14. Respiration in Plants

POINTS TO REMEMBER :

- The breaking of C-C bonds of complex compounds through oxidation within the cells, leading to release of considerable amount of energy is called **respiration.**
- The compound that oxidized during this process is known as**respiratory substrates.**
- In the process of respiration the energy is released in a series of slow step-wise reactions controlled by enzymes and is trapped in the form of ATP.
- ATP acts as the energy currency of the cell.

Glycolysis :

- The term has originated from the Greek word, glycos =glucose, lysis = splitting or breakdown means breakdown of glucose molecule.
- It is also called **Embeden-Meyerhof-Paranus pathway**. (EMP pathway)
- It is common in both **aerobic** and **anaerobic** respiration.
- It takes place outside the mitochondria, in the **cytoplasm.**
- One molecule of glucose (Hexose sugar) ultimately produces two molecules of pyruvic acid through glycolysis.
- Glucose and fructose are phosphorylated to give rise to glucose-6-phosphate, catalyzed by **hexokinase.**
- This phosphorylated form of glucose is then isomerizes to produce **fructose-6-phosphate.**
- ATP utilized at two steps:
    - First in the conversion of glucose into glucose-6-phosphate
    - Second in fructose-6-phosphate→fructose 1, 6-diphosphate.

- The fructose-1, 6-diphosphate is split into dihydroxyacetone phosphate and 3-phosphoglyceraldehyde (DPGA).
- In one step where NADH + H^+ is formed form NAD^+; this is when 3-phosphogleceraldehyde (PGAL) is converted into 1, 3-bisphophoglyceric acid (DPGA).
- The conversion of 1, 3-bisphophoglyceric acid into 3-phosphoglyceric acid is also an energy yielding process; this energy is trapped by the formation of ATP.
- Another ATP synthesized when phosphoenolpyruvate is converted into pyruvic acid.
- During this process 4 molecules of ATP are produced while 2 molecules of ATP are utilized. Thus net gain of ATP is of 2 molecules.

FERMENTATION :

- There are three major ways in which different cells handle pyruvic acid produced by glycolysis:
    - Lactic acid fermentation.
    - Alcoholic fermentation.
    - Aerobic respiration.

- **Alcoholic fermentation :**
    - The incomplete oxidation of glucose to achieved under anaerobic conditions by sets of reactions where pyruvic acid is converted into CO_2 and ethanol.

- The enzyme pyruvic acid decarboxylase and alcohol dehydrogenase catalyze these reactions.
- $NADH + H^+$ is reoxidised into NAD^+.

- **Lactic acid fermentation:**
  - Pyruvic acid converted into lactic acid.
  - It takes place in the muscle in anaerobic conditions.
  - The reaction catalysed by lactate dehydrogenase.
  - $NADH + H^+$ is reoxidised into NAD^+.

- **Aerobic respiration:**
  - Pyruvic acid enters into the mitochondria.
  - Complete oxidation of pyruvate by the stepwise removal of all the hydrogen atoms, leaving three molecules of CO_2.
  - The passing on the electrons removed as part of the hydrogen atoms to molecular oxygen (O_2) with simultaneous synthesis of ATP.

AEROBIC RESPIRATION:

- The overall mechanism of aerobic respiration can be studied under the following steps :
- Glycolysis (EMP pathway)
- Oxidative Decarboxylation
- Krebs's cycle (TCA-cycle)
- Oxidative phosphorylation

Oxidative decarboxylation:

- Pyruvic acid formed in the cytoplasm enters into mitochondria.
- Pyruvic acid is converted into Acetyl CoA in presence of **pyruvate dehydrogenase complex.**
- The pyruvate dehydrogenase catalyses the reaction require several coenzymes, including NAD^+ and Coenzyme A.
- During this process two molecules of NADH are produced from metabolism of two molecules of pyruvic acids (produced from one glucose molecule during glycolysis).
- The Acetyl CoA (2c) enters into a cyclic pathway, tricarboxylic acid cycle.

Tri Carboxylic Acid Cycle (Krebs cycle) or Citric acid Cycle :

- This cycle starts with condensation of acetyl group with oxaloacetic acid and water to yield citric acid. This reaction is catalysed by citrate synthase.
- Citrate is isomerised to form isocitrate.
- It is followed by two successive steps of decarboxylation, leading to formation of α-ketoglutaric acid and then succinyl-CoA.
- In the remaining steps the succinyl CoA oxidized into oxaloacetic acid.
- During conversion of succinyl CoA to succinic acid there is synthesis of one GTP molecule.
- In a coupled reaction GTP converted to GDP with simultaneous synthesis of ATP from ADP.
- During Krebs cycle there production of :
  - 2 molecule of CO_2
  - 3 $NADH_2$
  - 1 $FADH_2$

  - 1 GTP.
- During the whole process of oxidation of glucose produce:
  - CO_2
  - 10 $NADH_2$
  - 2 $FADH_2$
  - 2 GTP.(2 ATP)

Electron transport system and oxidative phosphorylation :

- The metabolic pathway, through which the electron passes from one carrier to another, is called **Electron transport system**.
- it is present in the inner mitochondrial membrane.
- ETS comprises of the following:
  - Complex I – NADH Dehydrogenase.
  - Complex II – succinate dehydrogenase.
  - Complex III – cytochromes bc1
  - Complex IV – Cytochromes a-a_3 (cytochromes c oxidase).
  - Complex V – ATP synthase.

- $NADH_2$ produced in the citric acid cycle oxidized by NADH Dehydrogenase, and electrons are then transferred to ubiquinone located in the inner membrane.
- $FADH_2$ is oxidized by succinate dehydrogenase and transferred electrons to ubiquinone.
- The reduced ubiquinone is then oxidized with transfer of electrons to cytochrome *c* via cytochromes *bc1* complex.
- Cytochrome c is small protein attached to the outer surface of the inner membrane and acts as a mobile carrier for transfer electrons from complex III and complex IV.
- When electrons transferred from one carrier to another via complex I to IV in the electron transport chain, they are coupled to ATP synthase for the synthesis of ATP from ADP and Pi.
- One molecule of $NADH_2$ gives rise to 3 ATP.
- One molecule of $FADH_2$ gives rise to 2ATP.
- Oxygen plays a vital role in removing electrons and hydrogen ion finally production of H_2O.
- Phosphorylation in presence of oxygen is called oxidative phosphorylation.

Total ATP Production -

Process Total ATP produced :

- Glycolysis 2ATP + 2$NADH_2$ (6ATP) = 8ATP
- Oxidative decarboxylation 2$NADH_2$ (6ATP) = 6ATP
- Krebs's Cycle 2GTP (2ATP) + 6$NADH_2$ (18ATP) + 2$FADH_2$ (4ATP) = 24 ATP
- Energy production in prokaryotes during aerobic respiration = 38 ATP
- Energy production in eukaryotes during aerobic respiration = 38 − 2 = 36 ATP
- (2ATP are used up in transporting 2 molecule of pyruvic acid in mitochondria.)

Abbreviations :

ATP − Adenosine tri phosphate

ADP − Adenosine di phosphate

NAD − Nicotinamide Adenine dinucleotide

NADP − Nicotinamide Adenine dinucleotide Phosphate

NADH − Reduced Nicotinamide Adenine dinucleotide

PGA − Phosphoglyceric acid

PGAL − Phospho glyceraldehyde

FAD − Flavin adenine dinucleotide

ETS − Electron transport system

ETC − Electron transport chain

TCA − Tricarboxylic acid

OAA − Oxalo acetic acid

FMN − Flavin mono nucleotide

PPP − Pentose phosphate pathway