Respiration in Plants

11 Chapter

1 INTRODUCTION

- All living organisms need energy for carrying out daily life activities, like absorption, transport, movement, reproduction or even breathing.
- All the energy required for 'life' processes is obtained by oxidation of macromolecules, called food.
- Cellular respiration is the mechanism of breakdown of food material within the cell to release energy, and trapping it for synthesis of ATP. The process takes place in the cytoplasm and in the mitochondria.
- The compounds that are oxidised during this process are called the respiratory substrates like carbohydrates, proteins, fats and even organic acids.
- The process involves a series of slow step-wise reactions controlled by enzymes and the released energy is trapped as chemical energy in the form of ATP, which is broken down whenever and wherever energy needs to be utilised.

2 DO PLANTS BREATHE?

- Plants have systems in place to ensure O_2 availability, *i.e.* stomata and lenticels for this purpose.
- Each plant part takes care of its own gas-exchange needs. There is very little transport of gases from one plant part to another.
- Roots, stems and leaves respire at rates far lower than animals do.
- Most cells of a plant have at least a part of their surface in contact with air.
- Complete combustion of glucose produces CO_2 and H_2O as end products and yields energy most of which is given as heat.

  $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{Energy}$
- But plants oxidise glucose in several small steps and energy released is coupled to ATP synthesis.
- Facultative and obligate anaerobes, can respire in absence of O_2.
- All organisms retain this strategy of partial glucose oxidation in absence of oxygen called GLYCOLYSIS.

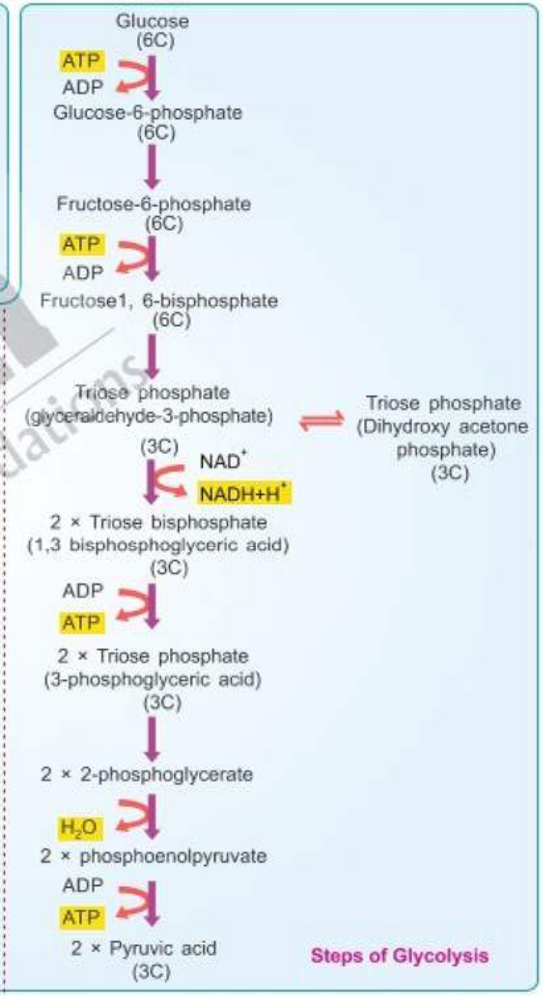
3 GLYCOLYSIS

- Greek-glycos = sugar and lysis = splitting
- Scheme given by Embden, Meyerhof and Parnas, referred as EMP-pathway.
- In anaerobic organisms, it is the only process in respiration.
- Occurs in CYTOPLASM and present in all living organisms.
- In this process glucose undergoes partial oxidation to form two molecules of pyruvic acid.
- In plants, glucose comes from sucrose (the end product of photosynthesis) or from storage carbohydrates.
- Sucrose is converted into glucose and fructose by invertase and these monosaccharides enter the glycolytic pathway readily.
- In glycolysis, a chain of ten reactions produces pyruvate from glucose by the help of different enzymes.
- In glycolysis 2 ATP are utilised and total 4 ATP, 2 $NADH+H^+$ and 2 molecules of pyruvic acid are produced.
- Pyruvic acid is the key product of glycolysis and its metabolic fate depends on cellular need.

PYRUVIC ACID → Three major fates
- 1. Lactic acid fermentation
- 2. Alcoholic fermentation

← UNDER ANAEROBIC CONDITIONS

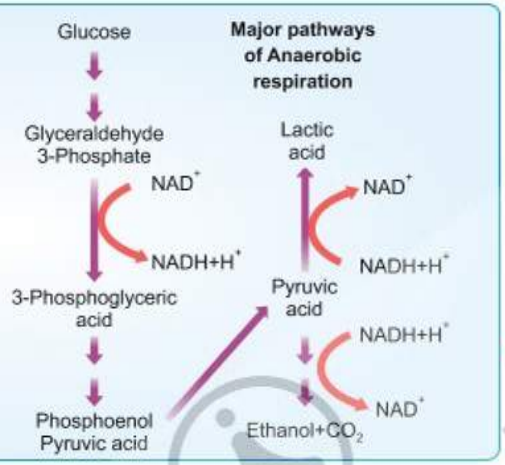
- 3. Krebs' cycle ← AEROBIC; Needs O_2 supply



Steps of Glycolysis

(4) FERMENTATION

- In fermentation, by yeast, incomplete oxidation of glucose is achieved under anaerobic conditions to produce CO_2 and ethanol, by the help of enzymes pyruvate decarboxylase and alcohol dehydrogenase.
- Bacteria and in animal cells (muscles during exercise, when oxygen is inadequate for cellular respiration) pyruvate is reduced to lactic acid by lactate dehydrogenase.
- Less than 7% of the energy in glucose is released.
- Also the processes are hazardous as either acid or alcohol is produced.
- Yeast poison themselves to death when concentration of alcohol reaches about 13%.



(5) AEROBIC RESPIRATION

- In eukaryotes, it takes place in mitochondria. Leads to complete oxidation of organic substances, in the presence of oxygen and releases CO_2, water and a large amount of energy present in the substrate.
- This type of respiration is most common in higher organisms.
- For aerobic respiration to take place within mitochondria, the final product of glycolysis is transported into mitochondria from cytoplasm.
- Crucial events of aerobic respiration are:
  a. Complete oxidation of pyruvic acid - site = Mitochondrial matrix.
  b. ETS and synthesis of ATP - site = Inner mitochondrial membrane.

(6) TRICARBOXYLIC ACID CYCLE (TCA cycle or Kreb's cycle)

(In mitochondrial matrix)

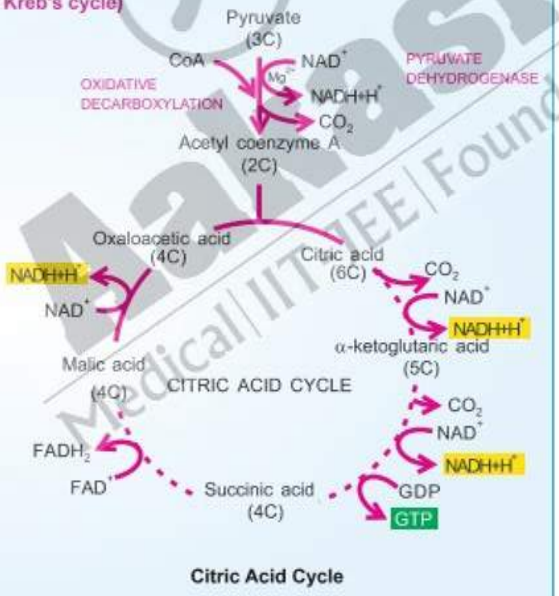
- Acetyl CoA produced by oxidative decarboxylation of pyruvic acid enters the TCA cycle more commonly known as Krebs' cycle. (Scientist Hans Kreb)
- First reaction of Kreb's cycle is condensation, then isomerisation.

$$OAA \xrightarrow[\text{Citrate synthase}]{\text{AcetyCoA}} \text{Citric Acid} \xrightarrow{\text{Isomerises}} \text{Isocitrate}$$

- Followed by two successive decarboxylation to form α-ketoglutarate and the succinyl CoA.
- During conversion of succinyl CoA to succinic acid, substrate level phosphorylation takes place to produce GTP which in a coupled reaction simultaneously produces ATP.
- The summary equation for this phase of respiration is:

$$Pyruvate + 4NAD^+ + FAD^+ + 2H_2O + ADP + Pi \xrightarrow[\text{MATRIX}]{\text{MITOCHONDRIAL}} 3CO_2 + 4NADH + 4H^+ + FADH_2 + ATP$$

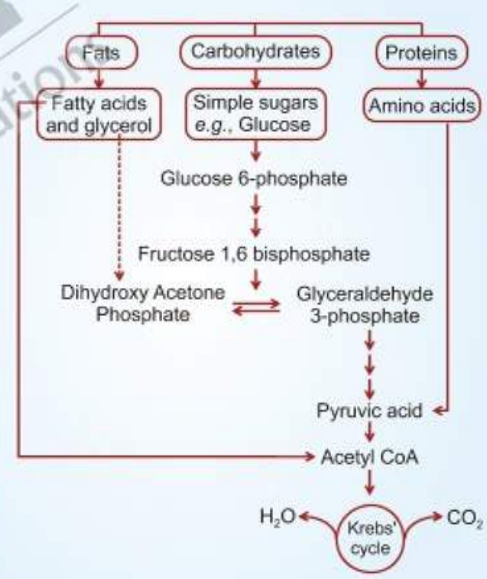
- So, per molecule of glucose, 8 $NADH+H^+$, two $FADH_2$ and 2 ATP are synthesised from pyruvic acid.



Citric Acid Cycle

(7) AMPHIBOLIC PATHWAY

- Respiratory pathway is involved in both anabolism and catabolism hence it is called amphibolic pathway.



Interrelationship among Metabolic pathways

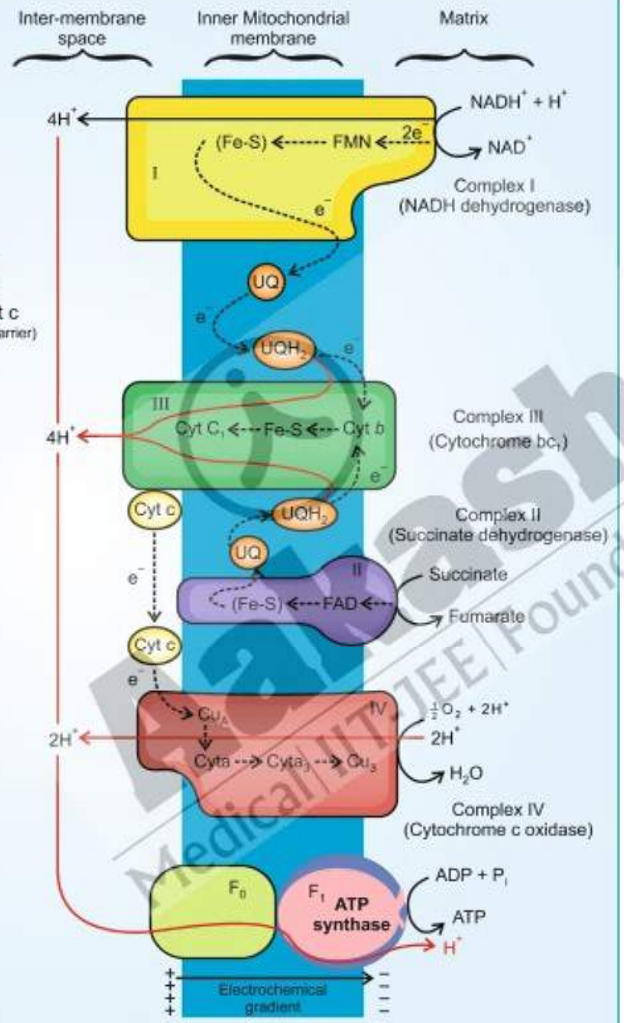
8 ELECTRON TRANSPORT SYSTEM (ETS) AND OXIDATIVE PHOSPHORYLATION

- NADH+H^+ and $FADH_2$ are oxidised through ETS and the electrons are passed on to O_2 resulting in formation of H_2O through various complexes in the inner - mitochondrial membrane.
- NADH dehydrogenase (Complex-I) and $FADH_2$ (Complex-II) transfers electrons to

Ubiquinone → Ubiquinol (reduced ubiquinone) → cyt bc_1 (complex III) → cyt c → Complex IV (Cytochrome c oxidase) (Mobile carrier)

- When electrons pass from one carrier to another via complex-I to IV in ETC, they are coupled to ATP synthase (complex-V) for production of ATP from ADP and inorganic phosphate.
- Oxidation of one NADH gives 3 ATP, while one $FADH_2$ gives two ATP.
- The role of oxygen is limited to the terminal stage. Yet the presence of oxygen is vital, since it drives the whole process by removing hydrogen from the system. Oxygen is the final acceptor of hydrogen.
- Complex-V has two major components, F_1-F_0. F_1 is peripheral membrane protein complex and contains site for ATP synthesis and F_0 forms the channel through which protons cross the inner membrane.

  The passage of protons through the channel is coupled to the catalytic site of F_1 for production of ATP. For each ATP produced, $2H^+$ passes through F_0 from the intermembrane space to matrix down the electrochemical proton gradient.



Electron Transport System (ETS)

9 RESPIRATORY BALANCE SHEET

(In reality it is a theoretical exercise, as all pathways work simultaneously and do not take place one after another. Enzymatic rates are controlled by multiple means.)

- There can be a net gain of 38 ATP molecules during aerobic respiration of one molecule of glucose.
- In fermentation there is net gain of only 2 ATP for each molecule of glucose degraded.
- NADH is oxidised to NAD^+ slowly in fermentation, however the reaction is very vigorous in case of aerobic respiration.

10 RESPIRATORY QUOTIENT = (RQ)

- The ratio of volume of CO_2 evolve to the volume of O_2 consumed is RQ.

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

- It depends on the type of respiratory substrate, used during respiration.
- For, carbohydrates = 1
  Fat = less than 1, (eg-tripalmitin=0.7)
  Protein = about 0.9

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- Breaking of C-C bonds of complex organic molecules leads to release of lot of energy in cellular respiration.
- Glucose is the preferred substrate, though fats and protein can also yield energy.
- Fermentation takes place in many prokaryotes, unicellular eukaryotes and in germinating seeds.
- In aerobic respiration O_2 is ultimate electron acceptor and it gets reduced to water.

Sharpen Your Understanding

1. Which of the following organisms can prepare their own food by the process of photosynthesis? [NCERT Pg. 226]
   (1) Herbivores
   (2) Saprophytes
   (3) Cyanobacteria
   (4) Heterotrophs
2. In anaerobic organisms, the only process in respiration is [NCERT Pg. 228]
   (1) EMP pathway
   (2) Tricarboxylic acid cycle
   (3) Krebs' cycle
   (4) Citric acid cycle
3. Sucrose is converted into glucose and fructose by the help of the enzyme [NCERT Pg. 229]
   (1) Amylase
   (2) Invertase
   (3) Maltase
   (4) Zymase
4. In glycolysis, a chain of ten reactions, under the control of different enzymes, takes place to produce [NCERT Pg. 229]
   (1) Sucrose from glucose
   (2) Glucose from fructose
   (3) Pyruvate from acetyl CoA
   (4) Pyruvate from glucose

NCERT Based MCQs

5. During glycolysis ATP is utilised in the conversion of [NCERT Pg. 229]
   (1) Glucose into glucose-6- phosphate
   (2) Glucose-6- phosphate into Fructose-6-phosphate
   (3) Phosphoenol pyruvate into pyruvic acid
   (4) 3-phosphoglyceric acid into 2-phosphoglycerate
6. The key product of glycolysis is [NCERT Pg. 229]
   (1) DHAP
   (2) Pyruvic acid
   (3) Phosphoenolpyruvate
   (4) Acetyl CoA
7. For complete oxidation of glucose to CO_2 and H_2O organisms adopt [NCERT Pg. 230]
   (1) Lactic acid fermentation
   (2) Alcoholic fermentation
   (3) Krebs' cycle
   (4) Substrate-level phosphorylation
8. Yeasts poison themselves to death when the concentration of alcohol reaches about [NCERT Pg. 230]
   (1) 5 percent
   (2) < 5 percent
   (3) < 8 percent
   (4) 13 percent
9. The enzyme which catalyses the conversion of pyruvate into acetyl CoA in the mitochondrial matrix is [NCERT Pg. 231]
   (1) Lactate dehydrogenase
   (2) Succinate dehydrogenase
   (3) Pyruvate dehydrogenase
   (4) Pyruvate kinase
10. Substrate level phosphorylation in the TCA-cycle takes place during the conversion of [NCERT Pg. 232]
    (1) Succinyl-CoA to succinic acid
    (2) Oxaloacetic acid to citric acid
    (3) Malic acid to oxaloacetic acid
    (4) Citric acid to isocitric acid
11. Which of the following complex refers to cytochrome-c oxidase complex containing cytochromes a and a_3 and two copper centres? [NCERT Pg. 233]
    (1) Complex-V (2) Complex-IV
    (3) Complex-II (4) Complex-I
12. What will be the respiratory quotient value (RQ) for the fatty acid, tripalmitin? [NCERT Pg. 237]
    (1) >1
    (2) 0.9
    (3) 4.0
    (4) 0.7

13. If fatty acids were to be utilised in the respiratory pathway, they would first be degraded to [NCERT Pg. 235]
(1) Oxaloacetate (2) Pyruvic acid
(3) Acetyl CoA (4) PGAL

14. The respiratory pathway should be considered as [NCERT Pg. 235]
(1) Amphibolic (2) Anabolic only
(3) Catabolic only (4) Synthetic

15. What will be the net gain of ATP molecules for each molecule of glucose used in fermentation? [NCERT Pg. 235]
(1) 36 ATP (2) 38 ATP
(3) 7 ATP (4) Only 2 ATP

16. The peripheral membrane protein complex, which contains the site for synthesis of ATP from ADP and inorganic phosphate, present on the inner mitochondrial membrane is called [NCERT Pg. 234]
(1) F_1 component
(2) F_0 component
(3) Ubiquinone
(4) Cytochrome-c

17. The complex-I of the electron transport system (ETS) present on the inner-mitochondrial membrane is known as: [NCERT Pg. 233]
(1) Succinate dehydrogenase complex
(2) NADH dehydrogenase complex
(3) Cytochrome bc_1 complex
(4) Cytochrome-c oxidase

18. Substrate level phosphorylation in glycolysis takes place during conversion of [NCERT Pg. 229]
(1) 2-phosphoglycerate to 3-PGA
(2) 2-phosphoglycerate to PEP
(3) PEP to pyruvic acid
(4) Glucose-6-phosphate to Fructose-6-phosphate

19. Glycerol would usually enter the respiratory pathway after being converted to [NCERT Pg. 235]
(1) Fructose
(2) PGAL
(3) Amino acid
(4) Proteases

20. The small protein attached to the outer surface of the inner mitochondrial membrane and acts as a mobile carrier for transfer of electrons between complex III and IV in the electron transport system (ETS) is [NCERT Pg. 233]
(1) Ubiquinone
(2) Ferredoxin
(3) Cytochrome-c
(4) F_1 – particle

Thinking in Context

1. In plants, stomata and lenticels allow gaseous exchange by _____ [NCERT Pg. 237]

2. The breaking of C-C bonds of complex organic molecules by oxidation in the cells leading to the release of a lot of energy is called _____ [NCERT Pg. 237]

3. The ratio of the volume of CO_2 evolved to the volume of O_2 consumed in respiration is called the _____ or _____ [NCERT Pg. 236]

4. The NADH synthesised in glycolysis is transferred into the _____ and undergoes oxidative phosphorylation [NCERT Pg. 234]

5. Although the aerobic process of respiration takes place only in the presence of oxygen, the role of oxygen is limited to the _____ of the process. [NCERT Pg. 233]

6. When the electrons pass from one carrier to another via complex I to IV in the electron transport chain, they are coupled to _____ for the production of ATP. [NCERT Pg. 233]

7. The TCA cycle starts with the _____ of acetyl group with oxaloacetic acid and water to yield citric acid. [NCERT Pg. 231]

8. Fermentation takes place under _____ in many prokaryotes and unicellular eukaryotes [NCERT Pg. 230]

9. In glycolysis, glucose and fructose are phosphorylated to give rise to glucose-6-phosphate by the activity of the enzyme _____. [NCERT Pg. 229]

10. In plants, glucose is derived from _____, which is the end product of photosynthesis. [NCERT Pg. 228]

11. The scheme of glycolysis was given by Gustav Embden, Otto Meyerhof and J. Parnas, and is often referred to as the _____. [NCERT Pg. 228]

12. There are sufficient reasons to belive that the first cells on this planet lived in an atmosphere that _____.[NCERT Pg. 228]

13. All living organisms retain the enzymatic machinery to partially oxidise glucose without the help of oxygen, this breakdown of glucose to pyruvic acid is called _____. [NCERT Pg. 228]

14. In _____ glycolysis is the only process in respiration. [NCERT Pg. 228]

15. Some organisms adapted to anaerobic conditions are _____, while in others the requirement for anaerobic condition is obligate. [NCERT Pg. 228]

16. The compounds that are oxidised during the process of respiration are known as _____. [NCERT Pg. 227]

17. What is important to recognise is that ultimately all the food that is respired for life processes comes from _____. [NCERT Pg. 227]

18. Usually _____ are oxidised to release energy, but proteins, fats and even organic acids can be used as respiratory substances in some plants, under certain conditions. [NCERT Pg. 227]

19. In both lactic acid fermentation and alcoholic fermentation, the reducing agent is A which is reoxidised to B . [NCERT Pg. 230]

20. Photosynthesis, takes place within the chloroplasts, whereas the breakdown of complex molecules to yield energy takes place in the A and in the B also only in Eukaryotes. [NCERT Pg. 227]

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