Chapter 8

PLANT PHYSIOLOGY

STUDENTS' LEARNING OUTCOMES

After studying this chapter, the students will be able to:

- List the macro and micronutrients of plants highlighting the role of each nutrient.
- State the examples of carnivorous plants.
- Explain the role of stomata and palisade tissue in the exchange of gases in plants.
- Relate transpiration with gas exchange in plants.
- Describe the structure of xylem vessel elements, sieve tube elements, companion cells, tracheids and relate their structures with functions.
- Describe the movement of water between plant cells, and between the cells and their environment in terms of water potential.
- Describe the movement of water through roots in terms of symplast, apoplast and vacuolar pathways.
- Explain the movement of water in xylem through TACT mechanism.
- Describe the mechanisms involved in the opening and closing of stomata.
- Explain the movement of sugars within plants.
- State movement of water into or out of the cell in isotonic, hypotonic, and hypertonic conditions.
- Explain the osmotic adjustments in hydrophytic (marine and freshwater), xerophytic and mesophytic plants and plants in saline soil.
- List the adaptations in plants to cope with low and high temperatures.
- Explain the turgor pressure and its significance in providing support to herbaceous plants.
- Describe the structure of supporting tissues in plants.
- Explain primary and secondary growth in plants.
- Justify the formation of annual rings.
- Explain influence of apical meristem on the growth of lateral shoots.
- Outline the role of important plant growth regulators.
- Explain the types of movement in plants in response to light, force of gravity, touch and chemicals.
- Define photoperiodism.
- Classify plants with examples on the basis of photoperiodism.
- Describe the mechanism of photoperiodism with reference to the mode of action of phytochrome.
- Explain the role of low temperature treatment on flower production especially to biennials and perennials.

8.1- NUTRITION IN PLANTS

Organisms require nutrition for their survival and maintenance. A **nutrient** is a substance that provides the body with essential ingredients required for metabolism. Specific nutrients, such as carbohydrates, lipids, and proteins, serve as sources of energy. Other nutrients, including water, electrolytes, minerals, and vitamins, are necessary for the metabolic process. **Nutrition** refers to the collective processes involved in the intake and utilization of nutrients for growth, repair, and maintenance of activities in an organism.

Macronutrients and Micronutrients

All autotrophic organisms need carbon dioxide and water, which supply carbon, oxygen and hydrogen. These are the predominant elements which serve as nutrients and are required by plants for the synthesis of organic molecules. There are many other nutrients that plants get from environment. The nutrients of plants can be divided into two groups.

Macronutrients are needed in relatively larger amounts. There are nine macronutrients i.e., carbon, hydrogen, oxygen, nitrogen, potassium, calcium, phosphorus, magnesium and sulphur.

- **Carbon, oxygen and hydrogen** are required for making organic compounds.
- **Nitrogen** is necessary for plant growth as it plays an essential role in energy metabolism and the production of proteins. A deficiency of nitrogen results in leaf loss and stunted growth.
- **Phosphorus** is a part of ATP. It also plays a role in promoting root growth and favours flowering in the aerial zone. A deficiency of phosphorus leads to delayed flowering, as well as the browning and wrinkling of the leaves.
- **Potassium** is involved in water regulation and the transportation of the plant's reserve substances. It enhances the ability of plants to carry out photosynthesis, reinforces cellular tissue, and stimulates the uptake of nitrates. Dark patches are formed on the leaves when there is shortage of potassium.
- **Calcium** provides stability to the cell wall and promotes the development of the cell wall. It also plays a role in cellular proliferation and maturation, and aiding in the development of seeds. Insufficient calcium leads to the development of yellow and brown patches on the leaves.
- **Magnesium** constitutes the core of the chlorophyll molecule and is therefore essential for photosynthesis. It promotes the absorption and transportation of phosphorus and also contributes to the storage of sugars within the plant. Magnesium deficiencies result in weak stalks, loss of greenness in the oldest leaves, and the appearance of yellow and brown spots.
- **Sulfur** is a fundamental element in the metabolism of nitrogen. If there is a shortage of sulfur, the plant becomes lighter in colour.

Micronutrients are needed in very smaller amounts. There are seven micronutrients i.e., iron, manganese, zinc, molybdenum, copper, chlorine, and boron.

> Fertilizers are added to the soil to provide macro and micronutrients to the crops.

- **Iron** is essential for the synthesis of chlorophyll. It acts as a cofactor for several enzymes which are involved in energy

> Manganese is important for the activity of antioxidant enzymes, such as superoxide dismutase (SOD), which help mitigate

transfer and nitrogen metabolism. Its deficiency results in interveinal chlorosis.

oxidative stress in plants under adverse environmental conditions.

- **Manganese** is involved in the processes of photosynthesis, nitrogen metabolism, carbohydrate metabolism and activation of enzymes. Its deficiency results in the premature falling of the leaf and delayed maturity.
- **Zinc** facilitates chlorophyll synthesis, root development and uptake of nutrients. Deficiency of zinc can lead to stunted growth.
- **Molybdenum** is critical for nitrogen fixation, nitrogen reduction, sulfur metabolism, phosphorus metabolism and iron utilization. Its deficiency can result in chlorosis of older leaves and stunted growth.
- **Copper** is necessary for lignin synthesis providing strength and rigidity to cell wall. It is involved in nitrogen metabolism, reproductive development and also acts as a cofactor for enzymes. Its deficiency can result in chlorosis, twisted leaves and stunted growth.
- **Chlorine** is involved in stomatal regulation, osmotic adjustment and transport of nutrients. Its deficiency can affect the health and growth of plants.

Nutrition in Insectivorous Plants

Some plants supplement organic molecules into their food in addition to inorganic nutrients. These organic chemicals are acquired through the process of capturing and breaking down insects and tiny animals. All insectivorous plants are true autotrophs. However, their development accelerates when they capture prey. Apparently, nitrogenous compounds of animal body are of benefit to these plants. The captured insects are broken down by enzymes that are released by the leaves. Pitcher plant, Venus fly trap and sundew are some of the known insectivorous plants.

Pitcher plant has leaves modified into a sac or a pitcher, partly filled with water **(Fig.8.1)**. The leaf's terminal portion is altered to create a hood, which partially covers the exposed opening of the pitcher. It has numerous stiff hairs that prevent little insects from crawling out once they fall inside it.

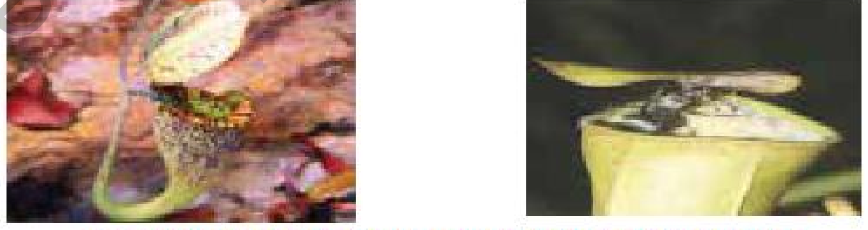

Figure 8.1: Pitcher plant, insects are entrapped within the leaf.

Venus-fly trap has a "trap" consisting of two lobes that are hinged at the end of each leaf. The inner surfaces of the lobes contain **trichomes**, which are hair-like projections that trigger the lobes to close rapidly upon contact with prey **(Fig.8.2)**. The hinged traps are lined with fine bristles that interlock upon closure, preventing the prey from escaping. The trapped insect is then digested by the enzymes secreted from the glands on the leaf surface and the products are then absorbed.

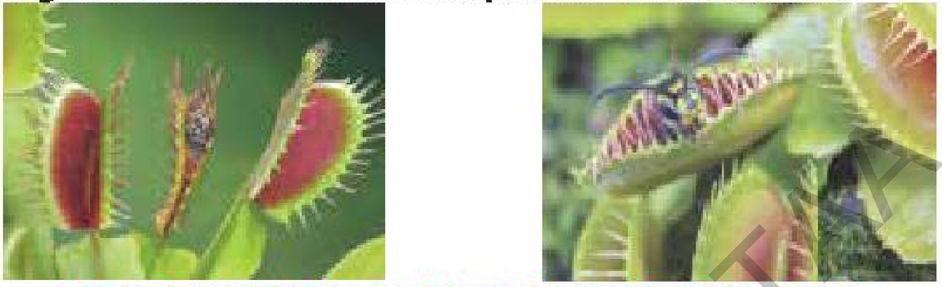

Figure 8.2: Venus-fly trap, prey is trapped between the lobes of a leaf.

Sundew catches its prey with shiny drops of "dew," where the plant's common name comes from **(Fig. 8.3)**. The leaves are covered with tiny hairs that look like tentacles. Each leaf has gland and has a single drop of dew at the tip. The insects, attracted by plant's odour are trapped by tentacles. The trapped insects are digested by enzymes and products are absorbed.

Figure 8.3: Sundew, insects are entangled by the tentacles.

8.2- GAS EXCHANGE IN PLANTS

Stomata (singular = stoma) are the tiny openings or pores present within the plant tissues which are necessary for gaseous exchange. These are typically found in leaves but can even be present in some stems. The stomata are surrounded by specialized cells or the guard cells that facilitate the opening and closing of the stomatal pores. Guard cells are bean-shaped and contain chloroplasts. Guard cells can open and close depending on environmental conditions. The opening and closing of stomata control the **transpiration rate** in plants.

Figure 8.4: Scanning electron micrograph (SEM) of open and closed stomata on a lavender leaf

During daylight, stomata open to allow CO_2 to enter the plant for photosynthesis. The opening of stomata is primarily regulated by guard cells. At night, when photosynthesis ceases due to lack of light, stomata typically close to conserve water. However, plants still respire, taking in O_2 and releasing CO_2. The closure of stomata at night helps minimize water loss through transpiration.

Opening and Closing of Stomata

The guard cells function as multisensory hydraulic valves **(Fig.8.4)**. The two hypotheses which may explain the opening and closing of stomata are starch sugar hypothesis and influx of k^+ ion.

Starch sugar hypothesis

In 1856, German botanist H. Van Mohl proposed that guard cells in leaf epidermis are solely responsible for photosynthesis, producing sugars during the day. As sugar concentration increases in guard cells, the water potential drops. Water moves into guard cells causing them to become turgid and open the stomata. At night, photosynthesis ceases, and sugars are converted to insoluble starch or used for respiration, leading to a decline in free sugars. Consequently, water moves out of guard cells and they lose turgor pressure. So, they become flaccid and close the stomata. However, this mechanism does not fully explain the rapid turgor changes in guard cells during stomatal movements.

Influx of K^+ Ion

The opening of stomata in plants is facilitated by the active transport of potassium ions (K^+) into guard cells, which reduces their osmotic potential. This influx of K^+ leads to water entering the guard cells through osmosis, causing them to become turgid and open the stomata. Blue light enhances this process by acidifying the surrounding environment, promoting K^+ uptake and subsequent water absorption. At night, K^+ passively diffuses out of the guard cells, resulting in water loss and causing the guard cells to become flaccid, thereby closing the stomata.

> Hormones are involved in stomatal movement in plants. At high temperature when leaf cells start wilting, a hormone called abscisic acid, is released by mesophyll cells. This hormone stops the active transport of K^+ into guard cells, overriding the effect of light and CO2 concentration. So, K^+ pumping stops and stomata close.

Palisade tissue is primarily located just beneath the upper epidermis of the leaf. It consists of elongated, tightly packed cells that are rich in. The arrangement of these cells is organized to maximize light absorption and allowing plants to efficiently convert light energy into chemical energy.

Carbon dioxide from the atmosphere diffuses into the leaf through the stomata. Once inside, the gas travels through air spaces within the spongy mesophyll and then into the palisade mesophyll cells, where it is used in photosynthesis. Oxygen produced during photosynthesis diffuses out of the palisade cells back through the spongy mesophyll and exits the leaf through the stomata.

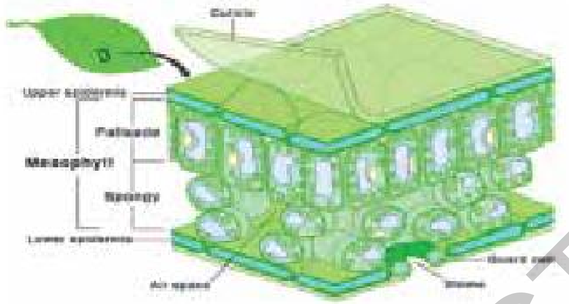

Figure 8.5: Structure of a leaf showing cuticle, epidermis, palisade mesophyll, spongy mesophyll, guard cells and stoma.

8.3- Support In Plants

Supporting tissues play an important role in maintaining the structural integrity, support and flexibility of plants. These tissues consist of parenchyma, collenchyma, sclerenchyma, xylem and phloem.

1. Parenchyma

The parenchyma tissue provides support to herbaceous plants and parts of larger plants. The parenchyma cells of the epidermis, cortex, and pith absorb water. This water creates an internal hydrostatic pressure known as **turgor pressure** that maintains the rigidity of cells.

Turgor pressure arises from the elevated osmotic pressure within the cell vacuole. The membrane that surrounds the vacuole is called the **tonoplast**. It has many active transport mechanisms that move ions into the vacuole, even when the concentration within is higher than that of the surrounding fluid. Due to the elevated ionic concentration, water is drawn into the vacuole, resulting in turgidity and providing mechanical support to the plant's soft tissues.

2. Collenchyma

Collenchyma cells are specialized cells that are grouped in the form of strands or cylinders. They are found beneath the epidermis of young stems, leaf stalks and along veins in leaves. Collenchyma cells lack secondary walls. Their primary walls are thickened at the corners, due to extra deposition of cellulose. They elongate when stem or leaf grows lengthwise. They provide support to the young parts of plant in which secondary growth has not taken place.

3. Sclerenchyma

This tissue also provides structural support to the plants. Typically, the cells of sclerenchyma tissue possess thick secondary cell walls. These walls are saturated with lignin, an organic compound that confers strength and rigidity to the walls. The majority of sclerenchyma cells are non-living. The main function of this tissue is to provide support to the various components of the plant. There are three types of sclerenchyma cells which are fibres, sclereids and vessels.

Fibers (Tracheids) are elongated and cylindrical in shape. They can be found either as compact bundles inside the xylem or as bundle caps. **Sclereids** are smaller in size as compared to fibers and are present in the seed coats and shells of nuts. Their function is to offer protection. **Vessels (Tracheae)** are long tubular structures that are joined end to end to form a long water conducting pipe in xylem.

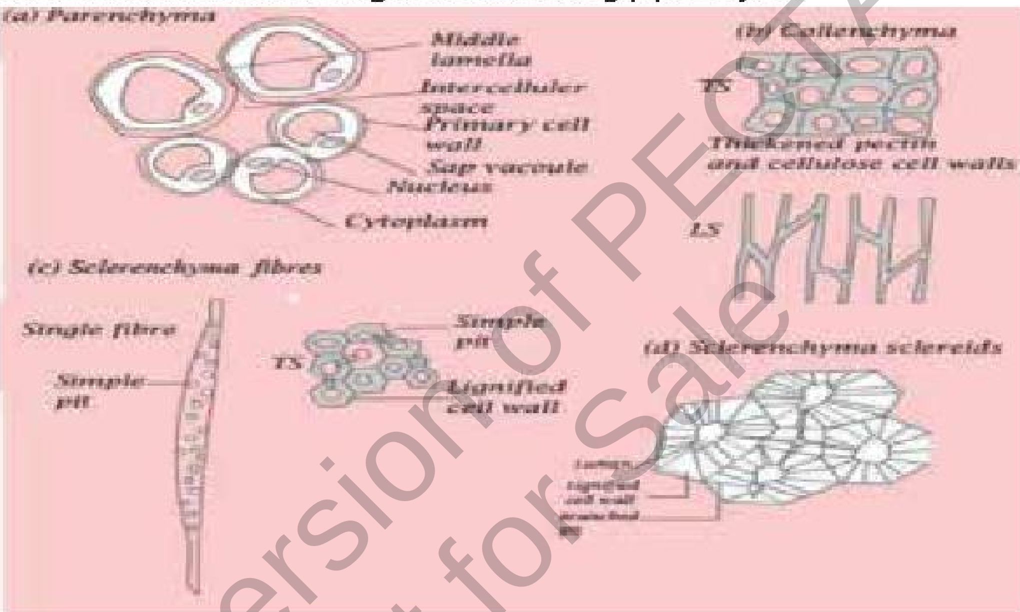

Figure.8.5: Specialized plant cells; (a) Parenchyma (b) Collenchyma (c) Sclerenchyma

8.4- Water Potential

Water molecules possess kinetic energy which means that in liquid or gaseous form they move about rapidly and randomly from one place to another. So, greater the concentration of the water molecules in a system the greater is the total kinetic energy of water molecules. This is called water potential (symbolized by Greek letter psi = Ψ_w). In plant cells, two factors determine water potential i.e., Solute potential (Ψ_s) and Pressure potential (Ψ_P).

Pure water has maximum water potential which by definition is zero. Water moves from a region of higher Ψ_w to lower Ψ_w. All solutions have lower Ψ_w than pure water and so have negative value of Ψ_w (at atmospheric pressure and at a defined temperature). So, the **osmosis** can be defined as the movement of water molecules from a region of higher water potential to a region of lower water potential through a partially permeable membrane.

Solute Potential (Ψs)

The solute potential or osmotic potential is a measure of the change in water potential (Ψ_w) of a system due to the presence of solute molecules. Ψ_s is always a negative value, so if more solute molecules are present, lower (more negative) is the Ψ_s.

Pressure Potential (ΨP)

It is the part of water potential which is due to the pressure exerted by water. If pressure greater than atmospheric pressure is applied to pure water or a solution, its water potential increases. When water enters plant cells by osmosis, pressure may be built up inside the cell making the cell turgid and increasing the pressure potential.

Thus, the total water potential (Ψ_W) is sum of solute potential (Ψ_s) and pressure potential (Ψ_P):

$$\Psi_W = \Psi_S + \Psi_P$$

If we use the term water potential, the tendency for water to move between any two systems can be measured; not just from cell to cell in a plant but also from soil to root, from leaf to air and from soil to air. The steeper the potential gradient the faster is the flow of water along it.

8.5- TRANSPORT OF WATER IN PLANTS

Uptake of Water by Roots

Roots of plants provide large surface area for absorption by their extensive branching systems. You know that roots have tiny root hairs, which are actually extensions of epidermal cells of roots. Most of the uptake of water and minerals in roots takes place through root hairs.

From soil, water and minerals enter the root epidermal cells by active and passive transport. From root epidermis, they move to cortex, and then into the xylem tissue in the centre of root. Inside roots, water and minerals move in three different pathways to reach the xylem.

1. The Apoplast Pathway

It is a continuous pathway that involves a system of adjacent cell walls in the plant roots. The apoplast pathway becomes discontinuous in the endodermis in the roots due to the presence of Casparian segments.

2. The Symplast Pathway

In symplast pathway, water and minerals move through interconnected protoplasts of root cells. The protoplasts of neighbouring cells are interconnected through **plasmodesmata**, which are cytoplasmic strands that extend through pores in adjacent cell walls. The symplast pathway is less important, except for minerals in the region of endodermis.

3. The Vacuolar Pathway

In vacuolar pathway, water and minerals move through cell membranes, cytoplasm and tonoplast (membranes of vacuoles) and vacuoles. They move from vacuole to vacuole and bypass the symplast and apoplast pathways. Movement in vacuolar pathway is negligible.

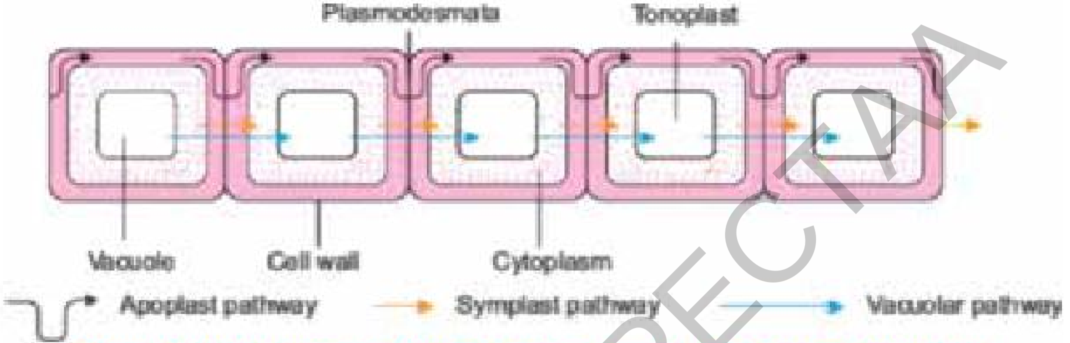

Figure 8.7: Water movement through apoplast, symplast and vacuolar pathways.

Structure of Xylem Tissue

Xylem is the vascular tissue in plants that carries water and dissolved minerals from the roots to the stem and leaves. It is also a key structural component which provides mechanical support to the plant body.

Xylem comprises of tracheids, vessels, xylem fibres and xylem parenchyma (Fig. 8.7).

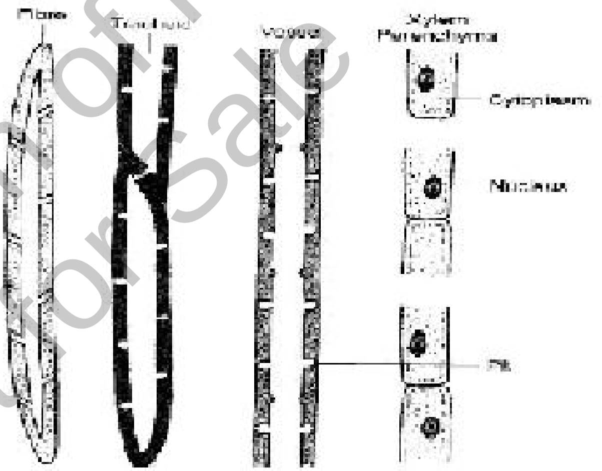

Figure 8.8: Different components of xylem tissue

Tracheids are elongate and thin cells that have thick walls made of lignin. The ends of the cells are tapered and they are linked to each other by bordered pits, which enable the lateral movement of water between cells. **Vessels** are shorter and broader compared to tracheids. They are arranged in a linear fashion, forming continuous channels. Perforation plates are present at the outer edges of these structures, enabling efficient movement of water. **Xylem fibres** are elongated cells with thickened lignified walls. At maturity, they are dead and enhance the structural integrity of the xylem. They offer additional structural support to the plant. **Xylem parenchyma** are living cells with thin walls that have the ability to retain and hold nutrients and water. Xylem parenchyma cells participate in the lateral translocation of water and nutrients and can also contribute to the healing and regeneration of xylem tissue.

The Movement of Water through Xylem

The movement of water within plants, from roots to leaves, occurs primarily through specialized vascular tissue known as xylem. The TACT (Transpiration, Adhesion, Cohesion, Tension) mechanism is a widely accepted model explaining how water moves against gravity through the xylem to reach all parts of the plant. This mechanism depends on both physical and chemical properties of water and the plant's interaction with its environment.

Transpiration is the process by which water evaporates from the surface of plant leaves, specifically through stomata. As water vapour exits the leaf, a **negative pressure** is generated within the leaf tissue. This negative pressure creates a pulling force, drawing water upward from the roots through the stem and toward the leaves. Transpiration, therefore, act as the primary driving force behind water transport in the xylem.

Adhesion is the attraction between water molecules and the walls of the xylem vessels. Due to this attraction, water molecules stick to the walls of xylem vessels as they move upward. This property prevents any break in the water column within xylem. Adhesion thus play a crucial role in maintaining the continuity of the water column, especially in tall plants where gravity exerts a significant downward force on the water column.

Cohesion refers to the attractive force between water molecules themselves, caused by hydrogen bonding. Water molecules within the xylem stick together, forming an unbroken column from the roots to the leaves. This cohesive property of water ensures that the **"pull"** initiated by transpiration at the leaf level extends down through the entire water column.

Tension is the negative pressure created by the pulling force of the transpiration at the leaf level. As water evaporates from the leaf surface, it creates a low-pressure area that extends through the xylem. This tension pulls the cohesive water column upwards. Tension is therefore vital for the continuous ascent of water within the xylem.

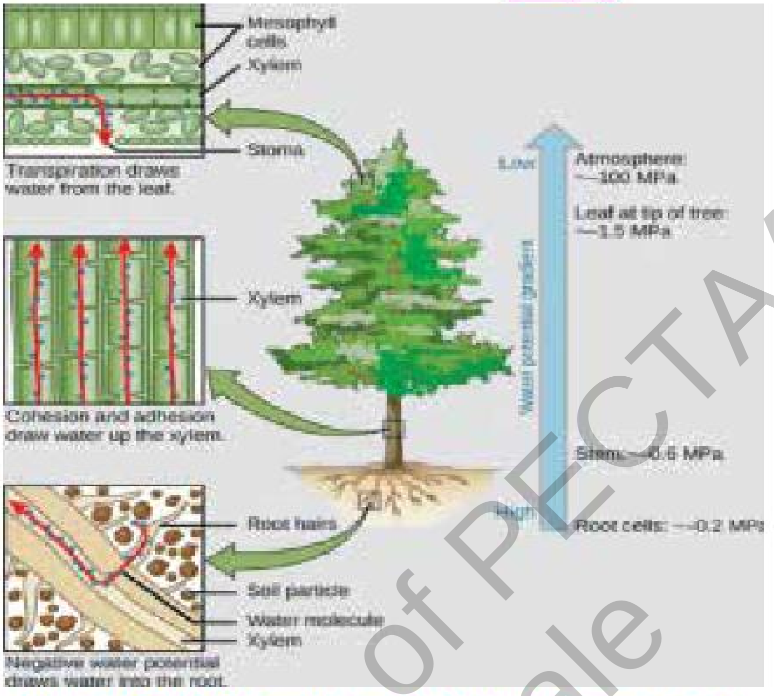

Figure 8.9: The TACT mechanism of water flow from root to leaf.

8.6- TRANSLOCATION OF FOOD IN PLANTS

Structure of Phloem

Phloem is a vascular tissue in plants responsible for the transport of organic nutrients, particularly the products of photosynthesis, from the leaves to other parts of the plant where they are needed or stored. The phloem is generally found on the outer side of both primary and secondary vascular tissue in plants with secondary growth. The phloem constitutes the inner bark.

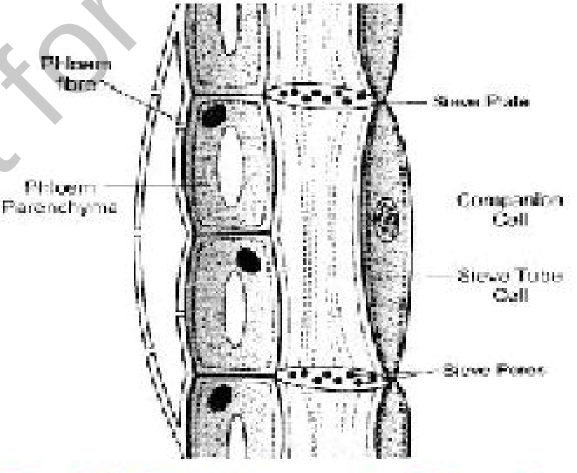

Figure 8.10: Different components of phloem tissue.

Phloem comprises of sieve elements, companion cells, phloem fibres and phloem parenchyma **(Fig. 8.10)**.

The cells of phloem that transport sugars and other organic material throughout the plant are called **sieve tube elements or cells**. Sieve tube elements have **'sieve areas'**, which are the portions of the cell wall where pores interconnect the sieve tube elements. Some of the sieve areas are generally formed in end walls of sieve tube elements where the individual cells are joined together to form a longitudinal series called a **sieve tubes**. Each sieve tube element is associated with one or more companion cells. Sieve tube elements and companion cells are in communication with each other by plasmodesmata. Companion cells supply ATP and proteins to sieve tube elements. **Phloem parenchyma** stores substances, such as sugars, resins, latex, and mucilage, which are important for plant defence and moisture retention.

Mechanism of Translocation

The transport of sugars in plants takes place through phloem tissue. Passive theories of phloem transport include:

Diffusion is far too slow, to account for the velocities of sugar movement in phloem, which on the average is 1 meter per hour, while the rate of diffusion is 1 meter per eight years.

Pressure flow theory: The pressure–flow theory, also known as the mass-flow hypothesis, is the most widely accepted explanation for the transport of sugars in plants through the phloem. This process of translocation moves sugar from the **source** (where they are synthesized) to the **sink** (where they are consumed or stored). This theory was proposed by **Ernst Munch** in 1930. This theory relies on the principle of osmotic pressure differences between source and sink regions. Following steps explain the pressure-flow theory.

1. The glucose formed during photosynthesis in mesophyll cells, is used in respiration. The excess of glucose is converted into non-reducing sugar i.e., sucrose.
2. Sucrose is actively transported from mesophyll cells to the companion cells of phloem. From here, sucrose diffuses to sieve tubes, through plasmodesmata. So, the concentration of sucrose in sieve tubes increases.
3. Due to higher sucrose (solute) concentration in sieve tubes, water moves into them by osmosis from the nearby xylem of leaf. It results in an increase in the water potential at the source end of sieve tubes.
4. At the sink end, sugar is actively unloaded from sieve tubes and water also follows by osmosis. The exit of water lowers the water potential at the sink end. So, there is a higher water potential at the source end while a lower water potential at the sink end.
5. The difference in water potential causes water to flow from source to sink. Since sucrose is dissolved in water, it is carried along from source to sink along with water.

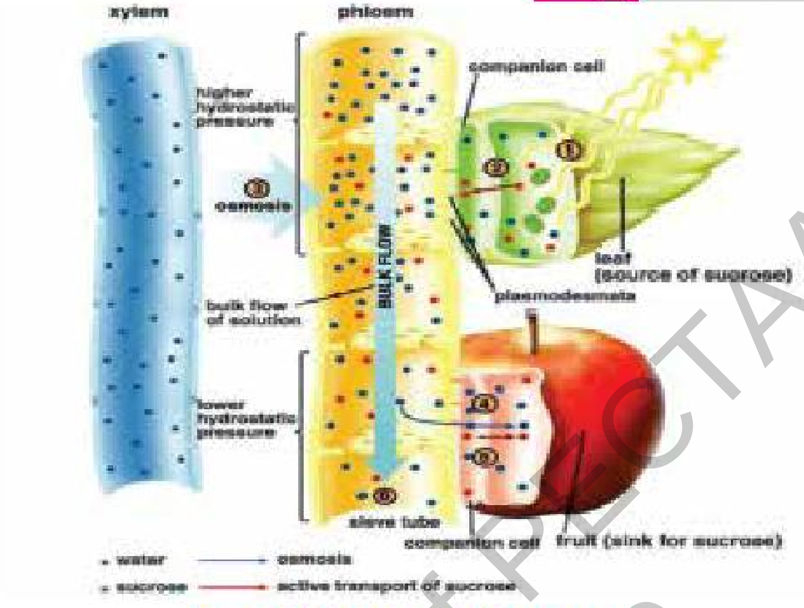

Figure 8.11: The pressure flow theory

8.7- Growth In Plants

Growth in plants refers to a permanent increase in size, which can occur in various dimensions such as height, width, and mass. Throughout life, the plant adds organs such as branches, leaves, and roots. Its organs increase in size from the tips but the rate of growth is not uniform throughout the body. In lower plants, the entire plant body is capable of growing, but in higher plants, growth is limited to certain regions known as **growing points.** These growing points consist of groups of cells, called **meristems,** that are capable of continuous cell division.

Types of Meristems

There are three types of meristems in plants i.e., apical meristems, intercalary meristems and lateral meristems **(Fig.8.13)**.

Apical meristems are found at the tips of roots and shoots. They are primarily responsible for the extension of the plant body. These are perpetual growth zones found and are responsible for the increase in the number of cells at the tips of roots and stems. They play an important role in primary growth.

Intercalary Meristems are separated from the apex by permanent tissues. They are situated at the bases of internodes in many plants such as grasses and play an important role in the production of leaves and flower. These are temporary.

Lateral meristems are cylinders of dividing cells present along the peripheral regions. They are responsible for growth in thickness of stems and roots. They are found in woody plants and are crucial for secondary growth. There are two main forms of lateral meristems; vascular cambium and cork cambium. **Vascular cambium** is located between the xylem and phloem and is responsible for production of secondary xylem and secondary phloem. **Cork cambium** is formed in the outer layer of stems and roots. This tissue produces cork cells which replace the epidermis and forms the outer protective bark.

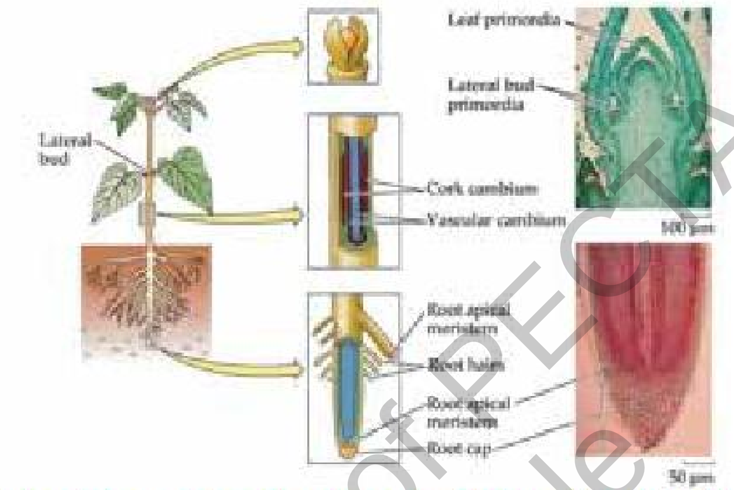

Figure 8.12: Apical meristem produces the primary plant body and lateral meristem produces be secondary plant body.

Types of Growth

In plants, there are two types of growth i.e., primary growth and secondary growth **(Fig.8.14)**.

Primary Growth

Primary growth is responsible for an increase in the length of the plants. It is facilitated by the activity of apical meristems. Herbaceous plants generally display primary growth with little secondary growth as compared to woody plants.

The process of primary growth in plants occurs in three phases.

1. **Cell Division:** The cells of apical meristems undergo divisions and the number of cells is increased. It happens at the tips of apical meristems of root and shoot. The area of apical meristem where cell division occurs, is called **zone of cell division**. In this zone, cells are non-vacuolated and small. These cells have spherical nuclei in the centre of cytoplasm.
2. **Cell Elongation:** After the formation of new cells, their volume increases due to uptake of water. Plasticity of cell wall increases and wall pressure is reduced. It happens at a little distance from the tips of apical meristems. The area where cell elongation occurs, is called **zone of cell elongation**. In this zone, cells are vacuolated and large. They have nuclei in the peripheries of cytoplasm. During this phase, different cells elongate in different dimensions and the final size of cells is attained. For example, the cells which are determined to develop into pith, cortex

etc. do not elongate much length-wise while the cells which are determined to develop into xylem tissue elongate more length-wise.

3. **Cell Differentiation:** After the cells have got their final size and shape, elongation stops and cells are specialized to perform specific functions. Their cell walls become thicker and many new structural features develop. It happens in the area next to the zone of elongation. This area is called zone of cell differentiation. In this zone, cells are fully differentiated and each type of cell performs specific function.

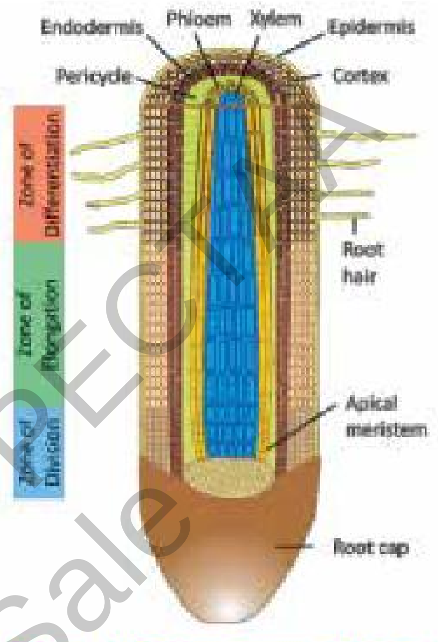

Figure 8.13: Primary growth in a root

Secondary Growth

Secondary growth refers to the increase in thickness or girth of stems and roots. It is due to the activity of lateral meristems, specifically the vascular cambium and cork cambium. It is more prominent in woody perennial plants, while herbaceous plants show only primary growth.

The cells of vascular cambium divide and produce new cells on both of its outer and inner margins. Cells produced on outer margins of vascular cambium make secondary phloem while the cells produced on its inner margins make secondary xylem. Secondary tissues (particularly secondary xylem) cause increase in plant's thickness. Division in cork cambium produces cells on both outer and inner sides. These cells make new cork. The region of mature stem outside of the vascular cambium, which contains secondary phloem, cork cambium and cork, is collectively called bark.

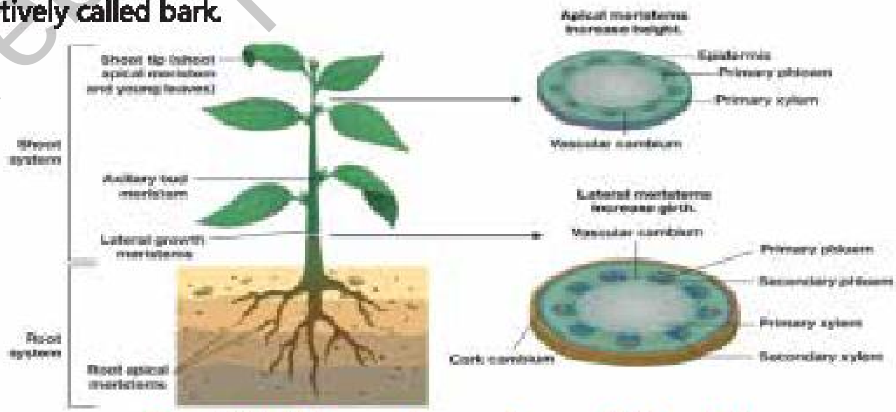
Figure 8.14: Primary and secondary growth in a plant.

Annual rings are formed due to the seasonal activity of the cambium layer in trees. This process is influenced by environmental factors and results in the production of two distinct types of wood each year: **spring wood** (early wood) and **autumn wood** (late wood). These rings provide valuable information about the age of the tree and the environmental conditions experienced during each growing season.

> Dendrochronology is the scientific method of dating and studying tree rings to analyse past climate conditions and events.

The cambium is a meristematic tissue that generates new vascular tissues i.e., xylem and phloem. In spring, when conditions are favourable, the cambium is highly active, producing a large volume of xylem with wider vessels, resulting in lighter-coloured spring wood. As the season changes to autumn, the cambium's activity decreases. It produces fewer xylem elements, which are narrower and denser, leading to the formation of darker autumn wood. The combination of spring wood and autumn wood forms a complete annual ring. Each year, a new ring is added, allowing for the determination of a tree's age through dendrochronology.

The transition between these two types of wood is gradual from spring to autumn, but the shift from autumn back to spring in the following year is abrupt, marking a clear distinction between the growth periods. This data is valuable for studying long-term climate variability and changes.

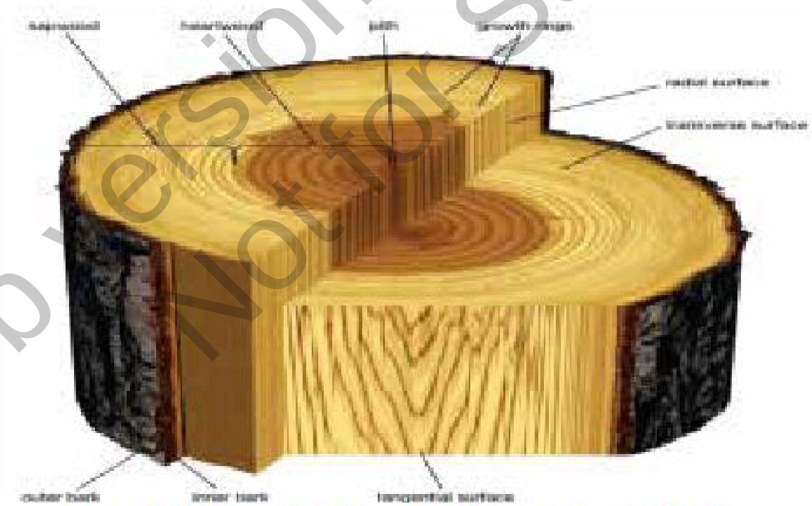

Figure 8.15: Anatomy of a tree trunk showing annual rings

Plant Growth Regulators

Plants regulate the rates of growth and the rate of metabolism in their cells. Special chemical messengers, called plant growth regulators or **plant hormones** regulate their growth. There are five major groups of plant growth regulators i.e., auxins, cytokinins, gibberellins, abscisic acid, and ethylene.

Auxins

These are indole acetie acid (IAA) or its variants. These regulate following activities:

- In stem, promote cell enlargement in region behind apex.
- Promote cell division in cambium.
- In root, promote growth at very low concentrations. Inhibit growth at higher concentrations, e.g., geotropism. Promote growth of roots from cuttings and calluses.
- Promote bud initiation in shoots but sometimes antagonistic to cytokinins and is inhibitory.
- Promote apical dominance and fruit growth. They can sometimes induce parthenocarpy.
- Cause delay in leaf senescence (aging) in a few species.
- Inhibit abscission.

Gibberellin

Gibberellins are produced in the apical portions of roots and shoots, and transported to other parts. Gibberellins contain Gibberellic acid and there are more than 110 different gibberellins. They preform following activities:

- Promote cell enlargement in the presence of auxins. Also promote cell division in apical meristem and cambium.
- Promote 'bolting' of some rosette plants.
- Promote bud initiation in shoots of chrysanthemum callus.
- Promote leaf growth and fruit growth. May induce parthenocarpy.
- In apical dominance, enhance action of auxins.
- Break bud and seed dormancy.
- Sometimes may substitute for red light. Therefore, promote flowering in long-day plants, while inhibit in short-day plants.
- Cause delay in leaf senescence in a few species.

Cytokinins

They are usually produced in roots, young fruits, and in seeds. Cytokinins promote cytokinesis during cell division. They increase the rate of DNA replication and the rate of RNA and protein synthesis. They perform the following:

- Promote stem growth by cell division in apical meristem and cambium.
- Inhibit primary root growth.
- Promote lateral root growth.
- Promote bud initiation and leaf growth.
- Promote fruit growth but can rarely induce parthenocarpy.
- Promote lateral bud growth, also break bud dormancy.
- Cause delay in leaf senescence.

- Promote stomatal opening.

Abscisic acid

Abscisic acid (ABA) is synthesized mainly in mature green leaves, fruits, and root caps. It performs the following functions:

- Inhibits stem and root growth notably during physiological stress, e.g., drought, and waterlogging.
- Promotes bud and seed dormancy.
- Promotes flowering in short day plants, and inhibits in long day plants (antagonistic to gibberellins).
- Sometimes promotes leaf senescence.
- Promotes abscission.
- Promotes closing of stomata under conditions of water stress (wilting).

Ethylene

It is a natural product of the metabolism of plants. Inhibits stem growth, notably during physiological stress.

- Inhibits root growth.
- Breaks dormancy of bud.
- Promotes flowering in pineapple.
- Promotes fruit ripening.

8.8- OSMOREGULATIONIN PLANTS

Osmoregulation refers to the process by which an organism maintains a stable internal equilibrium of water and dissolved substances, irrespective of the surrounding environmental conditions. Many marine organisms undergo osmosis without the requirement for regulatory systems since their cells have the same osmotic pressure as that of the sea. However, some organisms must actively acquire, retain, or eliminate water or salts in order to regulate their internal water and mineral balance.

Types of Solutions

Hypotonic solution: A solution having reduced solute concentration relative to the intracellular environment of a cell. As a result, water enters the cell by osmosis resulting in the swelling.

Hypertonic solution: A solution having high solute concentration relative to the intracellular environment of a cell. As a result, water moves out of the cell which causes the cell to shrink due to loss of water, a condition called **plasmolysis**.

Isotonic solution: A solution whose solute concentration resembles to the intracellular environment of the cell. Net movement of water between the cell and its environment is zero in this case.

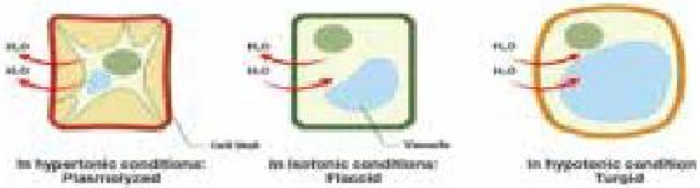

Figure 8.16: Effect of Hypertonic, Hypotonic and Isotonic solution to plant cell.

Osmotic Adjustments In Plants

Plants are distributed in different habitats of aquatic, moderate, severely dry terrestrial and saline nature, thus termed as hydrophytes, mesophytes, xerophytes and halophytes, respectively.

Hydrophytes are adapted to aquatic environments, including marine and freshwater ecosystems, through specialized osmotic adjustment mechanisms. **Marine hydrophytes** thrive in saline (hypertonic) conditions, where water tends to leave their cells. They excrete excess salts using specialized salt glands and synthesize organic solutes like proline, glycine betaine, and sugars to retain water by increasing their internal osmotic potential. They have thick cuticles which further reduce water loss, and they exhibit halophytic traits to tolerate high salinity. **Freshwater hydrophytes** grow in hypotonic environments, where water continuously enters their cells. These plants expel excess water through structures like hydathodes or vacuoles to avoid overhydration. They actively absorb essential ions, such as potassium and calcium, to maintain osmotic balance and compensate for the dilute surroundings. With thin or absent cuticles, these plants facilitate water exchange and often have reduced root systems, relying on direct nutrient and water absorption from their environment. Examples of hydrophytes are water lilies, lotus, seaweeds and tape grass **(Fig. 8.17)**.

Figure 8.17: (a) Waterlily floating in freshwater. (b) Tape grass in freshwater lake.

Mesophytes live in moderate environments that are neither too dry nor too wet. They prefer soil that is not waterlogged and has a moderate salt content and humidity. Mesophytes have well-developed roots and shoots with a fully formed vascular system. They do not require any special adaptations to survive. Their leaves are flat, broad, and green with stomata on the surface. Examples of mesophytes include rose, tomatoes, and daisies **(Fig.8.18)**.

Figure 8.18: Examples of mesophytes, left (rose) and right (daisy).

Xerophytes are plants that are adapted to survive in dry conditions. They have special adaptations to minimize water loss and store water. Plants that store water are known as **succulents**. They possess fleshy stems that can store water and used when needed. Other adaptations in xerophytes include waxy coatings on leaves to reduce water loss, leaf dropping during dry periods, and leaf folding or repositioning to absorb sunlight efficiently. Examples of xerophytes include thorn trees, desert marigold, and blue agave **(Fig. 8.19)**.

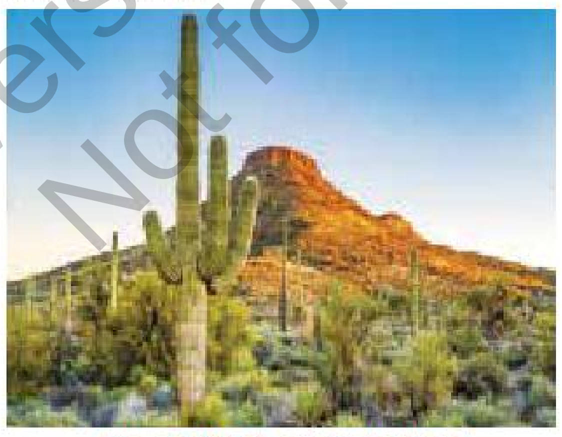

Figure 8.19: A xerophytic plant

Halophytes inhabit saline soil with high concentrations of salts like NaCl, $MgCl_2$, $MgSO_4$, or saline water. On such a substratum, only such plants can grow which can tolerate a relatively high concentration of these salts. These plants have succulent leaves and sometimes the stem is also succulent. In certain cases, leaves are modified into spines. Examples of halophytes are sea arrowgrass and sea lavender.

Figure 8.20: Sea Arrowgrass

Halophytes growing in marshy places near seashore form a special vegetation known as the mangrove or tidal woodland. These are also called Helophilous halophytes.

8.9- THERMOREGULATION IN PLANTS

Thermoregulation is a homeostasis in which organisms maintain their body temperature despite variations in environmental temperature. **High temperature** denatures the enzymes and damages the metabolism. Plants use evaporative cooling to cope with high temperature. Hot and dry weather, however, causes water deficiency resulting in closing of stomata, thus plants suffer in such conditions. Most plants have adapted to survive in heat stress as the plants of temperate regions face the stress of 40°C and higher temperature. The cells of these plants synthesize large quantities of special proteins called **heat-shock proteins.** These proteins embrace enzymes and other proteins thus help to prevent their denaturation.

Low temperature, on the other hand alters the fluidity of the cell membrane, because lipids of the membrane become locked into crystalline structures, which affects the transport of the solutes. The structure of the membrane proteins is also affected. Plants respond to cold stress by increasing proportion of unsaturated fatty acids, which help membrane to maintain structure at low temperature by preventing crystal formation. This adaptation requires time. Because of this reason, rapid chilling of plants is more stressful than gradual drop in air temperature. Freezing temperature causes **ice crystal formation**. The confinement of ice formation around cell wall does not affect as badly and plants survive. However, formation of ice crystals within protoplasm perforates membranes and organelles hence killing the cells. The plants native to cold region such as oaks, maples, roses and other plants have adapted to bring changes in solutes composition of the cells, which causes cytosol to super cool without ice formation, although ice crystals may form in the cell walls.

8.10- MOVEMENTS IN PLANTS

Organisms react to both external and internal stimuli. Animals may exhibit locomotion in reaction to stimuli but the plants are fixed, hence they can only alter their growth pattern.

Tropic movements: The growth movements in plants that are triggered by a stimulus, are collectively called tropic movements or tropisms. Such movements occur as a curvature of whole organ towards or away from stimuli such as light, touch, chemical, water and gravity. Following are the major types of tropic movements in plants:

1. **Phototropism**: It is the movement of part of plant, in response to stimulus of light and is caused by the differential growth of part of a plant like stem or root. The tips of shoots usually show positive phototropism while roots show negative phototropism.
2. **Geotropism**: It is the movement of plant parts in response to gravity. Roots display positive geotropism and shoots negative geotropism.
3. **Thigmotropism**: It is the movement in response to stimulus of touch, for example climbing vines. When they come in contact with some solid object, the growth on the opposite side of contact increases and the tendril coils around the support.
4. **Chemotropism**: The movement in response to some chemicals is called chemotropism. The hyphae of fungi are chemotropic.

8.11 - PHOTOPERIODISM

The response to changes in day length that enables plants to adapt to seasonal changes in their environment is termed as **photoperiodism**. Simply, it is response of plants to the length of day and night.

Effect of photoperiodism was first studied in 1920 by Garner and Allard. They studied that tobacco plant flowers only after exposure to a series of short days. Tobacco plant naturally flowers under same conditions, in autumn, but flowering could be induced by artificially exposing to short days. With further studies they were able to classify flowering plants into **long-day plants**, which require long days for flowering, **short-day plants**, which require short days for flowering and **day-neutral plants** which flower without being influenced by photoperiod. Later on, further studies indicated that it is really the length of the dark period which is critical. Thus, short-day plants are really long-night plants. If they are grown in short days, but the long night is interrupted by a short light period, flowering is prevented. Long-day plants will flower in short days if the long night period is interrupted.

Mechanism of Flower Induction

Phytochrome, a photoreceptor protein exists in two forms i.e., P_{660} and P_{730}. P_{660} is a quiescent form. It absorbs red light at a wavelength of 660 nm and is converted to active P_{730} which absorbs far red light at 730 nm and is converted to P_{660}. In nature, the P_{660} to P_{730} conversion takes place in day light and P_{730} to P_{660} conversion occurs in the dark. The rate at which P_{730} is converted to P_{660} provides the plant with a **"clock"** for measuring the duration of darkness.

It has been found that red light inhibits flowering in short-day plants but promotes flowering in long-day plants, under conditions during which flowering normally takes place. This observation led to the hypothesis that the P_{730}-P_{660} interconversion might be the plant time-regulator for flowering. According to this hypothesis, P_{730}, converted from P_{660} by the absorption of red light, would inhibit flowering in short day plants but promote flowering in long day plants. Because P_{730} accumulates in the day and diminishes at night, short day plants could flower only if the night were long enough, during which a great amount of P_{730} would not be completely inactivated, so that enough P_{730} would remain at the end of night to promote flowering. But now it is generally agreed that the time measuring phenomenon of flowering is not totally controlled by the interconversion of P_{660} to P_{730}. Other factors, like presence or absence of light and length of dark or light period also play an important role in flowering. The biological clock once stimulated causes production of **florigen** hormone in leaves, which travels through phloem to the floral buds, initiating flowering.

Table 8.2: Classification of plants according to photoperiodic requirements for flowering

Short-day plants (SDPs)	Long-day plants (LDPs)	Day-neutral plants (DNPs)
Flowering induced by dark periods longer than a critical length, e.g., cocklebur 8.5 h; tobacco 10-11h.	Flowering induced by dark periods shorter than a critical length, e.g., henbane 13h.	Flowering independent of photoperiod.
Examples include cocklebur (Xanthium), chrysanthemum, soyabean, tobacco, strawberry.	Examples include henbane (Hyoscyamus niger), snapdragon, cabbage, spring wheat, spring barley	Examples include cucumber, tomato, garden pea, maize, cotton.

8.12- VERNALISATION

Biennial and perennial plants are stimulated to flowering by exposure to low temperature. This is called **vernalisation.** The low temperature stimulus is received by the shoot apex of a mature stem or embryo of the seed but not by the leaves as in photoperiodism.

For some plants, vernalisation is an absolute requirement while in some cases it simply assists in inducing flowering. The duration of low temperature (chilling) treatment required varies from four days to three months. Temperature around 4°C is found to be very effective in this regard. It stimulates the production of a hormone **"vernalin"** which induces vernalisation. Photoperiodism and vernalisation serve to synchronise the reproductive behaviour of plants with their environment, ensuring reproduction at favourable times of year. They also ensure that members of the same species flower at the same time, encouraging cross pollination for genetic variability.

EXERCISE

SECTION 1: MULTIPLE CHOICE QUESTIONS

1. Process by which water evaporates from surface of leaf primarily through stomata:
   (a) Transpiration (b) Guttation (c) Imbibition (d) Cohesion
2. Through which structure does most of transpiration occurs?
   (a) Root hairs (b) Phloem (c) Xylem (d) Stomata
3. The TACT theory primarily explains
   (a) The movement of nutrients in the plants
   (b) The transport of water in plants
   (c) The absorption of minerals
   (d) The process of photosynthesis
4. Which of the following is not a function of xylem?
   (a) Transport of water (b) Transport of minerals
   (c) Transport of food (d) Mechanical support
5. Which of the following has a perforated cell wall?
   (a) Vessel (b) Fibre (c) Tracheid (d) Sclereid
6. Exposure to low temperature stimulates the process of flowering in biennial or perennial plants:
   (a) Dormancy (b) Photoperiodism (c) Vernalization (d) All of above
7. Plants that are adapted to survive in dry conditions:
   (a) Xerophhytes (b) Hydrophytes (c) Mesophytes (d) Halophytes
8. When sugar content in a cell increases the concentration of solute increases, what happens to the water potential?
   (a) Raises (b) Drops (c) Unchanged (d) None of these
9. In higher plant, transport of food materials occurs through:
   (a) Companion cells (b) Sieve tubes
   (c) Vessel elements (d) Tracheids
10. The plant hormone which inhibits the stem and root growth is
    (a) Auxin (b) Ethylene (c) Cytokinin (d) Gibberellin
11. The leaves of some hydrophyte float on the surface of water. In such a leaf, stomata are found in:
    (a) Lower epidermis (b) Upper epidermis
    (c) Sides of leaf (d) Deep depressions in leaf

12. Mesophytes are adapted to survive in:

(a) Moderate environments (b) Dry conditions
(c) Water environments (d) All of above

SECTION 2:SHORT QUESTIONS

1. Differentiate between macronutrients and micronutrients?
2. What is water potential?
3. What are the main three pathways for the movement of water between plant cells?
4. Differentiate between hypertonic and hypotonic solution?
5. What are halophytes?
6. Differentiate between long day plants and short day plants?
7. Write down the phases of plant growth?
8. Differentiate between Vernalin and Florigen.
9. Differentiate between Thigmotropism and Geotropism.
10. How intercalary meristem is different from apical meristem?

SECTION 3: LONG QUESTIONS

1. Describe osmoregulation in Hydrophytes and Halophytes?
2. Describe the Physiological adaptation of plants to extreme conditions. How do plants adjust their cell membrane composition and protein structures to survive high and low temperatures?
3. What is the role of meristem in the growth of plants?
4. Describe the mechanism of opening and closing of stomata?
5. Explain the concept of photoperiodism and its influence on plant flowering. How do short-day, long-day and day-neutral plants differ in their flowering responses, and what role does phytochrome plays in this process?

INQUISITIVE QUESTIONS

1. Can you explain the hypothesis regarding the opening and closing of stomata?
2. What mechanisms enable carnivorous plants to supplement their nutrient uptake despite being autotrophs?
3. How can you say that parenchyma and schlerenchyma provide support to plants?
4. How do the annual rings depict climatic variability?
5. How does Pressure Flow Theory explain the movement of sugars through a plant?
6. What strategies would you adopt to induce flowering in a plant?