Republic of Iraq
Ministry of Higher Education
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Lecture 5

Loss of water from the plant

1. Transpiration
2. Guttation
3. Bleeding

For
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Loss of water from the plant

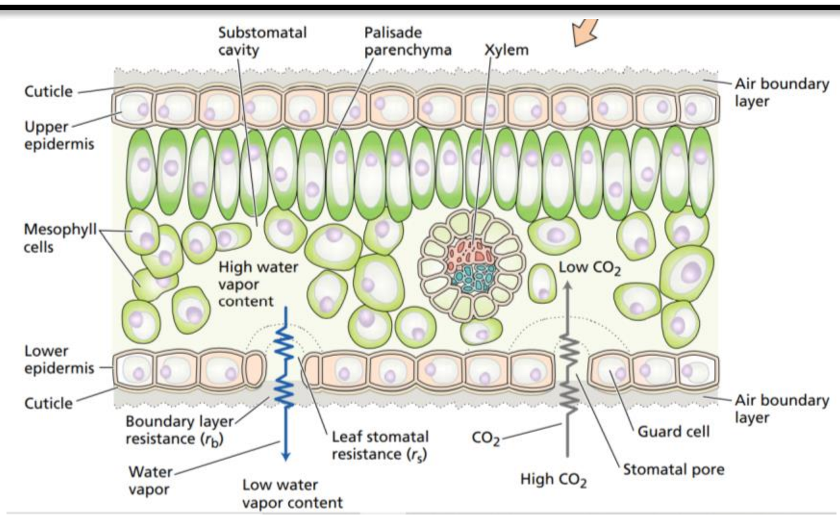
1. Transpiration

It is the process of lossing water from plants in the form of steam, there are three types of transpiration in plants:

a. **Cuticular transpiration:** is the loss of water from the surface of the plant. This type of transpiration takes place when cuticle is very thin and there is no water scarcity. It accounts for only 2-5% of water loss. The waxy cuticle that covers the leaf surface is a very effective barrier to water movement.
b. **Lenticular transpiration:** transpiration is through lenticels present on the bark and in the peel of some fruits (e.g., apple). Water loss through lenticels is minimal.
c. **Stomatal transpiration**: takes place through stomata, and more than 95% of water loss takes place through stomatal openings present on the leaf epidermis. This process takes place in two steps:
    - Water evaporation from the cell surface into the intercellular air space
    - Water vapor diffusion from the intercellular air space out of the leaf.

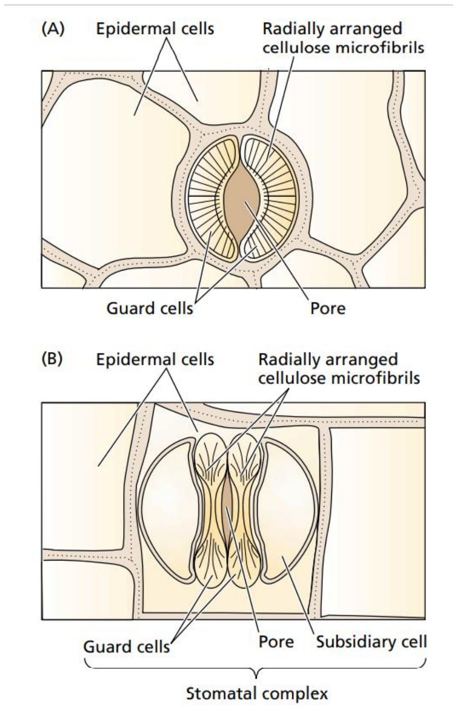
This water movement is controlled by the concentration gradient of water vapor. The substomatal air space is saturated with water vapors, while the immediate air around leaves is unsaturated. This gradient around the substomatal area and air around the leaves lead to vapor loss through transpiration. Large amount of water is being evaporated from plants, and the heat required for vaporization is being drawn from leaf. It helps plants to maintain the temperature and tolerate harsh environmental pressures. The main advantage of transpiration is creation of suction pressure for uptake of water and minerals from the soil. Once plants build up enough transpirational pull during early hours of the day, water uptake by the plants begins. Transpiration is definitely a necessary evil.

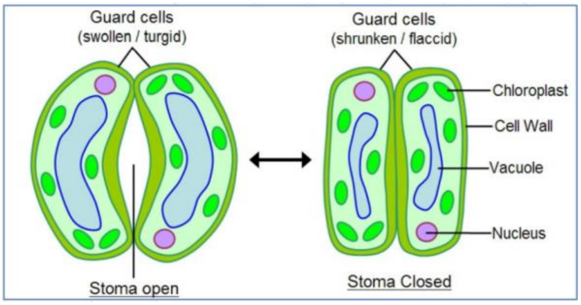
The epidermis of leaves contains pores that provide the exchange of gases between the internal air spaces and the external environment. This minute opening is called stomata (singular stoma). Stomata occur in the epidermis of all parts of the shoot system, even in flower parts such as stamens and pistils. The opening, or stoma, is bordered by a pair of unique cells called guard cells. In most cases the guard cells are in turn surrounded by specialized, differentiated epidermal cells called subsidiary cells. Subsidiary cells provide a reservoir of water and ions that move into and out of the guard cells as they change shape during stomatal opening and closing. In dicot plants and non-grasses monocots, kidney-shape guard cells occur. Dumbbell shaped guard cells occur mainly in grasses. The stoma, together with its bordering guard cells and subsidiary cells, is referred to as the stomatal complex, or stomatal apparatus. The stomata make up 15–40% of the total leaf volume. However, the stomatal pore accounts for only 1% of the total surface area, and it is responsible for more than 90% of water loss due to transpiration. In addition to structural differences from epidermal cells, guard cells lack plasmodesmatal connections and have chloroplasts. The wall of the lining of pore is thicker than the outer wall of the guard cells, Guard cells are crucially important functional elements: they regulate stomatal apertures, thereby controlling rates of CO2 uptake and water loss and hence influencing photosynthesis and water status of the plant. Transpiration undergoes considerable resistance by stomata and vapors present in the atmosphere. There are two main boundaries that create high resistance to water movement. The first one is at the stomatal pore, called the leaf stomatal resistance, and the other is the air immediately around the leaf, called boundary layer resistance.Changes in stomatal resistance are important for the regulation of water loss by the plant and for controlling the rate of carbon dioxide uptake necessary for sustained CO2 fixation during photosynthesis.



Opening and closing of stomata:

The stomatal opening and closing take place due to the movement of guard cells. On a sunny morning when the supply of water is abundant and the solar radiation incident on the leaf favors high photosynthetic activity, the demand for CO_2 inside the leaf is large, and the stomatal pores are wide open, decreasing the stomatal resistance to CO_2 diffusion. Microfibrils are located around the circumference of the elongated guard cell. When water enters into the guard cells, it cannot increase much in its diameter due to the presence of radial microfibrils. However, it increases in length, especially along its outside thin wall. With the increase in size, guard cells exert pressure on the microfibrils, and, in turn, microfibrils pull the inner (thicker) wall of the stomata, leading to the opening of pore. Stomatal apertures-open during the day, closed at night. At night, when there is no photosynthesis and thus no demand for CO_2 inside the leaf, stomatal apertures are kept small, preventing unnecessary loss of water. Water loss by transpiration is also substantial under these conditions, but since the water supply is plentiful, it is advantageous for the plant to trade water for the products of photosynthesis, which are essential for growth and reproduction. On the other hand, when soil water is less abundant, the stomata will open less or even remain closed on a sunny morning. By keeping its stomata closed in dry conditions, the plant avoids dehydration. The uptake of CO_2 for photosynthesis requires moist surface, but when water is exposed, it gets evaporated. Plants face this challenge of taking more carbon dioxide and at the same time loss of water. Plants lose 400–600 molecules of water while gaining 1 molecule of carbon dioxide. Thus, both photosynthesis and loss of water by transpiration are inseparable processes in the life of green plants.





Factors Affecting Rate of Transpiration

The rate of transpiration is affected by the plant water status, its anatomy, as well the environmental factors. The most important environmental factors are humidity, light, temperature, wind velocity, and availability of soil water. These factors are discussed here individually, but in natural habitat, they are influencing each other and affect the rate of transpiration.

1. **Ecological factors**

- **Humidity**

Whenever there is a rise in relative humidity, the rate of transpiration decreases.

Temperature

The rise in temperature, with all other factors nearly constant, increases the rate of transpiration. The increase in temperature also increases the difference in vapor pressure of the leaf and outside the atmosphere. Hence, the rate of transpiration increases. However, stomata close at temperature higher than 35°C .

- **Wind Velocity**

An increase in the rate of transpiration is not directly proportional to wind velocity. During high wind velocity, stomata close. Therefore, the rate of transpiration also drops. But wind at low velocity increases the rate of transpiration. As wind disperses the air around the leaf and reduces the vapor pressure in the immediate vicinity of stomata, it increases the rate of transpiration

2. **Internal Factors**

One of the most important factors affecting transpiration rate is **leaf-shoot ratio.** The magnitude of transpiration will be more in leaves with greater **leaf area**. However, the rate of transpiration has no correlation with leaf size when per unit leaf area is considered. The **leaf structure** is very important in regulating the rate of transpiration. Leaf adapts many strategies to reduce transpiration . **Stomatal frequency** (number of stomata present in per unit area of leaf), **pore size**, and **distribution** show tremendous variation in plants growing in different habitats .

Ecological Adaptations to Reduce:

Transpiration Plants develop many adaptations to avoid water loss due to transpiration. The presence of thick cuticle, sunken stomata, and stomata only on the lower side of the leaves are some of the adaptive mechanisms developed by plants. Plants growing in desert experience more water crisis. They need to restrict the rate of transpiration.

The ecological adaptations of desert plants are reduction of leaf area, presence of thick cuticle, sunken stomata, and stomata opening during night, special water storage capacity, modified root structure, and C_4 photosynthesis.

Antitranspirants:

These are the chemicals which decrease water loss from plants due to transpiration. They are also useful for avoiding transplantation shock to the nursery plants and plants raised in tissue culture. An antitranspirant should be nontoxic and affect only stomata. It should not cause permanent damage to stomatal mechanism, and the effect should persist only for short duration. There are mainly four types of antitranspirants: **stomatal-closing types**: some fungicides, like phenyl mercuric acetate (PMA), and herbicides, like atrazine, act as antitranspirants by closing the stomata.

Film-forming type: These chemicals form coating on the surface of leaves. Hence, stomatal pores are blocked resulting in reduction in the rate of transpiration. The material used is either plastic or waxy in nature.

Reflectance type: These are white materials which form a coating on the leaves and increase the leaf reflectance. Materials like kaolin, hydrated lime, calcium carbonate, magnesium carbonate, and zinc sulfate are used to reduce transpiration in this category.

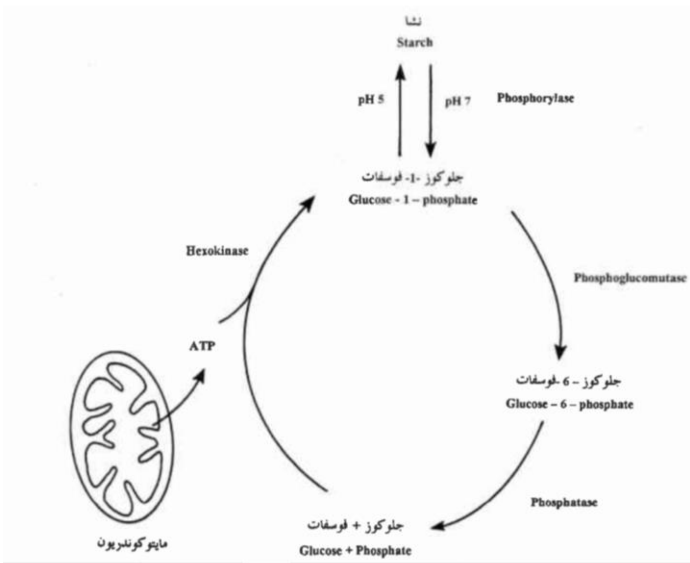
Growth retardant: ABA can bring stomatal closure. Chemicals like cycocel reduce shoot growth and increase root growth, thus enabling the plants to resist drought. It is useful for improving water status of the plant.

Mechanism of Stomatal Opening and Closing:

Opening and closing of stomata takes place due to changes in turgor of guard cells. Generally, stomata are open during the day and close at night. The actual mechanism responsible for entry and exit of water to and from the guard cells has been explained by several theories. These theories are described below:

The Starch - Sugar interconversion Theory:

This theory was put forward by Steward in 1964. According to him, during day time phosphorylase enzyme converts the starch into sugar due to which osmotic potential of guard cell increased and allow the entry of water into the cell. During the night same reaction occur in reverse direction which closes the guard cell i.e. stomata is closed during night. The stomata are opened in the light, where the photosynthesis process reduces the carbon dioxide content and raises the pH value inside the guard cells, and this will encourage the conversion of starch into sugar and the accumulation of sugar leads to a decrease in the osmotic and water stress and the withdrawal of water from the cells adjacent to the guard cells and their swelling, thus opening the stomata, In the dark, the opposite happens, as the amount of CO_2 increases and the pH value decreases, and the enzyme's work in this case is in favor of converting sugar into starch (inactive osmosis), thus raising the value of the osmotic and water potential and the exit of water from the guard cell and its shrinkage and closure of the stomata.



Proton - Potassium Pump Hypothesis:

Levit in 1974 combined the points in Scarth's and Steward's hypothesis and gave a modified version of the mechanism of stomatal movement which was called the proton - potassium pump hypothesis. According to this hypothesis K^+ ions are transported into the guard cells in the presence of light. The sequence of events taking place are as follow:

➢ Under the influence of light, protons formed by dissociation of malic acid move from cytoplasm into the chloroplasts of guard cells.

➢ To counter the exit of protons, K^+ ions enter the guard cells from the surrounding mesophyll cells.

➢ K^+ ions react with the malate ions present in the guard cells to form potassium malate.

➢ Potassium malate causes increase in the osmotic potential of guard cells causing entry of water into the guard cells as a result of which the stoma opens.

➢ At night the dissociation of potassium malate takes place and K^+ ions exit out of guard cells causing loss of water from guard cells and so the stoma closes

Synthesis of organic solutes:

blue light also stimulates the starch degradation and malate biosynthesis. Malate is an organic acid. In plants, malate is synthesized in the guard cell cytosol from the compound generated from the hydrolysis of starch. The enzyme phosphoenol pyruvate carboxylase (PEP carboxylase) binds carbon dioxide to PEP to produce oxaloacetate, which is then reduced to malate and stored in the vacuole. In the presence of light, guard cells also perform photosynthesis. It increases the osmotically active solutes such as sucrose. Thus, in the presence of light, concentration of K+ , Cl- , malate and sucrose increases. The increase in these osmotically active substances in the guard cells causes water to move passively into these cells and as their turgidity increase, the stomatal pore opens.

Factors Affecting Stomatal Movement:

Environmental factors

- **Light**

Stomata of most plants open during daytime and close during nighttime. However, in succulent plants stomata open during nighttime and close in the presence of light. This adaption of CAM plants leads to carbon dioxide absorption during nighttime when transpiration stress is low.

- **Carbon dioxide concentration and pH**

Generally high pH favors closing while low pH favors opening of stomata. pH regulates K+ movement in the guard cells. Mostly alkaline pH enhances the K+ outflow and results in stomatal closure.

- **Temperature**

The stomatal pore closes as the temperature rises above 30–35°C. To ensure gas exchange at high temperature, stomata opens during nighttime. Temperature has indirect effect on stomatal movement. It affects the balance of respiration and photosynthesis. Whenever there is increase in temperature, it leads to rise in respiration rate. Due to high rate of respiration, the level of CO_2 increases and it causes closure of stomata. In some plants, high temperature induces stomatal opening to increase the transpiration rate (cooling effect) so that temperature of leaf is maintained.

- **Water Stress**

Water stress increase starch content in guard cell and abscisic acid Which encourage the closure of the stomata.

2. Guttation

Guttation is the process of extrusion of liquid droplets from the leaves through special structures called water stomata or hydathodes. During early morning in summer, when relative humidity is very high, small droplets appear on the vein endings of grasses or serrate margins of certain leaves.

3. Bleeding

It is the phenomenon of water leaving through mechanical damage that occurs in plant tissues such as wounds and scratches.

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