CHAPTER

10 Photosynthesis in Higher Plants

Early Experiments

Scientist name	Discovery/Hypothesis
Joseph Priestley	Plants restore to the air whatever breathing animals and burning candles remove.
Jan Ingenhousz	Sunlight is essential to the plant process that somehow purifies the air fouled by burning candles or breathing animals. Only the green part of the plants could release oxygen.
Julius von Sachs	Green parts in plants is where glucose is made, and that the glucose is usually stored as starch.
T.W Engelmann	Described the first action spectrum of photosynthesis.
Cornelius van Niel	Photosynthesis is essentially a light-dependent reaction in which hydrogen from a suitable oxidisable compound reduces carbon dioxide to carbohydrates. O_2 evolved by the green plant comes from **H_2O**, not from carbon dioxide.

Where does photosynthesis take place?

- In the chloroplast.
- The membrane system is responsible for trapping the light energy and also for the synthesis of ATP and NADPH.
- In stroma, enzymatic reactions synthesise sugar, which in turn forms starch.

How many types of pigments are involved in photosynthesis?

- Four pigments: Chlorophyll a (bright or blue green), Chlorophyll b (yellow green), Xanthophylls (yellow), Carotenoids (yellow to yellow-orange)
- Most of the photosynthesis takes place in the **blue and red** regions of the spectrum.
- Chlorophyll a is the **chief pigment** associated with photosynthesis.
- Chlorophyll b, xanthophylls and carotenoids are called **accessory pigments**, which absorb light and transfer the energy to chlorophyll a. They also protect chlorophyll a from photo-oxidation.

What is light reaction?

- 'Photochemical' phase: include light absorption, water splitting, oxygen release, and the formation of high-energy chemical intermediates, ATP and NADPH.
- PS I and PS II contain photosynthetic pigments which absorb light.
- The single chlorophyll a molecule forms the reaction centre of each photosystem.
- In PS I the reaction centre chlorophyll a has an absorption peak at 700 nm, hence is called P_{700}, while in PS II it has absorption maxima at 680 nm, and is called P_{680}.

The electron transport

- PS II absorbs light of 680 nm. Its e^- excite and are picked up by an electron acceptor which passes them to an electrons transport system made up of **cytochromes,** finally passed on to PS I, producing **ATP** as a byproduct.
- The e^- lost by PS II are compensated by photolysis of water, thus producing e^- and O_2.
- Simultaneously, PSI absorbs light of 700 nm. Its e^- excite and are transported by cytochromes to $NADP^+$ which is reduced to **$NADPH + H^+$.**
- This is called **Z-scheme** of electron transport.

Cyclic and non-cyclic photophosphorylation

- ATP synthesis using light energy is called phosphorylation.
- When the two photosystems work in a series, first PS II and then the PS I, a process called non-cyclic photo-phosphorylation occurs. Both ATP and $NADPH + H^+$ are synthesised by it. Occurs in granal lamellae.
- Stromal lamellae lack PS II as well as NADP reductase enzyme, only PS I is functional, the electron is circulated within it, thus causing cyclic photo-phosphorylation.

Chemiosmotic Hypothesis

- Explains how actually ATP is synthesised in the chloroplast.
- A proton gradient develops across the thylakoid membrane during light reaction in 3 steps:

- Protons or hydrogen ions that are produced by the splitting of water accumulate within the lumen of the thylakoids.
- As electrons move through the photosystems, protons are transported across the membrane by the activity of a proton carrier which also acts as a electron transporter.
- Protons are removed from stroma for reduction of $NADP^+$ to $NADPH + H^+$.

- Hence, within the chloroplast, protons in the stroma decrease in number, while in the lumen there is accumulation of protons.
- This proton gradient is used by ATP synthase (present in the thylakoid membrane) for synthesis of ATP.
- Chemiosmosis requires a membrane, a proton pump, a proton gradient and ATP synthase.
- ATP and $NADPH + H^+$ are used in the biosynthetic phase of photosynthesis (dark reaction).

Calvin cycle

- Process of synthesis of sugar by reducing atmospheric CO_2.
- Primary acceptor of CO_2 is a 5-C sugar called RuBP.
- Three stages: carboxylation, reduction and regeneration.
  - Carboxylation-fixation of CO_2 to form two molecules of 3-PGA, the most crucial step of the Calvin cycle, catalysed by the enzyme RuBP carboxylase (RuBisCO).
  - Reduction-a series of reactions reduce fixed CO_2 into glucose, by utilizing 2 molecules of ATP for phosphorylation and two of NADPH for reduction per CO_2 molecule fixed.
  - Regeneration-involves regeneration of RuBP to continue uninterrupted calvin cycle. Uses one ATP.
- For every CO_2 molecule entering the Calvin cycle, 3 molecules of ATP and 2 of NADPH are required.

C_4 pathway

- Hatch and Slack cycle.
- First stable product of CO_2 fixation in mesophyll cells is a 4-C compound OAA.
- RuBisCO is absent in the mesophyll cells of such plants.
  - In mesophyll cells, PEPcase converts PEP into OAA by using atmospheric CO_2, and converted to malic acid or aspartic acid.
  - The C_4 acid is transported to bundle sheath cells, converted to a 3-C compound by releasing CO_2. This CO_2 is fixed by RuBisCO to synthsize glucose. The 3-C compound thus produced is transported back to the mesophyll cell and converted to PEP.
- Present in plants like Maize, sugarcane and sorghum.
- Kranz anatomy: large bundle sheath cells form several layers around the vascular bundles; have a large number of chloroplasts, thick walls impervious to gaseous exchange and no intercellular spaces.
- The photosynthetic efficiency of C_4 plants is better than C_3 plants.

Photorespiration

- In C_3 plants some O_2 binds to RuBisCO, and hence CO_2 fixation is decreased.
- Here the RuBP instead of being converted to 2 molecules of PGA binds with O_2 to form one molecule of phosphoglycerate and phosphoglycolate (2 Carbon).
- Sugar and ATP not synthesized, hence called a wasteful process.
- Absent in C_4 plants.

Factors affecting photosynthesis

- **Light:** rarely a limiting factor in nature. There is a linear relationship between incident light and CO_2 fixation rates at low light intensities. At higher light intensities, gradually the rate does not show further increase as other factors become limiting.
- **CO_2 concentration:** Major limiting factor. C_4 plants show saturation at about 360 μlL^{-1} while C_3 only beyond 450 μlL^{-1}.
- **Temperature:** The dark reactions being enzymatic are temperature controlled. The C_4 plants respond to higher temperatures and show higher rate of photosynthesis while C_3 plants have a much lower temperature optimum.
- **Water:** Water stress causes wilting of leaves and the stomata to close hence reducing the CO_2 availability.