Respiration in Plants

Cellular Respiration & Glycolysis

Cellular Respiration

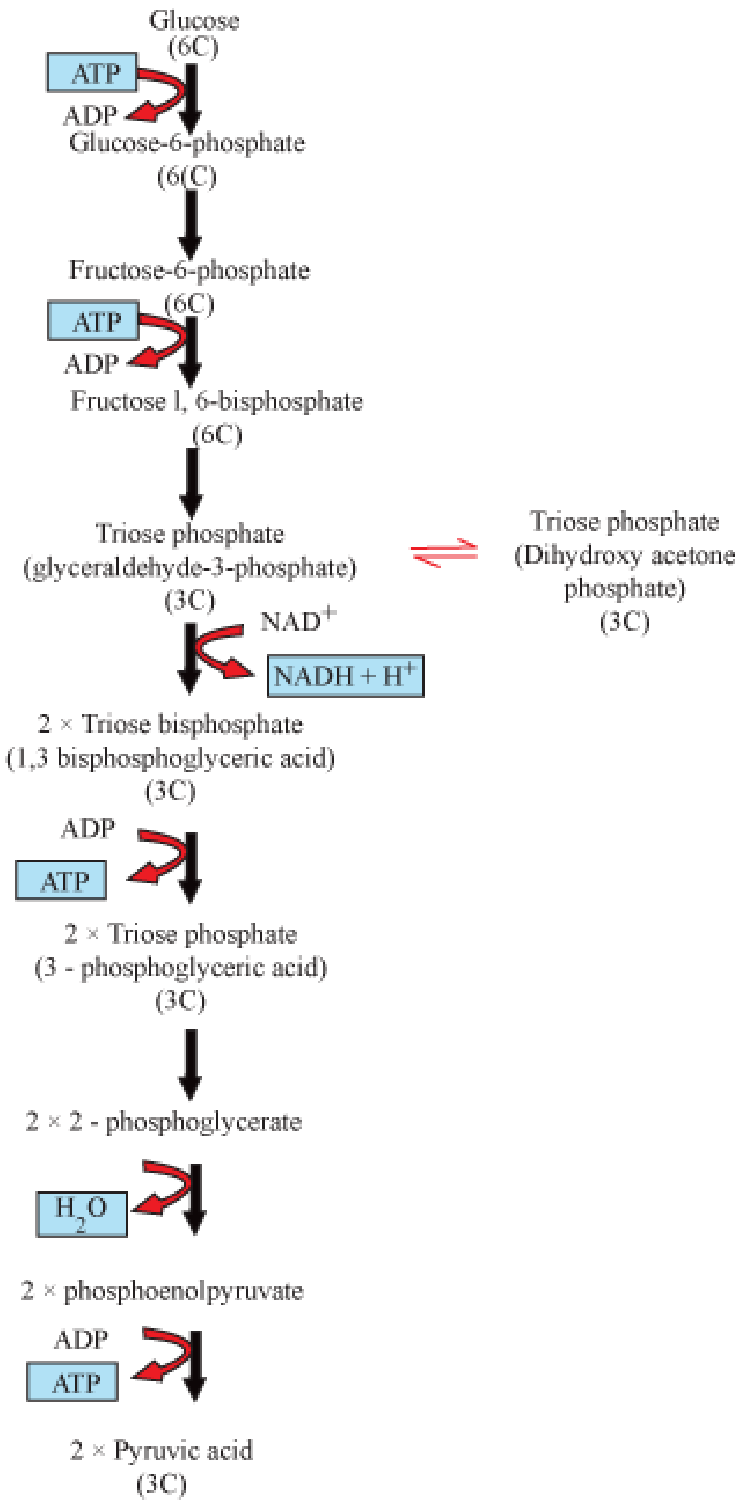
- Mechanism of breakdown of food materials within the cell to release energy, and the trapping of this energy for ATP synthesis.
- Respiratory substrates: Compounds oxidised during respiration; usually carbohydrates; these can also be proteins, fats or organic acids
- ATP: Energy currency of a cell; broken down whenever energy is needed
- Plants do not need specialised organs for respiration because:
- Gaseous exchange occurs in each part of a plant.
- Gaseous exchange is not a much-needed factor. During photosynthesis, the need for gaseous exchange is met.
- Each living cell is located close to the surface of a plant. So the distances that the gases must diffuse are not great.
- Equation for respiration:

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

Glycolysis (*Glycos* − Sugar, *Lysis* − Splitting)

- Breakdown of glucose to pyruvic acid by partial oxidation
- Scheme given by Embden, Meyerhof and Parnas
- Common pathway for aerobic and anaerobic cellular respiration
- Occurs in the cytoplasm of a cell
- Present in all living organisms
- In plants, sucrose is converted into glucose.
- $\text{Sucrose} \xrightarrow{\text{Invertase}} \text{Glucose} \rightarrow \text{Enters the glycolysis}$

- A chain of 10 reactions converts glucose into pyruvate.
- Hexokinase: Enzyme that phosphorylates glucose to produce glucose − 6 − phosphate
- 2 ATPs are utilised in two steps:
- Glucose → Glucose − 6 − phosphate (1 ATP)
- Fructose − 6 − phosphate → fructose 1, 6 − bisphosphate (1 ATP)
- Fructose 1, 6 bisphosphate splits into glyceraldehyde − 3 − phosphate and dihydroxy acetone phosphate.
- Glyceraldehyde − 3 − phosphate converts into two molecules of 1, 3 bisphosphoglycerate (BPGA), with subsequent conversion of NAD^+ to $NADH + H^+$.
- 4 ATPs are yielded in two steps:
- BPGA → PGA ($1 \times 2 = 2$ ATPs)
- Phosphoenol pyruvate → Pyruvic acid ($1 \times 2 =2$ ATPs)
- ATPs produced directly = 4 (produced) − 2 (consumed) = 2 ATPs
- Net ATPs Produced = 2 ($NADH+ H^+$) = 6 ATPs + 2 (Directly synthesised) = 8 ATPs



Steps of glycolysis

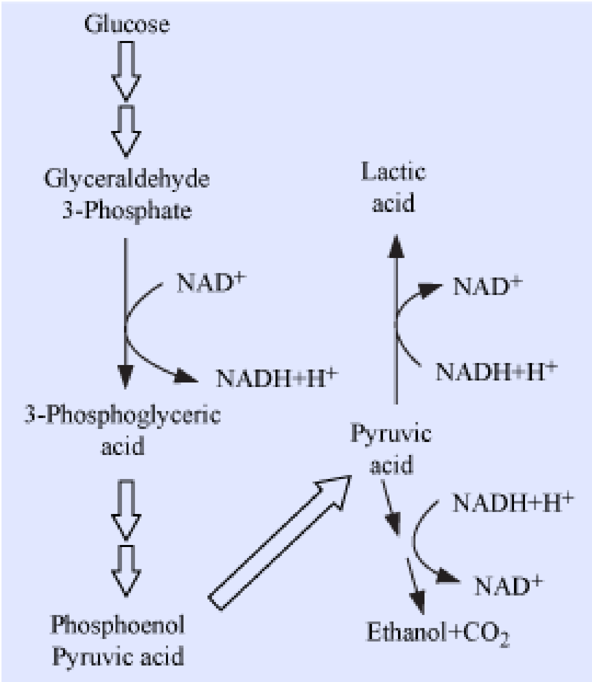
- The pyruvate, so produced, may undergo:
- Lactic acid fermentation

- Alcoholic fermentation
- Aerobic respiration (Krebs cycle)

Fermentation

- Fermentation: Incomplete oxidation of glucose under anaerobic conditions
- In yeast fermentation:
- Pyruvic acid → Ethanol + CO_2
- Enzymes involved − Pyruvic acid decarboxylase, Alcohol dehydrogenase
- In bacterial fermentation:
- Pyruvic acid → Lactic acid
- Enzyme involved − Lactate dehydrogenase
- Similar reaction occurs in animal muscles in anaerobic conditions, say during exercise.
- Reducing agent in both reactions is NADH.

  $NADH + H^+ \rightarrow NAD^+$
- Only 7% of energy of glucose is released during fermentation.
- Process can be hazardous as alcohol or acid is produced. Yeasts poison themselves to death when alcohol concentration reaches about 13%.



Tricarboxylic Acid Cycle

Aerobic Respiration

- Site: Mitochondria
- Events:
- **TCA cycle** (in the mitochondrial matrix) − complete oxidation of pyruvate by stepwise removal of all hydrogen atoms, which leaves three molecules of CO_2
- **Electron Transport Chain and Oxidative phosphorylation** (in the inner membrane of the mitochondria) − electrons removed as a part of hydrogen atoms are passed on to molecular oxygen, with the simultaneous synthesis of ATP

Formation of Acetyl Coenzyme A

- The product of glycolysis, i.e., pyruvate, on entering the mitochondrial matrix, undergoes *Oxidative Decarboxylation*, thereby producing acetyl CoA which enters Krebs cycle.

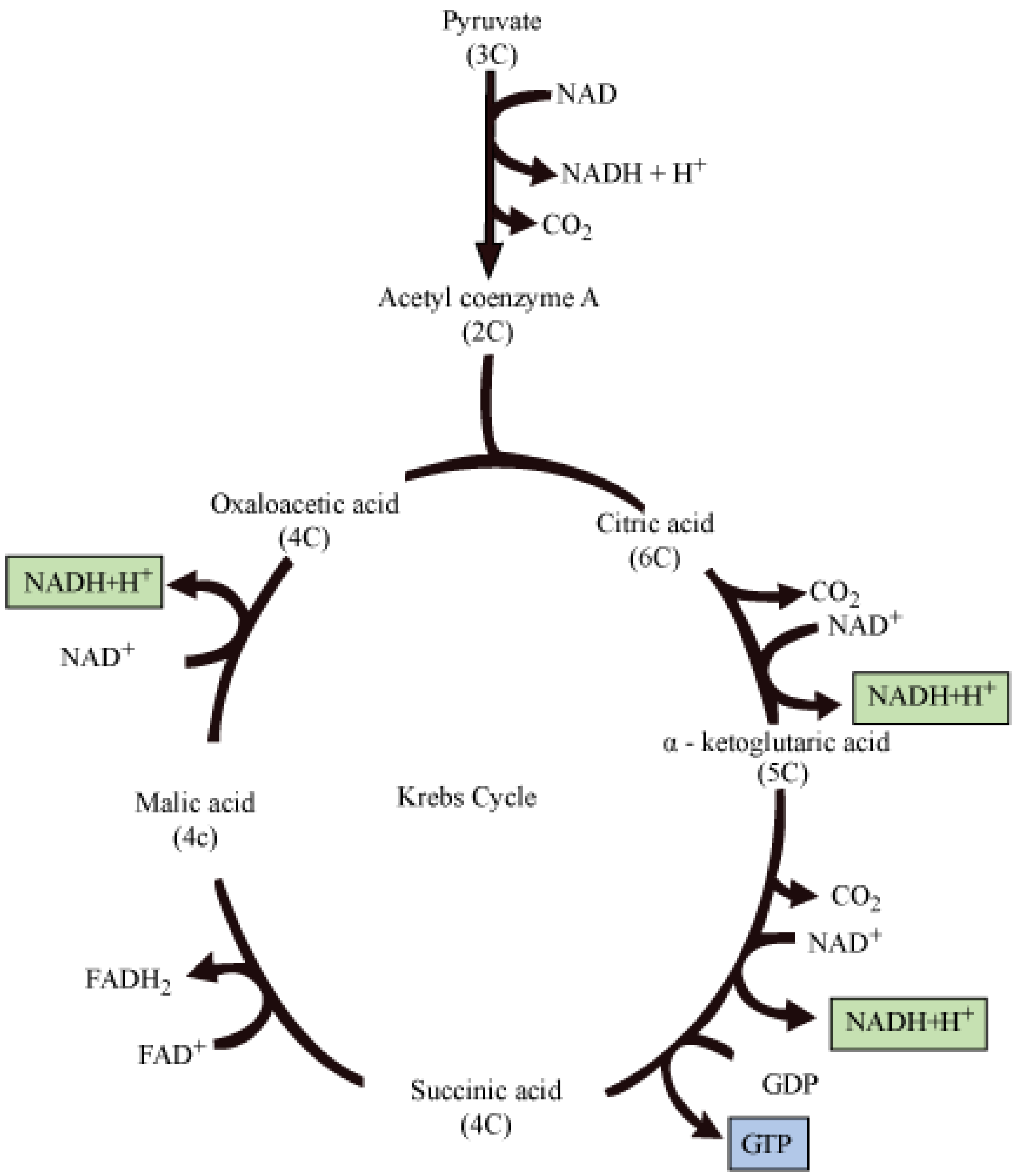
$$\text{Pyruvic acid} + \text{CoA} + \text{NAD}^+ \xrightarrow[\text{pyruvate dehydrogenase}]{\text{Mg}^{2+}} \text{Acetyl CoA} + \text{CO}_2 + \text{NADH} + \text{H}^+$$

Krebs cycle (Tricarboxylic acid cycle; TCA)

- Acetyl group condenses with oxaloacetic acid and water to yield citric acid (catalysed by the enzyme citrate synthase)
- Citrate isomerises into isocitrate
- Two successive decarboxylation steps follow, leading to the formation of α ketoglutaric acid, followed by succinyl CoA
- This is followed by the conversion of succinyl CoA into succinic acid. During this process, GDP is converted into GTP (substrate level phosphorylation).
- In a coupled reaction, GTP is converted into GDP, simultaneously synthesising ATP from ADP.
- Conversion of one molecule of pyruvate into acetyl CoA yields 1 molecule of CO_2 and 1 NADH.
- One Kreb's cycle yields 2 CO_2 + 3 NADH + 1 $FADH_2$ + 1 ATP
- Overall equation:

$$\text{Pyruvic acid} + 4NAD^+ + FAD^+ + 2H_2O + ADP + Pi \xrightarrow[\text{Matrix}]{\text{Mitochondrial}} 3CO_2 + 4NADH + 4H^+ + FADH_2 + ATP$$

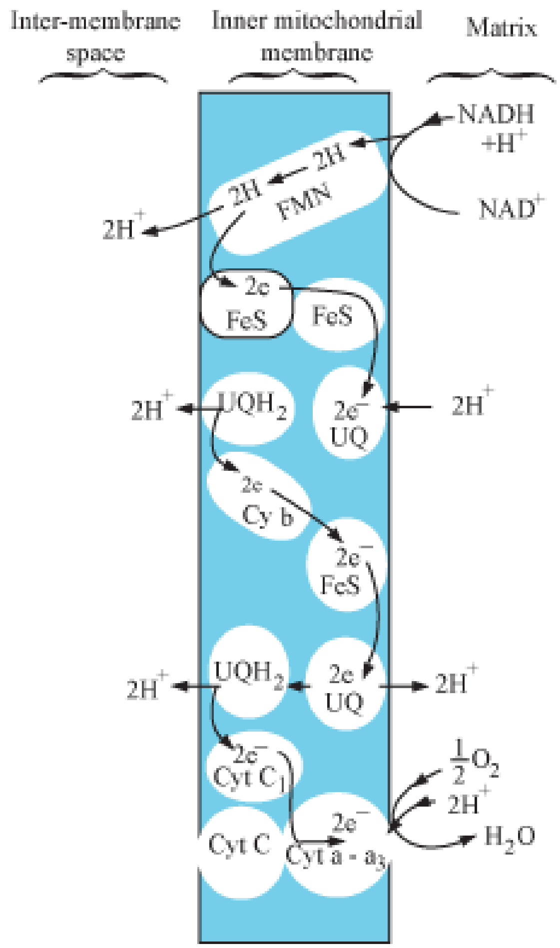
- For continued oxidation of acetyl CoA in TCA 2 things are required:
- Continued replenishment of oxaloacetic acid
- Regeneration of NAD^+ and FAD^+ from NADH and $FADH_2$ respectively.



Electron Transport Chain and Oxidative Phosphorylation

Electron Transport Chain (ETS)

- NADH and $FADH_2$ are oxidised to release the energy stored in them.
- Electrons are passed from one carrier to another, and finally to oxygen, resulting in the formation of water.



Electron Transport System (ETS)

- Electrons produced by NADH in the mitochondrial matrix are oxidised by **Complex I** (NADH dehydrogenase).

- Electrons are then transferred to ubiquinone, located in the inner mitochondrial membrane. Ubiquinone receives reducing equivalents through **Complex II** ($FADH_2$).

- Reduced ubiquinone (ubiquinol) is then oxidised by the transfer of electrons from **Complex III** (cytochrome bc_1 complex) to cytochrome *c*.

- Cytochrome *c* transfers the electrons between Complex III and **Complex IV** (Cytochrome *c* − oxidase complex consists of cyt *a* and a_3, along with two copper centres).

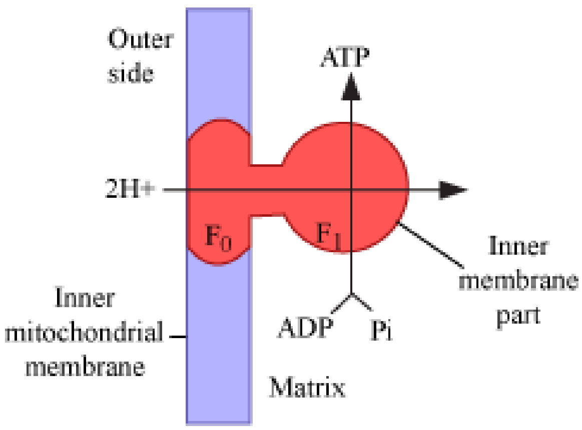
- In the course of passing from one carrier to another, electrons couple with **Complex V** (ATP synthase) and produce ATP.

- Oxidation of 1 NADH produces 3 ATPs.
  Oxidation of 1 $FADH_2$ produces 2 ATPs.

- Role of oxygen in the terminal stage of ETS: It acts as the final hydrogen acceptor; removes hydrogen from the process and drives the whole process

Oxidative Phosphorylation

- Production of proton gradient needed for the production of ATP is provided by the energy of oxidation−reduction reaction. Therefore, the process is called oxidative phosphorylation.
- **Complex V** (ATP synthase) is involved. It has two major components
- F_0 − integral membrane protein; forms a channel through which H^+ cross the inner membrane
- F_1 − passage of H^+ induces conformational changes in F_1, which forms a site for synthesis of ATP from ADP; for each ATP produced, $2H^+$ pass through F_0, down the electrochemical proton gradient



Respiratory Balance Sheet and Respiratory Quotient

Respiratory Balance Sheet

- It gives the net gain of ATP for every 1 molecule of glucose oxidised.
- Certain assumptions are made for calculating the net gain of ATP:
- An orderly pathway is followed − Glycolysis, followed by TCA cycle, followed by ETS
- NADH synthesised during glycolysis enters the mitochondria to undergo oxidative phosphorylation.
- Except glucose, no other substrate enters the pathway at any stage.

- Intermediates do not synthesise any other compound in the pathway.

- There can be a net gain of 36 ATPs during aerobic respiration of 1 molecule of glucose.
  Glucose + $6O_2$ + 36ADP + 36Pi → $6CO_2$ + $42H_2O$ + 36ATP

Comparison between fermentation and aerobic respiration

Fermentation	Aerobic Respiration
1. Partial breakdown of glucose	1. Complete breakdown of glucose into CO_2 and H_2O
2. Net gain of only 2 molecules of ATP	2. Net gain of 36 molecules of ATP
3. Here, oxidation of NADH to NAD^+ is a slow reaction	3. Here, oxidation of NADH to NAD^+ is a vigorous reaction

Amphibolic Pathway

- Favoured substrate for respiration is glucose. All carbohydrates first convert into glucose to enter the pathways.

- Other substrates do enter the respiratory pathways, but not during the first stage.

- Fats:

- Fats → Glycerol + Fatty acid

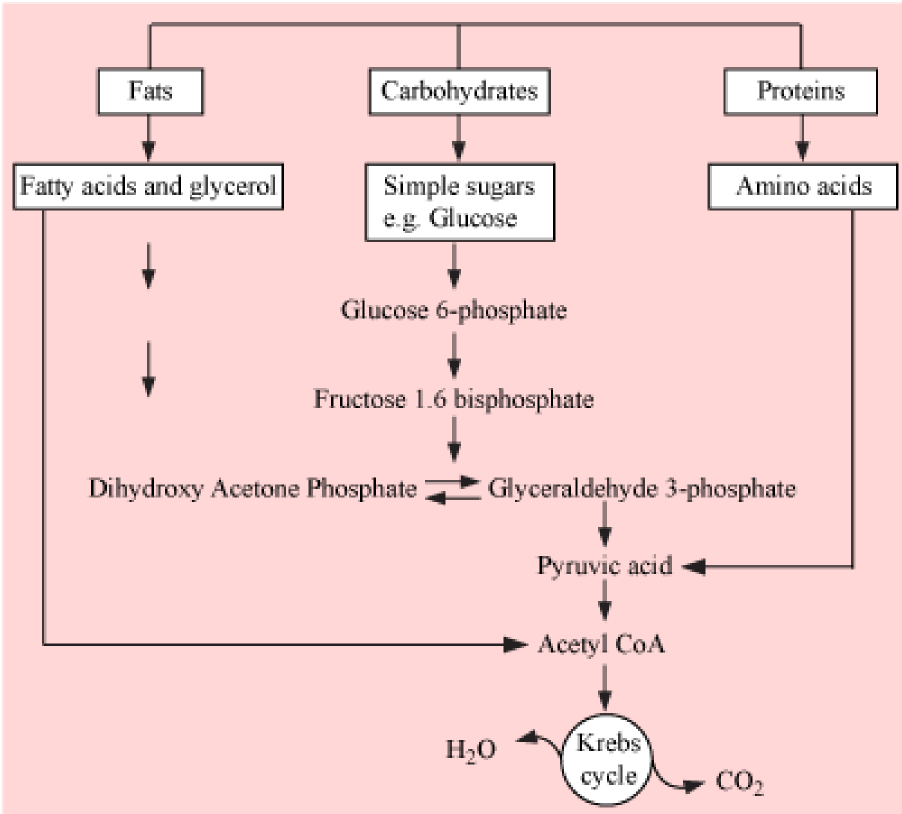
- Fatty acids → Acetyl CoA
  Acetyl CoA enters the pathway

- Glycerol → PGAL

- Proteins:

- Proteins $\xrightarrow[\text{deamination}]{\text{Proteases}}$ Amino acids

- Enter intermediate stages of TCA



- Amphibolic pathway: Involved in both anabolism and catabolism
- Fatty acids break into acetyl CoA to enter the respiratory pathway (Anabolism).
- Acetyl CoA is removed from the respiratory pathway whenever fatty acids need to be synthesised (catabolism).
- Thus, respiratory intermediates form a link during anabolism and catabolism.

Respiratory Quotient (RQ)

- Ratio of the volume of CO_2 evolved to the volume of O_2 consumed during respiration is called the respiratory quotient (RQ).
- RQ = $\frac{\text{Volume of } CO_2 \text{ evolved}}{\text{Volume of } O_2 \text{ consumed}}$
- Depends upon the type of respiratory substrate
- RQ = 1 (When carbohydrate is used as substrate)

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

  RQ = $\frac{6CO_2}{6O_2} = 1.0$

- RQ < 1 (When fat is used as respiratory substrate)

  E.g. When fatty acid, tripalmitin is used, RQ = 0.7

- RQ ≈ 0.9 (When protein is used as substrate)

- RQ is infinity in anaerobic respiration as CO_2 is evolved, but O_2 is not utilised.