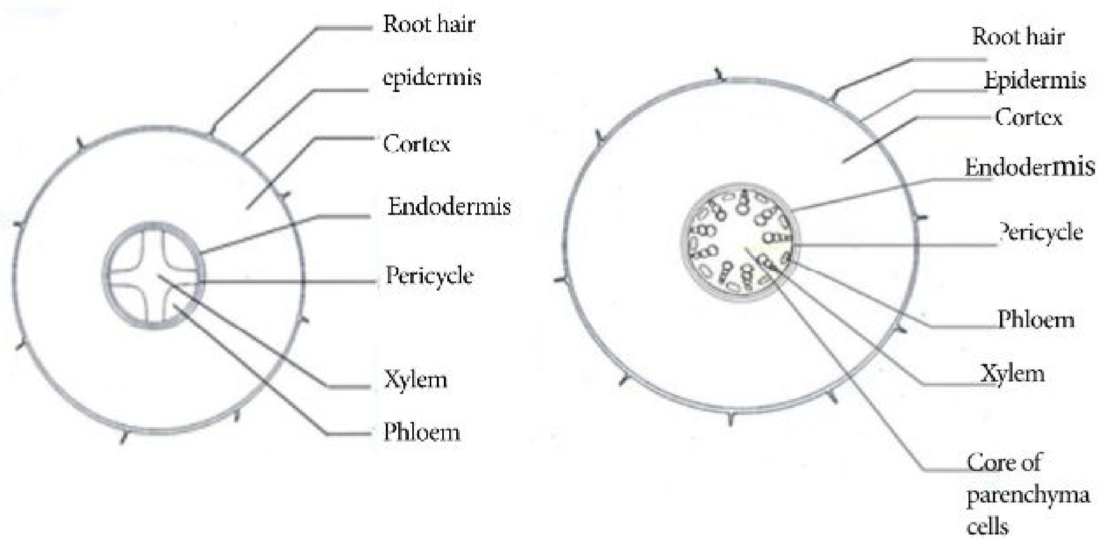


Fig- 4.8 Primary structure of typical Dicot and Primary structure of typical monocot root

- Outermost cell layer is epidermis. Cells have unicellular outgrowths called root hairs. Epidermis protects inner parts while root hairs involve in the absorption of water and minerals.
- Between epidermis and vascular cylinder there is a ground tissue known as cortex which is made up of mostly parenchyma cells with intercellular spaces.
- Cortex mainly stores carbohydrates, and also ransports water and minerals towards the endodermis.
- Innermost single cell layer of the cortex is the endodermis.
- Endodermis contains a suberin belt called casparian strip and no inter-cellular spaces. Therefore, it blocks cortical apoplast from the vascular apoplast.
- Interior to endodermis there is a pericycle containing two or three parenchyma cell layers. These cells in dicot roots have meristematic function and involve in the formation of lateral roots and secondary growth of the root.

- Inner to pericycle there is vascular tissues as a solid core. Xylem can be found in the middle and it is star shaped in a cross section of a dicot root. Phloem is located in the groove between the arms of xylem.
- In monocot roots, vascular tissue consists of a central core of parenchyma cells surrounded by a ring of alternating xylem and phloem. Pericycle in monocot roots is not meristematic

Primary structure of dicotyledonous plant stem :

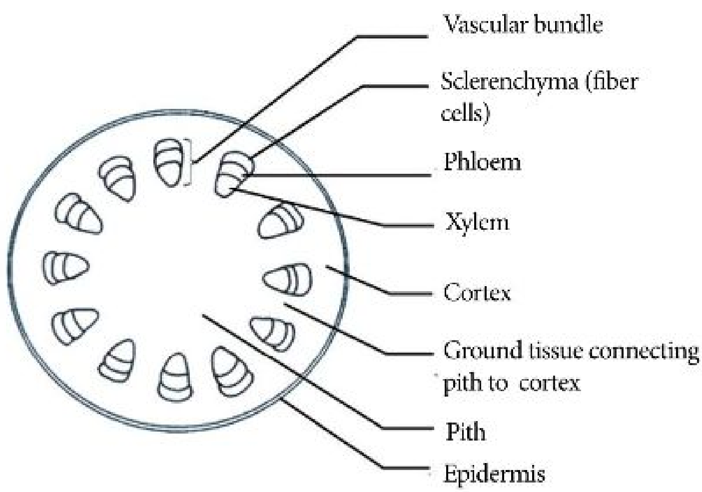


Fig 4.9 Primary structure of T.S of dictolyledonous plant stem

- The outermost epidermal cell layer protects inner parts from desiccation and infections. The epidermis is interrupted by pores called stomata.
- Interior to epidermis is cortex mostly containing parenchyma cells.
- Collenchyma cells may also be present just beneath the epidermis to provide strength.
- Sclerenchyma such as fibers are also present in the cortex to provide additional support.
- Vascular bundles arranged as a ring. Vascular bundle contains primary phloem towards cortex primary xylem towards pith and in-between a cambium tissue.
- Outside vascular bundle, there is a cluster of sclerenchyma cell.
- Inner to vascular bundles large pith which is also made up of parenchyma cells can be found.
- Lateral shoots develop from axillary buds

Primary structure of the monocotyledonous stem:

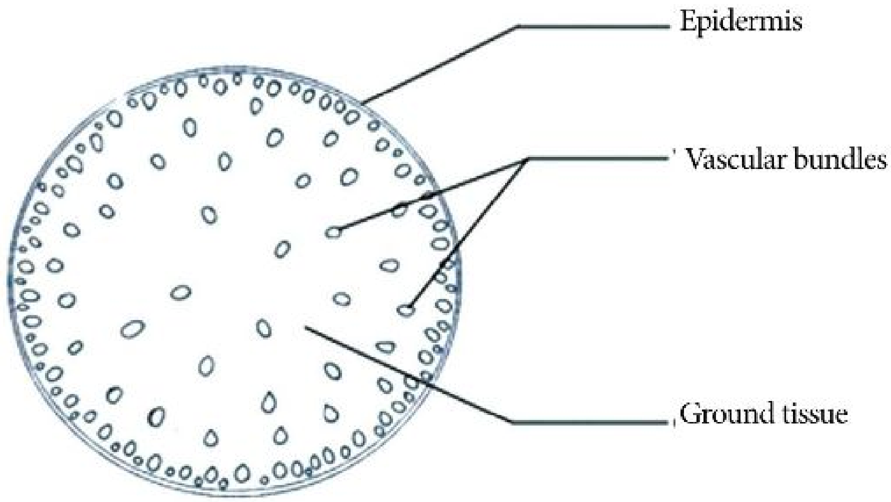


Fig :4.10 Primary structue of cross section of typical monocot stem

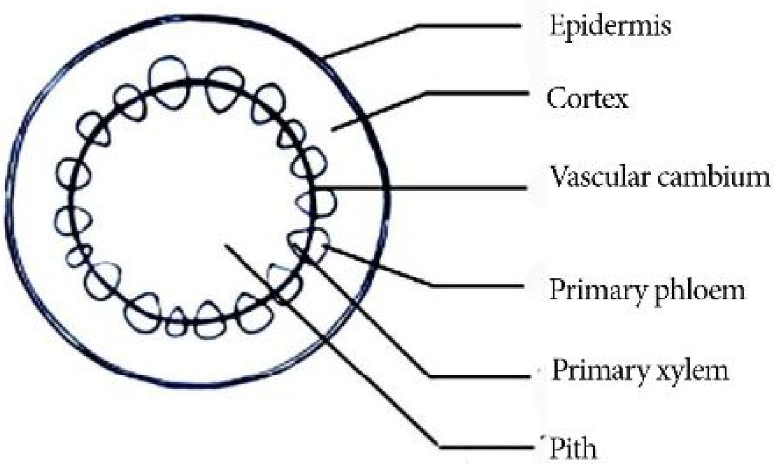
- Ground tissue of monocot shoot is not differentiated into cortex and pith
- The vascular bundles are scattered throughout the ground tissue in most monocot stems.
- Each vascular bundle is surrounded by sclerenchyma. It consists of a xylem tissue and a phloem tissue but no cambium inbetween xylem and phloem.

Secondary growth :

- Increase in the diameter of stems and roots in plants due to the new cells produced by lateral meristems is called secondary growth.
- This occurs in stems and roots of woody perennial plants including, all gymnosperms species and many dicot species.
- Lateral meristems, namely vascular cambium and cork cambium produce cells and tissues in the secondary growth.
- The vascular cambium adds secondary xylem (wood) towards primary xylem and secondary phloem towards primary phloem, increasing vascular flow and support for the shoots.
- The cork cambium produces tough thick covering consisting mainly of wax impregnated cells that protect the stem from water loss and from invasion of insects, bacteria and fungi.
- In woody plants, primary growth and secondary growth occur simultaneously. As the primary growth adds new cells and lengthens stems and roots in the younger regions of a plant, secondary growth increases the diameter of stems and roots inolder regions where. primary growth has ceased.

- Secondary vascular tissue is produced by the action of vascular cambium.
- In a typical woody stem, the vascular cambium consists of a continuous cylinder of undifferentiated cells of often only a single cell layer in thickness, located outside the pith and primary xylem and to the inside of the cortex and primary phloem.
- In a typical woody root, the vascular cambium forms laterally exterior to the primary xylem and interior to the primary phloem and pericycle.
- As these meristematic cells divides they increase circumference of the vascular cambium and also add secondary xylem to the inside of the cambium and secondary phloem to the outside.
- Viewed in a cross section, the vascular cambium appears as a ring of initials.
- Some initials are elongated and are oriented with their long axis parallel to the axis of stem or root.
- They produce cells such as tracheids, vessel elements, parenchyma and fibers of the xylem, as well as sieve-tube elements companion cells, phloem fibers and phloem parenchyma.
- The other initials are shorter and oriented perpendicular to the axis of the stem or root.
- They produce vascular rays-mostly parenchyma cells that connect secondary xylem and phloem, store carbohydrates and aid in wound repairing.
- As the secondary growth continues over many years, layers of secondary xylem (wood) accumulate.
- The walls of the secondary xylem cells are heavily lignified and account for the hardness and strength of wood.
- During early stages of secondary growth, the epidermis pushed outwards, causing it to split, dry and falls off the stem or root.
- It is replaced by two tissues produced by cork cambium, a cylinder of dividing cells that arises in the outer layer of cortex in stems and in the outer layer of pericycle in the roots.
- Cork cambium produces cork cells to exterior.
- Cork cambium and tissues it produces are collectively called periderm
- As the cork cells mature, they deposit a waxy, hydrophobic material called suberin in their walls and they become dead cells.
- The cork tissues function as a barrier that helps protect the stem or root from water loss, physical damages and pathogens.
- Each cork cambium and the tissues it produces comprise a layer of periderm which is impermeable to water and gasses.

- For gaseous exchange small pores are present in the periderm known as lenticels which are formed by loosely arranged cork cells. They appear as horizontal slits.
- Further growth of stem or root breaks the layer of cork cambium and it lacks its meristematic activity and its cells become cork cells
- A new cork cambium is initiated inside which with produce a new layer of periderm.
- As new cells are added, the outer regions of cork will crack and peel off in many tree trunks.
- Due to the tissue layers produced by vascular cambium and cork cambium, girth of the stem or root increases in secondary growth.
- Bark is all tissues out of the vascular cambium (cork is commonly and incorrectly referred to as bark). Its main components are secondary phloem and periderm.



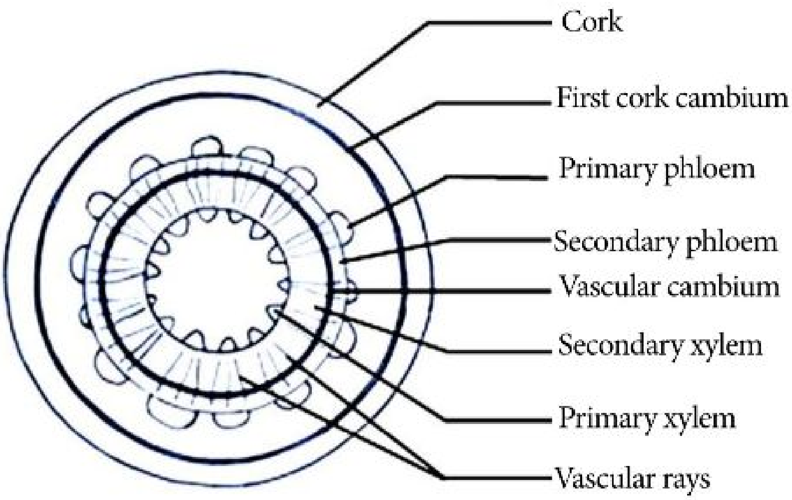


Fig. 4.11- The process of secondary growth of dicot woody plant

Heart Wood and Sap wood:

- As a woody plant ages, the older layers of secondary xylem no longer transport water and minerals.
- These layers are called heartwood because they are close to the centre of the stem or root.
- The newest outer layers of secondary xylem, still transport xylem sap are known as sapwood.
- The heartwood is generally darker than sapwood because of resins and other compounds that permeate the cell cavities and help protect the core of the tree from fungi and wood-boring insects.
- Only the young secondary phloem functions in phloem translocation and old secondary phloem is sloughed off.

Hard wood and soft wood

- Hard wood is the secondary xylem of dicot angiosperms while wood of gymnosperms are named soft wood
- Xylem vessels are absent in soft wood

Growth rings:

- The thickness of secondary xylem and the lumen of vessels are larger in periods of warm and wet seasons compared to other growth season of the year. These differences are visible in a cross section as lighter and darker rings. These are referred as growth rings.
- In temperate regions, wood that develops early in spring is known as spring wood. This xylem tissue consists of xylem vessels with large lumens and thin walls. This structure maximizes delivery of water to new leaves.
- The wood produced during rest of the growing season is called summer wood. These xylem tissues consist of xylem vessels with thick walls and small lumen, do not transport much water but provide more support.
- These two woods collectively known as an annual ring. A year's growth appears as distinct ring in the cross section of most tree trunks and roots. Therefore age of the tree can be estimated by counting annual rings in trees growing in temperate regions.

Shoot, architecture and light capture

- Length of the stem and branching pattern are designed to capture maximum light.
- Plants grow tall to avoid shading from neighboring plants.

Stem

- Most tall plants have thick stem with strong mechanical support.
- Woody plants undergo secondary growth thereby make their tall stem stronger.
- Vines rely on other objects to reach higher levels to capture more light.

Branching pattern

- There is a variety in branching pattern.
- Some plants are unbranched and still others are well branched.
- This variation in branching pattern enables the plant to absorb maximum light in the ecological niche it occupies.

Leaves

Leaf size

- Size of the leaf vary, based on the place where the plant grows.
- Largest leaves are found in plants growing in rain forests.
- Smallest leaves are found in plant species inhabiting dry or very cold environments.

Phyllotaxy

- This is the arrangement of leaves on the stem.
- The arrangement may be one leaf, two leaves or several leaves per node.
- Phyllotaxy helps the plant to capture maximum sunlight.

Leaf orientation

- Leaves may be horizontally oriented.
- They capture light efficiently in low light conditions.
- Some plants have vertically arranged leaves. e.g. Grasses
- This is to avoid the possible damage caused by exposure of leaf to the over intense light. When leaves are nearly vertical, light rays are parallel to the leaf surfaces, so no leaves receive too much of light.

Process of Gaseous Exchange in Plants

Anatomy of typical dicot and monocot leaves

In most vascular plants, leaves are the main photosynthetic organs. The exchange of gases occurs through stomata in the upper and lower epidermis. Epidermis is usually a single cell layer. In between the upper and lower epidermis, there is a ground tissue called the mesophyll. This tissue consists of parenchyma cells, specialized for photosynthesis.

In dicot leaves, stomata are, mainly found in the lower epidermis. The mesophyll consists of two distinct layers called palisade and spongy. Palisade mesophyll consists of elongated cells that are arranged in one or more layers. This can be found in the upper part of the leaf, just beneath the upper epidermis.

The spongy mesophyll can be found between the palisade layer and lower epidermis. They are loosely arranged with many air spaces. Spongy mesophyll cells have less chloroplasts than in palisade mesophyll cells.

The vascular tissue of the leaf is continuous with vascular tissue of the stem. Veins in the leaf is highly branched (net like venation) in the mesophyll layer. Each vein is protected by a bundle sheath layer.

In monocot leaves, stomata are present in both lower and upper epidermis. Mesophyll is not differentiated into palisade and spongy layers. Chloroplasts are abundant in all mesophyll cells. Veins are parallelly arranged (parallel venation).

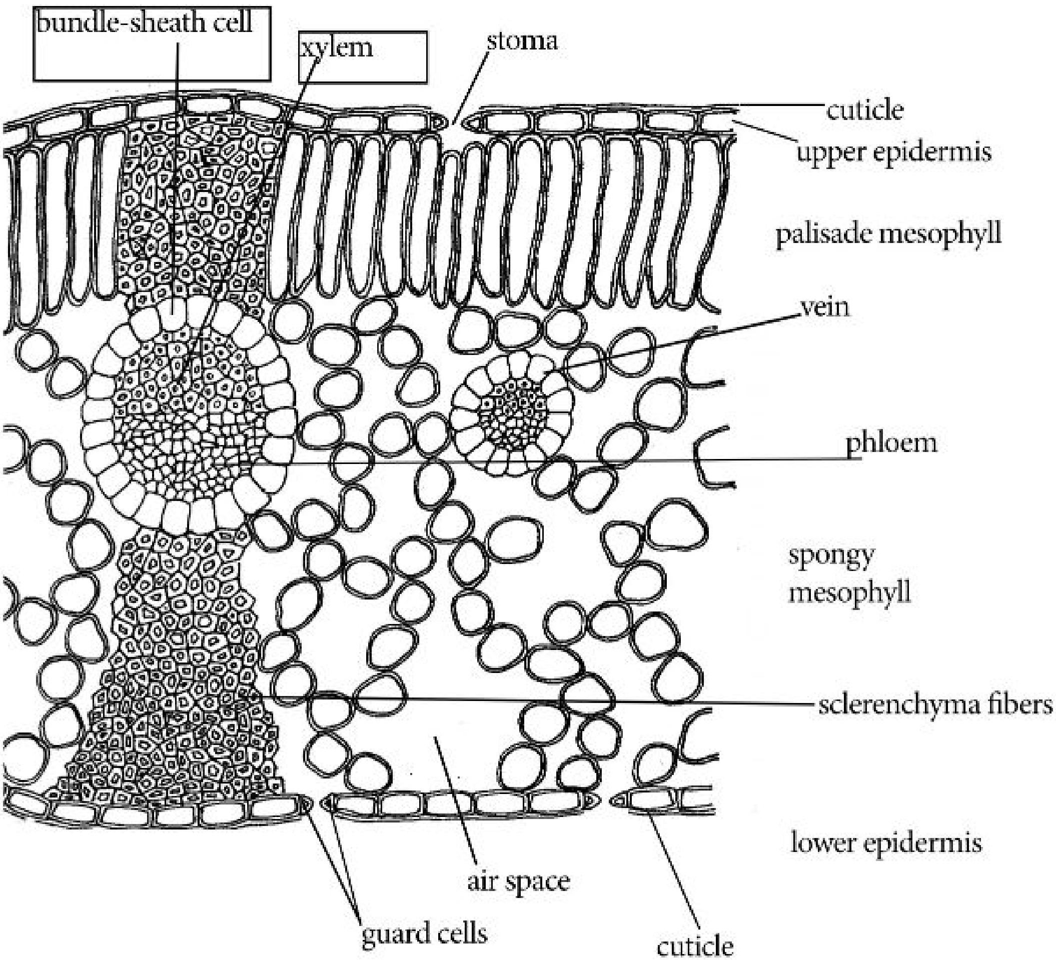


Fig. 4.12 T.S of typical Dicot Leaf

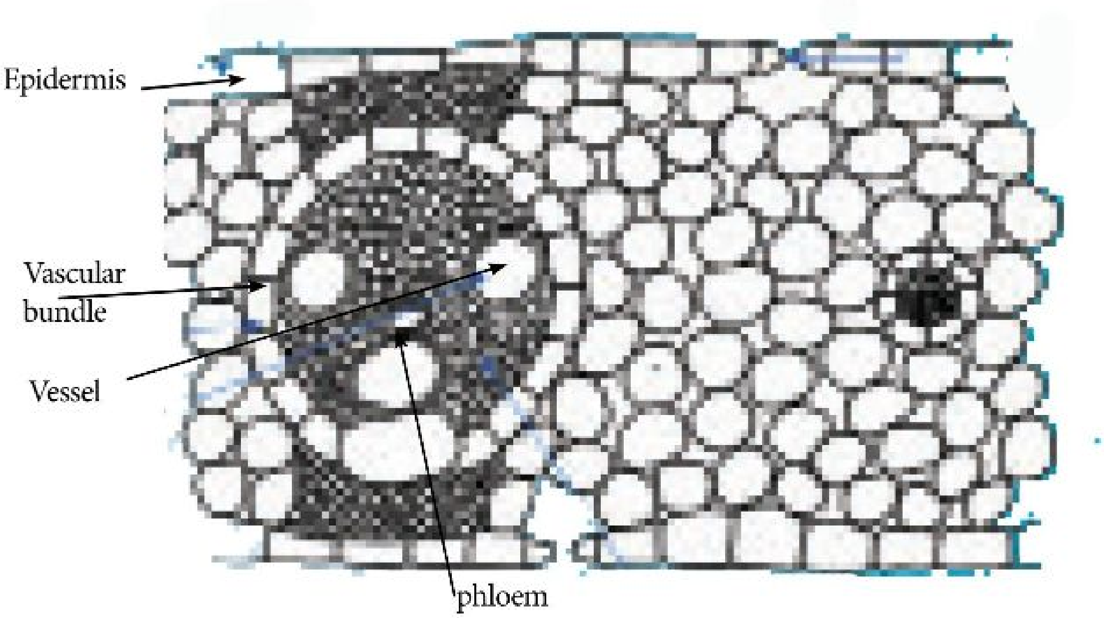


Fig 4.13 T.S of typical Monocot Leaf

Structure of Stomata

Stomata are pores surrounded by guard cells in the epidermis of the leaves and stems of plants which can open and close. Guard cells are modified epidermal cells which have a distinct shape and are the only epidermal cells that contain chloroplasts. Guard cells are typically bean shaped in angiosperms. The guard cell walls are unevenly thickened. The inner cellulose wall is thicker and less elastic than the outer wall. Some of the cellulose microfibrils are radially arranged to form inelastic hoops around guard cells.

Guard cells regulate the diameter of the stomata by changing shape, widening or narrowing the gap between the pair of guard cells.

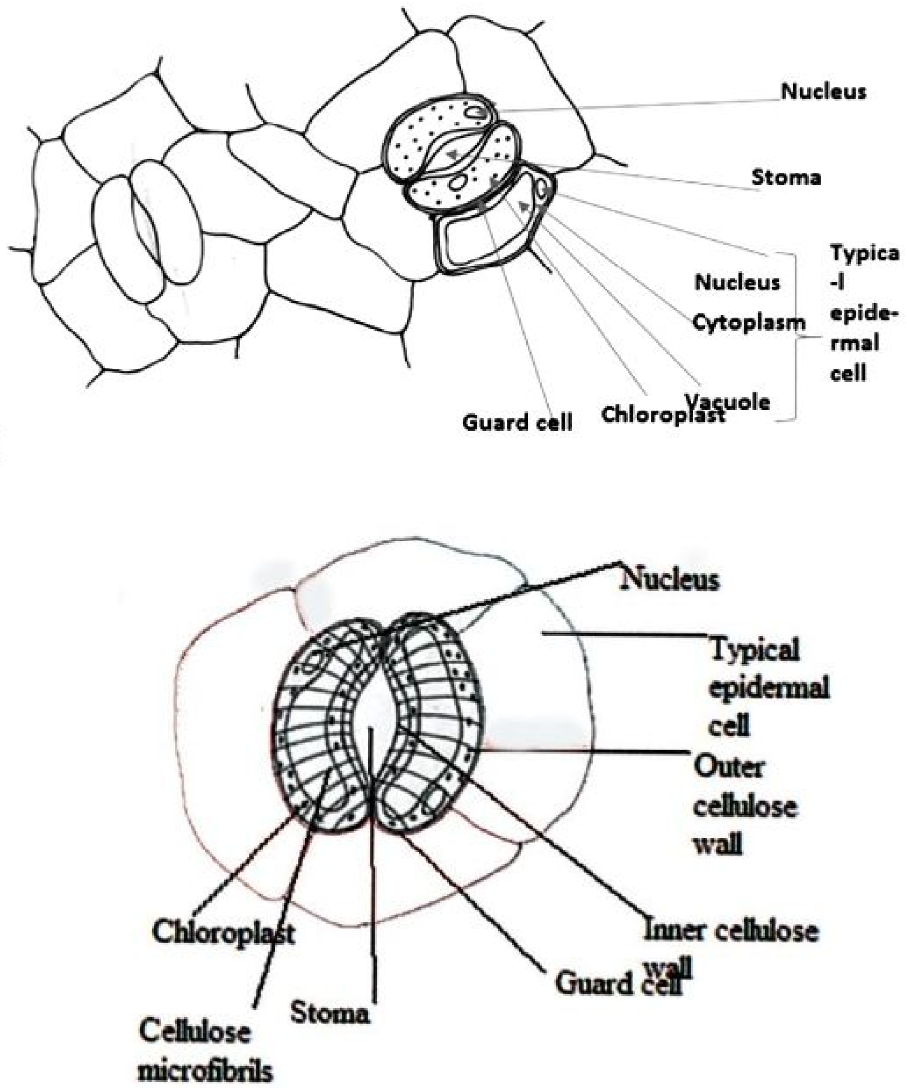


Fig - 4.14 Structure of the stomata

Gaseous exchange

Gaseous exchange is the exchange of gases between the cells of the organism and the environment. In plants gaseous exchange is possible via stomata and lenticels. In addition to these a small amount of gases can be exchanged via cuticle. There is no special system within plants for the transport of O_2 and CO_2. These gases move entirely by diffusion.

Mechanism of opening and closing of stomata

Stomatal opening and closing depends on changes in turgor of the guard cells. If water flows into the cells by osmosis their turgor increases, and they expand, but they do not expand uniformly in all directions. The relatively inelastic inner walls make them bend and draw away from each other. The result is that the pore opens. If the guard cells lose water, the reverse happens- their turgor decreases, and their inner walls become straighter thus closing the pore.

The K+ influx hypothesis explains the mechanism.

K+ influx hypothesis

During the day time, the guard cells actively accumulate K+ from neighboring epidermal cells, thus lowering their water potential that leads to the inflow of water by osmosis from the surrounding epidermal cells. As a result the turgor pressure in guard cells increase, opening stomata.

The accumulation of K+ in the guard cells requires the energy which is provided by the transfer of electrons during photosynthesis of the chloroplast in guard cells.

Stomatal closing occurs by loss of K+ from guard cells to neighbouring epidermal cells. It leads to exosmosis of water from guard cells. As a result the turgor pressure in guard cells decrease, closing stomata.

Abscisic acid (ABA) also plays a role in K+ influx mechanism

Role of ABA in stomatal closure in drought

- ABA is produced in roots and leaves in response to water deficiency.
- Production of ABA leads to close the stomata by removal of K+in guard cells.
- This prevents the wilting of the plant.

Factors affecting stomatal action

- Stomata open during day and mostly closed at night. Light stimulates accumulation of K+ in guard cells.
- Decrease in CO_2 concentration in substomatal cavity lead to open stomata
- Internal clock in the guard cells controlling their daily rhythm of opening and closing of stomata.
- Environmental stresses such as drought, high temperature and wind can cause stomata to close during the day time.

Acquisition of water and minerals

Need for transport

As land plants evolved and increased in number, competition for light, water and nutrients also increased. As a result, the size and complexity of plant body increased. Therefore the simple ways of transportation of water and material became inadequate leading to the evolution of vascular tissues, consisting of xylem and phloem to carryout long distance transport in plants.

e.g. the xylem transports water and minerals from roots to shoots.

the phloem transports products of photosynthesis from where they are made or stored to where they are needed.

Methods of water and solutes movement

Both active and passive transport mechanisms occur in plants

- Active transport
- Passive transport
  - Diffusion
  - Osmosis
  - Imbibitions
  - Facilitated diffusion
  - Bulk flow- long distance

(Diffusion, Osmosis, Imbibitions, Facilitated diffusion: Short distance)

Passive transport occurs spontaneously, and it does not require metabolic energy (ATP).

Movement of some materials across membranes takes place using ATP and that process is called an active transport.

Diffusion

Molecules have an energy called thermal energy, due to their constant motion. One result of this motion is diffusion.

In the absence of other forces, the movement of molecules of a substance from a place where it is more concentrated to place where it is less concentrated, due to random motion of molecules is called diffusion.

The motion of a molecule is random, but movement of a population of molecules by diffusion is directional.

Therefore, diffusion takes place according to a concentration gradient, spontaneously and not using metabolic energy (ATP).

Diffusion takes place across the membrane also, if the membrane is permeable to those molecules.

e.g. Water and soluble materials can diffuse through the cellulose cell wall

O_2 and CO_2 can diffuse through the plasma membrane

Osmosis

Osmosis is a special type of diffusion. The diffusion of free water molecules across a selectively permeable membrane is called osmosis.

Free water is water molecules that are not bound to solutes or surfaces.

Imbibition

The physical adsorption of water molecules by hydrophilic materials is called imbibition.

e.g. adsorption of water molecules by the cellulose cell walls.

Facilitated diffusion

Movement of water and hydrophilic solutes across the membranes passively with the help of transport protein that span the membrane is called facilitated diffusion.

Transport proteins are very specific. They transport some substances but not the others. This movement also takes place along concentration gradient and it is a passive movement.

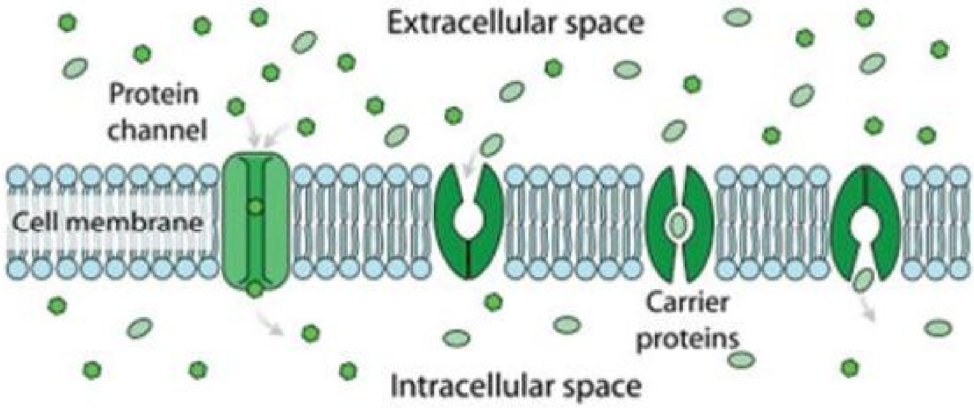


Fig 4.15 -The process of as facilitated morcment

Bulk flow

Bulk flow is the movement of liquid and the materials (entire solution) in response to pressure gradient. Always the bulk flow transports materials from higher pressure to lower pressure region.

It is a long-distance transport method. This flow does not occur through the membranes and occurs at much greater speed than diffusion. This method of transport is independent of solute concentration gradient.

Concept of water potential

The physical property that predicts the direction in which water will flow governed by solute concentration and applied pressure is called water potential. Water potential is related to potential energy of water molecules.

Any system that contains water has a water potential. Free water moves from regions of higher water potential to regions of lower water potential, if there is no barrier to its flow.

Water potential is denoted by Ψ. Ψ is measured in a unit of megapascal (MPa). Arbitrary the Ψ of pure water in a container open to the atmosphere under standard conditions (at sea level and room temperature) is 0 MPa.

Both solute concentration and physical pressure can affect water potential; as expressed in the water potential equation.

$\Psi = \Psi s + \Psi p$

Ψ= water potential

Ψs= solute potential

Ψp= pressure potential

Solute potential

Solute potential (Ψs) is directly proportional to the molarity of a solution. (Ψs is also called osmotic potential. Solutes affect the direction of osmosis.)
The solutes in plants are typically mineral ions and sugars.

Ψ of pure water is 0 MPa.

When solutes are added, they bind water molecules and reduce free water molecules, reducing capacity of the water to move and do work.

In this way an increase in solutes has a negative effect on water potential. Therefore, Ψs of a solution is always expressed as a negative number. As the solute concentration increases, Ψs will become more negative.

e.g: Ψs of the 0.1M sugar solution is -0.23MPa

Pressure potential

Pressure potential (Ψp) is the physical pressure on a solution. Ψp can be positive or negative relative to atmospheric pressure.

e.g: Ψp of a xylem vessel is usually less than -2 MPa as xylem vessels are under tension (negative pressure)

Ψp of a living cell is a positive value because living cell is usually under positive pressure due to osmotic uptake of water.

The cell contents press the plasma membrane against the cell wall. Then press against the protoplast, producing a pressure called turgor pressure. When turgor pressure increases, the Ψ of cell also increases.

Water potential of a cell

Cell is a system containing water. Therefore, it has a water potential. The protoplast is an aqueous system and it contains solutes. Therefore, it has a solute potential (Ψs) which is negative. Because of Ψs, Ψ of the cell is decreased.

Due to the turgor pressure internal pressure of protoplast increases and increases pressure potential (Ψp) of the cell. Because of Ψp, Ψ of cell increased.

Therefore, water potential (Ψ) of a cell is given by the following equation.

$\Psi = \Psi s + \Psi p$

Entry of water into vacuolated cell across the cell membrane

If a cell is placed in a solution, direction of water movement depends on the water potential of external solution and protoplast.

Take a fully flaccid cell; (as a result of water losing)

The Ψp of that cell is 0;

$\Psi p = 0$; $\Psi s = \Psi$

Ψs of pure water is 0 and addition of solutes will increase the negative value of Ψs or become more negative. Suppose this flaccid cell is placed in a solution of higher solute concentration (more negative solute potential) than the cell itself, since the external solution has a lower (more negative) water potential, water diffuse out of the cell. The protoplast of the cell shrinks and pulls away from the cell wall. This process is known as plasmolysis.

Suppose this flaccid cell is placed in pure water ($\Psi = 0$ MPa). The cell has a lower water potential than the pure water as it contains solutes. Therefore, water enters the cell by osmosis. Then the protoplast of the cell begins to swell and press the plasma membrane against the cell wall. The partially elastic cell, exerting a turgor pressure, contains the pressurized protoplast. Therefore, Ψp is increased gradually. The maximum value of $\Psi p = \Psi s$ of the cell. Therefore, Ψ becomes 0. This matches the water potential of extracellular environment, 0 Mpa. Then a dynamic equilibrium is formed and there is no further net water movement. If the cell has the maximum value for Ψp, (it equal to the Ψs of the cell) the cell is said to be in fully turgid state. (fully turgid or fully flaccid cells are not found in nature).

Therefore, if non-woody tissue is placed in a solution with higher water potential, it is stiffened and is very rigid. Therefore, turgor pressure helps support of non woody plants. Turgor pressure is also important in cell elongation. Loss of turgor results in wilting, a condition where leaves and stem droop.

Movement of water and minerals from soil solution to plant root

The cells near the root tips of the roots are important because most of the absorption of water and minerals occurs there. In this region, the epidermal cells are permeable to water and many are differentiated to root hairs. Root hairs account for much of the absorption of water by roots, due to increase in surface area.

The root hairs absorb the soil solution, which consists of water molecules and dissolved mineral ions that are not bound tightly to soil particles. This absorption takes place across the plasma membrane. Water can enter root hair by osmosis, a passive movement along the concentration gradient.

But in the root hairs concentration of mineral ions is greater than that of soil solution. K+ concentration in the root hair is hundreds of time greater than in the soil solution. Therefore, mineral ions transport occurs against concentration gradient, by an active transport.

The soil solution is also absorbed into hydrophilic walls of the epidermal cells and passes freely along the cell walls and the extracellular spaces into the root cortex.

Radial transport

Transport of water and minerals entered from soil to root cortex into the xylem of the root is known as radial transport.

The endodermis, the innermost layer of cells in the cortex, functions as the last check point for selective passage of the minerals from the cortex into the vascular cylinder. All materials which enters root through cell walls and extracellular spaces should cross the membranes of endodermis. Therefore, unwanted materials can be selectively excluded.

Three routes are used in the radial transport. They are:

1. apoplastic route
2. symplastic route
3. transmembrane route

Apoplastic route

The apoplastic route consists of everything external to the plasma membrane of living cells and includes cell walls, extracellular spaces and the interior of dead cells such as vessel elements and tracheids.

Water and solutes move along continuum of the cell walls and extracellular spaces and it is known as apoplastic route.

Uptake of soil solution by the hydrophilic walls of root hairs provides access to the apoplast. Water and minerals then can diffuse into cortex along this matrix of walls and extracellular spaces.

Endodermis blocks apoplastic route by a barrier located in the transverse and radial walls of endodermal cells, called the casparian strips. It is a belt made of suberin which is impervious to water and mineral salts. Thus water and minerals cannot cross the endodermis and enter the vascular cylinder via apoplast. Therefore, water and minerals cross the selectively permeable plasma membrane before entering the vascular tissue and keep unneeded and toxic materials out.

The endodermis also prevents solutes that have accumulated in the xylem from leaking back into the soil solution.

Symplastic route

The symplast consists of the entire mass of cytosol of all living cells in a plant, as well as plasmodesmata, the cytoplasmic channels that interconnect them.

In the symplastic route, water and solutes move along the continuum of cytosol. This route requires substance to cross a plasma membrane once, when they first enter the plant. After entering one cell, substances can move from cell to cell via plasmodesmata.

Transmembrane route

The transmembrane route requires repeated crossing of plasma membranes as water and solutes exit one cell and enter the next.

As the soil solution moves along the apoplast, some water and minerals are transported into the protoplast of the cells of the epidermis and cortex and then move via the symplast.

Some substances can use more than one route. The least resistence for the transport is found in apoplastic route. Therefore, more water use apoplastic route.

Finally, water and minerals enter into the tracheids and vessel elements of xylem. These waters conducting cells lack protoplasts when mature and therefore they are parts of the apoplast. Endodermal cells and living cells of the vascular tissues discharge minerals from their protoplast to their own cell walls. Both diffusion and active transport involve in transport of solutes from symplast to apoplast. Then water and minerals can enter the tracheids and vessel elements to the transport to shoot system by bulk flow only through the apoplast.

Upward movement of water and minerals in a plant

Water and minerals which enter to vascular cylinder are transported to upper parts of the plant and this transport is known as ascent of xylem sap.

Xylem sap, the water and dissolved minerals in the xylem, gets transported by bulk flow, which is much faster than diffusion.

To explain the process involved in the ascent of xylem sap, cohesion-tension hypothesis is put forward. According to this hypothesis, transpiration provides pull for the ascent of xylem sap and cohesion of water molecules transmits this pull along the entire length of xylem from shoots to roots. Hence xylem sap is normally under tension (negative pressure).

The negative pressure potential helps water to move up through xylem and water moves according to the water potential gradient.

Adhesion and cohesion facilitate transport water by bulk flow. Due to high adhesion water molecules are attracted to cellulose molecules in the xylem walls. Cohesion of water molecules is unusually high due to hydrogen bonds among water molecules. Therefore, a continuous water column is formed within xylem vessels and tracheids. Transpiration pull can extend down to the root only through an unbroken chain of water.

As water evaporates from the mesophyll cells, water potential of mesophyll reduces, and water moves from cells of petioles to the mesophyll cells. It reduces the water potential of cells of petioles. then water pulls upward due to this transpiration pull.

The xylem sap is driven by difference in pressure potential. Therefore, the water potential gradient within xylem is essentially a pressure gradient.

The tensile force on xylem sap is transmitted all the way from the leaves to the root tips and even into the soil. Therefore, water potential gradient between the soil solution and atmosphere through the plant body also help ascent of xylem sap, against the gravity.

The plants do not need energy to lift the xylem sap.

Mechanism of mineral absorption into root

Mineral ions are absorbed by the plant roots mainly from the soil solution. Epidermal cells are permeable to water and many epidermal cells are modified to form root hairs. Root hair cells are unicellular structures which absorb dissolved mineral ions from the soil solution. Soil solution has a lower concentration of ions than that of the cell sap of root hair cells. Therefore, absorption takes place against a concentration gradient.

The process involved in transport of material in phloem

Basic characteristics of phloem transport

The transport of the product of photosynthesis is carried out by the phloem tissue, known as phloem translocation.

In angiosperms, the sieve-tube elements of the phloem are specialized cells for translocation.

Phloem sap, the aqueous solution that flows through sieve tubes differs from xylem sap mainly because it contains sucrose (as 30% by weight) and it may also contain amino acids, hormones and minerals.

Phloem sap moves from sites of sugar production to site of sugar use or storage. Therefore, it takes place from sugar source to a sugar sink.

Sugar source is an organ that is a net producer of sugar, by photosynthesis or by breakdown of starch.

Plant leaves are sources whereas growing roots, stems, buds and fruits are sinks.

Storage organs such as tubers and bulbs, may be a source or a sink, depending on its function.

Mechanism of phloem translocation

Sinks usually receive sugar from the nearest sugar sources. For each sieve tube, the direction of transport depends on the locations of the sugar source and sugar sink that are connected by that tube. Therefore, neighbouring sieve tubes may carry sap in opposite directions if they originate and end in different locations.

The first step in translocation of sugar is to transport or load into sieve tube elements. In some species, it moves from mesophyll cells to sieve tube elements via symplast, passing through plasmodesmata.

In many plants, sugar movements into phloem requires active transport because sucrose is more concentrated in sieve tube element and companion cells than mesophyll cells.

Sucrose is unloaded at the sink end of the sieve tube. The process varies by species and organ. However, the concentration of free sugar in sink is always lower than in the sieve tube because the unloaded sugar is consumed during growth and metabolism of cells of sinks or converted to insoluble polymers such as starch. As a result of concentration gradient, sugar molecules diffuse from phloem into the sink and water follows by osmosis.

Phloem sap moves from source to sink at a rate about 1m/hr and it moves by bulk flow driven by positive pressure, known as pressure flow.

Phloem translocation of angiosperms is explained by pressure flow hypothesis. In this translocation, following processes take place.

1. Loading of sugar into the sieve tube reduces water potential inside the sieve tube elements at the source
2. This causes the sieve tube to take up water from the xylem by osmosis.
3. This uptake of water generates a positive pressure that forces the sap to flow along the tube
4. The pressure is reduced by unloading of sugar and consequent loss of water from phloem to the xylem at the sink

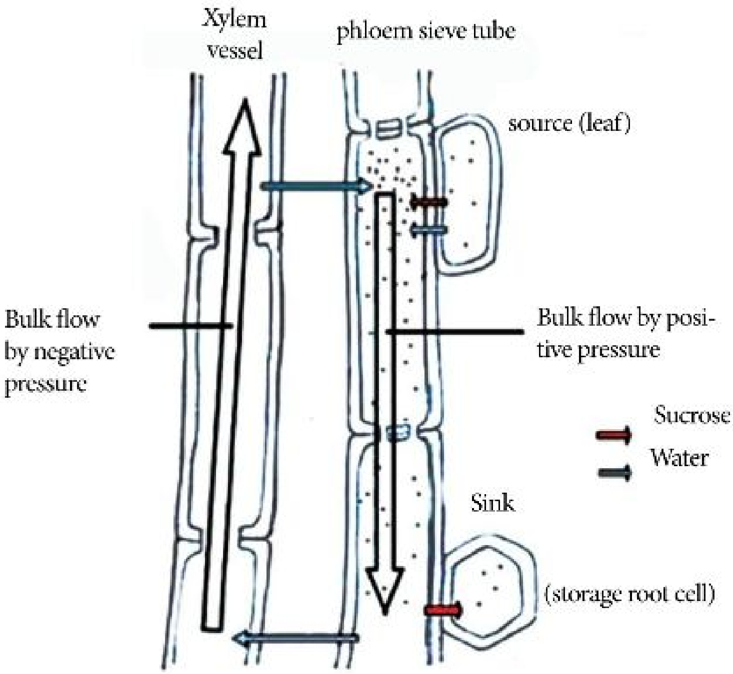


Fig 4.16 : The Process phloem transportation

Process of water loss in plants

Transpiration

Removal of water from leaves and other aerial parts of the plant body as water vapour by diffusion is known as transpiration.

This water loss takes place in plants mainly;

through stomata.-stomatal transpiration

upto some extent through cuticle-cuticular transpiration

and through lenticels- lenticular transpiration.

About 95% of water in plants is lost through stomatal transpiration.

In the day time, air in the intercellular air spaces is saturated with water vapour because they are in contact with the moist cell walls. Normally air outside the plant is drier than inside. Hence water potential of outside air is lower than that of inside. Therefore water vapour in the air spaces of the plant diffuses down its water potential gradient and exits the plant.

Stomatal Transpiration

Water is brought to the leaf in the xylem of vascular bundle and subsequently spread from a fine branching network throughout the leaf. These branches end in one or few xylem vessels or tracheids possessing little lignification. Therefore water can release easily through their cellulose walls to mesophyll cells. Water moves through the mesophyll cells by apoplast, symplast and transmembrane pathways according to water potential gradient.

Then water evaporate from the wet walls of the mesophyll cells into the intercellular air spaces particularly into the large substomatal air spaces. From here water vapour diffuses through the stomata to the atmosphere.

Immediately next to the leaf is a thin layer of stationary air through which water vapour diffuses out and swept away by moving air.

There is a diffusion gradient from the stationary layer back to the mesophyll cells. Each stomata has a diffusion gradient or diffusion shell around it. The diffusion shell of neighbouring stomata overlap in still air to form one overall diffusion shell (Layer). Thickness of the diffusion shell depends on the surface features of the leaf and wind speed.

Factors affecting the rate of transpiration

1. Light intensity
2. Temperature
3. Humidity
4. Wind speed
5. Concentration of CO_2
6. Available water in soil

Light intensity

Stomata usually open in the light and close in darkness. With the increase of light intensity the rate of transpiration increases.

Temperature

In the presence of light, the external factor which has the greatest effect on transpiration is temperature. The higher the temperature, the greater the rate of evaporation of water from mesophyll cells which result the greater saturation of the leaf atmosphere with water vapour. At the same time, a rise in temperature lowers the relative humidity of the air outside the leaf. Both events result in a steeper concentration gradient of water molecules from leaf to external atmosphere. The steeper this gradient is the faster the rate of diffusion.

Humidity

Low humidity outside environment of the leaf increases transpiration, because it makes the diffusion gradient of water vapour from the moist leaf atmosphere to drier external atmosphere. As the concentration of water vapour in the external atmosphere is high when humidity rises, the diffusion gradient becomes less steep result in lower transpiration.

Wind speed

In still air, a shell of highly saturated air builds up around the leaf thus reducing the steepness of the diffusion gradient between leaf atmosphere and external atmosphere which makes the transpiration rate low.

In windy condition, flow of air will generally sweep away the shell. Therefore, windy condition increases transpiration rate.

Availability of soil water

As soil dries out, water usually binds more tightly to soil particles reducing the amount of available water. The soil solution becomes more concentrated and its water potential decreases. Therefore, tendency for water to enter by osmosis is lower. This reduces water uptake by plants and as a result transpiration rate is also reduced. There is greater resistance to movement of water through the plant due to less steep water potential gradient from the soil through the plant to the atmosphere.

Significance of transpiration to plants

1. Distribute minerals and water throughout the plant.
2. Ascent of water in the xylem.
3. Uptake of water and minerals by roots from the soil solution.

Root pressure and guttation

At night, when the relative humidity is high approaching 100%, transpiration rate is very low or zero. Root cells continuously pump water and mineral ions into xylem tissue. The endodermis prevents ions from leaking back into the cortex and soil. Therefore more mineral ions accumulate in the vascular cylinder and reduce water potential. Therefore water moves from the cortex. It generates a root pressure and upward push of xylem sap.

Due to root pressure, more water enters to the leaves than lost by transpiration. This results in removal of water droplets from leaf tips or leaf margins of some herbaceous plants. That process is known as guttation. Guttation fluid differs from dew, which is condensed moisture of the atmosphere.

Many plants do not generate any root pressure and therefore there is no guttation. Even in plants that display guttation, root pressure cannot match the water loss by transpiration after sun rise and therefore no guttation is seen in the day time, because then xylem sap is not pushed but pulled upward by transpiration.

Root pressure is never sufficient to push water up distance over meters. Guttation takes place through the hydathode which are formed by special groups of cells located near the ends of small veins and does not take place through the stomata.

e.g. *Alocasia,* *Colocasia*

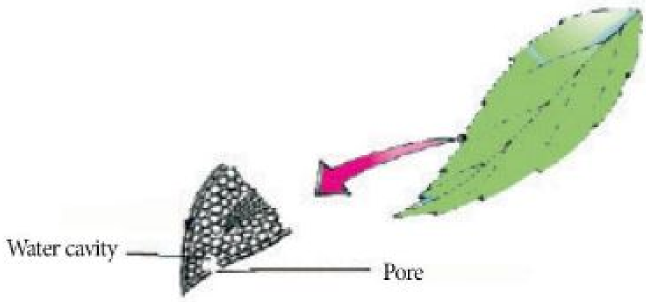


Fig 4,17: The general structure of the hydathode

Diversity of nutritional processes in plants

Nutrition is the process of acquiring raw materials and energy from the environment for the metabolic activities of organisms.

Plants require nutrients for their growth, development and reproduction.

Modes of nutrition in plants

Autotrophic nutrition (autotrophism)

The organisms who exhibit autotrophism are referred to as autotrophs. Autotrophs synthesize organic materials from CO_2 and inorganic materials.

Plants are photoautotrophs which utilizes light energy in order to synthesize organic molecules from inorganic material.

- **Symbiosis**

Symbiosis is an ecological relationship in which two species live in close contact with each other. There are three types; they are mutualism, parasitism, and commensalism.

- **Mutualism**

A symbiotic relationship in which both participants are benefited.

e.g: legume root nodules with nitrogen fixing bacteria (*Rhizobium*)

mycorrhizae- symbiotic association of roots of higher plants with fungi

corolloid root of *Cycas with Anabaena*

- **Commensalism**

It is an interaction between two species in which benefits one of the species and neither harm nor benefits the other.

e.g: epiphytic orchids

- **Parasitism**

It is a close association between two different species which is beneficial to one (the parasite) and harmful to the other (the host).

e.g. semi parasitic–*Loranthus* and host plant

parasitic - *Cuscuta* (Dodder plant) and host plants

- **Special mode of nutrition**

Carnivorous plants

These plants are photosynthetic but obtain nitrogen and minerals by killing and digesting insects and other small animals. They live in habitats where the soil is poor in nitrogen and other minerals.

e.g : *Nepenthes, Drosera , Utricularia*

Nutritional requirements for the optimal growth of plants

Essential elements: Elements which are required for a plant to complete its life cycle and produce another generation.

Seventeen essential elements are needed by all plants

C,O,H,N,P,S,K,Ca, Mg, Cl, Fe, Mn, B, Zn, Cu, Ni, Mo,

Essential elements are two types

Macronutrients

Macronutrients: plants need these elements in large amounts.

e.g: C,O,H,N,P,S,K,Ca, Mg (9 elements)

Micronutrients

Plants require these elements in small amounts.

e.g: Cl, Fe, Mn, B, Zn, Cu, Ni, Mo

Table 4.2- Macro elements and their functions and deficiency symptoms

Element	Form/ forms of intake	Source	Function	Deficiency symptoms
C	CO_2	Atmospheric air	One of the major components of organic molecules in plants	Poor growth
O	CO_2	Atmospheric air and soil solution	Major components of organic molecules in plants	Poor growth
H	H_2O	Soil solution	Major components of organic molecules in plants	Poor growth, wilting
N	NO_3^-, NH_4^+	Soil solution	Component of amino acids, proteins, nucleotides, nucleic acids, chlorophyll, coenzymes, enzymes	Stunted growth and strong chlorosis, particularly of older leaves
K	K^+	Soil solution	operation of stomata, cofactors of many enzymes	Yellow and brown leaf margins , weak stems, poorly developed roots
Ca	Ca^{2+}	Soil solution	Component of cell walls and middle lamella, maintenance of membrane structure and permeability, signal transduction	Crinkling of young leaves, death of terminal buds
Mg	Mg^{2+}	Soil solution	Component of chlorophyll molecule, Activates many enzymes.	Chlorosis between veins, found in older leaves
P	H_2PO^24-	Soil solution	Component of ATP and nucleic acids, phospholipids	Healthy appearance but very slow development, thin stems, purpling of veins, poor flowering and fruiting
S	SO_4-^{2-}	Soil solution	Components of some amino acids and proteins	Chlorosis in younger leaves

Micro elements, their functions and deficiency symptoms

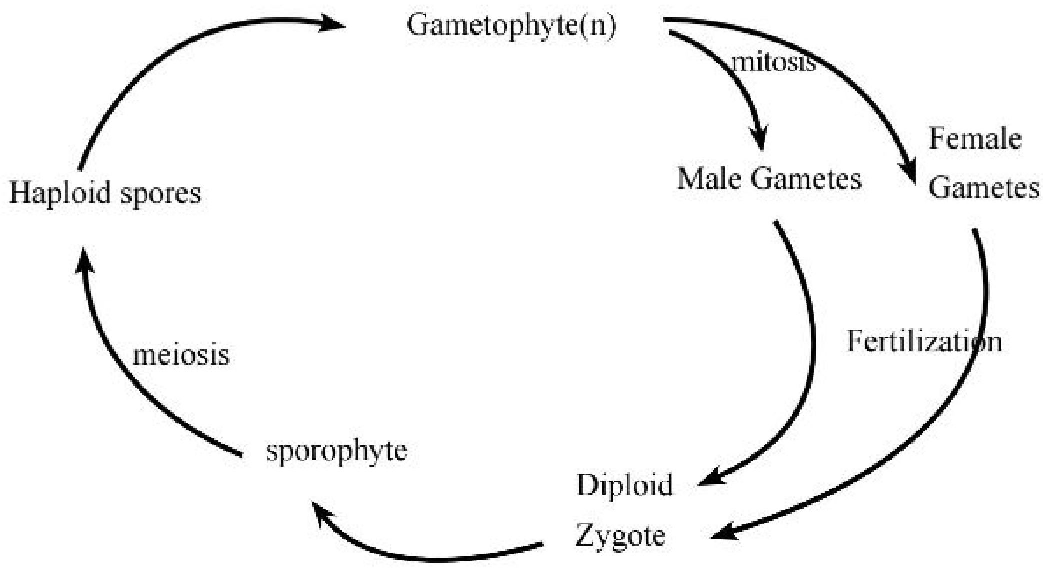
Element	Form/ form of intake	Source	Function	Deficiency symptoms
Cl	Cl-	Soil solution	Osmosis and ionic balance, in photosynthesis	Wilting, stubby roots, leaf mottling (uncommon)
Fe	Fe^{2+},Fe^{3+}	Soil solution	Chlorophyll synthesis in photosynthesis, N_2 fixation	Chlorosis between veins, particularly in young leaves
Zn	Zn^{2+}	Soil solution	Activator of many enzymes and activate formation of Chlorophyll, need for DNA transcription	Crinkled leaves, reduced internode length
B	$H_2BO_3^-$	Soil solution	Cofactor in chlorophyll synthesis, role in cell wall function, pollen tube growth	Death of meristems, thick leathery, and discolored leaves
Cu	Cu2+ , Cu+	Soil solution	Activator or component of certain enzymes	Light green color throughout young leaves, with drying of leaf tips, roots stunted and excessively branched
Mo	MoO_4^{2-}	Soil solution	Nitrogen metabolism	Death of root and shoot tips, chlorosis in older leaves
Ni	Ni^{2+}	Soil solution	Nitrogen metabolism	Death of leaf tips, chlorosis in older leaves
Mn	Mn^{2+}	Soil solution	Activates some enzyme require in photosynthesis	chlorosis between veins, found in young leaves

Reproductive process in Plants

Trends in life cycles to relate the adaptations of plants for a terrestrial life

Sexual reproduction of terrestrial plants

- The life cycles of all land plants exhibit alternation of generations, which means the presence of haploid generation and diploid generation alternatively, with each producing the other.
- The two multicellular body forms that alternate in the life cycles of land plants are the haploid gametophyte and diploid sporophyte which are morphologically different. Therefore called heteromorphic alternation of generations. Their reproductive organs (gametangia and sporangia) are protected by sterile cell layers to prevent desiccation of mother cells. (gamete forming cells and spore forming cells).
- Gametophytes produce gametes by mitosis.
- All land plants carryout internal fertilization to prevent desiccation of gametes.
- Female egg (ovum) is retained in the archegonium and male gametes (antherozoids) are released from the antheridium. Seedless plants depend on external water for fertilization, but seed plants do not depend on external water for their fertilization.
- After fertilization, diploid zygote is retained within the gametophyte to produce an embryo which is nourished by the gametophyte. Embryo develops into the diploid sporophyte.
- Delay of meiosis after fertilization results in creating a diploid sporophytic generation.
- Diploid sporophyte produces haploid spores by meiosis.
- Spores grow into haploid gametophytes.
- In the course of evolution of land plants, diploid sporophytic generation acquire adaptations needed for successful colonization on land and become dominant plant in the life cycle. Gametophytic generation gradually reduced and has become dependent on the sporophytic generation in seed plants.



Life cycle of Pogonatum

- Gametophyte is the dominant plant, larger and longer-living than sporophyte.
- Gametophyte is photosynthetic.
- 'Stem', 'leaves', and rhizoids are present in the gametophyte
- Gametophytes are dioecious (unisexual). Mature male gametophytes produce antheridia in which several sperms are produced.
- Female gametophytes produce archegonia. A single egg is produced within the archegonium
- The egg is not released.
- Flagellated, motile sperm swims through external water towards egg, entering the archegonium in response to chemical attractants.
- Sperm fuses with the ovum resulting diploid zygote. This occurs in the archegonium.
- After fertilization zygote develops into the embryo.
- The embryo is also retained within the archegonium and develops into the diploid sporophyte by obtaining nutrients from the gametophyte.
- The sporophyte remains attached to the gametophyte.
- The sporophyte consists of a foot, seta and a capsule (sporangium).
- The foot absorbs nutrients and water from the gametophyte.
- The capsule produces spores by meiosis. Homosporous.
- If spores are dispersed to a favourable habitat, (such as moist soil or tree bark) they may germinate and grow into a green, branched filament called protonema.
- Protonema produces buds that grow into gametophytes.

Life cycle of *Nephrolepis*

- Sporophyte is dominant
- Gametophyte is reduced and short lived.
- Both sporophytes and gametophytes are independent and photosynthetic.
- Sporophytes have more complex structure.
    - Plant body is differentiated into roots, stem and leaves.
    - Cuticle is found on aerial parts of the plant body
    - Stomata are developed on aerial parts for gaseous exchange.
    - Two types of vascular tissues, xylem and phloem are developed
    - They have fiddlehead young leaves
    - Stem is an underground rhizome
    - Leaves are compound pinnate leaves
    - Long underground branches called stolons arise from the rhizome \ which gives rise to new plantlets.
    - Sporangia are developed as clusters called sori on the underside of mature leaflets. Sori are covered by the indusium, protecting the young sporangia from desiccation. Spores are produced in the sporangium by meiosis and are homosporous.
- When the sorus matures, indusium dries up and shrivels, exposing mature sporangia.
- Under dry environmental conditions sporangium wall ruptures, releasing spores.
- Spores are dispersed by wind.
- When spores are dispersed to a favourable habitat they may germinate and grow into a gametophyte
- Gametophyte is a small heart shaped, macroscopic, green coloured photosynthetic thallus.
- Rhizoids develop on the ventral surface.
    - Gametophytes are monoecious (bisexual). Antheridia and archegonia are developed on the ventral side.
    - Antheridium produces flagellated sperms and releases them into the external environment.
    - Archegonium produces one egg and retains it.
    - Motile sperms swim through external water towards egg entering the archegonium in response to chemical attractants.
    - Sperm fuses with the egg resulting the diploid zygote.
    - After fertilization zygote develops into the embryo and then to the young sporophyte while retained in the gametophyte.
    - All the developmental stages are nourished by the gametophyte.

- When the young sporophyte develops its photosynthetic tissues, it becomes an independent plant.

Life cycle of *Selaginella*

- Sporophytes are dominant and photosynthetic.
- Gametophytes are reduced in structure and short-lived, partially depend on the sporophyte.
- Sporophyte plant body is differentiated into roots, stem and leaves. Vascular tissues present. Herbaceous.
- Heterophyllous leaves are arranged as pairs.
- Stem is dorsiventrally flattened.
- Sporangia are borne on the specialized leaves called sporophylls.
- Sporophylls are compactly arranged in a terminal strobilus.
- Two types of sporophylls called megasporophyll and microsporophyll are arranged in the same strobilus.
- Megasporophyll produces a single megasporngium and microsporophyll produces a single microsporangium.
- Morphologically two different types of spores are produced. This nature is called heterospory.
- Megasporangium produces four large megaspores by meiosis.
- Microsporangium produces numerous small microspores by meiosis.
- Both types of spores have thick/tough walls.
- Microspores are retained in the microsporangium and develop into young male gametophytes.
- Young male gametophytes are enclosed by the wall of microspore which, are released by the microsporangium.
- In the external environment they become mature male gametophytes.
- Male gametophytes is microscopic, enclosed in the microspore wall, non-photosynthetic, depend on stored food.
- Male gametophytes produce flagellated sperms and release them into the external environment.
- Megaspores are released into the external environment. In the external environment they develop into female gametophytes.
- Female gametophyte is multicellular, surrounded by the thick wall of megaspore, Few rhizoids develop.
- Photosynthetic, but partially depend on stored food in the megaspore.
- Archegonia develop at the superficial regions and are fully embedded in the gametophytic tissue.

- One egg is produced inside the archegonium.
- Sperm swims towards the egg (n) using flagella through external water, entering into the archegonium and fertilizes the egg (n) resulting in a zygote(2n).
- Zygote develops to form an embryo and then embryo develops to form a young sporophyte by obtaining nutrients from the female gametophyte.
- Sporophyte generation is the larger and more complex form in the alternation of generation

Life cycle of *Cycas*

- Sporophytes are the dominant photosynthetic plants in the life cycle, gametophytes are reduced and depend on the sporophyte throughout its life.
- Sporophytes are a perennial tree with roots, stem and leaves.
- Stem is unbranched columnar and woody.
- Leaves are arranged in crowns.
- Compound leaves show xerophytic adaptations and young leaves are fiddleheads.
- Sporophytes are heterosporous and dioecious. Sporophytes have developed a tap root system.
- Secondary growth is present.
- Sporophytes which produce megaspores are called female plants and those which produce microspores are called male plants.
- Mature female plant produces a crown of megasporophylls.
- Megasporangium is enclosed in the protective layer called integument to form the ovule. Integument has a small pore in the distal end of the ovule called micropyle.
- One of the cells in the megasporangial tissue differentiates into a single megaspore mother cell. Megaspore mother cell undergoes meiosis to form four haploid megaspores out of which only one remains functional.
- The remaining megasporangial tissue functions as nucellus which provides nourishment.
- Megaspores are not released to the external environment megaspore develop into the female gametophyte (n) while within the ovule. Mature ovule contains the female gametophyte. The female gametophyte produces several archegonia. Each archegonium produces a single egg cell within it.
- Mature male plants produce male cones with microsporophylls which consist of microsporangia on the lower surface. Large numbers of microspores (n) are produced from microspore mother cells (2n) within the microsporangium by meiosis.

- They develop into pollen grains within the sporangium and then discharge.
- Pollen grains are dispersed by wind and deposited on the micropyle of a mature ovule is called pollination.
- Pollen grains enter into pollen chamber of the ovule through the micropyle. In the pollen chamber, pollen grains develop into male gametophytes. Male gametophyte consists of a branched pollen tube which involves in absorption of nutrients from the nucellus. Male gametophyte is short-lived.
- Produce two large sperms with a spiral band of numerous cilia.
- The basal end of the pollen tube ruptures releasing sperms into the archegonial chamber of the ovule. Sperms swim through the liquid medium and fertilize the egg resulting the 2n zygote.
- Zygote develops into the embryo
- Remaining female gametophyte becomes the endosperm which providesnutrients for the developing embryo during seed germination. Integument becomes the seed coat.
- The ovule becomes the seed.
- Seed is the dispersal unit which contains the embryo and stored food that are enclosed in the seed coat.
- Seeds are dispersed and under favorable environmental conditions seeds germinate producing the seedlings (young Sporophyte).

structures and functions associated with sexual reproduction in flowering plants

Life cycle of flowering plants

- Sporophyte is the dominant plant. Gametophytes are short-lived, microscopic, entirely depend on the sporophyte.
- Sporophyte produces the reproductive structures called flowers.
- A flower is a specialized shoot with four whorls of modified leaves named sepals, petals, stamens and carpels.
- Sepals are usually green, enclose and protect the flower before it opens.
- Petals are brightly coloured in most flowers and aid in attracting pollinators. (But wind pollinated flowers generally lack brightly coloured parts).
- The sepals and petals are sterile floral organs. They do not directly involve in reproduction.
- Stamens are the microsporophylls.
- The stamen consists of a stalk called filament and two terminal lobes called anther.

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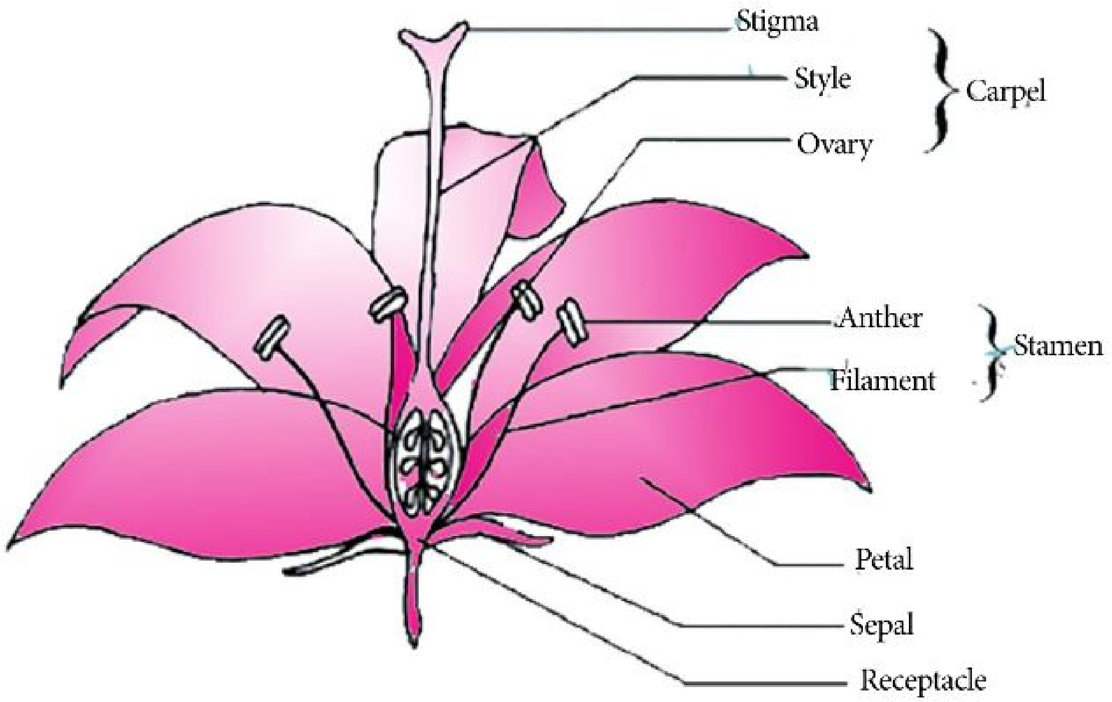

4.16 Structure of a typical angiosperm flower

- Anther is made up of microsporangia (pollen sacs) containing microspore mother cells which produce microspores by meiosis. Microspores develop into pollen grains within the anther.
- A pollen grain contains two nuclei, the tube nucleus and generative nucleus.
- Carpels are the megasporophylls. At the tip of the carpel is a sticky stigma that receives pollens. The swollen base of the carpel forms the ovary. Ovary contains one or more ovules A long, slender neck called style connects ovary with stigma.
- Ovule produces four megaspores by meiosis of which only one becomes functional.
- Functional megaspore develops into the female gametophyte called the embryo sac. It is a highly reduced microscopic structure.
- The mature embryo sac consists of eight nuclei contained within seven cells- three antipodal cells, two polar nuclei in the central cell, two synergids and one egg.
- Transfer of pollen grains to a mature stigma is known as pollination.
- In some plant species, pollen grains are transferred from an anther of a flower on to the stigma of the same flower. This is self-pollination
- Pollen may be transferred to a stigma of a different flower. This is cross pollination.

- Most angiosperm plants are adapted for cross pollination.
- Typical characteristics of flowers like such as colour and odour. favour cross pollination.
- In addition, some plants show special types of adaptations cross pollination.
  e.g. heterostyly, self infertility, unisexuality

Significance of cross pollination

Cross pollination results in cross fertilization. Cross fertilization allows shuffling of genes within a species, producing new genetic combinations resulting increased genetic variation within the species. These features are very important for survival and also might lead to evolution.

Fertilization

- The pollen grain germinates after it is placed on the stigma.
- It extends a pollen tube that grows down through the style of the carpel.
- The generative nucleus divides forming two sperm nuclei.
- When the pollen tube reaches the ovary, it moves through the micropyle (The pore in the integuments of the ovule) and discharges two sperm nuclei into the embryo sac.
- One sperm nucleus fuses with the egg cell forming a diploid zygote and the other sperm nucleus fuses with the 2 polar nuclei. This type of fertilization is called double fertilization and is unique to angiosperms.
- After double fertilization, the ovule matures into a seed. The zygote develops into the embryo. The triploid nucleus develops into the endosperm that store food.
- The significance of double fertilization is that it synchronizes with the development of the embryo.
- If fertilization does not occur that prevents plants from wasting nutrients on infertile ovules.
- The seed consists of the embryo, endosperm with store food and a seed coat.
- Seeds are enclosed in the fruit.
- Fruit is an enlarged and developed ovary, usually after being stimulated by fertilization. Fertilization triggers hormonal changes that cause the ovary to form a fruit.
- If a flower has not been pollinated, fruit does not develop, and entire flower falls away.
- During fruit development, the ovary wall gets converted to the pericarp.
  - In some plants fruits develop from the ovary without fertilization. This is called

parthenocarpy. Parthenocarpic fruits do not develop seeds. Parthenocarpy occurs naturally in some species.

e.g. Banana

- It also can be induced with plant growth substances to get seedless fruits.

  e.g. Grapes, Orange
- In some plants, seeds develop without fertilization. This is called parthenogenesis.

  e.g. certain grasses
- In parthenogenesis,
  - the egg is resulted by mitosis and hence is diploid,or
  - haploid ovum fuses with a polar nucleus, or
  - the genetic content of the egg is duplicated to become diploid, enabling seed development without fertilizing by the sperm.

Significance of development of seed and fruit

Seed

- Seed is the dispersal unit of seed plants which contains the embryo and stored food, surrounded by the seed coat
- The seed habit has a strategy for life on land: The presence of,
  - seed coat- helps to survive in extreme conditions
  - food reserves-provide nourishment to the embryo during development
  - dormancy period helps to survive during unfavorable conditions
  - adaptations for dispersal give a better chance for growth , development and survival.

Fruits

- Protects the enclosed seeds
- When mature, aids in their dispersal by wind , water or animals.
- After being dispersed, if environmental conditions are favourable, a seed may germinate to form a seedling.
- Inhibition of embryo within the seed at one stage of maturation, naturally prevents germination of seeds within fruit, which is called seed dormancy.
- Many seeds have mechanisms of inhibiting germination and remain dormant.
- Presence of inhibitors, presence of thick/strong seed coats, presence of seed coats impervious to water are common causes of seed dormancy.
- After breaking seed dormancy, when water, oxygen and suitable temperature are provided, seeds start to germinate.
- Absorption of water, activation of enzymes, mobilization of food resources

(nutrients) followed by rapid growth process of the embryo extending radical through the seed coat is called seed germination. Radical shows positive geotropism and plumule shows negative geotropism.

Plant responses to internal and external Signals

Responses of plants to different stimuli

Photomorphogenesis:

- Light triggers many key events in plant growth and development, collectively known as photomorphogenesis.
- Light reception also allows plants to measure the passage of days and seasons.
- Plants detect not only light signals, but also the direction, intensity and wave length (Color)
- A graph called an action spectrum depicts the relative effectiveness of different wave lengths of radiation in carrying out a particular process, such as photosynthesis.
- Action spectrum reveals that red and blue light are the most important colors in regulating plant's photomorphogenesis.
- The two major classes of light receptors in plants are the blue light photoreceptors and phytochromes (which absorb mostly red light)
- Blue- Light photo receptors initiates a variety of responses in plants, including phototropism, the light induced opening of stomata and the light induced slowing of hypocotyl elongation that occurs when a seedling breaks ground.
- Phytochrome photoreceptors regulate many plant responses to light, including seed germination and shade avoidance.

Effect of light on:

seed germination.

- As the nutrient reserves are limited, many types of seeds (especially small ones) germinate only when the light environment and other conditions are nearly optimal.
- Such seeds often remain dormant for years until light conditions change. (e.g.- Plowing a field or a death of a shady tree may create a favorable light environment for germination)

plant spacing

- Phytochromes provide the plant with information about the quality of light which enables the plant to get adapted to changes in outside light conditions.

e.g. "Shade Avoidance" response of a forest tree (below the canopy) that requires relatively high light intensity. As the forest canopy absorbs more red light allowing only far red light to pass through, the tree below the canopy will allocate more of its resources to grow taller.

- In contrast, exposure to direct sunlight increases the proportion of far red: red light and thereby stimulates branching and inhibits vertical growth.

flowering

- Photoperiod is the interval in a 24hour period in which the plant gets exposed to light.
- Photoperiod controls flowering in many types of plants.

Shoot elongation and Phototropism

- The growth of a shoot towards light (positive) or away from it (negative) is called phototropism.
- Positive phototropism strengthen photosynthesis.
- This response results from a differential growth of cells on opposite sides of the shoot; the cells in the darker side elongate faster than the cells on the brighter side.

Response to Gravity

Gravitropism

- Shoot of the plant grows upwards while root grows downwards, due to their response to gravity or gravitropism.
- Gravitropism can be either positive or negative.

  e.g. Roots display positive gravitropism while shoot display negative gravitropism.
- Gravitropism occurs as soon as a seed germinates. This ensure that the root grows into the soil and shoot grows towards sunlight.
- Plants may detect gravity by the settling of statoliths.
- Statoliths of vascular plants are specialized plastids containing dense starch grains.
- They can settle under the gravity, to the lower portions of the cell.
- In roots, they are located in certain cells of the root cap.

The statolith hypothesis:

The aggregation of statoliths at the low points of root cap cells triggers re-distribution of Ca^{2+} which causse lateral transport of auxin within the root. As a result, Ca and auxin get accumulated at lower side of elongation zone of root. At high concentration of auxin, cell elongation is inhibited resulting slow growth on lower side and more rapid elongation on upper side. Consequently, the root grows downwards.

Response to mechanical stimuli

Trees grow in windy environment normally have shorter stockier trunks than same species growing in normal environmental conditions. Advantage of this is that the tree could stand high winds. This exhibits the sensitivity of mechanical stress of plants. the changes in plant form due to mechanical disturbances is called thigmomorphogenesis.

During evolution, some plant species have become 'touch specialists'. Climbing plants have tendrils that coil rapidly around support. Tendril usually grows straight until it touches a support. The contact stimulates differential growth on opposite sides of the tendril. The directional growth of tendril towards support is called thigmotropism.

Other touch specialists, respond to touch by rapid leaf movements. E.g. Mimosa pudica collapses its leaflets when touched. Touching results in a sudden loss of turgor of cells in a specialized motor organ called pulvini, causing the leaflets to collapse. This response is called thigmonasty.

The role of plant growth substances/ hormones/ regulators in response to different stimuli

Hormones in general are signaling molecules which are produced in small quantities, get transported from the place they are produced to other parts of the organism and trigger responses in target cells. or/and effect on plant growth and development. With this definition, its hard to explain some physiological processes in plants. In addition, some signaling molecules that are considered as plant hormones act locally. Thus the broader term plant growth regulators seem more appropriate.

Plant growth regulators are natural or synthetic organic compounds which modify or control specific physiological process in plants.

Plant biologists prefer to use the term plant growth regulators rather than plant hormones, as there are certain differences in plant hormones and animal hormones.

Therefore, plant hormones and plant growth substances are considered as equal. But plant hormones are active even at very low concentration.

Major types of plant hormones/ growth regulators are auxins, gibberlin, cytokinin, abscisic acid, ethylene and Jasmonate (jasmonic acid).

Hormone	Functions
Auxin	• stimulates stem elongation in low concentration • promotes the formation of lateral and adventitious roots • regulates development of fruit • enhances apical dominance • functions in phototropism • functions in gavitotropism • promotes vascular differentiation • retards leaf abscission
Gibberellins	• stimulate stem elongation • stimulate pollen development • stimulate pollen tube growth • stimulate fruit growth • stimulate seed development and germination • regulate sex determination and transition from juvenile to adult phase
cytokinins	• regulate cell division in shoots and roots • modify apical dominance and promote lateral bud growth • promote movement of nutrients into sink tissues • stimulate seed germination • delay leaf senescence
Abscisic acid	• inhibits growth • promotes stomatalclousure during drought stress • promotes seed dormancy and inhibits early germination • promotes leaf senescence • promote dessication tolerance
Ethylene	• promotes ripening of many types of fruit • promote leaf abscission • promote triple response in seedlings (inhibition of stem elongation, promotion of lateral expansion, and horizontal growth) • enhance the rate of senescence • promote roots and root hair formation • promotes flowering in the pineapple family

Response of plants to some biotic and abiotic stresses

Stress

Certain factors in the environment may have a potentially adverse effects on a plants' survival, growth and reproduction.

Two types of stresses,

1. Abiotic stress
2. Biotic stress

Response of plants to some biotic and abiotic stresses

Stress

Certain factors in the environment may have potentially adverse effects on plants' survival, growth and reproduction.

Two types of stresses;

3. Abiotic stress(due to nonliving factors)
4. Biotic stress (due to living factors)

Abiotic Stress

Among several common abiotic stresses. Following three stresses are discussed.

1. Drought stress
2. Cold stress
3. Salt stress

1. Drought stress: Plants may wilt when water loss by transpiration exceeds water absorption. Prolonged drought may even kill a plant. Plants have control systems that enable them to cope with the drought/ water deficit conditions.

Water deficit stimulates increased synthesis and release of abscisic acid (ABA), which acts on guard cell membrane, closing stomata to reduce transpiration.

In grasses the leaves roll in to a tube-like shape which reduces the surface area to reduce transpiration. Some plants shed their leaves during seasonal drought.

2.Cold stress: When cell membrane cools below a critical temperature it looses its fluidity due to the lipids become locked in to crystalline structure. This blocks the transport across the membrane and affects the function of the cell.

Plants respond to cold stress by altering the lipid composition of their membranes. They increase the proportion of unsaturated fatty acids which keeps the membranes more fluid at low temperature.

Freezing is another cold stress. Water in the cell wall and intercellular spaces freezes before freezing the solute-rich water in the cytosol. The reduction of liquid water in the cell wall lowers the extracellular water potential causing water in the cytosol to leave.

This results high concentration of solutes in the cytoplasm which is harmful and may lead to cell death.

Before the onset of winter, the cell of frost-tolerant plants increases cytoplasmic levels of specific solutes such as sugars that help to reduce the loss of water from the cell preventing dehydration.

3. Salt stress: An excess of salts (high salinity) in soil lowers the water potential of soil resulting reduced water potential gradient from soil to root. This leads to reduction of water uptake by roots.

In general too high salinity in soil is toxic toplants.

Many plants can respond to moderate soil salinity by producing solutes that are well tolerated at high concentrations. These are organic compounds that keep the water potential of cell more negative than that of the soil solution.

A few plants that are salt-tolerant (halophytes) have developed salt glands, which secrete excess salts out of the plant across leaf surfaces. e.g. many mangrove plants

Biotic stress –

How plants defend themselves against pest and pathogens attack;

In plant defense mechanisms, some compounds and structures are already existed whilst some others are formed after infection or pest attack. Therefore, two categories of defense mechanisms called preexisting and induced mechanisms can be identified.

Preexisting structural and chemical defense mechanisms;

- Amount and quality of wax and cuticle that cover the epidermal cells
- The structure of the epidermal cell walls and thickness
- The size, location and shapes of stomata
- Toxic compounds, alkaloids (eg. Nicotine), phenolics (eg. Flavonoids, lignin & tannins), terpenoids (eg. Azadirachtin) and lectin
- Thorns, pricks, trichromes

Induced structural and chemical defense mechanisms;

- Morphological changes in the cell wall
- Formation of cork and abscission layers
- Phenolic compounds
- Toxic compounds
- Enzymes that can degrade fungal cell walls or damage insect organs