Respiration in Plants - Part 1

Objectives

After going through this lesson, the learners will be able to understand the following:

- The Basic Features of Respiration in Plants.
- The Process of Glycolysis.
- The Process of Anaerobic Respiration, Alcoholic and Lactic Acid Fermentation

Content outline

- Introduction-External Respiration and Cellular Respiration
- Types Of Respiration in Plants and Respiratory Substrates
- Do Plants Breathe – Gaseous Exchange in Plants
- Glycolysis
- The Fate of Pyruvate Generated in Glycolysis
- Anaerobic Respiration -Alcoholic Fermentation and Lactic Acid Fermentation
- Aerobic Respiration**:** Production of Acetyl Coenzyme A

Introduction-External Respiration and Cellular Respiration

The term respiration was originally used to describe the process of exchange of air between the organism and its environment i.e. the process of breathing (respire = to breath). Later the term was expanded to include the cellular processes by which organic compounds, usually sugars, are broken down in a stepwise manner to release energy which is stored in the form of ATP. As we shall see, in eukaryotes the breakdown of complex molecules to yield energy i.e. cellular respiration takes place in the cytoplasm and in the mitochondria.

Types of Respiration in Plants and Respiratory Substrates

During the process of respiration, oxygen is utilized, and carbon dioxide, water and energy are released as products. The reaction requires oxygen. But some cells live where oxygen may or may not be available. *Can you think of such situations where oxygen is not available?* There are sufficient reasons to believe that the first cells on this planet lived in an atmosphere that lacked oxygen.

This was possible because cellular respiration can be carried out by two different pathways. The cellular respiration that occurs in presence of oxygen is called aerobic respiration, and the one that occurs in absence of oxygen is anaerobic respiration. Compared to aerobic respiration, less energy is released in anaerobic respiration as the respiratory substrate is incompletely oxidized. Also some of the end products and intermediates of anaerobic respiration are toxic in higher concentration. For eg. Yeasts are poisoned to death when the cellular concentration of ethanol produced by fermentation reaches 13%. So anaerobic respiration is harmful over a long period of time

Almost all plants and animals (except some parasitic worms like *Ascaris* and *Taenia*) are essentially aerobes. Yeast is a facultative anaerobe i.e. it is an aerobic organism but can also survive under anaerobic conditions as it can respire anaerobically. Many eukaryotic cells also switch on their anaerobic respiration process in case the oxygen supply is low e.g., submerged roots of some waterlogged plants.

The substrates oxidized in respiration may be a carbohydrate, fat or under certain conditions a protein.

Hexose sugars like glucose and fructose, disaccharides like sucrose and even polysaccharides like starch may be used as substrates for respiration. The overall reaction for the complete oxidation of one molecule of glucose is as follows - $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + energy. Fats and proteins are comparatively richer sources of energy.

The cell breaks down the substrate molecule in a way such that all the liberated energy is not lost as heat. The key is to oxidize the substrate not in one step but in several small steps enabling some steps to be just large enough such that the energy released can be coupled to ATP synthesis. How this is done is the story of respiration.

Do Plants Breathe – Gaseous Exchange in Plants

As we have just learned, plants like animals require oxygen for aerobic respiration and they also release carbon-dioxide in the process. Unlike animals, plants have no specialized organs for gaseous exchange. However, plants have openings in the form of stomata and lenticels for this purpose. There are several reasons why plants can get along without respiratory organs. First, each plant-part takes care of its own gas-exchange needs. There is very little transport of gases from one plant part to another. Second, plants do not present great demands for gas exchange. Roots, stems and leaves respire at rates far lower than animals do. Only during photosynthesis are large volumes of gases exchanged. When cells photosynthesise, the oxygen released in photosynthesis is used for respiration.

Third, the distance that gases must diffuse even in large, bulky plants is not great. Each living cell in a plant is located quite close to the surface of the plant. Most cells of a plant have at least a part of their surface in contact with air. This is also facilitated by the loose packing of parenchyma cells in leaves, stems and roots, which provide an interconnected network of air spaces.

Glycolysis

The scheme for glycolysis (derived from the Greek word *glycos* meaning sugar and *lysis* meaning splitting) was given by Gustav Embden, Otto Meyerhof, and J. Parnas, and is often referred to as the EMP pathway.

Glycolysis is the first stage in respiratory carbon metabolism. It takes place in all living cells. In anaerobic organisms, it is the only process in respiration.

Glycolysis is an anaerobic process in which hexose sugars undergo a partial oxidation to form the 3 carbon pyruvic acid as the end product. A chain of ten reactions, under the control of different enzymes, takes place to produce pyruvate from glucose.

In plants malate may also be formed as an end product of glycolysis.

In animal cells glycolysis takes place in the cytosol. In plant cells glycolysis is not restricted to the cytoplasm but also takes place in the plastids. Starch stored in amyloplasts is converted into glucose and enters the glycolytic pathway. Similarly triose phosphates are exported from the chloroplasts to the cytosol as substrates for glycolysis. Fructose and glucose obtained from the hydrolysis of sucrose in the cytoplasm also enters the glycolytic pathway.

Glycolysis occurs in 2 phases (Fig. 1).

1. In the first phase the hexose sugar is phosphorylated and split into 2 triose phosphates
2. In the second phase triose phosphate is converted to pyruvate which is the end product of glycolysis.

In the initial phase of glycolysis, (Fig. 1, 1a) each hexose unit is phosphorylated twice to produce fructose-1, 6-bisphosphate. **2 ATP molecules are consumed in these two steps.**

1. First in the conversion of glucose into glucose 6-phosphate.

2. Second in the conversion of fructose6-phosphate to fructose 1, 6-bisphosphate. The hexose bisphosphate is split into 2 triose phosphates (Fig.1).

The second phase (Fig. 1, 1b) of glycolysis is the energy conserving phase. In this phase a dehydrogenase enzyme catalyzes the oxidative conversion of 3 phosphoglyceraldehyde to 1,3bis phosphoglycerate. NAD^+ is reduced to NADH in the process. As 2 triose phosphates are produced by every molecule of glucose, **2 NADH is produced in this step**. The NADH is oxidized back to NAD to maintain the cellular pool of NAD.

1,3 bis phosphoglycerate is converted by a series of reactions to pyruvic acid. ATP is produced in steps 7 and 10 of this process. Thus 2 ATP molecules are produced per triose phosphate. As 2 triose phosphates are produced by every molecule of glucose, **a total of 4 ATP s are produced** by every glucose molecule that enters the cycle.

In glycolysis ATP is produced through substrate-level phosphorylation as there is direct transfer of a phosphate group from a substrate to ADP to form ATP.
Thus, the net gain of ATP in glycolysis per molecule of glucose is as follows-
ATP consumed =2 molecules
ATP produced by substrate-level phosphorylation =4
Net gain =2 molecules of ATP.
2 molecules of NADH are also produced in glycolysis (figure 1, 1b step 6) .
Under aerobic conditions NADH is oxidized to NAD via the electron transport chain. 3 ATP molecules are produced by oxidative phosphorylation of each NADH.
Thus a total of 6 molecules **of ATP** is produced by oxidative phosphorylation.
Net ATP produced by glycolysis in aerobic respiration=8 ATP

However, under **anaerobic conditions only 2 molecules of ATP** are formed in glycolysis.

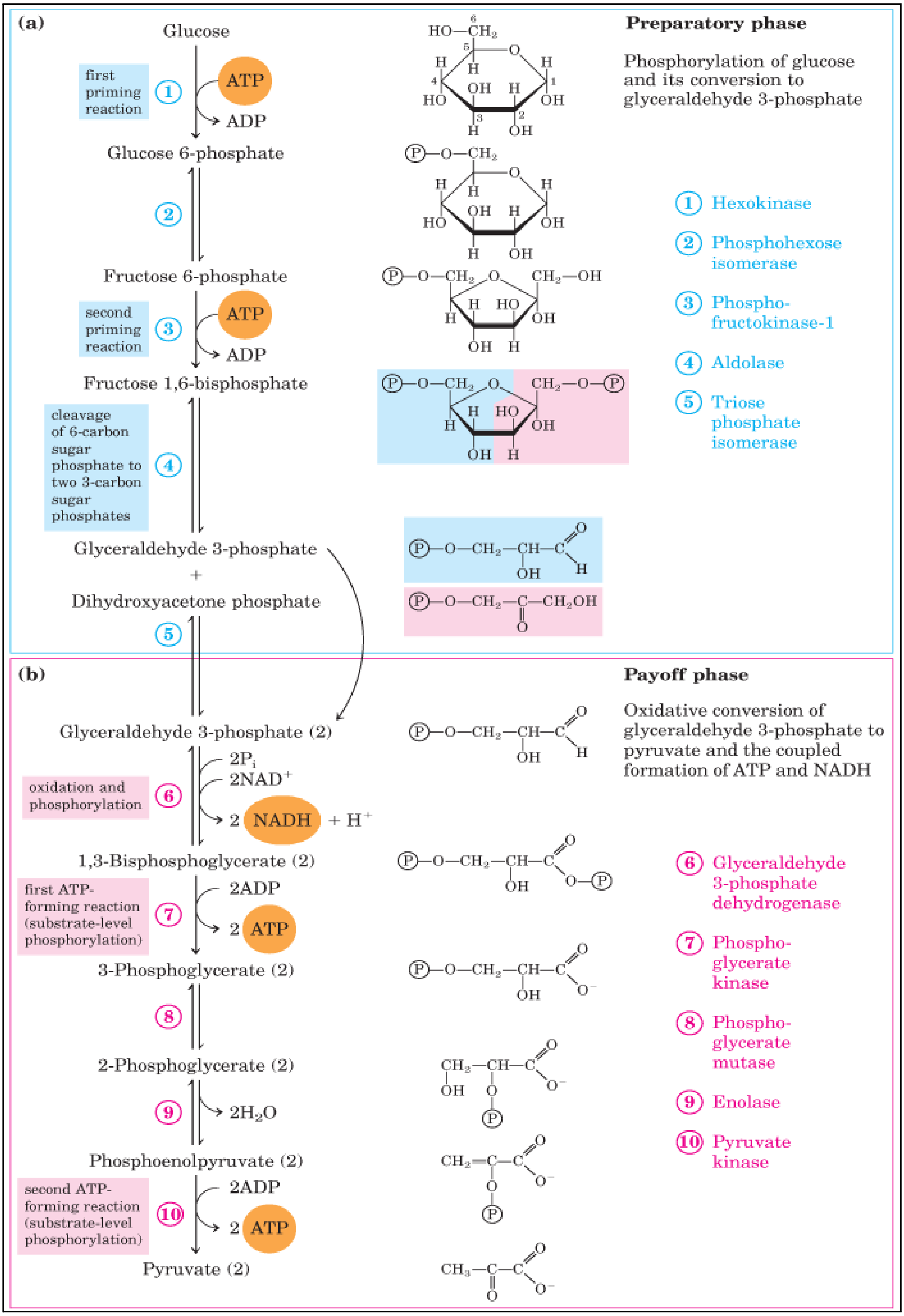

Figure 1: Steps in Glycolysis

The Fate of Pyruvate Produced in Glycolysis

Pyruvate is a key intermediate in cellular respiration. Its fate is decided primarily by the availability of oxygen. Thus, under anaerobic conditions it is incorporated in either the alcoholic fermentation cycle or lactic acid cycle. Under aerobic conditions it enters the Krebs cycle (Fig. 2).

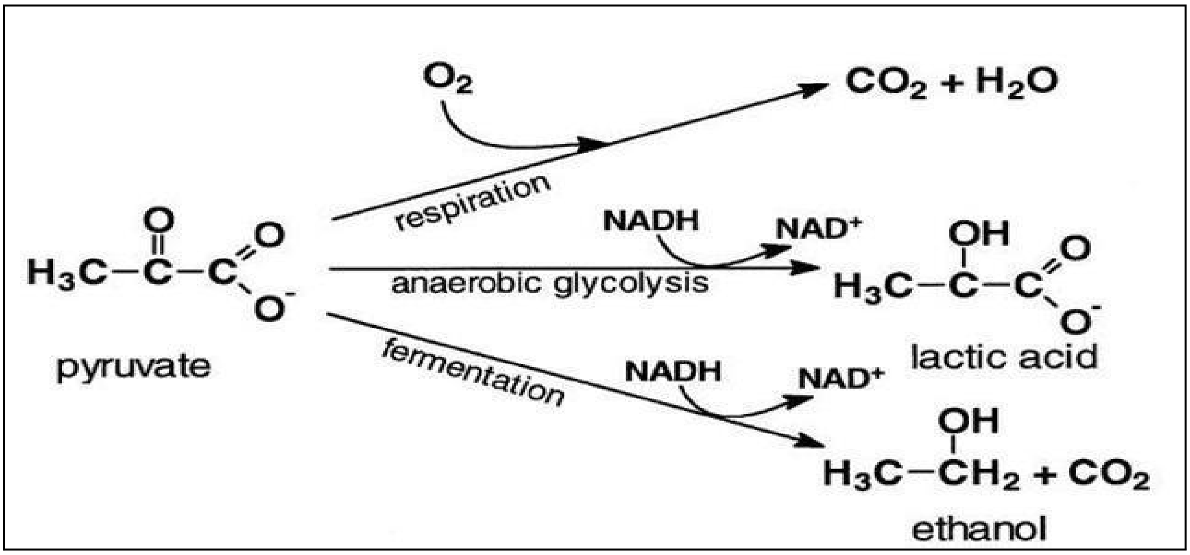

Figure 2: Alternative Pathways of Metabolism of the Pyruvate Produced in Glycolysis

Anaerobic Respiration - Alcoholic Fermentation and Lactic Acid Fermentation

A. **Fermentation:** Under anaerobic conditions pyruvate is converted to ethanol and the process called alcoholic fermentation is of considerable commercial importance. Alcoholic fermentation is common in plants but is more widely known from Brewer's yeast. Yeasts are facultative anaerobes. Under certain conditions plant tissues may be subjected to low or zero concentration of ambient oxygen e.g., roots of plants growing in waterlogged soils. The root cells will be forced to carry out fermentative metabolism of the pyruvate produced by glycolysis.

Two enzymes decarboxylase and dehydrogenase act sequentially on pyruvate to produce ethanol and carbon-dioxide and NADH is oxidized in the process (Fig. 3).

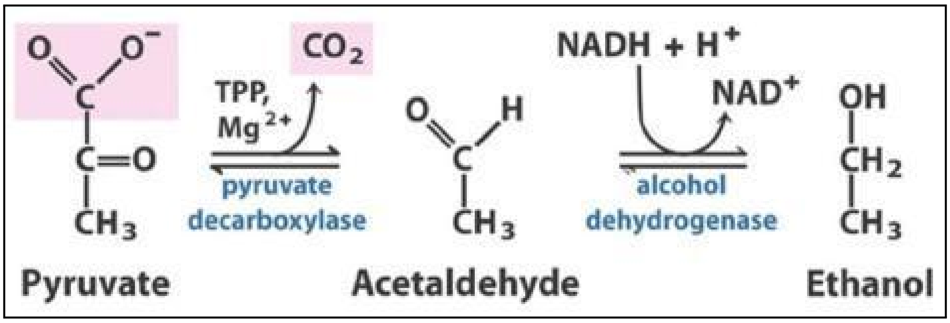

Figure 3: Alcoholic Fermentation of Pyruvate

Only 2 molecules of ATP are produced in this pathway. Fermentation liberates only 4% of the energy available in each sugar molecule.

B. **Anaerobic glycolysis of pyruvate to lactic acid:** In this reaction pyruvate is reduced to lactate by the enzyme lactate dehydrogenase (Fig. 4). The reducing agent is NADH. Lactic acid fermentation is common in mammalian muscles but also takes place in plants. For e.g., Initial response of some plants eg. corn to hypoxic concentrations of oxygen is to undergo lactic acid fermentation but subsequently it switches to alcoholic fermentation. A possible reason for the shift could be that alcohol is a less toxic end product as compared to lactic acid as it can diffuse out of the cell.

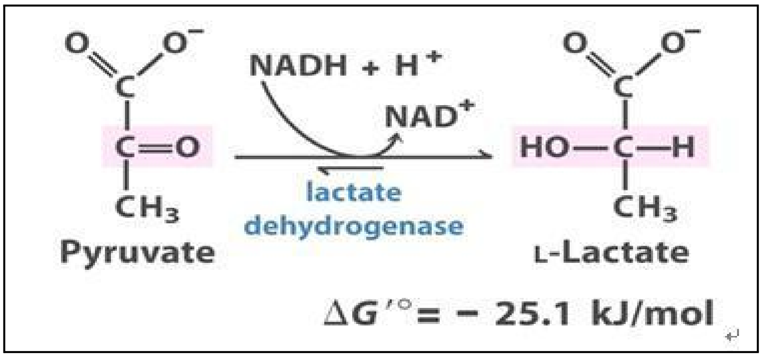

Figure 4: Lactic Acid Fermentation of Pyruvate

As in alcoholic fermentation, only 2 molecules of ATP are produced in this process.

Aerobic Respiration: Production of Acetyl Coenzyme A

In the presence of oxygen, the pyruvate enters the mitochondrial matrix where it is oxidatively decarboxylated by the enzyme pyruvate dehydrogenase. The products are carbon dioxide, NADH and acetic acid in the form of acetyl Coenzyme A (Fig. 5).

Acetyl CoA enters the citric acid cycle (also called the Tricarboxylic acid cycle i.e., TCA cycle or Krebs cycle after Hans Krebs, the scientist who elucidated the pathway) and is completely oxidized to carbon dioxide and water.

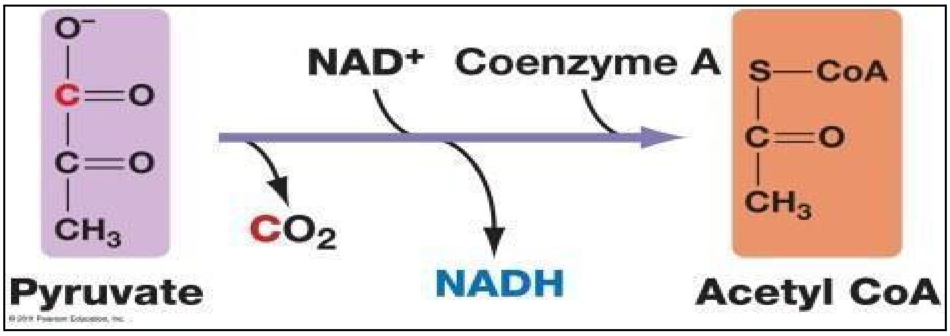

Figure 5: Metabolism of Pyruvate in Aerobic Respiration

The Citric acid cycle will be discussed in detail in the next module.