Quadrant II- Transcript and Related Materials

Programme : S. Y. B. Sc.

Subject : Botany

Course Code : BOC 104

Course Title : Plant Physiology

Unit : 5- Photosynthesis

Module Name : C3 and C4 pathway of Carbon fixation

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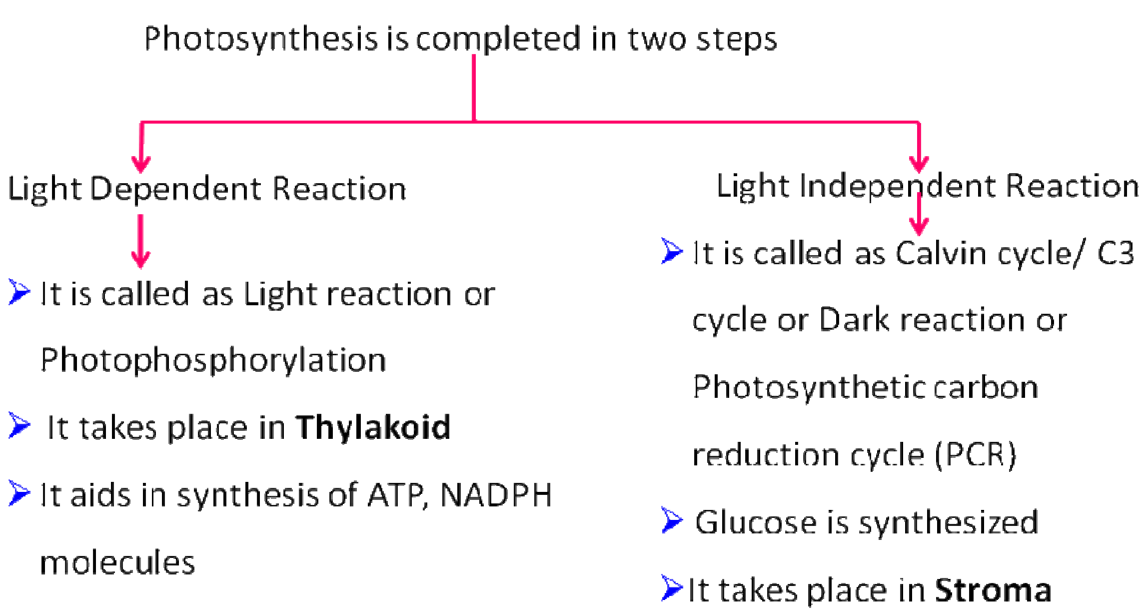
Notes:

Photosynthesis

- It is a process by which green plants synthesize organic matter in the presence of light.
- During photosynthesis light energy is converted into chemical energy and is utilized to fix Carbon in the form of carbohydrate along with O_2 as end product.
- Process requires raw materials: CO_2, H_2O, Light and pigments (Chlorophyll *a*).



C3 pathway of carbon fixation:

- The Calvin cycle was first observed by Melvin Calvin in the year 1957 in Chlorella, unicellular green alga.
- Calvin was awarded Nobel Prize for this work in1961.
- The first stable compound in Calvin cycle is a 3 Carbon compound (3PGA), cycle is called C3 cycle.
- It is known as Biosynthetic Pathway because using ATP and NADPH are produced in the light reaction. Sugar or Carbohydrate is also synthesized as byproduct.
- Examples of C3 plants are the cereals Barley, Oats, Rice, and Wheat, Cotton, Eucalyptus, Sunflower, Soybeans, Sugar beets, Potatoes, Tobacco etc.
- The cycle is completed in three steps:
  1. Carboxylation
  2. Reduction
  3. Regeneration

1. Carboxylation: Also called as carbon fixation. Three molecules of CO_2 are accepted by 3 molecules of 5C compound viz., Ribulose 1, 5 bisphosphate (RuBP which is present in the plant body, it is a carbon acceptor) to form three molecules of an unstable intermediate 6C compound. This compound immediately splits into two 3-C molecules of 3-phosphoglycerate (3PGA or 3 Phosphoglyceric acid). It is the first stable product of dark reaction of photosynthesis and since it is a 3 carbon compound, this cycle is known as C3 cycle. This reaction is carried out by the enzyme RUBISCO (Ribulose-1,5-bisphosphate carboxylase/oxygenase) which is present in plenty in the environment.

$$3\ CO_2 + 3\ \text{Ribulose 1, 5 bisphosphate} \xrightarrow{\text{RUBISCO}} 3PGA$$

2. Reduction: 3-phosphoglycerate is reduced to aldehyde which produces glucose with the help of energy rich ATP and NADPH. Six molecules of 3PGA are phosphorylated by 6 molecules of ATP (produced in the light reaction) to yield 6 molecules of 1-3 bisphosphoglyceric acid and 6 molecules of ADP.

   3 Phosphoglyceric acid + ATP $\longrightarrow$ 1,3 bisphosphoglyceric acid + ADP

   Six molecules of 1, 3 bisphosphoglyceric acid are reduced with the use of 6 molecules of NADPH2 (produced in light reaction) to form 6 molecules of 3 phospho glyceraldehyde.

   1,3 bisphosphoglyceric acid + NADPH2 $\longrightarrow$ 3 phospho glyceraldehyde + NADP .

   From 6 molecules of 3 phospho glyceraldehydes (PGAL or G3P), 1 molecule will undergo syntheses to produce Glucose.

3. Regeneration: Aldehyde undergo further reaction with the help of energy rich ATP to regenerate 5 Carbon RuBp CO_2 acceptor. 5 molecules of 3 phospho glyceraldehyde undergo various pathways to produce Ribose 5 Phosphate. Ribose 5 phosphate is converted into one molecule of ribulose monophosphate. The ribulose monophosphate is phosphorylated by ATP to form ribulose bisphosphate and ADP, thus completing Calvin cycle. Finally for every CO_2 entering Calvin Cycle, 3 molecules of ATP and 2 Molecules of NADPH are required.

C4 pathway of carbon fixation:

- It is the alternate pathway of C3 cycle for CO_2 fixation.
- The path way is also called as Hatch and Slack as they worked out the pathway in 1966 and it is also called as C4 dicarboxylic acid pathway.

- The first formed stable compound is a 4 carbon compound viz., Oxaloacetic acid. Hence it is called C4 cycle.
- This pathway is commonly seen in many Grasses, Sugarcane, Maize, Sorghum and Amaranthus.
- The C4 plants show a different type of leaf anatomy:
- The chloroplasts are dimorphic in nature. In the leaves of these plants, the vascular bundles are surrounded by bundle sheath of larger parenchymatous cells.
- These bundle sheath cells have chloroplasts. These chloroplasts of bundle sheath are larger, lack grana and contain starch grains.
- The chloroplasts in mesophyll cells are smaller and always contain grana.
- This peculiar anatomy of leaves of C4 plants is called Kranz anatomy.
- Under some environmental conditions RUBISCO act as a Oxygenase i.e. fixation of O_2 instead of CO_2.
- This process is refers to as Photorespiration, in plant metabolism where the enzyme RUBISCO oxygenates RuBP, wasting some of the energy produced in photosynthesis.
- This process reduces the efficiency of photosynthesis, potentially reducing photosynthetic output by 25% in C3 plants.
- To avoid photorespiration plants show modification in CO_2 fixation process called as C4 cycle.
- The C4 cycle involves two carboxylation reactions, one taking place in chloroplasts of mesophyll cells and another in chloroplasts of bundle sheath cells.
- Here CO_2 enters the mesophyll cells through stomata. First it reacts with the water present in surrounding and forms Carbonic acid with help of enzyme called Carbonic Anhydrase.

- Next carbonic acid dissociates into H^+ and Bicarbonate. CO_2 from bicarbonate is fixed as a 4 carbon compound of Oxalo-acetic acid (OAA) with the help of first Phosphoenol Pyruvic acid (PEP) and the enzyme Phosphoenolpyruvate carboxylase in mesophyll cells.
- Mesophyll cell has very less quantity of RUBP carboxylase which is higher in bundle sheath cells. Then Oxaloacetic acid converts to Malic acid or Aspartic acid with help of Malate dehydrogenase, then transports to bundle sheath cells.
- In the Bundle sheath where malic acid gets decarboxylated with the help of Malic enzyme and change into pyruvic acid while aspartic acid firstly changes to Oxalo-acetic acid and after decarboxylation then pyruvic acid. The CO_2 obtained from decarboxylation of either Malic acid or Oxaloacetic acid undergoes C3 cycle.
- While Pyruvic acid directly changes to Phosphoenolpyruvic acid. In this process AMP is formed from ATP not ADP. Hence two extra ATP is required to regenerate ATP from AMP and hence 12 additional ATP are needed in C4 cycle.
- C4 cycle is more energy expensive (30ATP /Glucose molecule).

Difference between C3 and C4 pathway of carbon fixation

C3 Plants	C4 Plants
Carboxylation takes place once	Carboxylation takes place twice
Photosynthetically less efficient	Photosynthetically more efficient
18 ATPs used to synthesize one Glucose	30 ATPs used to synthesize one Glucose molecule
Carbon pathway in photosynthesis is C3 pathway i.e Calvin cycle only	Carbon pathway in photosynthesis is C4-dicarboxylic acid pathway i.e Hatch-Slack pathway
First stable product is 3-C compound (PGA)	First stable product is 4-C compound (OAA)
Leaves have only diffused mesophyll type of chloroplast	Leaves have Krantz anatomy. Dimorphic chloroplast with compact mesophyll around bundle sheath
Photorespiration occurs	No photorespiration
CO_2 acceptor is RUBP in mesophyll tissue	PEP in Mesophyll and RUBP in Bundle sheath
Rice, Wheat, Potato etc.	Maize, Sugarcane, Sorghum etc.