CHAPTER 4
PLANT PHYSIOLOGY

Transport processes in plants include ***Transpiration, Water Absorption*** *from the soil,* ***Water Movement*** *and* ***Translocation.***

Transpiration

This is the process whereby water is lost from the plants through the stomata in the leaves. The guard cells in the stomata regulate the transpiration. As transpiration occurs, gas exchange also occurs, oxygen leaves the cells while carbon dioxide enters. The guard cell also regulates the rate of photosynthesis. During daylight when the sun is high, stomata open and allow transpiration and photosynthesis to occur. At night or when the sunlight is down, the stomata close. To regulate water loss (or transpiration), the stomata close under very high temperature, when water uptake of plants by the roots is less than transpiration rate.

Water Absorption

Water absorption in the plants occurs through the roots. The water can enter the root cells through the epidermis by simple diffusion, and continue from cell through cell (through plasmodesmata, the cytoplasmic connections of plant cell to plant cell) along the cortex until it enters into the xylem, where the vessels conduct it upwards through the plants, this is known as **symplastic movement.**

Water can also diffuse through the cytoplasm by traveling through the intercellular spaces in the cortex until it arrives at the endodermis where the **casparian strips** regulate its movement into the xylem, this is known as **apoplastic movement**. At the casparian strip, the water is distributed tangentially to other tissues in the roots through the symplastic process.

Transpiration-Cohesion Theory

When water molecules reach the xylem tissues, they move in the plants by cohesion and adhesion principles. Water molecules form hydrogen bonds among themselves and also cling to the walls of the vessels; this provides a continuous source of water pull that leaves the plants through the stomata (transpiration). This principle that explains the water movement is known as Transpiration-Cohesion Theory.

Translocation

This is the process where the sieve tube members of the phloem in the vascular tissues of the plants conduct solid molecules (food materials, example sugar) to areas where they are needed for use by the plants, or to be stored in the plants. The most common materials are sucrose, amino acids, minerals, and other organic compounds. Translocation uses the principles of mass Flow or Pressure Flow Hypothesis. This mass flow or pressure flow uses the diffusion principle that is based on concentration difference of food materials in the phloem cells.

METABOLISM

Metabolism incorporates all the chemical reactions that occur in the cells; this includes anabolic (synthesis) and catabolic (degradation) reactions. Metabolic reactions involve energy input or output. Plants use light energy to produce usable energy (ATP or adenosine triphosphate) in the cells. In all metabolic processes, enzymes are involved, enzymes act as catalysts to speed up the rates of these reactions.

PHOTOSYNTHESIS

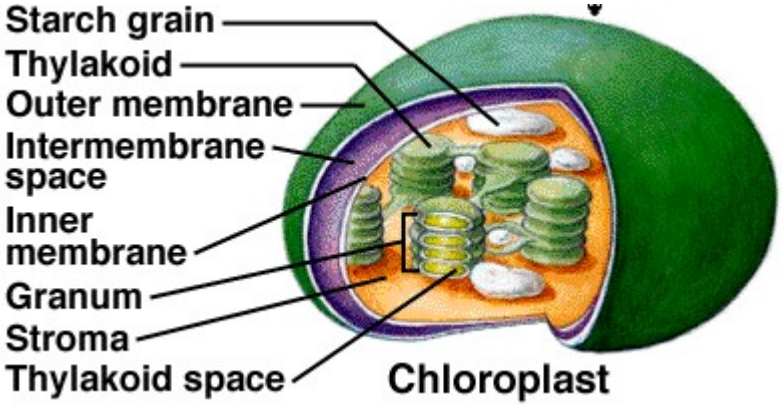

Figure 4.1. Structure of a chloroplast showing the stacks of thylakoids (or grana) inside.

Through the process of photosynthesis, the plants convert the sun energy into ATP, usable energy, and at the same time form food. The major organ of photosynthesis is the **chloroplast** in the leaf. The chloroplasts contain the pigments, **chlorophylls** (a and b) **carotenoids**, and **xanthophylls**. Chlorophylls are the plants' photosynthetic pigments. A chloroplast is made up of staked membranous sacs or **thylakoids**. Each stack is called a **granum** (grana, plural); inside the thylakoid is the chlorophyll (figure 4.1). The green chlorophylls absorb the red and the blue-violet lights, however it reflects yellow and green light (figure 4.2). There are two major phases of photosynthetic reactions: light reactions and dark reactions (or Calvin cycle).

Light Reactions

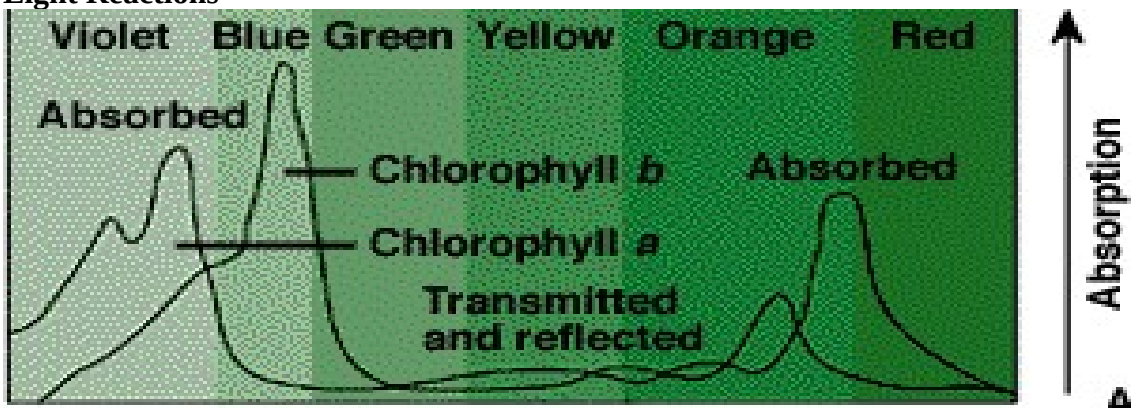

Figure 4.2. Chlorophyll Absorption Spectrum

The complex molecules of the pigments and the membrane proteins in the thylakoids form photosystems. There are two groups of photosystems (these photosystems contain P-700, photosystem 1 and P-680 cytochromes photosystem 2 respectively). The numbers indicate the wavelengths of light that these pigments can absorb. When the light energy is absorbed by these pigments, electrons are released.

In photosystem 1, these electrons are used to reduce the coenzymes necessary for the reactions. The main coenzyme is the $NADP^+$ (Nicotinic Adenine Dinucleotide Phosphate) in its oxidized form. $NADP^+$ gets reduced by electrons to NADPH.

In the photosystem 2, the light energy absorbed makes the P-680 to release more electrons. These electrons couple with reactions involving the splitting of water molecules (H_2O) into hydrogen and oxygen, during this process more electrons are released. These electrons are channeled through other electron carriers, and finally return to the photosystem 1 (P-700), a process known as cyclic photophosphorylation.

Summary of the Photosynthesis Reaction

$6CO_2 + 6H_2O + \text{Light Energy} \rightarrow C_6H_{12}O_6 + 6O_2$

Calvin Cycle Reactions or Carbon fixation Reactions

These reactions involve the fixation and reduction of carbon dioxide to form sugars. These reactions use the products of light reactions, and occur in the dark, therefore called the Dark Reactions. The pathway of these reactions was outlined by Melvin Calvin, Andrew Benson, and James Baasham; however it was named after Melvin Calvin as Calvin Cycle.

Summary of dark reactions:

CO_2 + Ribulose-1.5-bisphosphate $\rightarrow$ Phosphoglyceric acid $\rightarrow$ Glyceraldehyde Phosphate$\rightarrow$ Glucose.

The Calvin Cycle.

(***There are 6 cycles of Calvin reactions in order to produce 1 molecule of glucose***).

Some plants do not use the Calvin Cycle pathway in fixing carbon dioxide; they use C_4 pathway or CAM (Crassulacean Acid Metabolism) pathway. The C_4 pathway is used by most monocot plants. The C_4 pathway provides a more efficient way for photosynthesis to occur under high temperatures. The CAM pathway is used by desert plants. CAM plants close stomata during the day when transpiration occurs at a high rate, but open at night. This allows carbon fixation to occur at night.

Respiration

Respiration is the process, where glucose formed by plants can be completely oxidized into carbon dioxide, water.

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 36$ ATP

The step by-step reactions in this process occur in three stages:

1.**Glycolysis**

Glycolysis is the breakdown of glucose into pyruvic acid in the absence of oxygen.

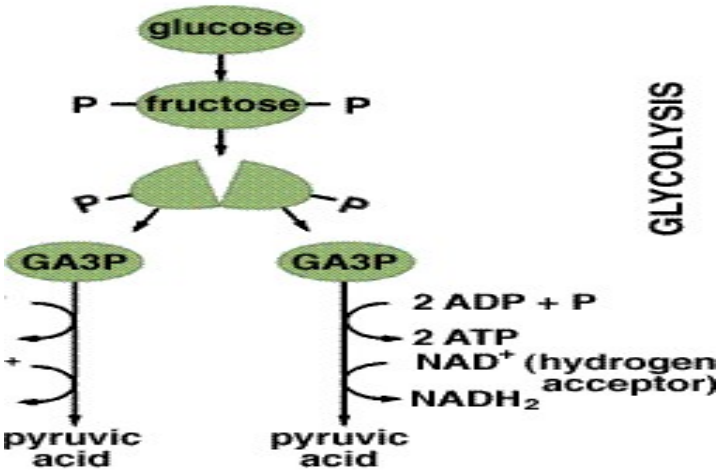

Figure 4.3: Reaction steps in glycolysis

2. Kreb's cycle

Kreb's cycle or Citric Acid cycle (also known as tricarboxylic acid cycle) is a series of oxidative reactions that occur in the mitochondria of the cell.

This process occurs on the cristae of the mitochondria in cells.

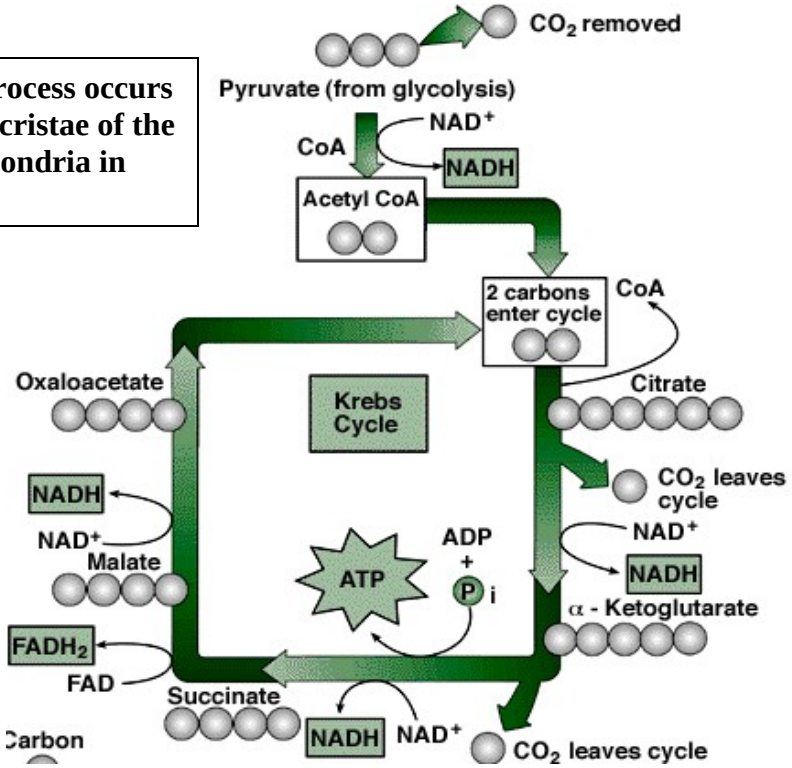

Figure 4.4. Kreb's Cycle.

The process involves further breakdown of the pyruvic acid that was produced during glycolysis into CO_2 and water in the presence of oxygen, enzymes and coenzymes all located on the cristae of mitochondria in a cell.

During Kreb's cycle, pyruvic acid is converted into acetyl coenzyme A complex; this acetyl coenzyme A complex combines with oxaloacetic acid to form citric acid. The citric acid goes through various intermediates with the release of 2 molecules of CO_2, reduced coenzymes (examples of coenzymes include, NADH, and FADH) and another one molecule of oxaloacetic acid. In each cycle, 2 molecules of carbon dioxide are released.

3. **Electron Transport Chain or ETC**

ETC reactions also occur inside the mitochondria. ETC is the process whereby the reduced coenzymes, NADH (Nicotinic Adenine Dinucleotide) and FADH (Flavo-Adenine Dinucleotide) released from the reactions of Kreb's cycle undergo oxidation, thereby generating electrons that are used to reduce oxygen into water. This involves highly exergonic (energy releasing) reactions.

**Reactions whereby oxygen is used to produce ATP are collectively known as oxidative phosphorylation reactions.*

**Another reaction that can allow the glucose to be broken down in the absence of oxygen is called fermentation. This is the process in which yeast (fungus) and bacteria can be used to produce wine.*

Key Points

Plant Physiology

1. Major transport processes that occur in the plants are: transpiration, water absorption, water movement, and translocation.
2. Transpiration (like evaporation) is the process whereby water is lost from the plants through the stomata in the leaves to the environment. Transpiration is regulated by the guard cells of the stomata.
3. Water absorption can occur through the roots by a special type of diffusion, a process known as SYMPLASTIC movement or by a process known as APOPLASTIC MOVEMENT. Symplastic movement of water involves the water molecules passing through tissues to the xylem where further transportation occurs. Apoplastic involves the movement of water molecules along intercellular spaces to the casparian strip in the central part of the root. The water molecules are further distributed diagonally to other tissues in the root by the casparian strip. Movement of water molecules in the xylem vessels is by formation of hydrogen bonds among themselves and causing a pull that makes them move from the roots, through stems to the leaves and ultimately to the external environment through the stomata. This is known as "Transpiration – Cohesion" theory
4. In the phloem sieve tube elements, another theory is used to explain the movement of food materials from leaves to storage; this theory is called MASS FLOW or PRESSURE FLOW HYPOTHESIS. This is a hypothesis based on the mass flow of materials due to concentration (or pressure) difference.

5. Photosynthesis is the process by which the plant leaves uses carbon – dioxide, water, light with enzymes to form starch, and release oxygen. The reactions are in two parts: the light reactions or photophosphorylation, and the dark reactions or carbon fixations. All reactions occur in the chloroplasts.
6. Photophophorylation are in two parts: cyclic photophosphorylation and non – cyclic photophosphorylation; both occur in the chloroplast. Inside the chloroplasts are stacks of membrane sacs known as grana containing pigments that absorb light energy at two wavelengths: P-700 and P-680. When P-700 (Photosystem 1) absorbs light, electrons are generated, these electrons reduce the oxidized coenzyme (co – requirement for metabolic enzymes to catalyze the reactions) NADP or Nicotime Adenine Dinucleotide Phospate to form a reduced coenzyme NADPH. When P-680 (Photosystem II) absorbs light the energy, electrons are also released. These electrons cause water to split into hydrogen and oxygen. During this process ATP is formed. The reactions in Photosystem II are non – cyclic while those in the Photosystem I are cyclic (non-cyclic photophosphorylation and cyclic photophosphorylation respectively). The significance of the light reaction of photosynthesis is to generate reduced coenzymes- NADPH and split water into hydrogen and oxygen.
7. The dark reactions pathway was outlined by 3 men; Calvin, Benson, and Baasham, however it is named after Calvin and Benson, hence the pathway is known as Calvin /-Benson Cycle. In the dark, the leaves uses the NADPH produced during the light reactions, carbon dioxide and ribulose -1.5 bisphosphate to produce glucose using an enzyme ribulose - 1.5 bisphosphate Carboxylase (RUBISCO) and 6 molecules of carbon dioxide.
8. Repsiration is the process whereby the formed food is broken down by enzymes to obtain energy (ATP) and release carbon - dioxide and water. Respiration in plants occurs mainly during seed germination. In some seeds the stored endosperm is broken down during germination.
9. Energy release from plants food can occur through many processes:
    - An aerobic process (Kreb's cycle, where pyruvic acid is converted into acetylCoA, and finally broken down completely into carbon – dioxide; electron transport chain reactions produce water and energy): in this process glucose is broken down in the presence of oxygen into carbon – dioxide water and energy in the mitochondria of the cell.
    - An anaerobic process: the breakdown of glucose in the absence of oxygen, example is glycolysis. In glycolysis, glucose is broken into pyruvic acid in the absence of oxygen or through fermentations, a process where glucose can be broken down into alcohol; an example is the use of yeast to produce alcohlol.

Study Questions

1. What do you understand by photosynthesis?

2. State the difference between photosynthesis and respiration.

3. Define / explain the following: enzymes, metabolism, transpiration, and translocation

4. Describe the following:

Transpiration – Cohesion / Adhesion Theory

Pressure Flow Hypothesis

5. Explain the following movements: Symplastic and Apoplastic

6. Mention 4 common pigments in the chloroplasts of plants.

7. Describe the structure of the chloroplasts.

8. Describe the events that occur during the light reactions of photosynthesis (or photophosphorylation); and the events that occur during the dark reactions of photosynthesis (carbon fixation).

9. What is fermentation?

10. Explain CAM pathway and the C4 pathway of carbon fixation in plants.