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NEET2025

BIOLOGY NOTES

BOTANY

RESPIRATION IN PLANTS

RESPIRATION IN PLANTS

Introduction:

- The breaking of the $C-C$ bonds of complex compounds through oxidation within the cells, leading to release of considerable amount of energy is called "respiration".
- "Cellular respiration" is an enzyme-controlled process of biological oxidation of food materials in a living cell, using molecular O_2, producing CO_2 and H_2O and release energy in gradual steps and storing it in biologically using forms i.e. ATP.
- Most of the respiration processes occur in the cytoplasm (prokaryotes) and in both cytoplasm and mitochondria in eukaryotes.
- Respiratory substrates are compounds that are oxidized during the process of respiration. Usually, carbohydrates are oxidized to release energy but proteins, fats and even organic acids can be used as respiratory substrate in some plants, under certain conditions.
- Respiration is catabolic, exothermic and oxidative process.

Do plants breathe:

- Plants required O_2 for respiration which occurs through stomata and lenticles.
- Roots, stems and leaves respire at rates far lower than animals only during photosynthesis, large volumes of gases are exchanged.
- During the process of respiration, the complete combustion of glucose takes place, which produces CO_2 and H_2O as end products, yields energy most of which is given out as heat.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

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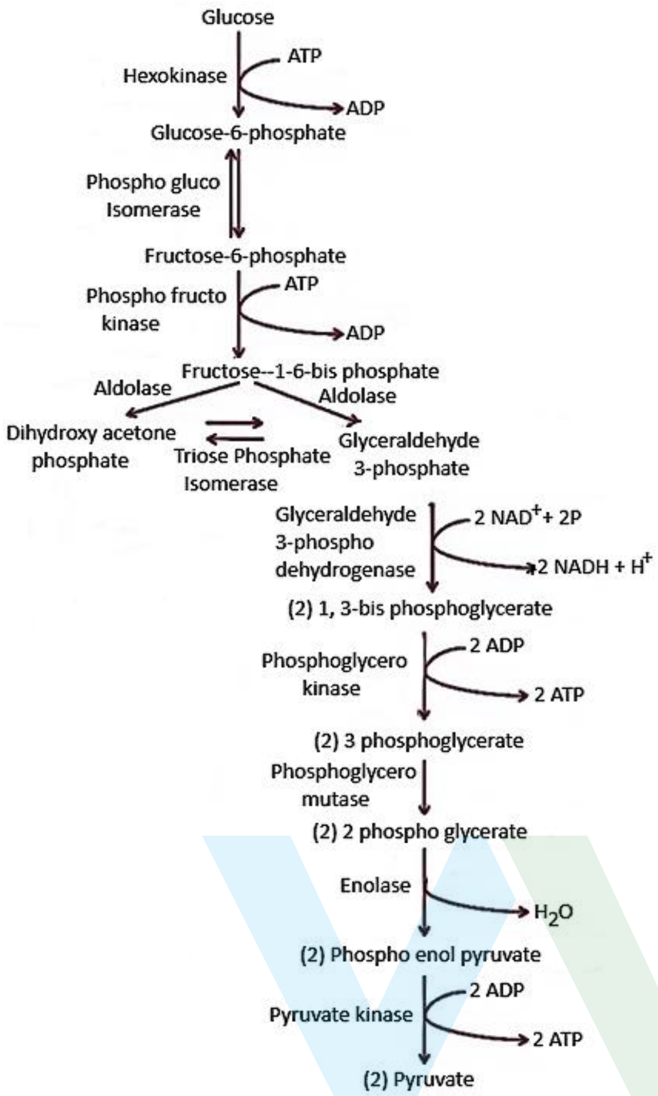
Glycolysis:

- All living organisms retain the enzymatic machinery to partially oxidise glucose without the help of oxygen. This breakdown of glucose into pyruvic acid is called "Glycolysis".
- The scheme of glycolysis was given by Gustav Embden, Otto Meyerhof and J. Parnas and is often referred to as the EMP pathway.
- Glycolysis involves a series of 10 biochemical reactions in cytoplasm.



Steps of Glycolysis:

- Glucose is phosphorylated to give rise to glucose-6-phosphate by the enzyme Hexokinase. In this a phosphate group is transferred from ATP to glucose.
- Glucose-6-phosphate isomerises to produce fructose-6-phosphate by phospho gluco isomerase.
- The other ATP molecule transfers a phosphate group to fructose-6-phosphate and converts it into fructose-1-6-bis phosphate by phospho fructo kinase.
- The fructose 1 6-bis phosphate is split into dihydroxyacetone phosphate (DHAP) and 3-phosphoglyceraldehyde (PGAL) by aldolase. DHAP and PGAL are isomers.
- Triose-phosphate isomerase converts DHAP into PGAL.
- Glyceraldehyde-3-phosphate is converted to 1,3-bisphosphoglycerate by the enzyme glyceraldehyde-3-phosphate dehydrogenase. This enzyme transfers hydrogen molecule from glyceraldehyde-3-phosphate to nicotinamide adenine dinucleotide to form $NADH + H^{+}$.
- Phosphate is transferred from 1,3-bis phosphate glycerate to ADP to form ATP by phosphoglycero kinase. Thus tow molecules of phosphoglycerate and ATP are obtained at the end of this reaction.
- 3-phospho glycerate is converted to 2-phosphoglycerate by the enzyme phosphor glycerol mutase.
- Enolase converts 2-phospho glycerate to phospho enol pyruvate by removing a water molecule.

- A phosphate from phospho enol pyruvate is transferred to ADP to form pyruvate and ATP by the enzyme pyruvate kinase.
- Two molecules of pyruvates, 2 ATP and 2 NADH molecules are obtained as the end products.

There are three major ways in which different cells handle pyruvic acid produced by glycolysis. These are Lactic acid fermentation, Alcohol fermentation and Aerobic respiration.

Fermentation:

Fermentation is the incomplete oxidation of glucose under anaerobic conditions by sets of reaction.

Fermentation is of 2 types:

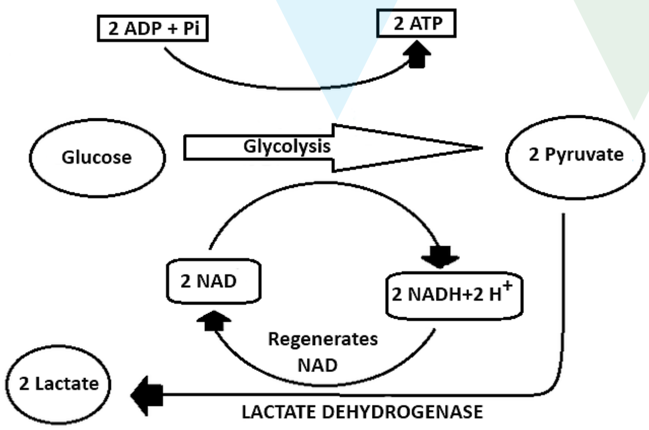
a. Alcohol fermentation:

In this, pyruvic acid is converted to CO_2 and ethanol by pyruvic acid decarboxylase and alcohol dehydrogenase.

$$\text{Glucose} \xrightarrow[CO_2]{} 2\ \text{Ethyl Alcohol} + 2\,\text{NADH}_2 + 2\ \text{ATP}$$

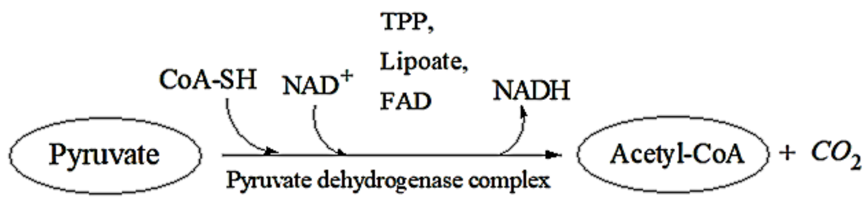
b. Lactic acid fermentation:

- The pyruvic acid is reduced to lactic acid with the help of reducing agent $\text{NADH} + \text{H}^+$, which reoxidises to NAD^+.
- This process produces two lactic acid molecules from two pyruvic acid molecules by the enzyme lactate dehydrogenase.



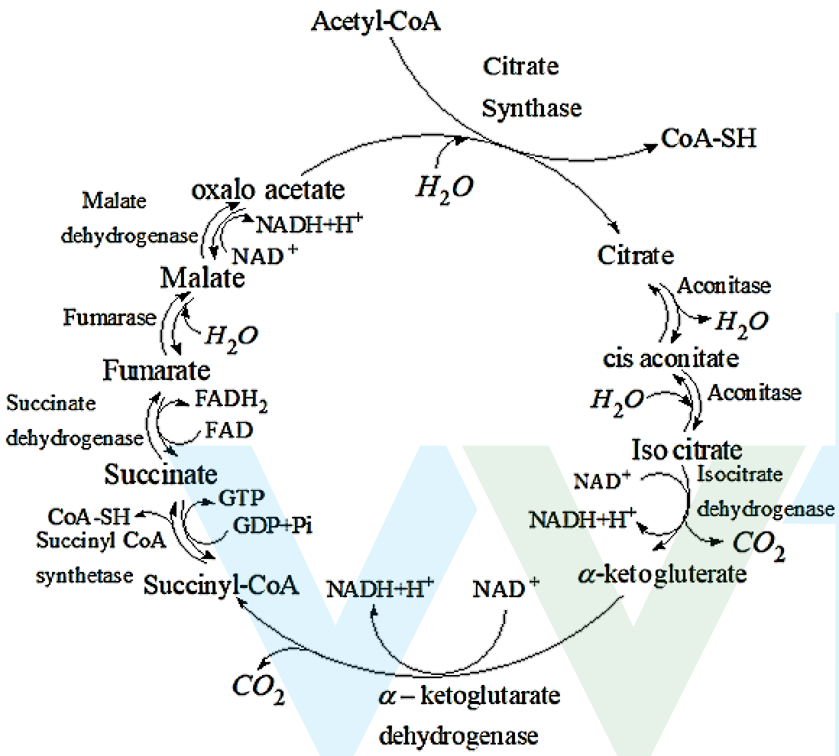
Aerobic Respiration:

- The breakdown of glucose and its successor molecules in the presence of oxygen to release energy is called "aerobic respiration".
- For aerobic respiration, pyruvate is transported from the cytoplasm in to the mitochondria.
- The complete oxidation of pyruvate by the stepwise removal of all hydrogen atoms, leaving three molecules of CO_2
- The first process takes place in the matrix of mitochondria i.e. pyruvate undergoes oxidative decarboxylation by a complex set of reactions catalysed by pyruvic dehydrogenase complex with the participation of several co-enzymes, including NAD^+ and co-enzyme A.



- The acetyl CoA then enters a cyclic pathway, tricarboxylic acid cycle, more commonly called as Kreb's cycle, citric acid cycle.

Tricarboxylic Acid Cycle (TCA Cycle):



- First, the condensation of acetyl group with oxalo acetic acid (OAA) and water takes place to yield citric acid, catalysed by the enzyme citrate synthase and a molecule of CoA is released.
- Citrate is then isomerized to isocitrate, which is followed by two successive steps of decarboxylation, leading to the formation of α –ketoglutaric acid and then succinyl-CoA.
- Succinyl-CoA is oxidized to OAA allowing the cycle to continue and during the conversion of succinyl-CoA to succinate a molecule of GTP is synthesized.
- The summary equation for this phase of respiration may be written as follows.

$$\text{Pyruvic acid} + 4\text{NAD}^+ + \text{FAD}^+ + 2H_2O + \text{ADP} + \text{Pi}$$
$$\xrightarrow{\text{Mitochondrial Matrix}} 3CO_2 + 4\text{NADH} + 4H^+ + \text{FADH}_2 + \text{ATP}$$

Total energy production in TCA Cycle:

$$\begin{array}{lcc} 6\ \text{NADH}\ (\text{NADH} \rightarrow 3\,\text{ATP}) & - & 18\ \text{ATP} \\ 2\ \text{GTP}\ (\text{GTP} \rightarrow 1\ \text{ATP}) & - & 2\ \text{ATP} \\ 2\,\text{FADH}_2\ (\text{FADH}_2 \rightarrow 2\ \text{ATP}) & - & 4\ \text{ATP} \\ \hline & & \underline{24\ \text{ATP}} \end{array}$$

Electron Transport System (ETS):

- The metabolic pathway through which the electron pass from one carrier to another is called “Electron Transport System”, and it is present in the inner mitochondrial membrane.
- The ETC is comprised of four complexes and two mobile carriers i.e. co-enzyme Q, a non-protein part of the chain.

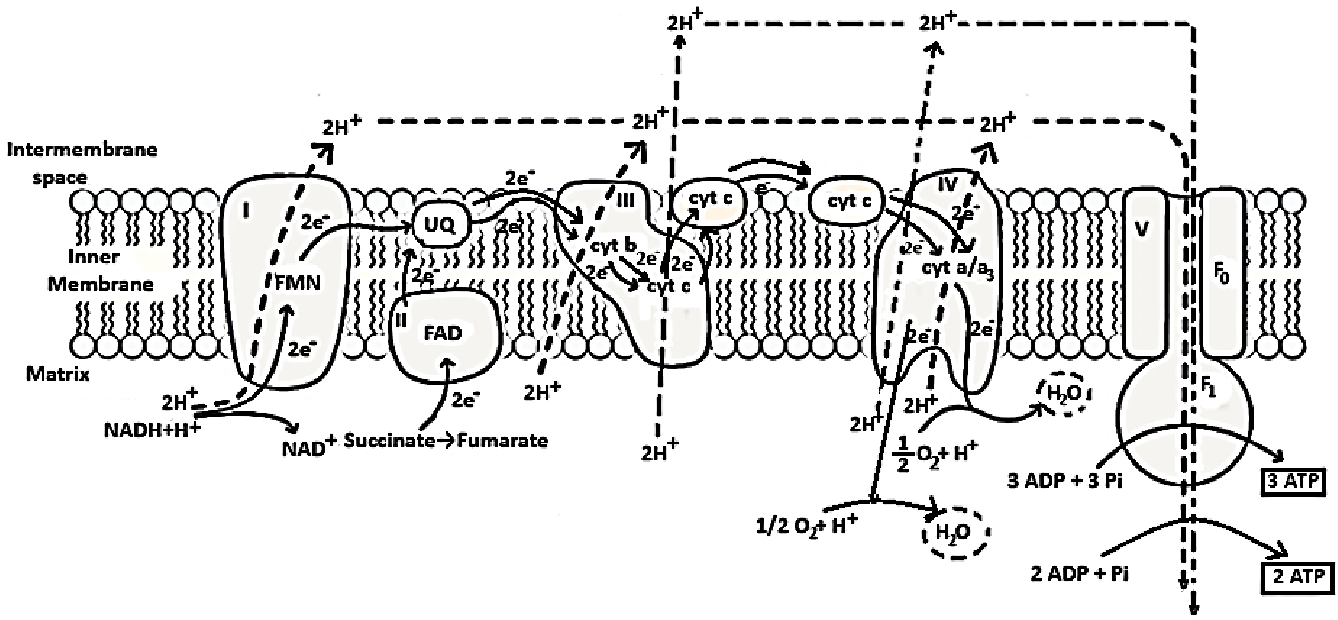
  → Complex I: Consists of flavoproteins of NADH dehydrogenase

  → Complex II: Consists of flavoproteins of succinate dehydrogenase

  → Complex III: Consists of cytochrome b and cytochrome c_1

  → Complex IV: Consists of cytochrome a and cytochrome a_3 of cytochrome c oxidate.

  → Complex V: ATP synthase
- The electrons either follow the pathway of complexes I, II and IV or II, III or IV
- Electrons from NADH produced in the mitochondrial matrix during citric acid cycle are oxidized by an NADH dehydrogenase (Complex I) and electrons are then transferred to ubiquinone located within the inner membrane.
- Ubiquinone also receives reducing equivalents via $FADH_2$ generated during the oxidation of succinate by succinate dehydrogenase (Complex II).
- The reduced ubiquinone called ubiquinol, is then oxidized by transfer of electrons to cytochrome c through cytochrome bc complex (Complex III).
- Cytochrome c acts as a mobile carrier between complex III and complex IV
- Complex IV refers to cytochrome c oxidase complex containing a and a_3 and two copper centres.
- When the electrons pass from one carrier to another carrier via complex I to IV in the electron transport chain, they are coupled to ATP synthase (Complex V) for the formation of ATP from ADP + Pi.



Respiratory Balance Sheet:

For Aerobic Respiration:

1. Glycolysis:

$$\text{Glucose} + 2\,\text{NAD}^+ \rightarrow 2\ \text{Pyruvate} + 2\ \text{ATP} + 2\,\text{NADH}$$

$$\left.\begin{array}{lcc} \text{a) Substrate level phosphorylation} & \rightarrow & 2\ \text{ATP} \\ \text{b) Oxidative phosphorylation} & \rightarrow & 2\ \text{NADH} \rightarrow 6\ \text{ATP} \end{array}\right\} 8\ \text{ATP}$$

2. Citric Acid Cycle:

$$\text{Pyruvate} + 4\ \text{NAD}^+ + \text{GDP} + \text{FAD} \rightarrow 3CO_2 + 4\ \text{NADH} + \text{FADH}_2 + \text{GTP}$$

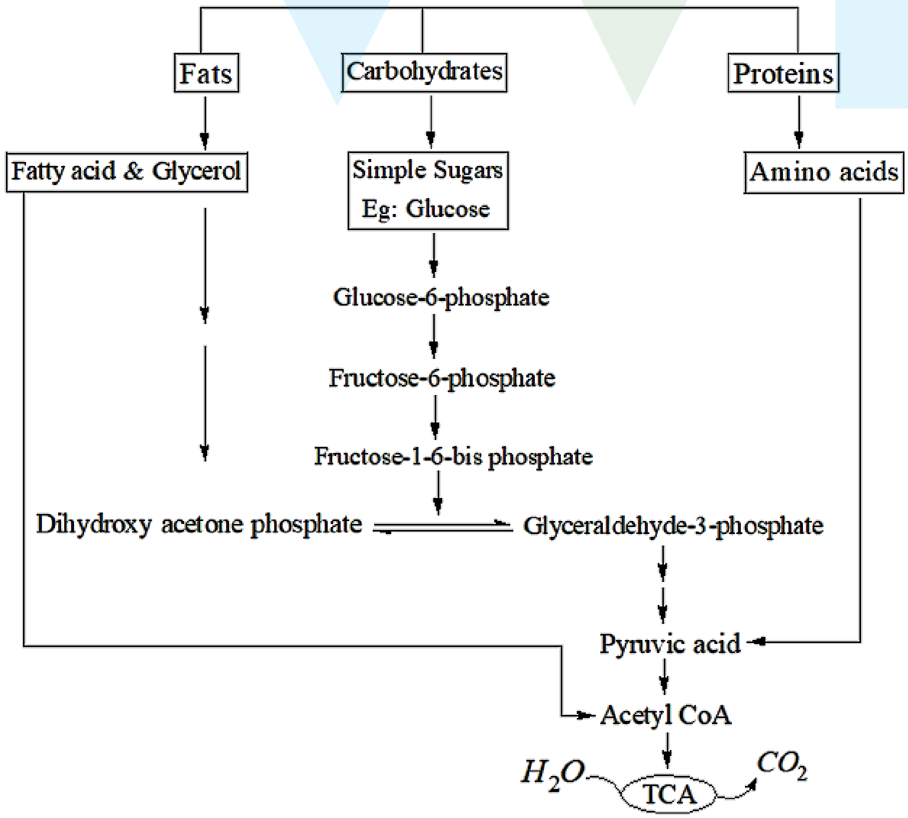
$$\left.\begin{array}{lcc} \text{a) Substrate level phosphorylation} & \rightarrow & \text{GTP} \rightarrow \text{ATP} \\ \text{b) Oxidative phosphorylation} & \rightarrow & 4\ \text{NADH} \rightarrow 12\ \text{ATP} \\ & & 1\ \text{FADH}_2 \rightarrow 2\ \text{ATP} \end{array}\right\} 15\ \text{ATP}(\times 2) \rightarrow 30\ \text{ATP}$$

3. Sum:

$$\text{Glycolysis} + \text{Citric Acid Cycle} \rightarrow 38\ \text{ATP per glucose}$$

Amphibolic Pathway:

- Respiration involves breakdown of organic compounds (glucose, pyruvate, acetyl CoA). So it has been considered as a catabolic process.
- Many amino acids and fatty acids precursors are formed, so it is also an anabolic process.
- As it constitutes both catabolic and anabolic process, it is known as an amphibolic process.



Respiratory Quotient:

The ratio of the volume of CO_2 evolved to the volume of O_2 consumed in respiration is called the Respiratory Quotient (RQ) or Respiratory Ratio.

$$\text{RQ} = \frac{\text{Volume of } CO_2 \text{ evolved}}{\text{Volume of } O_2 \text{ utilized}}$$

- Volume of R.Q depends upon the nature of respiratory substrate used, amount of CO_2 present in respiratory substrate, extent to which substrate is broken down, interconversion of one substrate into another in the cell.
- It is measured by Ganong's respirometer.

1. Carbohydrates:

$$C_6H_{12}O_6 + 6O_2 + 6H_2O \rightarrow 6CO_2 + 12H_2O + \text{Energy}$$

$$\text{RQ} = \frac{CO_2}{O_2} = \frac{6}{6} = 1\ (\text{Unity})$$

2. Fat / Oil:

$$2C_{51}H_{98}O_6 + 145\,O_2 \rightarrow 102\,CO_2 + 98\,H_2O + \text{Energy}$$

$$\text{RQ} = \frac{CO_2}{O_2} = \frac{102}{145} = 0.7\ (\text{Less than unity})$$

3. Organic acids:

$$\underset{\text{Malic Acid}}{C_4H_6O_5} + 3O_2 \rightarrow 4CO_2 + 3H_2O + \text{Energy}$$

$$\text{RQ} = \frac{CO_2}{O_2} = \frac{4}{3} = 1.33\ (\text{More than unity})$$

Oxalic Acid – R.Q = 4

Citric Acid – R.Q = 1.3

4. Proteins:

$$\text{RQ} = 0.8 \text{ or } 0.9 \text{ or } < 1$$

5. Incomplete oxidation of carbohydrates: (In Succulent i.e. Bryophyllum)

$$2C_6H_{12}O_6 + 3O_2 \rightarrow 3C_4H_6O_5 + 3H_2O$$

$$\text{RQ} = \frac{CO_2}{O_2} = \frac{0}{3} = 0$$

6. Anaerobic respiration:

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$$

$$\text{RQ} = \frac{CO_2}{O_2} = \frac{2}{0} = \infty$$

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