Unit-IV (Plant Physiology)

Photosynthesis

Synopsis

- Photosynthesis literally means building up (**anabolic**) or assembly by light (radiant energy).
- Alga, higher plants and certain types of bacteria can utilize the radiant energy for the synthesis of essential food materials.
- The major chemical pathway in photosynthesis is the conversion of carbon dioxide and water to carbohydrates and oxygen.

$$CO_2 + H_2O \xrightarrow[\text{green plants}]{\text{sun light}} (CH_2O) + O_2$$

- Carbon dioxide reduced to form carbohydrates. It is an **endergonic** pathway.
- The carbohydrates formed during this process possess more energy than the reactants ($CO_2 + H_2O$).
- Less than 1% of total light energy reaching the earth is used in photosynthesis.
- Light is a form of electromagnetic radiation. Photo synthetically active radiation lies in the range of 400nm----700nm.
- Certain bacteria utilize infra-red radiation and carry out a type of photosynthesis in that no O_2 is evolved.
- Importance of light in photosynthesis is shown by Jan Ingenhousz.
- T.W.Engelmann in his experiments using aerobic bacteria and green alga *Spirogyra* shown that red light more efficient than green light.
- Sachs demonstrated the formation of starch during photosynthesis.
- Ratio of CO_2 consumed to O_2 evolved is almost unity.
- Blackman suggested that photosynthesis is a two step mechanism, photochemical 'light' reaction and non-photochemical 'dark' reaction.
- The dark reaction which is enzymatic is slower than light reaction.
- In 1937 Robert Hill performed his experiments on isolated chloroplasts. Instead of CO_2 he used suitable electron acceptors (oxidants) like potassium ferrioxalate or potassium ferricyanide. One molecule of O2 is evolved for every equivalents of oxidants reduced.

This phenomenon is Hill reaction and oxidants are Hill reagents. The significance of Hill reaction is O_2 evolution and CO_2 reduction are separate reactions.

- Source of O_2 is the decomposing of H_2O, was established by Ruben and Kamen. They used O_2 isotope of mass 18 in their experiments.
- Van Neil, the Dutch microbiologist, in comparative studies of plant and bacterial photosynthesis showed that some bacteria can assimilate CO_2 in light without evolving O_2.
- Arnon demonstrated NADP reduction and photophosphorylation (light induced ATP synthesis) simultaneously with assimilation of CO_2 and evolution of O_2.
- Emerson and co-workers measured the quantum yields of photosynthesis in algae and observed that average quantum yield obtained by two super imposed light beams (680nm and 700nm) was higher than the average quantum yield (Emerson's enhancement effect) obtained by using two beams separately (Emerson's red drop). This is due to existence of two photo systems PS II, in which O2 evolution occurs and PS I in which ferrodoxin is photo reduced and NADP is formed.
- Hill and Bendall put forward 'Z' scheme of photosynthesis, showing the operation of two photo systems in series in photosynthetic electron transport and phosphorylation.
- Mitchell put forward chemiosmotic theory to explain ATP formation in biological membranes.
- The photosynthetic pigments are located inside the chloroplasts attached to the thylakoid membranes.
- These pigments can be extracted by using alcohol or other organic solvents. Separated by chromatography.
- The three major classes of pigments found in plants and algae are chlorophyll, carotenoids and phycobilins. Phycobilins are soluble in water and are present in algae Cyanophyceae and Rhodophyceae.
- Chorophylls are of different types, present green plants and algae. Chl a is universal found in all higher plants and algae. Chl b in higher plants and green algae. Chl c in Diatoms and brown algae. Chl d in red algae. Chl a is bluish green and Chl b is yellow green in colour. Their absorbance maximum at 660nm and 643nm respectively. The molecular formula for Chl a is $C_{55}H_{72}N_4O_5Mg$ (M= 892) and for Chl b is $C_{55}H_{70}N_4O_6Mg$ (M= 906).
- The chlorophyll molecule contains a porphyrin 'head' and a 'phytol' tail. Porphyrin nucleus is made up of a tetrapyrrole ring and a magnesium atom. Pheophytins are

chlorophylls without the central Mg atom are constituents of photosynthetic electron transport chain.

- In Chl a CH_3 group is attached to 2^{nd} pyrrole whereas in Chl b it is replaced with CHO group.
- Carotenoids and phycobilins are accessory photosynthetic pigments. They help chlorophylls from photo oxidation in excessive light. Carotenoids are yellow or orange pigments. Carotenes ($C_{40}H_{56}$) and Xanthophylls ($C_{40}H_{56}O_2$).
- Each photosynthetic unit or Light Harvesting Complex (LHC) consisting of central Chl as a reactive centre and surrounding pigments as antenna.
- Every LHC can absorb one photon of light energy. Pigments in the antenna absorb light energy and transfer by resonance trance to the reactive centre.
- PS I with Chl a 700nm and PS II with Chl a 660nm.
- Photolysis of water takes place in the lumen in the presence of oxygen evolution complex (OEC). 4 atoms of Mn is part of this complex. Chlorides, Calcium, and bicarbonates help in the function of this complex.
- Electron transport is of two types, non-cyclic and cyclic. During electron transport phosphorylation takes place.
- In non-cyclic electron transport $NADPH_2$, ATP and O_2 form. In cyclic electron transport only ATP forms.
- Electron acceptor from water during light reactions in non-cyclic transport is PS II. From PS II to pheophytin to PS I via Cytochrome b_6- f complex. In cyclic transport electron moves from PS I and reaches cyclically again to PS I.
- During electron transport across the membrane proton motive force develops (Mitchelle) which helps in ATP synthesis with the help of ATPase (coupling factor) a membrane bound protein present exposed to stroma. The number of protons translocated per molecule of ATP synthesized , **i.e**. the H^+/ATP ratio is approximately 3
- Approximately 8 quanta of light absorbed by chlorophyll are required for photosynthetic reduction of CO_2 and the evolution of O_2 molecule.
- NH_2OH, DCMU, KCN are some of the inhibitors of electron transport.
- Calvin, Benson and Bassham elucidated the path way of CO_2 reduction in stroma. They used *Chlorella*, *Scenedesmus* as their experimental tools. Chromatography and autoradiography techniques are used.
- The first stable compound formed is a 3 carbon compound Phosphoglyceric acid (PGA). In C_4 plants it is 4 carbon compounds.

- Ribulose bisphosphate (RuBP), a 5 carbon compound is the acceptor molecule in the carboxylation.
- In the reduction phase ATP, $NADPH_2$ produced in light reactions utilized. $1/6^{th}$ of 3 carbon compounds produced utilized in sugar (sucrose) production after export to the cytosol. The remaining $5/6^{th}$ help in the regeneration of RuBP.
- Starch synthesis takes place within the chloroplast during light. During dark periods it is broken down to sugars.
- In C_4 plants (Kortschak, Hatch-Slack) pathway of CO_2 fixation 4 carbon compound like oxaloacetate, malate and aspartate in addition to the carbon fixation by Calvin cycle. Calvin cycle (starch synthesis) takes place in bundle sheaths. Malate provides CO_2 for reduction.
- Normal granal plastids are present mesophylls and agranal plastids are present in bundle sheath.C4 plant show ‘kranz’ anatomy.
- Many succulent plants growing in arid regions fix CO_2 during night. This is Crassulacean Acid Metabolism (CAM).
- Environmental factors affect CO_2 assimilation in plants.
- CO_2 compensation point is an indicator of the capacity of the plant to absorb the CO_2 and assimilate in sun light. The lower the CO_2 compensation point the better the efficiency.