Republic of Iraq
Ministry of Higher Education
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Lecture 3

PLANT CELL – WATER RELATIONS

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PLANT CELL – WATER RELATIONS

All living cells contain approximately 60–95% of water, and water is required for their growth and reproduction. Even the dormant cells and tissues also have 10–20% of water. Water plays a crucial role in the life of plant. It is the most abundant constituents of most organisms. The distinct physical and chemical properties of water, namely, cohesion, surface tension, high specific heat, high heat of vaporization, lower density of ice, and solubility, are due to hydrogen bonding between water molecules. The uptake of water by cells generates a pressure known as turgor. Photosynthesis requires that plants draw carbon dioxide from the atmosphere, and at the same time exposes them to water loss. To prevent leaf desiccation, water must be absorbed by the roots, and transported through the plant body. Balancing the uptake, transport, and loss of water represents an important challenge for land plants. The thermal properties of water contribute to temperature regulation, helping to ensure that plants do not cool down or heat up too rapidly. Water has excellent solvent properties. Many of the biochemical reactions occur in water and water is itself either a reactant or a product in a large number of those reactions. Plants use water in huge amounts, but only small part of that remains in the plant to supply growth. About 97% of water taken up by plants is lost to the atmosphere, 2% is used for volume increase or cell expansion, and 1% for metabolic processes, predominantly photosynthesis.

Water consists of an oxygen atom covalently bonded to two hydrogen atoms The oxygen atom carries a partial negative charge, and a corresponding partial positive charge is shared between the two hydrogen atoms. This asymmetric electron distribution makes water a polar molecule.

Movement of substances from one region to another is commonly referred to as translocation. Mechanisms for translocation may be classified as either active or passive. It is sometimes difficult to distinguish between active and passive transport, but the translocation of water is clearly a passive process. Passive movement of most substances can be accounted for by bulk flow or diffusion. The diffusion of water across a selectively permeable barrier is known as osmosis.

Water Movement

1. Mass flow or bulk flow

Is pressure-driven movement of molecules. In contrast to diffusion and osmosis, mass flow is independent of solute concentration. The protoplasm streaming in plant cells during active growing season is an example of mass flow. The upward longitudinal transport of water and dissolved substances in the xylem elements and in phloem transport takes place through mass flow. Mass flow has a significant role in long-distance transport of water and minerals. During intercellular transport, mass flow faces many barriers, cell wall, plasma membrane, tonoplast, and plasmodesmata. Vascular cells have adopted many changes for bulk movement of water, e.g., removal of end walls in xylem vessels, enlargement of plasmodesmata, and depletion of protoplasm.

2. Diffusion

It is a physical process where movement of any substance or molecule takes place from the region of its higher concentration to the region of its lower concentration due to kinetic energy. Diffusion can take place in all three phases of matter. The rate of diffusion is affected by temperature, molecular density, diffusion medium, and chemical potential gradient. In plants, diffusion occurs in stomata to facilitate the exchange of carbon dioxide, oxygen, and water vapors between leaf cells and external atmosphere. Diffusion also plays an important role in gas exchange in lenticels present in the stem. The apoplastic and symplastic pathway of intercellular transport also involve diffusion. Imbibition during seed germination is also a special type of diffusion.

3. Osmosis

It is a special type of diffusion which takes place in solvents through semipermeable membrane. Osmosis is a biological process where the solvent molecules move from their higher concentration (lower solute concentration) to lower concentration (higher solute concentration) through a semipermeable membrane. It is controlled both by concentration and pressure gradient. The rate of osmosis can be increased by the addition of osmotically active substances and can be measured by osmometer. Osmosis is the process by which water is transported into and out of the cell. The growth, development, and turgidity of the cells are maintained by the process of osmoregulation.

Water Potential and Its Components

Water potential is a measure of free energy of water per unit volume (Jm^3). In terms of pressure units, water potential is expressed as MPa (megapascal). The lower the water potential of the plant, the greater is its ability to absorb water and vice versa.

**In a living cell, water potential refers to the sum of the following components:

Ψw= Ψs + Ψp + Ψm

where Ψw is the water potential, Ψs solute/osmotic potential, Ψp pressure potential and Ψm matric potential.

Solute Potential

Osmotic potential (Ψs) or solute potential refers to the effect of solutes on water potential. Solutes reduce the free energy of water. . It is always negative. The addition of solutes also changes the colligative properties of solutions. Macromolecules, like proteins, nucleic acids, and polysaccharides, have far less effects on the solute potential as compared to their respective monomers. The cell stores fuel as macromolecules (starch in plant cells or glycogen in animal cells), rather than glucose or other simple sugars to avoid drastic changes in osmotic potential.

Pressure Potential

It is the hydrostatic pressure of the solution. It is denoted by ψp and is measured in MPa. It is always positive. Pure water has minimum pressure potential, i.e., zero. Increase in pressure increases the water potential of a solution. In other words, pressure potential of a cell is the amount of pressure required to stop further entry of water in the cell. In a cell, pressure potential is responsible for maintaining the turgidity, and hence it is known as turgor pressure (TP). The turgor pressure (TP) of a cell is the difference between inside and outside hydrostatic pressures across the plasma membrane and cell wall. At equilibrium (i.e., when inside water potential is equal to outside water potential), TP will be equal to the difference in internal solute potential and that of external solute potential.

TP = Ψs inside - Ψs outside

In plants a fully turgid cell experiences an equal and opposite pressure, known as wall pressure. The presence of cell wall in plant cells allows it to withstand a wide range of osmotic variations. In contrast, an animal cell can only survive in an isotonic solution. The plant cell placed in pure water swells but does not burst.

Matric Potential

It is expressed as the adsorption affinity of water to colloidal substances and surfaces in plant cells. Matric potential is negligible in a hydrated cell but is of considerable importance in dehydrated cells and tissues such as seeds and desert plants. Under these conditions, water exists as a very thin layer bound to solid surfaces by electrostatic interactions. These interactions are not easily separated into their effects on solute and pressure potential and thus sometimes combined into matric potential. The adsorption of water by hydrophilic surfaces is known as hydration or imbibition. Matric potential is measured in the same unit as water potential.

Water absorption by roots

Absorption of water in plants is a vital process that is important for plant growth and other metabolic activities. Water absorption in lower plants takes place by the process of osmosis through the whole plant body. In higher plants, the mechanism of water absorption is through the root hairs.

Plants mainly absorb water from the soil by the capillary action. There are five types of water that are found in the soil, namely runway water, gravitational water, hygroscopic water, chemically combined water and capillary water. Among these types only the capillary water is useful for the plant.

Transport of water and minerals in the vascular strands is based on the differences in pressure and concentration gradients of both solutes and the solvent (water). The transport of minerals and water from the soil to xylem and from xylem to substomatal cavity is referred as short-distance transport. Once water enters the xylem elements, it is transported up to 100 m or more by the transpirational pull created in the leaves. Therefore, there is need to have an essential long-distance transport by two different transport systems involving transport in opposite directions.

Intimate contact between the surface of the root and the soil is essential for effective water absorption by the root. This contact provides the surface area needed for water uptake and is maximized by the growth of the root and of root hairs into the soil. Root hairs are microscopic extensions of root epidermal cells that greatly increase the surface area of the root, thus providing greater capacity for absorption of ions and water from the soil. The walls of root hairs are permeable and consist of pectic substances and cellulose which are strongly hydrophilic in nature. Water enters the root most readily in the apical part of the root that includes the root hair zone. More mature regions of the root often have an outer layer of protective tissue, called an

exodermis or hypodermis, that contains hydrophobic materials in its walls and is relatively impermeable to water such as suberin and cutin. water is transported predominantly by bulk flow.

Water movement mechanism in plants

In plants, following pathways are involved in the water movement.

1. **Apoplastic pathway**

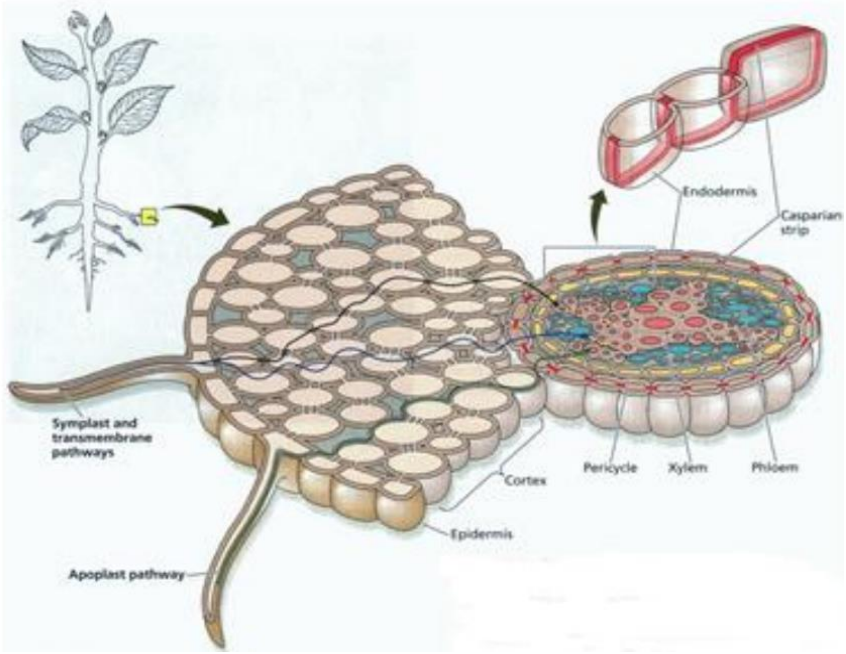
The apoplastic movement of water in plants occurs exclusively through the cell wall without crossing any membranes. The apoplast is the continuous system of cell walls and intercellular air spaces in plant tissues. The cortex receive majority of water through apoplastic way as loosely bound cortical cells do not offer any resistance. But the movement of water in root beyond cortex apoplastic pathway is blocked by casparian strip present in the endodermis. The Casparian strip breaks the continuity of the apoplast pathway, and forces water and solutes to cross the endodermis by passing through the plasma membrane.

2. **Symplastic pathway**

The movement of water from one cell to other cell through the plasmodesmata is called the symplastic pathway of water movement. This pathway comprises the network of cytoplasm of all cells inter-connected by plasmodermata.

3. **Transmembrane pathway**

In plant roots, water movement from soil till the endodermis occurs through apoplastic pathway i.e. only through cell wall. The casparian strips in the endodermis are made-up of wax -like substance suberin which blocks water and solute movement through the cell wall of the endodermis. As a result water is forced to move through cell membranes and may cross the tonoplast of vacuole. This movement of water through cell membranes is called transmembrane pathway.



External Factors Affecting Absorption of Water:

1. Available Soil Water:

Sufficient amount of water should be present in the soil in such form which can easily be absorbed by the plants. Usually the plants absorb capillary water i.e., water present in films in between soil particles. Other forms of water in the soil e.g., hygroscopic water, combined-water, gravitational water etc. are not easily available to plants. Increased amount of water in the soil beyond a certain limit results in poor aeration of the soil which retards metabolic activities of root cells like respiration and hence, the rate of water absorption is also retarded.

2. Concentration of the Soil Solution:

Increased concentration of soil solution (due to the presence of more salts in the soil) results in higher osmotic pressure. If the O.P. of soil solution will become higher than the O.P. of cell sap in root cells, the water absorption will be greatly suppressed.

3. Soil Air:

Absorption of water is retarded in poorly aerated soils because in such soils deficiency of O_2 and consequently the accumulation of CO_2 will retard the metabolic activities of the roots like respiration. This also inhibits rapid growth and elongation of the roots so that they are deprived of the fresh supply of water in the soil.

4. Soil Temperature:

Increase in soil temperature up to about 30°C favuors water absorption. At higher temperatures water absorption is decreased. At low temp, also water absorption decreases so much so that at about 0°C it is almost checked.

This is probably because at low temp:

(i) The viscosity of water and protoplasm is increased.

(ii) Permeability of cell membranes is decreased.

(iii) Metabolic activities of root cells are decreased.

(iv) Growth and elongation of roots are checked.

Long-Distance Transport

For the survival of land plants, long-distance transport of water and nutrients is an important process. Angiosperms and gymnosperms are the most advanced land plants with well-developed vascular systems. Water and nutrient entry into the xylary elements in roots and their transport against gravity to the top of the aerial parts of the plants is referred as long-distance transport.

Water Transport Through Xylem

The upward movement of water through the xylem tissues is referred as ascent of sap. Water travels long distances in plants through xylem strands. The upward movement of water is facilitated by transpirational pull and cohesive-adhesive properties of water molecules. Mature xylem consists of tracheids and vessels. It is responsible for upward movement of water. Xylem carries the water stream from the site of absorption (roots) to the site of evaporation (leaves). Water potential regulates the entry of water into the xylem. The upward transport of xylem sap is rapid during the daytime when transpiration rates are high.

Mechanism of Transport Across Xylem

1. **Root Pressure**

It is a positive hydrostatic pressure developed due to the difference in solute potential between the soil solution and xylem sap. It often develops at night when the rate of

transpiration is low or absent and humidity is high. In roots, the development of pressure takes place due to high salt concentration and presence of Casparian bands in endodermis. Ion accumulation decreases the solute potential of roots, and despite the absence of transpiration, water enters into the root and into the xylem. Root pressure is insignificant in tall trees but has a significant role in the young plants. During seed germination and bud growth, prior to the development of leaf and transpiration stream, water uptake is due to root pressure

2. Capillary Rise

Liquids in small tubes show a rise in the meniscus level due to adhesion of liquid with the wall of tube. This rise of meniscus of liquid in the tube is known as capillarity or capillary rise. Water has high tensile strength due to cohesion of its molecules. In addition, water also has adhesion between water molecules and xylem elements, and there exists surface tension among water molecules. These factors are responsible for capillary rise of water in plants. In order to reach a height of 100 m in tall trees by capillary rise, there have to be cells with diameter of 0.15 μm (which is much smaller than the diameter of smallest tracheids). Moreover, the capillary rise in small capillary tubes is due to open space in the tube, whereas water in xylem does not have this open space.

3. Cohesion-Adhesion and Tension Theory

Water in xylem is under constant tension due to transpirational pull. Many experiments gave evidence that xylem is constantly under three types of pressures, the driving force or the transpirational pull, cohesion force due to cohesion of water molecules, and adhesion force between water molecules and the wall of xylem elements. These three forces lead to the formation of a continuous column of water, which is pulled from roots to the leaves. One of the driving forces for ascent of sap is transpirational pull.

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