RESPIRATORY QUOTIENT

Respiratory Quotient (RQ) may be defined as "*the ratio between the volume of carbon dioxide given out and oxygen taken in simultaneously by a given weight of the tissue in a given period of time at standard temperature and pressure.*"

$$\text{Respiratory Quotient} = \frac{\text{Volume of } CO_2 \text{ evolved}}{\text{Volume of } O_2 \text{ absorbed}}$$

The value of RQ depends upon the nature of respiratory substrate or on the amount of oxygen present in the respiratory substrate and the extent to which substrate is broken down. Theoretically, the value of RQ should be unity but deviations in the value from unity are very common because of the deviations in the oxidation and reduction levels of the respiratory substrates. The value of RQ also depends upon whether all oxygen which is being absorbed is being used up in respiration or some of it is being utilised for some other purposes. Because of these reasons the value of RQ may be unity, more than unity, less than unity and even zero. The value of RQ provides some idea about the type of substrate being oxidised and of the degree of aerobic respiration preceding it. The RQ value of different substrates is discussed here as follows:

(1) Respiratory Quotient of Carbohydrates

Carbohydrates are principle respiratory substrates in plants and the commonest among them are starch, inulin, sucrose, glucose and fructose. Of these, complex carbohydrates are first hydrolysed to simple or hexose sugars because as such they can't be utilised as respiratory substrate.

Starch → polysaccharides → disaccharides → monosaccharides or hexoses

When these carbohydrates such as hexoses are used as respiratory substrate, the volume of CO_2 evolved is equal to the volume of O_2 absorbed as is evident from the equation given below. The RQ is found to be unity

$$\underset{}{C_6H_{12}O_6} + \underset{(6\text{ volumes})}{6O_2} \longrightarrow \underset{(6\text{ volumes})}{6CO_2} + 6H_2O$$

$$RQ = CO_2/O_2 = 6CO_2/6O_2 = 1 \text{ or unity}$$

In low oxygen concentration anaerobic respiration takes place in addition to aerobic respiration. As a result, the CO_2 production increases which results in raising the value of RQ.

During respiration, a part of carbon dioxide may be utilised non-photosynthetically by living cells in lengthening the carbon chains of their organic compounds. Therefore, RQ may appear less than unity in such cases of carbohydrates. Similarly, RQ may deviate from unity when (1) respiratory substrate is other than carbohydrate, (2) carbohydrates or other respiratory substrates are partially oxidised, (3) oxygen absorbed is used up in a process other than respiration or (4) CO_2 formed is utilised metabolically instead of being given out.

(2) Respiratory Quotient of Fats

Fats are not commonly found in vegetative parts of the plant but these are important as storage food in seeds. Nearly 80 per cent angiospermic seeds, prefer to store fat as a main reserve food. At the time of seed germination, a major portion of fat is converted into carbohydrates while the rest is utilised for respiration.

Fats are poorer in oxygen and the proportion of oxygen to carbon in fats is invariably less as compared to carbohydrates, hence they require more oxygen for complete oxidation. Apart from this, fats are not oxidised directly. They are first hydrolysed to fatty acids and glycerol. A fraction of oxygen is used up in this process. Due to these reasons equations given below indicate that the value of RQ of fats is found to be about 0.7, *i.e.*, less than unity.

$$\underset{\text{(Tripalmitin)}}{2\,C_{51}H_{98}O_6} + 145O_2 \longrightarrow 102CO_2 + 98H_2O$$

or

$$\begin{array}{l} CH_2OOC.C_{15}H_{31} \\ | \\ CHOOC.C_{15}H_{31} \\ | \\ CH_2OOC.C_{15}H_{31} \end{array}$$

$$RQ = \frac{CO_2}{O_2} = \frac{102\,CO_2}{145\,O_2} = 0.7$$

$$\underset{\text{(Triolein fat)}}{C_{57}H_{104}O_6} + 80O_2 \rightarrow 57CO_2 + 52H_2O$$

$$RQ = \frac{CO_2}{O_2} = \frac{57\,CO_2}{80\,O_2} = 0.7$$

However, simple fatty acids such as acetic acid liberate equal amount of CO_2 and in such cases RQ is unity.

$$\underset{\text{(Acetic acid)}}{CH_3COOH} + 2O_2 \longrightarrow 2CO_2 + 2H_2O$$

$$RQ = \frac{CO_2}{O_2} = \frac{2\,CO_2}{2O_2} = 1 \text{ or unity}$$

It is quite interesting to note that fats liberate more energy than carbohydrates. A gram of carbohydrate yields 3.8 kcal, while a similar amount of fat produces about 9.1 kcal. May be this is the reason why fats are common reserve food materials in seeds.

(3) Respiratory Quotient of Proteins and Derivatives

Proteins and amino acid derivatives serve normally as respiratory substrate only in seeds rich in proteins. The normal cells consume protein only during starving conditions. Otherwise, proteins are seldom respired.

Like fats, proteins are also compounds with lesser oxygen as compared to carbohydrates and the proportion of oxygen to carbon is invariably low. Proteins rarely serve as respiratory substrates but when they do serve their hydrolysis products require more oxygen for complete oxidation as a result of which, the value of RQ falls to less than unity. The RQ value of proteins fluctuates around 0.79. During protein oxidation, the value of RQ may be = 1.0(0.99) when ammonia is produced or 0.8 (0.79) when amide formation occurs. When amides are oxidised the RQ value rises above one.

(4) Respiratory Quotient of Succulents

In succulent plants such as *Opuntia* or members of the family *Crassulaceae* and in anthocyanin rich leaves, the complete oxidation of carbohydrate does not occur, as a result of which only intermediate products are formed without the production of CO_2. *At night,* when stomata are open in succulent plants, oxygen is absorbed and intermediate compounds are formed due to partial oxidation on account of which there is no evolution of CO_2 and the RQ value is found to be less than

one, mostly zero. In *day time*, when complete oxidation of intermediate acids occurs the CO_2 produced is used up in photosynthesis with the result that there is no evolution of CO_2 and RQ falls to zero.

$$2C_6H_{12}O_6 + 3O_2 \longrightarrow \underset{\text{(malic acid)}}{3C_4H_6O_5} + 3H_2O$$

$$2C_6H_{12}O_6 + 3O_2 \longrightarrow \underset{\text{(citric acid)}}{2C_6H_8O_7} + 4H_2O$$

$$RQ = \frac{CO_2}{O_2} = \frac{0}{3} = \text{Zero}$$

(5) Respiratory Quotient of Organic Acids

Organic acids are rich in oxygen and the proportion of oxygen to carbon is very high. When organic acids are used as respiratory substrate lesser oxygen is needed to be absorbed and more CO_2 is evolved with the result that RQ value is found to be more than unity.

$$\underset{\text{(Tartaric acid)}}{2C_4H_6O_6} + 5O_2 \longrightarrow 8CO_2 + 6H_2O$$

$$RQ = \frac{CO_2}{O_2} = \frac{8CO_2}{5O_2} = 1.6$$

$$\underset{\text{(oxalic acid)}}{2(COOH)_2} + O_2 \longrightarrow 4CO_2 + 2H_2O$$

$$RQ = \frac{CO_2}{O_2} = \frac{4CO_2}{1O_2} = 4$$

$$\underset{\text{(citric acid)}}{2C_6H_8O_7} + 9O_2 \longrightarrow 12CO_2 + 8H_2O$$

$$RQ = \frac{CO_2}{O_2} = \frac{12CO_2}{9O_2} = 1.33$$

$$\underset{\text{(malic acid)}}{C_4H_6O_5} + 3O_2 \longrightarrow 4CO_2 + 3H_2O$$

$$RQ = \frac{CO_2}{O_2} = \frac{4CO_2}{3O_2} = 1.33$$

Malic acid may also be converted into hexose, with the following intermediate stages. These reactions are popularly known as *Wood-Werkman reaction.*

$$2COOH.CH_2CHOH.COOH \longrightarrow 2COOH.CH_2CO.COOH + 4(H)$$

$$2COOH.CH_2CO.COOH \longrightarrow 2CH_3CO.COOH + 2CO_2$$

$$2CH_3.CO.COOH + 4(H) \longrightarrow \underset{\text{(hexose)}}{C_6H_{12}O_6}$$

If this hexose is partly respired, the RQ may increase to 1.33 or more. Sometimes RQ value is found to be 0.2 to 0.3 when the reaction gets associated with a combination of hexose respiration and organic acid synthesis at the expense of CO_2 *i.e.*,

$$C_6H_{12}O_6 + 2CO_2 \longrightarrow \underset{\text{(malic acid)}}{2C_4H_6O_5}$$

(6) Respiratory Quotient when Oxygen is Utilised for Other Metabolic Processes

Apart from respiration some other metabolic processes such as synthesis of anthocyanins and conversion of fats to carbohydrates also require oxygen. In such cases the amount of CO_2 evolved does not correspond to the amount of oxygen absorbed and, therefore, the value of RQ falls below unity. In *Bryophyllum,* leaves are capable of utilising CO_2 (liberated during respiration) for synthesizing organic acids in the dark, so the RQ value falls below unity.

(7) Respiratory Quotient of Maturing Fatty Seeds

During the maturation of fatty seeds simple carbohydrates are converted into fats. In the process oxygen is released but it is used up in respiration. As a result CO_2 is released during respiration but oxygen is not absorbed from outside. In such cases the value of RQ is found to be more than unity. But in germinating fatty seeds, RQ value falls below unity because of combined effect of the seed using fat substrate for respiration and also synthesizing carbohydrates from fats.

(8) Respiratory Quotient of Tissue Respiring in Absence of Oxygen

In absence of oxygen (anaerobic respiration) in which CO_2 is evolved without O_2 being absorbed, the RQ value is found to be more than unity.

$$C_6H_{12}O_6 \longrightarrow 2C_4H_5OH + 2CO_2$$

$$RQ = CO_2/O_2 = 2/0 = \text{infinity}$$

The following table enumerates RQ values in different plant parts and substrates.

Plants	*RQ*
1. Leaves rich in carbohydrate.	1
2. Darkened shoots of *Opuntia.*	0.03
3. Germinating starchy seeds	1
4. Germinating linseed (high fat).	0.64
5. Germinating buckwheat (high protein)	0.5
6. Germinating peas.	1.54-2.4