12. RESPIRATION

The cellular oxidation or break down of carbohydrates into CO_2 and H_2O, and release of energy is called as *respiration*. It is a reverse process of photosynthesis. In respiration, the oxidation of various organic food substances like carbohydrates, fats, proteins etc, may take place. Among these, glucose is the commonest.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{Energy (686 kcal)}$$

This oxidation process in not so simple and does not take place in one step. Breakdown of glucose involves many steps releasing energy in the form of ATP molecules and also forming a number of carbon compounds (intermediates). Respiration is a vital process that occurs in all living cells of the plant and the most actively respiring regions are floral buds, vegetative buds, germinating seedlings, stem and root apices.

Types of respiration

Degradation of organic food for the purpose of releasing energy can occur with or without the participation of oxygen. Hence, respiration can be classified into two types; aerobic and anaerobic respiration.

Aerobic respiration

Aerobic respiration takes place in the presence of oxygen and the respiratory substrate gets completely oxidized to carbon dioxide and water as end products.

$$\underset{\text{(Glucose)}}{C_6H_{12}O_6} + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{Energy (686 kcal)}$$

This type of respiration is of common occurrence and it is often used as a synonym of respiration.

Anaerobic respiration

It takes place in the absence of oxygen and the respiratory substrate is incompletely oxidized. Some other compounds are also formed in addition to carbon dioxide. This type of respiration is of rare occurrence but, common among microorganisms like yeasts.

$$\underset{\text{Glucose}}{C_6H_{12}O_6} \rightarrow \underset{\text{Ethanol}}{2C_2H_5OH} + 2CO_2 + 56 \text{ kcal}$$

Respiratory substrate

A respiratory substrate is an organic substance which can be degraded to produce energy which is required for various activities of the cell. The respiratory substrates include carbohydrates, fats, organic acids, protein etc.

Carbohydrates

The carbohydrates constitute the most important respiratory substrate and the common amongst them are starch, sucrose, glucose and fructose. The complex carbohydrates are first hydrolyzed to simple sugars and then they are utilized.

Starch $\rightarrow$ Disaccharides $\rightarrow$ Hexoses

Fats

The fats are important storage food in seeds. Nearly 80 per cent of the angiosperms have fats as the main storage food in their seeds. At the time of seed germination, large amount of fats are converted into carbohydrates while the remaining fats are utilized in respiration. Fats are first broken down to glycerol and fatty acids. The fatty acids are broken down to acetyl coenzyme by β-oxidation. The acetyl coenzyme enters Kreb's cycle for further degradation and releases energy. Glycerol can directly enter the respiratory channel via glyceraldehyde.

Organic acids

Organic acids normally do not accumulate in plants to any appreciable extent except in the members of the family, Crassulaceae. Organic acids are oxidized under aerobic conditions to carbon dioxide and water.

Proteins

Under normal conditions, proteins are used up as respiratory substrate only in seeds rich in storage proteins. In vegetative tissues, proteins are consumed only under starvation. The proteins are hydrolyzed to form amino acids. Later, the amino acids undergo deamination forming organic acids and the organic acids can enter Kreb's cycle directly.

Mechanism of Respiration

1. Glycolysis
2. Aerobic breakdown of pyruvic acid (Kreb's cycle)
3. Electron Transport System/ Terminal oxidation / oxidative phosphorylation
5. Pentose phosphate pathway

A. GLYCOLYSIS / EMBDEN – MEYER HOF – PARANAS (EMP) PATHWAY

Glycolysis can take place even in the absence of O_2. One molecule of the 6 carbon compound, glucose is broken down through a series of enzyme reactions into two 3-carbon compounds, the pyruvic acid. Glycolysis takes place in the cytoplasm and it does not require oxygen. Hence it is an anaerobic process.

1. Glucose molecules react with ATP molecules in the presence of the enzyme hexokinase to form glucose -6- phosphate.
   Glucose + ATP → Glucose -6- phosphate + ADP

2. Glucose-6-phosphate is isomerised into fructose-6-phosphate in the presence of phospho hexose isomerase.
   Fructose + ATP → Fructose -6- phosphate + ADP

3. Fructose-6-phosphate reacts with one molecule of ATP in the presence of phospho hexo kinase forming fructose 1, 6-disphosphate.
   Fructose – 6- phosphate + ATP → Fructose -1,6- biphosphate + ADP

4. Fructose 1, 6 diphosphate is converted into two trioses, 3-phospho glyceraldehyde and dihydroxy acetone phosphate in the presence of aldolase.
   Fructose -1,6- biphosphate → 3-phospho glyceraldehyde+ DHAP

5. 3-phosphoglyceraldehyde reacts with H_3PO_4 and forms 1,3-diphosphoglyceraldehyde where, the reaction is non –enzymatic.

6. 1, 3-Diphosphoglyceraldehyde is oxidized to form 1,3- diphosphoglycerate in the presence of triose-phosphate dehydrogenase and coenzyme NAD^+. The NAD^+ acts as hydrogen acceptor and reduced to $NADH^+ + H^+$ in the reaction.
   Glyceraldehde -3- phosphate + NAD + Pi → 1,3- diphosphoglycerate + NADH

6. 1, 3-Diphosphoglycerate reacts with ADP in the presence of phosphoglyceric transphorylase (kinase) to form 3 phosphoglyceric acid and ATP.

1,3- diphosphoglycerate + ADP → 3, Phosphoglycerate + ATP

7. 3, Phosphoglycerate → 2, Phosphoglycerate acid is isomerized into 2 phosphoglyceric acid in the presence of the enzyme, phospho glycero mutase

   3, Phosphoglycerate → 2, Phosphoglycerate

8. 2 phosphoglyceric acid is converted into 2-phosphoenolpyruvic acid in the presence of enolase.

   2, Phosphoglycerate → Phosphoenol pyruvate + H_2O

9. 2 phospho enol pyruvic acid reacts with ADP to form one molecule each of pyruvic acid and ATP in the presence of pyruvate kinase.

   Phosphoenol pyruvate + ADP → Pyruvate + ATP

Glycolysis or EMP pathway is common in both aerobic and anaerobic respiration.

The overall glycolytic process can be summarized as follows

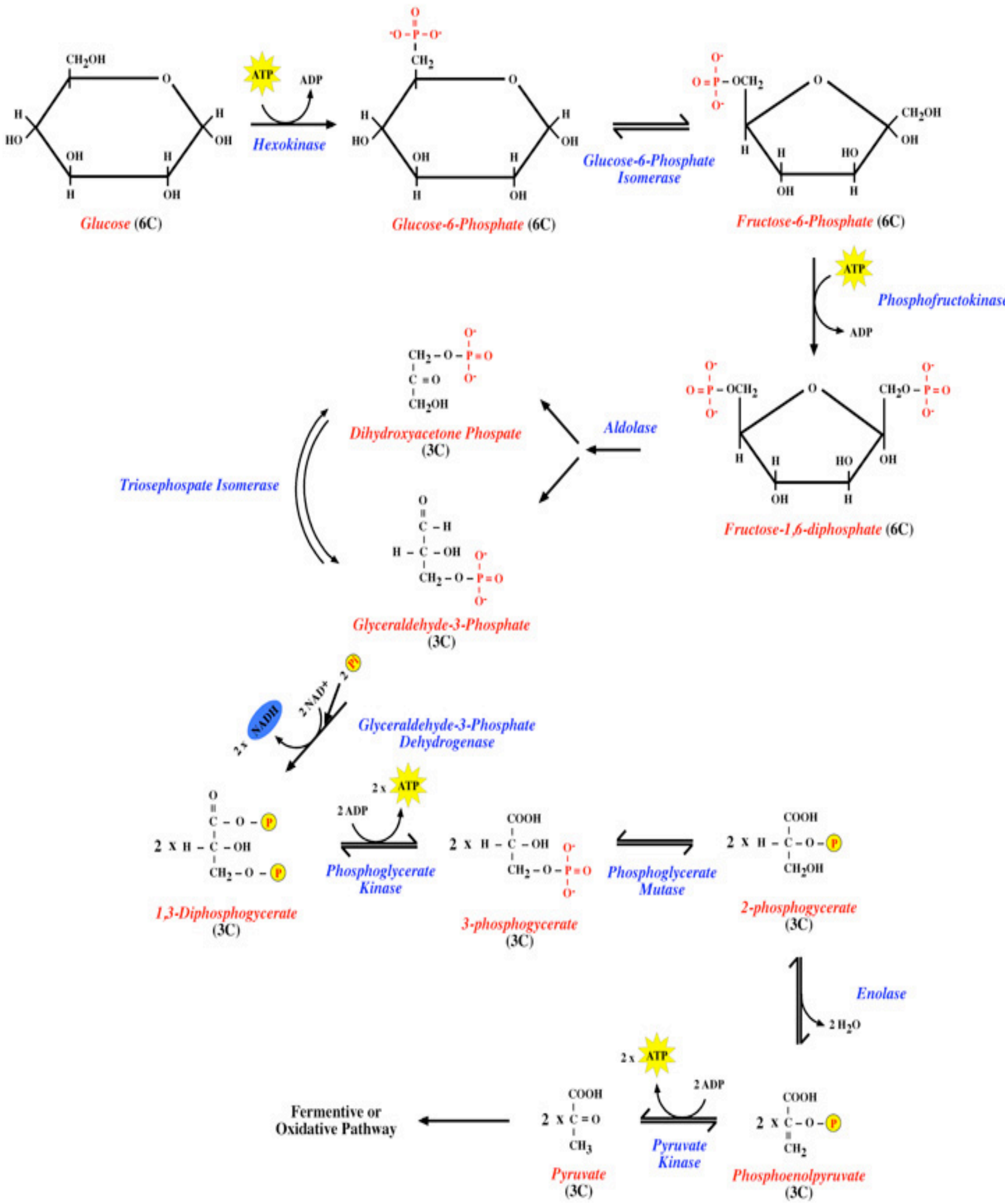
$$C_6H_{12}O_6 + 2ATP + 2NAD + 4ADP + 2H_3PO_4$$

$$\downarrow$$

$$\underset{\text{Pyruvic acid}}{2\ CH_3COCOOH} + 2ADP + 2NADH_2 + 4\ ATP$$

- Thus there is a gain of 4-2 = 2 ATP molecules per hexose sugar molecule oxidized during this process.
- Besides this, 2 molecules of reduced coenzyme $NADH_2$ are also produced per molecule of hexose sugar in glycolysis.
- During aerobic respiration, these two $NADH_2$ are oxidized via the electron transport chain to yield 3 ATP molecules each. Thus 6 ATP molecules are formed.

Glycolysis



<u>*Summary of Glycolysis*</u>

$$Glucose + 2\,ADP + 2\,Pi + 2\,NAD^{+} \longrightarrow 2\,Pyruvate + 2\,H_2O + 2\,ATP + 2\,NADH + 2H^{+}$$