RESPIRATION IN PLANTS

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.

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.

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 readily enter the glycolytic pathway
- 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
→ Lactic acid fermentation
→ Alcoholic fermentation
← UNDER ANAEROBIC CONDITIONS
→ Krebs' cycle ← AEROBIC; Needs O_2 supply

STEPS OF GLYCOLYSIS

Glucose (6C)
↓ ATP → ADP (Hexokinase)
Glucose-6-phosphate (6C)
⇅
Fructose-6-phosphate (6C)
↓ ATP → ADP
Fructose 1, 6-bisphosphate (6C)
⇅
Triose phosphate (glyceraldehyde- 3 phosphate) (3C) ⇌ Triose phosphate (Dihydroxy acetone phosphate) (3C)
⇅ NAD^+ → $NADH+H^+$ x 2
2 × Triose bisphosphate [1,3 bisphosphoglyceric acid) (3C)
⇅ ADP → 2 x ATP
2 × Triose phosphate (3-phosphoglyceric acid) (3C)
⇅
2 × 2-phosphoglycerate
⇅ 2 x H_2O
2 × phosphoenolpyruvate
↓ ADP → 2 x ATP
2 × Pyruvic acid (3C)

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%.

Major pathways of Anaerobic respiration

Glucose
↓
↓
Glyceraldehyde 3-Phosphate
↓ $NAD^+ \rightarrow NADH+H^+$
3-Phosphoglyceric acid
↓
↓
Phosphoenol Pyruvic acid → Pyruvic acid

Pyruvic acid → Lactic acid ($NADH+H^+ \rightarrow NAD^+$)

Pyruvic acid → Ethanol + CO_2 ($NADH+H^+ \rightarrow NAD^+$)

AEROBIC RESPIRATION

1. 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.
2. This type of respiration is most common in higher organisms
3. For aerobic respiration to take place within mitochondria, the final product of glycolysis is transported into mitochondria from cytoplasm
4. 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.

TRICARBOXYLIC ACID CYCLE (TCA cycle or Kreb's cycle) (In mitochondrial matrix)

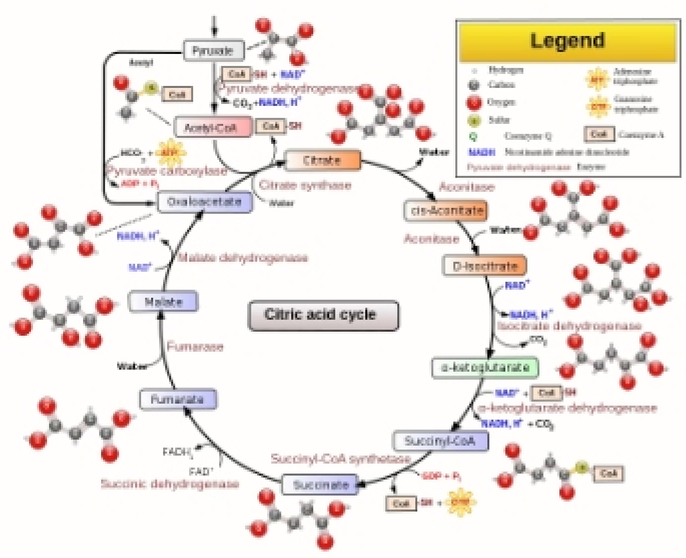
- Acetyl CoA produced by oxidative decarboxylation of pyruvic acid enters the TCA cycle more commonly known as Krebs' cycle. (Scientist → Hans Kreb)
- First reaction of Kreb's cycle is condensation, then isomerisation.

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

- 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:

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

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



AMPHIBOLIC PATHWAY

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

Fats → Fatty acids and glycerol

Carbohydrates → Simple sugars e.g., Glucose → Glucose 6-phosphate → Fructose 1,6 bisphosphate

Protein → Amino acids

Dihydroxy Acetone Phosphate ⟺ Glyceraldehyde 3-phosphate

Pyruvic acid

Acetyl CoA

H_2O Krebs' cycle CO_2

ELECTRON TRANSPORT SYSTEM (ETS) AND OXIDATIVE PHOSPHORYLATION

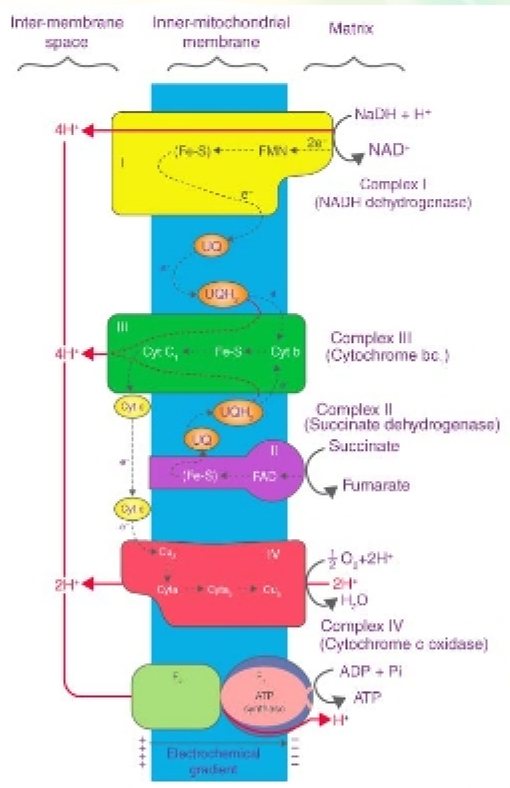
- $NADH+H^+$ and $FADH_2$ are oxidised through ETS and the electrons are passed on to O_2 resulting in formation of H_2O through various complexes in the inner mitochondrial membrane.

- NADH dehydrogenase (Complex-I) and $FADH_2$ (Complex-II) transfers electrons to

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

- 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 AOP 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 and electrons.
- Complex-V has two major components, 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



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.

RESPIRATORY QUOTIENT = (RQ)

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

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

02 It depends on the type of respiratory substrate, used during respiration

03 For, carbohydrates = 1
Fat = less than 1. (eg-tripalmitin=0.7)
Protein = about 0.9

- 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