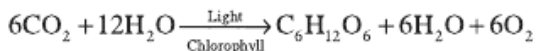


Chapter-13

PHOTOSYNTHESIS IN HIGHER PLANTS

POINTS TO REMEMBER

Photosynthesis : Photosynthesis is an enzyme regulated anabolic process of manufacture of organic compounds inside the chlorophyll containing cells from carbon dioxide and water with the help of sunlight as a source of energy.



Historical Perspective

Joseph Priestley (1770) : Showed that plants have the ability to take up CO_2 from atmosphere and release O_2 .

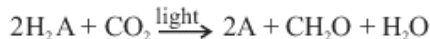
Jan Ingenhousz (1779) : Release of O_2 by plants was possible only in sunlight and only by the green parts of plants.

Theodore de Saussure (1804) : Water is an essential requirement for photosynthesis to occur.

Julius Von Sachs (1854) : Green parts in plant produce glucose which is stored as starch.

T. W. Engelmann (1888) : The effect of different wavelength of light on photosynthesis and plotted the first action spectrum of photosynthesis.

C. B. Van Niel (1931) : Photosynthesis is essentially a light dependent reaction in which hydrogen from an oxidisable compound reduces CO_2 to form sugar. He gave a simplified chemical equation of photosynthesis.



Hill (1937) : Evolution of oxygen occurs in light reaction.

Calvin (1954-55) : Traced the pathway of carbon fixation.

Hatch and Slack (1965) : Discovered C_4 pathway of CO_2 fixation.

Site for photosynthesis : Photosynthesis takes place only in green parts of the plant, mostly in leaves. Within a leaf, photosynthesis occurs in mesophyll cells which contain the chloroplasts. Chloroplasts are the actual sites for photosynthesis. The thylakoids in chloroplast contain most of pigments required for capturing solar energy to initiate photosynthesis. The membrane system (grana)

is responsible for trapping the light energy and for the synthesis of ATP and NADPH. Biosynthetic phase (dark reaction) is carried in stroma.

Pigments involved in photosynthesis :

Chlorophyll a : (Bright or blue green in chromatograph). Major pigment, act as reaction centre, involved in trapping and converting light into chemical energy.

Chlorophyll b : (Yellow green)

Xanthophyll : (Yellow)

Carotenoids : (Yellow to yellow-orange)

In the blue and red regions of spectrum shows higher rate of photosynthesis.

Light Harvesting Complexes (LHC) : The light harvesting complexes are made up of hundreds of pigment molecules bound to protein within the photosystem I (PSI) and photosystem II (PSII). Each photosystem has all the pigments except one molecule of chlorophyll 'a' forming a light harvesting system (antennae). The reaction centre (chlorophyll a) is different in both the photosystems.

Photosystem I (PSI) : Chlorophyll 'a' has an absorption peak at 700 nm (P700).

Photosystem II (PSII) : Chlorophyll 'a' has absorption peak at 680 nm (P680).

Process of photosynthesis : It includes two phases - Photochemical phase and biosynthetic phase.

(i) **Photochemical phase (Light reaction)** : This phase includes - light absorption, splitting of water, oxygen release and formation of ATP and NADPH.

(ii) **Biosynthetic phase (Dark reaction)** : It is light independent phase, synthesis of food material (sugars). (Calvin cycle)

Photophosphorylation : The process of formation of high-energy chemicals (ATP and NADPH).

Cyclic photophosphorylation : Two photosystems work in series – First PSII and then PSI. These two photosystems are connected through an electron transport chain (Z. Scheme). Both ATP and NADPH + H⁺ are synthesised by this process. PSI and PSII are found in lamellae of grana, hence this process is

Non-cyclic photophosphorylation : Only PSI works, the electron circulates within the photosystem. It happens in the stroma lamellae (possible location) because in this region PSII and NADP reductase enzyme are absent. Hence only ATP molecules are synthesised.

The electron transport (Z-Scheme) : In PS II, reaction centre (chlorophyll a) absorbs 680 nm wavelength of red light which make the electrons to become excited. These electrons are taken up by the electron acceptor that passes them to an electron transport system (ETS) consisting of cytochromes. The movement of electron is down hill. Then, the electron pass to PSI and move down hill further. (Fig. 13.5)

The splitting of water : It is linked to PS II. Water splits into H^+ , O and electrons.



Chemiosmotic Hypothesis : Chemiosmotic hypothesis explain the mechanism of ATP synthesis in chloroplast. In photosynthesis, ATP synthesis is linked to development of a proton gradient across a membrane. The electrons are accumulated inside of membrane of thylakoids (in lumen). ATPase has a channel that allows diffusion of protons back across the membrane. This releases energy to activate ATPase enzyme that catalyses the formation of ATP. (Fig. 13.7)

Biosynthetic phase in C_3 plants :

ATP and NADPH, the products of light reaction are used in synthesis of food. The first CO_2 fixation product in C_3 plant is 3-phosphoglyceric acid or PGA. The CO_2 acceptor molecule is RuBP (ribulose biphosphate). The cyclic path of sugar formation is called Calvin cycle on the name of Melvin Calvin, the discoverer of this pathway. Calvin cycle proceeds in three stages :

- (1) **Carboxylation :** CO_2 combines with ribulose 1, 5 bisphosphate to form 3 PGA in the presence of RuBisCo enzyme.
- (2) **Reduction :** Carbohydrate is formed at the expense of ATP and NADPH.
- (3) **Regeneration :** The CO_2 acceptor ribulose 1, 5-bisphosphate is formed again.

6 turns of Calvin cycles and 18 ATP molecules are required to synthesize one molecule of glucose. (Fig. 13.8)

The C_4 pathway : C_4 plants such as maize, sorghum, sugarcane have special type of leaf anatomy, they tolerate higher temperatures. In this pathway, oxaloacetic acid (OAA) is the first stable product formed. It is 4 carbon atoms compound, hence called C_4 pathway (Hatch and Slack Cycle). The leaf has two types of cells, mesophyll cells and bundle sheath cells (Kranz anatomy). Initially

CO₂ is taken up by phosphoenol pyruvate (PEP) in mesophyll cells and changed to oxaloacetic acid (OAA) in the presence of PEP carboxylase. Oxaloacetate is reduced to malate/aspartate that reach into bundle sheath cells.

The oxidation of malate/aspartate occurs with the release of O₂ and formation of pyruvate (3C). In high CO₂ concentration RuBisCo functions as carboxylase and not as oxygenase, hence the photosynthetic losses are prevented. RuBP operates now under Calvin cycle and pyruvate transported back to mesophyll cells and changed into phosphoenol pyruvate to keep the cycle continue. (Fig. 13.9)

Photorespiration : The light induced respiration in green plants is called photorespiration. In C₃ plants some O₂ binds with RuBisCo and hence CO₂ fixation is decreased. In this process RuBP instead of being converted to 2 molecules of PGA binds with O₂ to form one molecule of PGA and phosphoglycolate.



Law of Limiting Factors : If a chemical process is affected by more than one factor, then its rate will be determined by the factor which is nearest to its minimal value. It is the factor which directly affects the process if its quantity is changed.

Factors affecting photosynthesis :

1. Light : Rate of photo synthesis increases at low light intensities. At high intensities of light beyond a point the rate of CO₂ fixation decreases
2. Carbon dioxide : Increase in CO₂ concentration causes increase in CO₂ fixation
3. Temperature : The rate of photosynthesis at optimum temperature is high.
4. Water : Water is one of the reactants in photosynthesis, hence it affects the rate of CO₂ fixation. Low water content causes the stomata to close and reduces the CO₂ availability.

QUESTIONS

Very Short Answer Questions (1 mark each)

1. Name two photosynthetic pigments belonging to Carotenoids.
2. How many molecules of ATP are required for synthesis of one molecule of glucose in C₃ and C₄ pathways ?
3. What part of sunlight is most suitable for photosynthesis ?
4. Which one of the photosystems can carry on photophosphorylation independently ?

- Name two plants that can carry out photosynthesis at night.
- Name the enzyme which is found abundantly in the world.
- Name the scientist who proposed the C_4 pathway.
- Where does carbon fixation occur in chloroplast ?
- Which compound acts as CO_2 acceptor in Calvin cycle ?
- Name the end products of light reaction.

Short Answer Questions-II (2 marks each)

- Why does the rate of photosynthesis decline in the presence of continuous light ?
- Why do green plants start evolving carbon dioxide instead of oxygen on a hot sunny day ?
- Fill in the space, left blank in the given table to bring the difference between C_3 and C_4 plants :

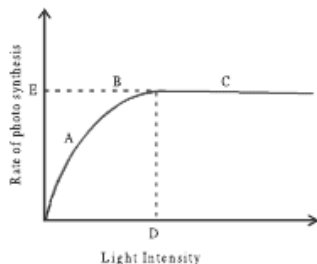
| S. No. | Characterisitics | C_3 plants | C_4 plants |
|--------|-------------------------------|---------------|------------------------------|
| 1. | Cell type | mesophyll | ...(a)... and mesophyll |
| 2. | CO_2 acceptor |(b)..... | Phosphoenolpyruvate (PEP) |
| 3. | First CO_2 fixation product | 3-PGA |(c)..... |
| 4. | Optimum temperature |(d)..... | $30^\circ C$ to $45^\circ C$ |

- State two functions of accessory pigments found in thylakoids.
- Why do C_4 plants are more expensive than C_3 plants ?

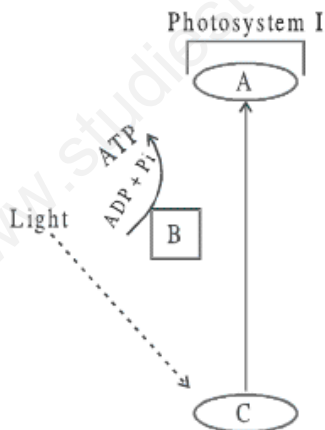
Short Answer Questions-I (3 marks each)

- The figure shows the effect of light on the rate of photosynthesis. Based on the graph, answer the following questions :
 - At which point(s) A, B or C in the curve, light is a limiting factor ?
 - What could be the limiting factor(s) in region A ?

(iii) What do region C and D represent on the curve ?



17. When and why does photorespiration take place in plants ? How does this process result in a loss to the plant ?
18. What are the steps that are common to C_3 and C_4 photosynthesis ?
19. Two potted plants were kept in an oxygen free environment in transparent containers, one in total darkness and the other in sunlight. Which one of the two is likely to survive more ? Justify your answer by giving the reason.
20. (a) In the diagram shown below, label A, B and C. What type of phosphorylation is possible in this ?



- (b) Give any two points of difference between cyclic and non-cyclic photophosphorylation.

Long Answer Questions (5 marks each)

21. Describe C_4 pathway in a paddy plant. How is this pathway an adaptive advantage to the plant ?
22. Explain the process of biosynthetic phase of photosynthesis occurring in chloroplast.

23. (a) Give steps of ATP synthesis in chloroplasts through chemiosmosis.
(b) Schematically represent non-cyclic photophosphorylation in plants.

ANSWERS

Very Short Answers (1 mark each)

1. Carotene and Xanthophyll.
2. In C_3 pathway = 18 ATP molecules
In C_4 pathway = 30 ATP molecules
3. Blue and red regions of the light spectrum are the most effective in photosynthesis.
4. PS-I.
5. Opuntia, Chenopodium, Bougainvillea.
6. RuBisCO.
7. Hatch and Slack.
8. Carbon fixation takes place in stroma.
9. Ribulose 1, 5 bisphosphate.
10. ATP, NADPH and O_2 .

Short Answers-II (2 marks each)

11. Increase in incident light beyond a point causes the breakdown of chlorophyll.
12. On a hot sunny day, enzyme RuBP carboxylase becomes active and its affinity for CO_2 decreases and for O_2 increases. Consequently more and more photosynthetically fixed carbon is lost by photorespiration.
13. (a) Bundle sheath
(b) RuBP
(c) OAA (oxaloacetic acid)
(d) $20^\circ C - 25^\circ C$
14. (a) Absorption of light and transfer of energy to chlorophyll 'a'.
(b) Protect chlorophyll 'a' from photooxidation.

15. Because they require more energy (30 ATPs) in synthesizing one glucose molecule as compared to C_3 - (18ATPs.)

Short Answers-I (3 marks each)

16. (i) 'B'
(ii) CO_2 and temperature
(iii) 'C' represents to constant rate of photosynthesis, 'D' is the light saturation intensity at which rate of photosynthesis is maximum.
17. Refer Page no. 220, NCERT, Text Book Biology for class XI.

18. **Hints :**

- (a) Photolysis of H_2O and photophosphorylation occurs in both C_3 and C_4 plants.
- (b) In both, dark reaction occurs in stroma.
- (c) Calvin cycle results in the formation of starch in both the plants.
- (d) During dark reaction both types of plants undergo the phases of carboxylation and regeneration.

19. **Hints :**

- The plant in sunlight will survive for longer period.
- Light is essential for photosynthesis.

20. (a) (A) e^- acceptor
(B) Electron transport system
(C) Chlorophyll P700
- (b) Refer Page no. 212, NCERT Text Book of Biology for Class XI.

Long Answers (5 marks each)

21. Refer Page no. 218, NCERT Text Book of Biology for Class XI.
22. Refer Page no. 216, NCERT Text Book of Biology for Class XI.

Hint : Three stages of Calvin cycle : Carboxylation, reduction and regeneration.

23. (a) Refer Page no. 213 (Chemiosmotic Hypothesis), NCERT Text Book of Biology for Class XI.
- (b) Refer Fig. 13.5 (Z-Scheme of light reaction), NCERT Text Book of Biology for Class XI.