Anaerobic Respiration in Plants

It is the process of release of energy in enzymatically controlled step-wise incomplete degradation of organic food without oxygen being used as oxidant.

Therefore, end products are never completely inorganic. The term anaerobic respiration is often used in connection with higher organisms where it occurs in the roots of some water-logged plants, muscles of animals and as supplementary mode of respiration in massive tissues.

Anaerobic respiration is the exclusive mode of respiration in some parasitic worms, many prokaryotes, several unicellular eukaryotes and moulds. In micro-organisms the term fermentation is more commonly used where anaerobic respiration is known after the name of product like alcoholic fermentation, lactic acid fermentation.

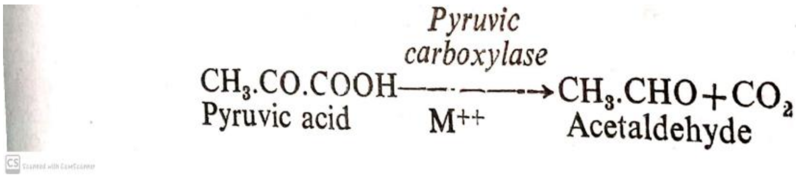
Carbon dioxide is evolved in some cases. It gives a frothy appearance (L. fermentum — to boil) to the medium.

Buchner (1897) was the first to find that fermentation could be caused without the living yeast cells by grinding them under pressure and mixing the extract with sugary solution. The enzyme complex present in the extract was named as zymase. Because of the latter, fermentation is also called zymosis. Commonly, fermentation is defined as the anaerobic breakdown of carbohydrates and other organic compounds into alcohols, organic acids, gases, etc. with the help of micro-organisms or their enzymes.

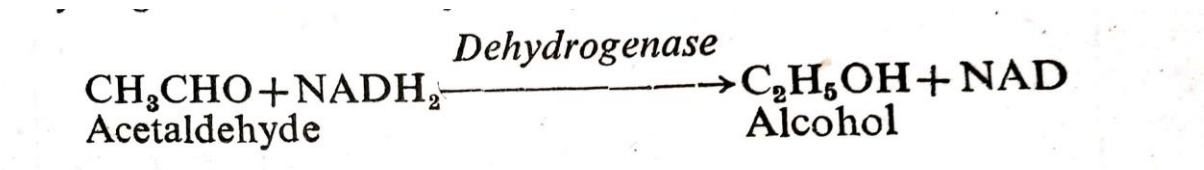
The mechanism of anaerobic respiration or fermentation is similar to common pathway of aerobic respiration up to glycolysis. Glycolysis breaks down glucose enzymatically in several steps to form two molecules of pyruvate, 2 ATP and 2 NADH ($+H^+$). Pyruvate is anaerobically broken down to yield various products depending upon the organism and the type of tissue.
The two common products are ethyl alcohol and lactic acid.

1.Alcoholic fermentation or Ethyl Alcohol Fermentation:
It is quite common in fungi (e.g., Rhizopus, Yeast) and bacteria. Yeast can respire both aerobically and anaerobically. In the presence of

pyruvate decarboxylase and TPP (thiamine pyrophosphate), pyruvate is broken down to form acetaldehyde. Carbon dioxide is released.



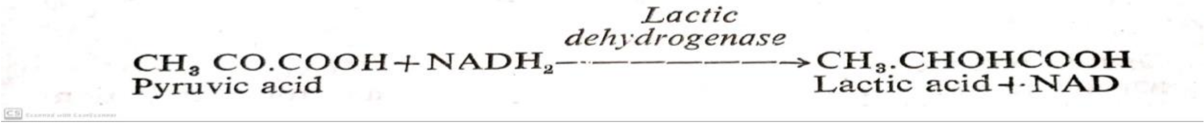
Acetaldehyde is reduced to ethyl alcohol or ethanol by alcohol dehydrogenase. Hydrogen is obtained from NADH produced during oxidation of glyceraldehyde 3-phosphate to 1: 3 diphosphoglycerate in glycolysis.



Since no ATP is produced in these two steps from pyruvic acid to Ethanol, instead two molecules of NADH2 produced in glycolytic reactions are used up in these two steps. Therefore, the total gain of ATP molecules in anaerobic oxidation of glucose is only 2.

2. Lactic Acid Fermentation:

The fermentation occurs in lactic acid bacteria (e.g., Lactobacillus), some fungi and muscles. In lactic acid fermentation pyruvic acid produced in glycolysis is directly reduced by NADH to form lactic acid. No Co_2 is produced. The enzyme is lactic dehydrogenase which requires FMN (Flavin Mono-nucleotide) and Zn^{2+}.



The total gain of energy in this case also like alcoholic fermentation is only 2 ATP molecules as $NADHH^+$ produced during the formation of pyruvic acid from glucose is used up in the formation of lactic acid from pyruvic acid.

Anaerobic respiration produces very little energy (about 5%) as compared to aerobic respiration.

The reasons are:
(a) There is incomplete breakdown of respiratory substrate,

(b) At least one of the products of anaerobic respiration is organic. It can be further oxidised to release energy.

(c) NADH produced during glycolysis is often used up.

(d) ATP formation does not occur during regeneration of NAD^+.
(e) Electron transport chain is absent,

(f) Oxygen is not used for receiving electrons and protons.

Obligate Anaerobes and Facultative Anaerobes:
Most of the microorganisms are obligate anaerobes because they carry out only anaerobic respiration and are unable to use O_2. They are so sensitive to oxygen that they are inhibited or even killed by oxygen. So far as is known, obligate anaerobes belong to three groups of microorganisms: a wide variety of prokaryotes, a few fungi, and a few protozoa.
One of the best-known group of obligately anaerobic bacteria belongs to the genus Clostridium.

Facultative anaerobes are the organisms which can exit either in the presence or absence of oxygen. Eg: Staphylococcus spp., Streptococcus spp., Escherichia coli,

Importance of Anaerobic Respiration (Fermentation):
(i) Anaerobic respiration is important during periods of oxygen deficiency.

(ii) Alcoholic fermentation is used in brewing industry for the production of various types of beers, whisky and other wines.

(iii) Carbon dioxide of alcoholic fermentation is used in baking industry for making the bread spongy.

(iv) Vinegar is obtained by the fermentation activity of acetic acid bacteria.

(v) Dairy industry depends upon the action of lactic acid bacteria which convert milk sugar to lactic acid. Lactic acid coagulates the milk protein casein and the droplets of milk fat fuse.

(vi) Production of industrial alcohols and organic acids.

(vii) Tea and tobacco leaves are cured (or removed of their bitterness) and provided with a fine flavour.

(viii) Retting or separation of stem fibres is carried out with the help of bacterial fermentation of softer tissues.

(ix)Decomposition of organic remains is carried out by fermentation. However, the fermenting organisms also spoil out food and may cause food poisoning by releasing toxins or ptomaine.

Pasteur's effect:

The **Pasteur effect** is an inhibiting effect of oxygen on the fermentation process. It is a sudden change from anaerobic to aerobic process.

In his studies on alcoholic fermentation Pasteur in 1861 found that under anaerobic conditions much more sugar was taken up per quantity of yeast present than was consumed in the presence of O_2 (or aerobic conditions). This inhibition by O_2 of the rate of carbohydrate breakdown is often called as Pasteur's effect. Previously the existence of this effect was known only in yeasts and animal tissue but now this is also known to be operative in a variety of tissues of higher plants e.g., barley leaves, apple fruits, potato tubers, carrot roots etc.

Explanation

The effect can be explained; as the yeast being facultative anaerobes can produce energy using two different metabolic pathways. While the oxygen concentration is low, the product of glycolysis, pyruvate, is turned into ethanol and carbon dioxide, and the energy production efficiency is low (2 moles of ATP per mole of glucose). If the oxygen concentration grows, pyruvate is converted to acetyl CoA that can be used in the citric acid cycle, which increases the efficiency to 31 or 29.5 moles of ATP per mole of glucose (it depends on which shuttle is used for reducing the reducing equivalent, NADH, that is formed in the cytosol). Therefore, about 15 times as much glucose must be consumed anaerobically as aerobically to yield the same amount of ATP.[1]

Under anaerobic conditions, the rate of glucose metabolism is faster, but the amount of ATP produced (as already mentioned) is smaller. When exposed to aerobic conditions, the ATP and Citrate production increases and the rate of glycolysis slows, because the ATP and citrate produced act as allosteric inhibitors for phosphofructokinase 1, the third enzyme in the glycolysis pathway. The Pasteur effect will only occur if glucose concentrations are low (<2 g/L) and if other nutrients, mostly nitrogen, are limited.

Respiratory Quotient

During aerobic respiration, oxygen is consumed and carbon dioxide is released. The ratio of the volume of carbon dioxide given out to the volume of oxygen absorbed in respiration, i.e., CO_2/O_2 is called **respiratory quotient (RQ) or respiratory ratio.**
RQ = volume of CO_2 evolved/volume of O_2 consumed.
The value of respiratory quotient depends upon the nature of respiratory substance used during respiration. This varies for different types of substrates.

Carbohydrates (RQ Equal to Unity):
The value of respiratory quotient is unity (one) when hexose sugars are consumed in respiration. Here equal volumes of CO_2 and O_2 are evolved and consumed, respectively. This is obvious from overall equation of respiration.

Fats (RQ Less than Unity):
When substances poorer in oxygen than carbohydrates, e.g., fats are oxidised in respiration, the value of respiratory quotient is less than one.

RQ in above-mentioned examples is less than unity, i.e., 0.7, because fats contain less oxygen than the carbohydrates, and therefore, they require relatively greater amount of oxygen for oxidation.

In case of proteins RQ is 0.5 (approximately).

Anaerobic Respiration (RQ Infinity):

In anaerobic respiration CO_2 is evolved but O_2 is not consumed, and therefore RQ is infinite (∞).

Equation is as follows:

$$C_6H_{12}O_6 \xrightarrow[\text{enzyme}]{\text{zymase}} 2C_2H_5OH + 2CO_2 + \text{energy}$$

$$RQ = \frac{CO_2}{O_2} = \frac{2}{0} = \text{Infinity } (\infty)$$

Significance of RQ:

From an RQ value, one can obtain a rough indication of the nature of substrate being oxidised.

It also helps in knowing the type of respiration being performed. It may also provide some information about major transformation of food materials.