1. Details of Module and its structure

Module Detail	
Subject Name	Biology
Course Name	Biology 02 (Class XI, Semester - 2)
Module Name/Title	Respiration in Plants: Part – 3
Module Id	kebo_21403
Pre-requisites	Basic knowledge about Understanding of understanding of glycolysis, Krebs cycle, ETS, oxidative phosphorylation
Objectives	After going through this lesson, the learners will be able to understand the following: • Calculate the number of ATP produced in aerobic and anaerobic respiration, have an idea about the efficiency of respiration • To convey the concept that respiration is a catabolic as well as a anabolic process, to define RQ and explain that different substrates have distinct RQs.
Keywords	Respiratory Balance Sheet, Respiration – an amphibolic pathway, Respiratory quotient (RQ)

2. Development Team

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1. The respiratory balance sheet

It is possible to make calculations of the net gain of ATP for every glucose molecule oxidised; but in reality this can remain only a theoretical exercise.

These calculations can be made only on certain assumptions that:

- There is a sequential, orderly pathway functioning, with one substrate forming the next and with glycolysis, TCA cycle and ETS pathway following one after another.
- The NADH synthesised in glycolysis is transferred into the mitochondria and undergoes oxidative phosphorylation.
- None of the intermediates in the pathway are utilised to synthesise any other compound.
- Only glucose is being respired – no other alternative substrates are entering in the pathway at any of the intermediary stages.

But this kind of assumptions are not really valid in a living system; all pathways work simultaneously and do not take place one after another; substrates enter the pathways and are withdrawn from it as and when necessary; ATP is utilised as and when needed; enzymatic rates are controlled by multiple means. Yet, it is useful to do this exercise to appreciate the beauty and efficiency of the living system in extracting and storing energy.

Energy contained in respiratory substrates is not released in a single step or released free into the cell. Rather energy is released slowly in a series of stepwise reactions controlled by enzymes, and is trapped as chemical energy in the form of ATP.

Let us recall the products formed in the two steps of aerobic respiration.

Step 1. Glycolysis

In glycolysis each glucose molecule is broken down to produce 2 molecules of pyruvic acid. Two molecules of NADPH and two molecules of ATP are also produced in the process.

The NADPH is re-oxidised via the electron transport chain resulting in the production of three

ATP/ NADPH oxidised.

Therefore, oxidation of NADPH produces 2x3 = 6molecules of ATP.

Total ATP produced in glycolysis =2+6 = 8 ATP.

Step 2. Complete oxidation of pyruvic acid through the TCA cycle

Recall from the previous module that

The summary for the oxidative phosphorylation of one molecule of pyruvic acid is as follows

Pyruvic acid+ 4NAD+FAD+H_2O + ADP + Pi= 3CO_2 +4NADH +4H +$FADH_2$ +ATP

4NADH=4x3=12 ATP (oxidation of one molecule of NADH produces 3molecules of ATP)

1 FADH2= 2x1= 2 ATP (oxidation of one molecule of FADH2 produces 2molecules of ATP)

Substrate phosphorylation = 1 ATP

Total = 15 ATP.

As the degradation of glucose produces two molecules of pyruvic acid, the number of ATP s produced by the complete oxidation of one molecule of glucose by the TCA cycle is 15x2=30 ATP

Therefore the complete oxidation of one molecule of glucose by aerobic respiration produces= 30 + 8=38 ATP

Efficiency of respiration is the percentage of energy captured /stored as ATP during complete oxidation of a mole of the respiratory substrate.

Respiration Efficiency = Energy captured in ATP per mole of substrate oxidised/Total energy released per mole of substrate oxidized x 100

For I molecule of glucose = 38x8.15/686x100=45%

Thus, in biological systems the respiratory efficiency during complete oxidation of glucose is 45% and the remaining 55% of the energy stored in glucose is lost as heat.

Only two molecules ATP are formed in anaerobic respiration processes like alcoholic fermentation and lactic acid fermentation. This is because glucose is partially breakdown of in these processes whereas in aerobic respiration it is completely degraded to CO_2 and H_2O. The

NADH produced is oxidised to NAD^+ rather slowly in anaerobic respiration due to absence of oxygen.

2. Respiration – an amphibolic pathway

Glucose is the favoured substrate for respiration. All carbohydrates are usually first converted into glucose before they are used for respiration. Other substrates can also be respired, as has been mentioned earlier, but then they do not enter the respiratory pathway at the first step. Fats would need to be broken down into glycerol and fatty acids first. If fatty acids were to be respired they would first be degraded to acetyl CoA and enter the pathway. Glycerol would enter the pathway after being converted to PGAL. The proteins would be degraded by proteases and the individual amino acids (after deamination) depending on their structure would enter the pathway at some stage within the Krebs' cycle or even as pyruvate or acetyl CoA. In other words, different substrates enter the cycle if they are to be respired and used to derive energy. What is important to recognise is that it is these very substrates that would be withdrawn from the respiratory pathway for the synthesis of the compounds from which the substrates were formed . Hence, fatty acids would be broken downto acetyl CoA before entering the respiratory pathway. But when the organism needs to synthesise fatty acids, acetylCoA would be withdrawn from the respiratory pathway for it. Hence, the respiratory pathway comes into the picture both during breakdown and synthesis of fatty acids.

We have learnt that respiration includes 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 i.e respiration is a catabolic process.

However as discussed, many of the intermediate substrates of the glycolytic pathway and the TCA cycle serve as precursors for the biosynthesis of important biomolecules. Some examples will illustrate the process.

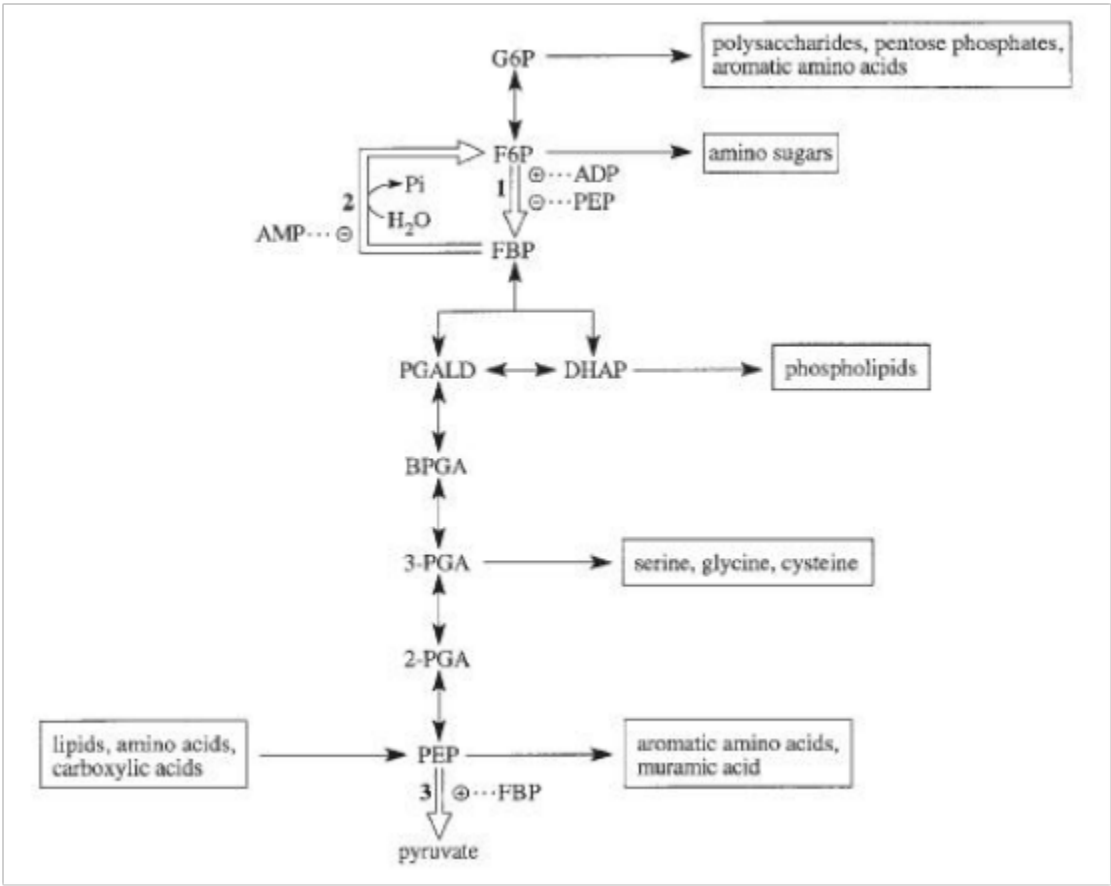

Figure 1. Intermediates of the glycolytic pathway are used for biosynthesis of many compounds As shown in Figure 1 Glucose 6 phosphate is used for biosynthesis of polysaccharides , pentose phosphates and aromatic amino acids.

Fructose 6- phosphate is used in the biosynthesis of amino sugars and phosphoglyceraldehyde is used in synthesis of phospholipids. Other intermediates are used for the synthesis of various amino acids, lipids and organic acids as shown in figure1.

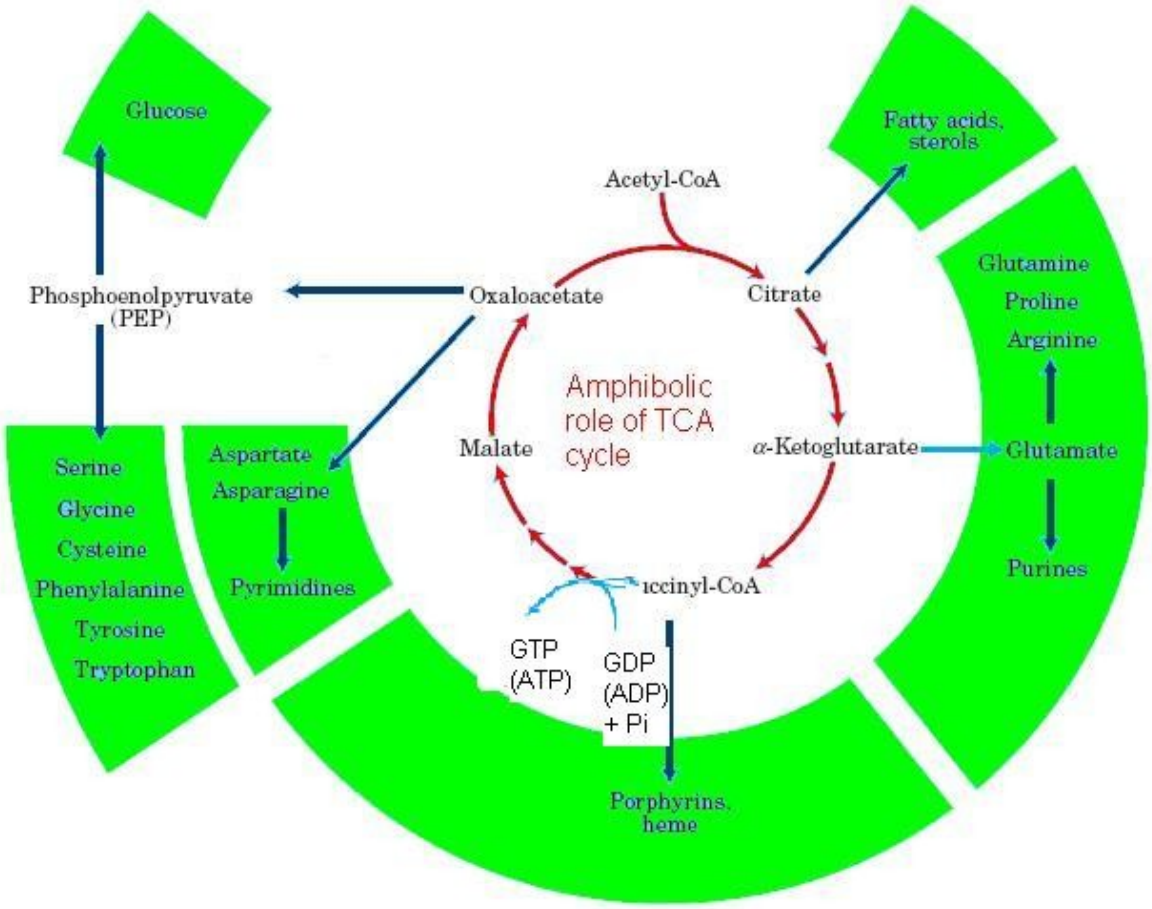

Figure 2: Intermediates of the TCA cycle are used for biosynthesis of many compounds

Similarly many intermediate compounds formed in the TCA cycle are also used in biosynthetic pathways to produce useful end products.

Fatty acids are synthesized from citric acid

Aspartate and glutamate are synthesized from the TCA intermediates oxaloacetate and α ketoglutarate by a transamination reaction. The aspartate and glutamate can be further used to synthesize other amino acids and nucleotides.

Oxaloacetate regenerated in the TCA cycle can be converted into glucose by a process called gluconeogenesis.

Succinyl-CoA produced in the TCA cycle can be diverted to the synthesis the of Haem groups of cytochromes.

Thus the glycolytic pathway and the TCA cycle in addition to their catabolic role, also provide intermediaries for many anabolic i.e. biosynthetic pathways. This emphasizes the fact that not all the carbon that enters the respiratory pathway is oxidised to carbon dioxide. Because the

respiratory pathway is involved in both anabolism and catabolic processes, it is considered to be an amphibolic pathway rather than a catabolic one.

3. Respiratory quotient (RQ)

In aerobic respiration, O_2 is consumed and CO_2 is released. The ratio of volume of CO_2 evolved to the volume of O_2 consumed in respiration is called the respiratory quotient (RQ).

The value of RQ depends on the substrate being oxidised i.e. the RQ value will be different for the respiration of fats, sugars, organic acids etc. Conversely, a measure of the RQ value provides an idea about the nature of the substrate being used in respiration.

When carbohydrates are used as substrate and are completely oxidised, the RQ will be 1, because equal amounts of CO_2 and O_2 are evolved and consumed, respectively, as shown in the equation below

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

$$RQ = 6CO_2/6O_2 = 1$$

When fats are used in respiration, the RQ is less than 1.

$$C_{16}H_{32}O_{2(\text{Palmitic acid})} + 23\ O_2 \rightarrow 16\ CO_2 + 16\ H_2O$$

$$RQ = 16\ CO_2 / 23O_2 = 0.696$$

Fats have fewer oxygen atoms as compared to atoms of carbon and oxygen. Therefore the oxidation of fats requires more oxygen and as a result the RQ value for fats is less than one.

When organic acids are used in respiration, the RQ value is more than1.

$$C_4H_6O_5(\text{Malic acid}) + 3O_2 \rightarrow 4CO_2 + 3H_2O$$

Organic acids are rich in oxygen. Therefore they require less oxygen for oxidation and as a result the RQ value for organic acids is more than one .

When proteins are respiratory substrates the ratio would be about 0.9.

What is important to recognise is that in living organisms respiratory substrates are often more than one.