Plant Physiology and Metabolism PYQ 2020

Q1. Comments upon 'Transpiration is a necessary evil'. What does girdling experiment demonstrate? Discuss the most widely accepted theory to explain the ascent of sap in plants.

Ans. The statement "Transpiration is a necessary evil" highlights the dual nature of transpiration in plants. Transpiration is the process by which water is lost from the aerial parts of plants, primarily through small openings called stomata in leaves**. While it might seem like a wasteful process as it results in water loss for the plant, it serves several essential functions:**

Water Uptake: Transpiration creates a negative pressure or tension in the plant, which helps in the uptake of water and minerals from the soil through the roots. This process is crucial for the plant's survival.

Transport of Nutrients: It plays a vital role in the transport of nutrients and minerals from the roots to various parts of the plant.

Cooling Mechanism: Transpiration helps in cooling the plant, similar to how sweating cools the human body. It prevents overheating and maintains the plant's temperature.

Maintaining Turgor Pressure: It helps in maintaining turgor pressure, which is essential for the plant's structural support.

However, excessive transpiration can lead to water stress and dehydration in plants, especially in arid or dry conditions. That's why it's often referred to as a necessary evil, as it's crucial for plant functioning but can also lead to water loss and stress.

The girdling experiment demonstrates the importance of the phloem in the transport of organic nutrients, such as sugars, from the leaves to other parts of the plant. Girdling involves removing a ring of bark, including the phloem, from around the stem of a woody plant. This disrupts the flow of nutrients through the phloem, leading to a buildup of sugars in the leaves above the girdle. Below the girdle, the plant begins to suffer from nutrient deprivation, affecting its growth and eventually leading to its death.

The widely accepted theory to explain the ascent of sap in plants is the Cohesion-Tension Theory, also known as the Transpiration-Cohesion-Tension (TCT) Theory. According to this theory:

Transpiration Pull: Transpiration in leaves creates a negative pressure or tension in the xylem vessels, pulling water from the roots to the leaves.

Cohesion: Water molecules exhibit cohesion, meaning they are attracted to each other. This cohesion helps maintain a continuous column of water from the leaves to the roots.

Adhesion: Water molecules also adhere to the walls of the xylem vessels, preventing the water column from breaking.

Tension: The tension created by transpiration pull, combined with cohesion and adhesion forces, allows water to be transported against gravity from the roots to the upper parts of the plant.

In essence, it's the combination of these physical properties of water and the process of transpiration that enables the upward movement of sap in plants. This theory has substantial experimental evidence and is widely accepted in the field of plant physiology.

Q2. What imparts pink color to the nodule and what is its significance to nitrogen fixation? Also describe the process of nodulation in legumes.

Ans. The pink color in the root nodules of leguminous plants is primarily due to the presence of a pigment called leghemoglobin. Leghemoglobin is similar in structure to hemoglobin found in the blood of animals, and it serves a similar function in the root nodules. Its significance to nitrogen fixation lies in its ability to maintain a low-oxygen environment within the nodules.

Here's how it works:

1. **Low-Oxygen Environment:** Leghemoglobin has a high affinity for oxygen. When oxygen is present within the nodule, leghemoglobin binds to it, effectively reducing the oxygen concentration. This is important because the enzyme nitrogenase, responsible for converting atmospheric nitrogen ($N2$) into ammonia ($NH3$) during nitrogen fixation, is highly sensitive to oxygen. Nitrogenase can be irreversibly damaged by even small amounts of oxygen.
2. **Protection of Nitrogenase:** By reducing oxygen levels within the nodule, leghemoglobin protects nitrogenase from being inactivated. This allows nitrogenase to function optimally in its role of converting atmospheric nitrogen into a form that the plant can use for its growth.

As for the process of nodulation in legumes:

1. **Recognition:** It starts with the recognition of specific rhizobium bacteria by the root hairs of leguminous plants. This recognition is mediated by chemical signals.
2. **Infection:** The rhizobium bacteria enter the root hairs and multiply. From there, they penetrate the root cortex and enter the plant's cells.
3. **Nodule Formation:** As a response to the presence of rhizobia, the plant forms nodules on its roots. These nodules are specialized structures where nitrogen fixation takes place.
4. **Symbiotic Relationship:** Inside the nodules, the plant provides the rhizobia with carbohydrates and a protected environment with low oxygen levels due to leghemoglobin. In return, the rhizobia fix atmospheric nitrogen into ammonia, which the plant can use as a nutrient source.
5. **Ammonia Conversion:** The ammonia produced by rhizobia is further converted into other nitrogen compounds like amino acids, which the plant can transport and use for its growth.

This symbiotic relationship between leguminous plants and rhizobia is highly beneficial, as it allows the plants to thrive in nitrogen-deficient soils by accessing atmospheric nitrogen through biological nitrogen fixation. The pink coloration of the nodules due to leghemoglobin is a visible indicator of this crucial process.

Q3. Discuss the criteria of essentiality of elements. Explain the role of carriers, channels and pumps in the transport of ions across membrane.

Ans. Criteria of Essentiality of Elements:

In biology and biochemistry, essential elements are those chemical elements that are necessary for the normal growth and development of an organism**. The criteria for essentiality of elements are as follows:**

1. **Element must be vital for the organism:** An essential element must play a specific role in the growth, development, and physiology of the organism. This often involves being part of a biomolecule or having a specific biological function.
2. **No Substitute:** There should be no other element that can fully substitute for the essential element in carrying out its function. If a substitute is available, the element may not be considered essential.
3. **Direct Role in Biochemistry:** The element should have a direct role in the biochemistry of the organism. It should be incorporated into important biomolecules, enzymes, or cofactors.
4. **Detrimental Effects:** A deficiency of the element should lead to adverse physiological effects. Its absence should result in impaired growth, reproduction, or other vital functions.

Role of Carriers, Channels, and Pumps in Ion Transport Across Membranes:

The transport of ions across cell membranes is crucial for maintaining cellular homeostasis and various physiological processes**. Carriers, channels, and pumps are integral membrane proteins that facilitate the movement of ions across biological membranes:**

Carriers (Transporters):

- Carriers are proteins that bind to specific ions or molecules and undergo conformational changes to transport them across the membrane.
- They work through facilitated diffusion or active transport.
- Carriers are highly selective, and their conformational changes ensure that ions are transported in a controlled manner.

Example: Glucose transporters (GLUTs) facilitate the transport of glucose across cell membranes.

Channels:

- Channels are proteins that form pores or channels in the membrane through which ions can pass.
- They allow for the rapid movement of ions down their electrochemical gradients.
- Channels are selective based on ion size and charge.

Example: Sodium channels, potassium channels, and chloride channels are involved in nerve signal transmission.

Pumps (Ion Pumps or Transport ATPases):

- Pumps are enzymes that actively transport ions against their electrochemical gradients, typically using energy derived from ATP hydrolysis.
- They maintain ionic gradients necessary for various cellular processes.

Example: Sodium-potassium pump (Na^+/K^+ pump) helps maintain the proper balance of sodium and potassium ions in animal cells.

Together, these proteins play essential roles in regulating ion concentrations inside and outside cells, influencing cell excitability, osmotic balance, and the electrical properties of cells. Dysregulation of ion transport can lead to various diseases and disorders.

Q4. State the physiological and biochemical changes associated with fruit ripening. Give commercial applications of auxins, gibberellins and ethylene and explain the role of the dark period in photoperidism.

Ans. Physiological and Biochemical Changes Associated with Fruit Ripening:

Fruit ripening is a complex physiological process involving a series of biochemical and structural changes**. Some of the key changes include:**

1. **Color Change:** Fruits often change color, usually from green to red, orange, yellow, or other bright colors. This is due to the breakdown of chlorophyll and the synthesis of pigments such as carotenoids and anthocyanins.
2. **Softening:** The fruit becomes softer as enzymes break down cell wall components like pectin, leading to a change in texture from firm to soft or even mushy.
3. **Flavor Development:** The accumulation of sugars, organic acids, and volatile compounds contributes to the development of the fruit's characteristic flavor and aroma.
4. **Sugar Accumulation:** There is an increase in the sugar content, primarily due to the conversion of starches into sugars, such as glucose and fructose.
5. **Acid Degradation:** Organic acids, like citric acid and malic acid, may decrease in concentration, reducing the fruit's acidity.
6. **Aroma and Ethylene Production:** Ethylene, a plant hormone, is often produced in greater quantities during ripening and acts as a signaling molecule to coordinate various ripening processes.

Commercial Applications of Plant Growth Regulators (Hormones):

1. **Auxins:** Auxins like indole-3-acetic acid (IAA) are used to stimulate root formation in cuttings, promote fruit thinning, and delay senescence (aging) in fruits like apples.
2. **Gibberellins:** Gibberellins are employed to increase fruit size, improve fruit setting, and promote seedless fruit development (parthenocarpy).
3. **Ethylene:** Ethylene is widely used to ripen fruits artificially. It is applied to unripe fruits in controlled environments, accelerating the ripening process.

Role of the Dark Period in Photoperiodism:

Photoperiodism is the physiological response of organisms to the relative lengths of day and night. **The dark period (night) is crucial in photoperiodism for the following reasons:**

1. **Critical Night Length:** Photoperiodic responses, such as flowering in plants, depend on the duration of the dark period. The critical night length is the minimum uninterrupted period of darkness required to trigger a specific response. If the dark period is interrupted by light, it may not be effective.
2. **Floral Induction:** Many plants require a specific dark period (usually longer nights) to induce flowering. This dark period allows for the accumulation of a flowering hormone or the inhibition of a flowering inhibitor, both of which are light-sensitive processes.

3. **Resetting the Internal Clock:** The dark period helps reset the internal biological clock of the organism, which can vary depending on the species. This clock keeps track of day length and is responsible for regulating various developmental processes.

In summary, the dark period in photoperiodism is essential for the accurate measurement of night length, which influences the timing of critical developmental events like flowering in plants.

Q5. Give detail account on how ATP and NADPH+H molecules are synthesized in light dependent phase? Explain how these molecules are consumed to reduce atmospheric CO2 in light independent phase?

Ans. The synthesis of ATP and NADPH+H molecules in the light-dependent phase (also known as the light reactions) of photosynthesis occurs in the thylakoid membranes of the chloroplasts. These molecules are subsequently used in the light-independent phase (Calvin cycle) to reduce atmospheric carbon dioxide (CO_2) and produce glucose and other organic molecules**. Let's break down the process step by step:**

Synthesis of ATP and NADPH+H in Light-Dependent Phase:

1. **Light Absorption:** Chlorophyll and other pigments in the thylakoid membranes absorb photons (light energy) from sunlight. This energy excites electrons in the chlorophyll molecules, causing them to move to higher energy levels.
2. **Electron Transport Chain (ETC):** The excited electrons are transferred through a series of protein complexes in the thylakoid membrane, collectively known as the electron transport chain (ETC). As the electrons move through the ETC, they release energy.
3. **Proton Pumping:** As the electrons move through the ETC, they also pump protons (H+ ions) from the stroma (the fluid-filled space inside the chloroplast) into the thylakoid space, creating a concentration gradient of protons.
4. **ATP Synthase:** Protons in the thylakoid space flow back into the stroma through a protein complex called ATP synthase. This flow of protons provides the energy required for ATP synthesis. ATP synthase uses this energy to convert adenosine diphosphate (ADP) and inorganic phosphate (Pi) into ATP.
5. **Reduction of NADP+:** Simultaneously, electrons from the ETC combine with NADP+ (nicotinamide adenine dinucleotide phosphate) and H+ ions to form NADPH+H, which is a high-energy molecule that carries electrons and protons.

Consumption of ATP and NADPH+H in Light-Independent Phase (Calvin Cycle):

The ATP and NADPH+H molecules synthesized in the light-dependent phase are utilized in the light-independent phase, also known as the Calvin cycle, to reduce atmospheric CO_2 and produce organic molecules like glucose.

1. **Carbon Fixation:** Atmospheric CO_2 is captured and incorporated into a five-carbon compound called ribulose-1,5-bisphosphate (RuBP) with the help of an enzyme called ribulose-1,5-bisphosphate carboxylase/oxygenase (RuBisCO).
2. **Reduction Phase:** ATP and NADPH+H from the light-dependent phase are used to convert the resulting 3-phosphoglycerate molecules into a three-carbon sugar called glyceraldehyde-3-phosphate (G3P). This is a reduction process that consumes ATP and NADPH+H.

3. **Regeneration of RuBP:** Some of the G3P molecules are used to regenerate RuBP, which is essential for the continuous operation of the Calvin cycle. This step also consumes ATP.
4. **Glucose Formation:** The remaining G3P molecules are used to synthesize glucose and other carbohydrates. Multiple turns of the Calvin cycle are required to produce one molecule of glucose.

In summary, the light-dependent phase of photosynthesis generates ATP and NADPH+H molecules, which are subsequently used in the light-independent phase (Calvin cycle) to reduce atmospheric CO2 and produce organic molecules, including glucose. This process allows plants to convert solar energy into chemical energy stored in glucose, which serves as a source of energy for the plant and, indirectly, for other organisms in the food chain.

Q6. Distinguish between the lock and key and induced-fit models for binding of a substrate to an enzyme. What is Km and its significance? Explain competitive and non-competitive enzyme inhibitions and their effect on Vmax and Km values.

Ans. Lock and Key Model vs. Induced-Fit Model:

Lock and Key Model:

- In the lock and key model, the active site of an enzyme is considered as a rigid and pre-formed structure that perfectly matches the shape and chemical characteristics of its substrate.
- The substrate is envisioned as the "key" that fits into the enzyme's "lock." This model implies that only substrates with the exact shape and properties can bind to the enzyme and form the enzyme-substrate complex.
- This model suggests that the active site is unaltered upon substrate binding.

Induced-Fit Model:

- The induced-fit model, on the other hand, proposes that both the enzyme and the substrate undergo conformational changes upon binding. It recognizes that the active site of the enzyme is somewhat flexible and can adjust its shape to accommodate the substrate.
- When the substrate binds to the enzyme, the active site undergoes a conformational change, adapting to the shape and chemical properties of the substrate. This conformational change enhances the binding affinity and catalytic efficiency.
- In this model, the binding of the substrate induces a change in the enzyme's structure.

Km (Michaelis-Menten Constant) and Its Significance:

- Km is a constant in the Michaelis-Menten equation that represents the substrate concentration at which the reaction rate is at half of its maximum velocity (Vmax).
- It is a measure of the affinity of an enzyme for its substrate. A lower Km value indicates a higher affinity between the enzyme and substrate.
- Km is often used to compare the relative affinities of different enzymes for their substrates.
- It is a critical parameter for understanding enzyme kinetics and helps determine how efficient an enzyme is at a given substrate concentration.

Competitive and Non-competitive Enzyme Inhibition:

Competitive Inhibition: In competitive inhibition, a molecule that closely resembles the substrate, called a competitive inhibitor, binds to the active site of the enzyme. This blocks the substrate from binding. It competes with the substrate for the active site.

- **Effect on Vmax:** Vmax remains unchanged because, at high substrate concentrations, the substrate can outcompete the inhibitor.
- **Effect on Km:** Km increases because more substrate is required to achieve half of Vmax.

Non-competitive Inhibition: In non-competitive inhibition, the inhibitor binds to a site on the enzyme distinct from the active site, altering the enzyme's conformation. This prevents the enzyme-substrate complex from forming or interferes with catalysis.

- **Effect on Vmax:** Vmax decreases because the inhibitor directly affects enzyme activity.
- **Effect on Km:** Km remains unchanged because the inhibitor doesn't affect substrate binding.

In summary, the lock and key model and induced-fit model describe different views of enzyme-substrate interactions. Km is a critical parameter in enzyme kinetics, reflecting substrate affinity. Competitive inhibition involves a competitive inhibitor binding to the active site, while non-competitive inhibition involves an inhibitor binding elsewhere on the enzyme. These inhibitors have distinct effects on Vmax and Km values.