RESEARCH PAPER | International Journal of Agricultural Engineering | Volume 6 | Issue 2 | October, 2013 | 398–402

Mathematical modeling of respiration rate of moringa pods

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Received : 20.06.2013; **Revised :** 28.09.2013; **Accepted :** 27.10.2013

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■ **ABSTRACT :** Respiration rate is dependent on factors like storage temperature and composition of storage atmosphere, a mathematical approach to predict the respiration rate under given conditions would be an immense help in both design and process control of such storage systems. Experimental data were generated at temperatures of 14 and 28°C for moringa pods using the closed system method. The generated data were used in the model developed by Menon and Goswami (2008) for mango model based on regression analysis. The model was tested for its validity at 21°C and it showed good agreement with the experimentally estimated respiration rate.

■ **KEY WORDS :** Respiration rate, Oxygen, Carbon dioxide

■ **HOW TO CITE THIS PAPER :** Amuthaselvi , G., Varadharaju, N. and Ganapathy, S. (2013). Mathematical modeling of respiration rate of moringa pods. *Internat. J. Agric. Engg.*, **6**(2) : 398-402.

Moringa pod is a popular vegetable in South Indian food and valued for its distinct flavour and its nutritional values. All parts of the moringa tree are edible and have long been consumed by humans. The World Health Organization (WHO) stated that *Moringa oleifera* is a low cost supplement enhancer in the poorest countries around the world (WHO Readers Forum, 1999) and it promotes the use of the moringa plant to help those countries suffering from malnutrition, which is one of the major causes of death worldwide.

As there is an increasing demand for the leaves, pods, flowers and seed, its cultivation is eventually extended to larger areas every year. Production of moringa during peak seasons is in excess of local demand and hence, the farmers are not able to get remunerative price for their produce. It has been estimated that about one-fourth of all moringa produce harvested is spoiled before consumption (Arun Prabhu *et al.,* 2005).

Respiration can be defined as the metabolic process that provides energy for plant biochemical processes. It involves oxidative breakdown of organic reserves to simpler molecules, including CO_2 and water, with the release of energy. The significance of respiration in extending the shelf-life of fresh fruits and vegetables stems from the fact that there exists an inverse relationship between respiration rate and the shelf-life of the commodity. Respiration rate, which is commonly expressed as rate of O_2 consumption and/or CO_2 production per unit weight of the commodity, reflects the metabolic activity of the fruit tissue in the form of biochemical changes associated with ripening and senescence (Fonseca *et al.,* 2002).

Modelling of respiration rate gives an advanced insight into the respiratory kinetics of the storage system. This helps select appropriate packaging materials when designing modified atmosphere (MA) packaging systems, identifying the vital heat in calculation of refrigeration load, select fan size and location for optimal air flow within controlled atmosphere (CA) facilities and formulate appropriate process control for ventilating storage facilities. Thus, the accurate modelling of respiration kinetics is an important step in the successful design and operation of storage techniques for horticultural produce (Menon and Goswami, 2008).

Many models have been proposed for the prediction of respiration kinetics of different fruits and vegetables under different storage conditions. Respiration rate is dependent on multiple factors including storage temperature, gas composition, variety and maturity of the commodity. Most models have been developed by either considering the respiration rate as a function of the gas concentration or the time elapsed (Yang and Chinnan, 1988; Cameron *et al.,* 1989; Talasila *et al.,* 1992; Makino *et al.,* 1996; Lee *et al.,* 1991). Model parameters are then suitably modified for temperature dependence based on an Arrhenius type of relationship (Lakakul *et al.,* 1999; Hertog *et al.,* 1998).

The controlling mechanisms of all these models are

either based on best fit, the principle of enzyme kinetics or adsorption theory. Among the models, the most theoretically based model is the Michaelis–Menten equation which is based on the principle of enzyme kinetics but simplifies the complex pathway of respiration assuming it to be based on one limiting enzymatic reaction where the substrate is O_2. The objective of the study was to conduct the respiration study of moringa pods and tested with the model developed by Menon and Goswami (2008) for mango and for its suitability to predict the respiration rate of moringa pods (local variety) as a function of O_2 and CO_2 concentrations and the storage temperature.

METHODOLOGY

In this study, moringa of cultivar local variety harvested in August 2012 in a farmer's field located in Thondamuthur was used. Matured vegetables of uniform size pods were selected and washed with water to remove the adhering dirt and used for respiration study.

Respiration rate of moringa was determined using closed system approach. Respiration chambers for moringa were designed using PVC pipe. The PVC pipes, 75 cm long and of 15 cm diameter were enclosed at the bottom with an end cap and at the top with a specially designed PVC flange. The capacity of the respiration chamber was 13 litres. A rubber gasket was provided between the top flange and the pipe section and air tightness was ensured by means of 12 bolts and nuts. Two septum were provided on the top flange for drawing gas samples for analysis.

One kg of moringa was used in all experiments. The free volume in the respiration chamber was estimated as 12.5 litre. The influence of temperature on respiration rate was determined by conducting experiments at 14 and 28º C. Three replications were done for each experiment. For 14ºC gas samples were taken at an interval of 24 h and for 28ºC, 3 h interval was maintained owing to rapid rate of respiration at higher temperature.

Gas samples were analyzed quantitatively for O_2 and CO_2 concentrations using a gas analyzer (MAP check combi model of PBI-Dansensor). The respiration rate was estimated using the following equations of mass balance (Cameron *et al.,* 1989).

$$\mathbf{RRO_2} = \frac{(\mathbf{Y_{O_2}^{t_i} - Y_{O_2}^{t_f}}) \mathbf{x\ V}}{\mathbf{100\ x\ M\ x\ (t_f - t_i)}} \quad (1)$$

$$\mathbf{RRCO_2} = \frac{(\mathbf{Y_{CO_2}^{if} - Y_{CO_2}^{ti}}) \mathbf{x\ V}}{\mathbf{100\ x\ M\ x\ (t_f - t_i)}} \quad (2)$$

RRo_2 and $RRco_2$– Respiration rate, in terms of O_2 and CO_2, respectively, ml/kgh.

Yo_2^{ti} and Yo_2^{tf}- Volumetric concentration of O_2 at initial and final time, respectively, %.

Yco_2^{ti} and $Y\ co_2^{tf}$ - Volumetric concentration of CO_2 at initial and final time, respectively, %.

t_i and t_f - Initial and final time, respectively, h

M - Mass of the stored product , kg

V - Free volume , L.

The respiration rate of a commodity is assumed as a function of oxygen concentration at a determined temperature and the respiration rate was modeled based on enzyme kinetic reactions as per Michaelis- Menten type of equation. The generated experimental data were fitted in the model developed by Mahajan and Goswami (2001) as given in Eqn. (3) and (4).

$$\mathbf{G_{O_2}} = \mathbf{0.21} - \left(\frac{\mathbf{t}}{\mathbf{at + b}}\right) \quad (3)$$

$$\mathbf{G_{co_2}} = \left(\frac{\mathbf{t}}{\mathbf{at + b}}\right) \quad (4)$$

where ,

t = Storage time, h

G_{CO2} = Carbon dioxide concentration, decimal

G_{O2} = Oxygen concentration, decimal.

In the Eqn. 3 and 4 was fitted to the experimental data and the respiration rate was plotted as a function of oxygen and carbon dioxide concentration. The constants 'a' and 'b' were obtained using non-linear regression using Sigmaplot 8.0 software.

Testing the model :

The model was tested against experimental data determined at 21ºC for their validity. The respiration rates at 21ºC were determined from the experimental data using Eqs. (1) and (2). Predicted values for respiration were estimated using the model. The experimental and predicted values were then compared using the mean relative deviation modulus as shown in Eqn. 5. to identify the best fit of the model (McLaughlin and O'Beirne, 1999).

$$\mathbf{E} = \frac{\mathbf{100}}{\mathbf{N}} \sum_{\mathbf{1}}^{\mathbf{N}} \left(\frac{\mathbf{R_{exp} - R_{pre}}}{\mathbf{R_{exp}}}\right) \quad (5)$$

where,

E is the mean relative deviation modulus in %

N is the number of respiration data points

R_{exp} is the experimental respiration rate in ml/kg. h

and R_{pre} is the predicted respiration rate in ml/kg. h.

RESULTS AND DISCUSSION

The results of the present study as well as relevant discussions have been presented under following sub heads:

Change in oxygen concentration in the chamber due to respiration

In moringa pods, oxygen and carbon dioxide

concentration during respiration study were recorded and presented in Fig. 1.

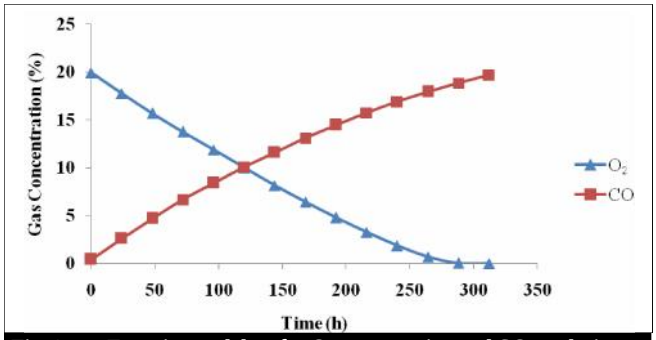

Fig. 1 : Experimental data for O_2 consumption and CO_2 evolution at 14°C for moringa pods (Local variety)

Initial oxygen concentration in the chamber with one kg of moringa was found to be 19.91% at 14ºC and 19.92 % at 28°C. The oxygen concentration in all the chambers continued to decrease with time, and oxygen was completely depleted in 312 h at 14ºC and 57 h at 28ºC. In these experiments, oxygen consumption rate increased with temperature.

The initial respiration rates of (RO_2) of moringa were 9.23 and 39.05 ml kg^{-1} h^{-1} at 14 and 28°C, respectively. The average respiration rate was 6.07 ml kg^{-1} h^{-1} at 14º C (Fig. 2). At 28ºC the average respiration rate was 30.33 ml kg^{-1} h^{-1} at 28ºC (Fig. 3). The concentration of oxygen dropped from 19.6 to 2 per cent within 36 h at 28ºC and where as it took 216 h to drop to 2 per cent at 14ºC. The experimental data revealed that the respiration rate increased with the increase of temperature. Aerobic respiration may be reduced by decreasing the available O_2, but only to a critical level below which anaerobic respiration starts.

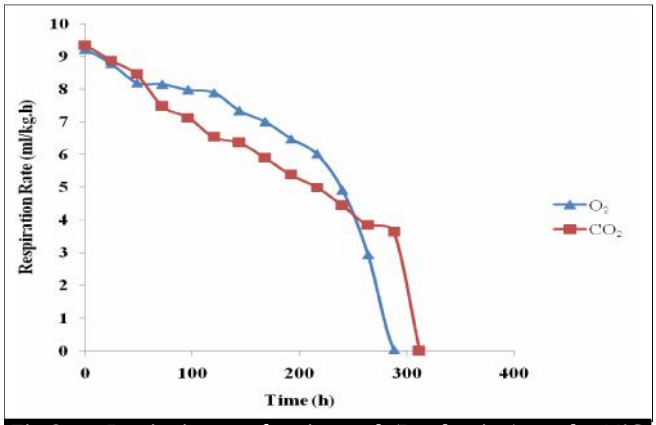

Fig. 2 : Respiration rate of moringa pods (Local variety) stored at 14°C

These data suggest that in all these cases the rate of respiration is constrained by the progressive depletion of oxygen within the chamber. Therefore, true value of

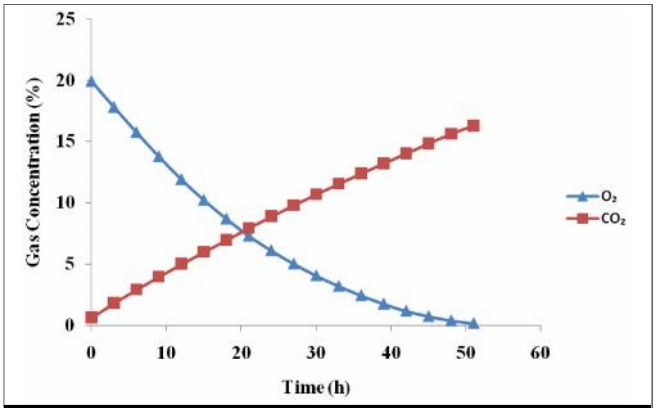

Fig. 3 : Experimental data for O_2 consumption and CO_2 evolution at 28°C for moringa pods (Local variety)

respiration rate is reflected only in the initial spell before reaching a peak value. Respiration rates obtained at the latter periods do not reflect the true respiration.

The temperature has been identified as the most important factor influencing the respiration behavior of fruits and vegetables (Saltveit, 2004). The high temperature hastens the respiration process, with subsequent increase in substrate breakdown (Ramaswamy and Raghavan, 1995).

The data show that the respiration was less at lower temperatures. There was more than eight fold increase in the respiration rate when temperature was increased from 14°C to 28°C. Such a behavior signifies that low temperature is desirable to gradually slow down the respiration process and allow the minimum possible respiration rate that could keep the tissues alive for longer periods. The fast decline in the respiration rate at high temperature could also attribute to the malfunctioning of the enzymes which catalyses the respiration process. Enzymes are made of protein compounds which are easily denatured if the surrounding temperature is beyond their optimum level. A similar trend was observed for the respiration of banana by Bhande *et al.* (2008).

Spinach, like many leafy vegetables, has limited reserves of substrates (Burton, 1974), therefore, the respiration rate is likely to start declining just a few hours after storage.

Limited oxygen could reduce the respiration rate by interfering with the enzymatic activities that occur simultaneously with the respiration process. In the glycolytic pathway, the enzyme which catalyses conversion of fructose-6-phosphate to fructose biphosphate is reported to be inhibited by ATP and citric acid. Both compounds are formed in an oxygen dependent TCA cycle (Burton, 1982 and Kays, 1991).

Change in carbon dioxide concentration in the chamber due to respiration :

The initial carbon dioxide concentration in the chamber

was 0.4 % at 14ºC (Fig. 1). The respiration rate (RCO_2) decreased gradually from an initial value of 11.72 ml kg^{-1} h^{-1} to a final value of 6.16 ml kg^{-1} h^{-1}in a time period of 240 h (Fig. 4).

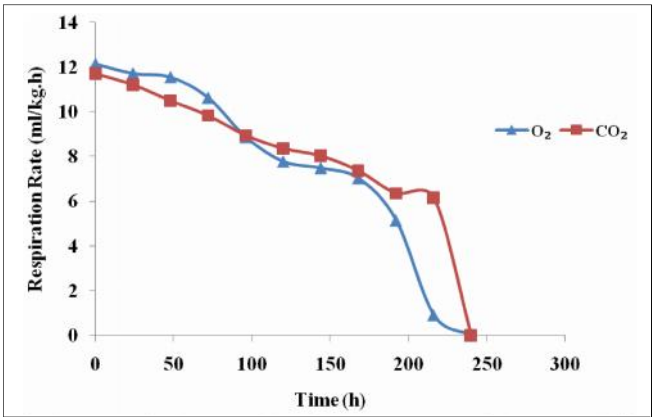

Fig. 4 : Respiration rate of moringa pods (Local variety) stored at 14°C

The initial carbon dioxide concentration in the chamber was 0.6 % at 28ºC (Fig. 3). The respiration rate (RCO_2) decreased gradually from an initial value of 39.05 ml kg^{-1} h^{-1} to a final value of 18.22 ml kg^{-1} h^{-1}in a time period of 57 h (Fig. 4.). The gas concentrations reached their upper limit (CO_2 > 18%) after 288 h at 14ºC and 51 h at 28ºC. The CO_2 evaluation was an average rate of 5.88 ml kg^{-1} h^{-1} at 14ºC and 27.43ml kg^{-1} h^{-1} at 28ºC. It is observed that the respiration rate decreased with the increase of carbon dioxide concentration. High temperature increased the impact of high carbon dioxide on the respiration rate of moringa pod.

The high carbon dioxide may have impeded the forward reaction which resulted in the breakdown of sugars. Some researchers have also attributed the effect to the increase in the concentration of CO_2 in the cell sap, which normality changes the balance of reactants and products of other subsidiary metabolic pathways prevailing in the plant cells (Burion, 1982).

Peiris *et al.* (1997) conducted study using immature pods of moringa at four different storage temperatures namely 0,5,10 and 20ºC. Carbon dioxide concentration was recorded and respiration rate was reported. The carbon dioxide respiration rate of moringa was 28, 58, 141 and 301.6 mg/kg. h at 0,5,10 and 20°C, respectively. Comparatively in this study, the value is 16.96 per cent lower to the above result which was due to respiratory climacteric

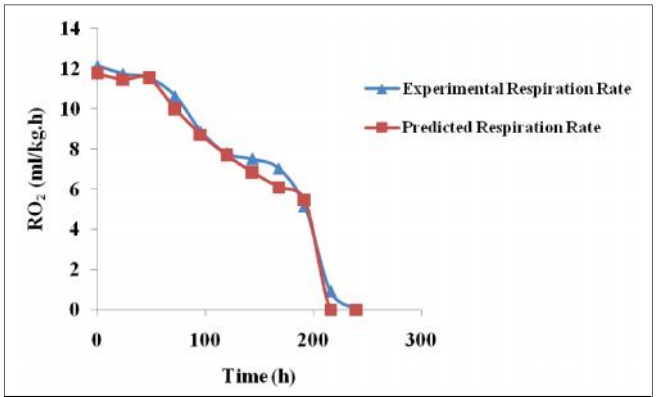

Fig. 5 : Measured and predicted respiration rates of oxygen for moringa pods at 21°C

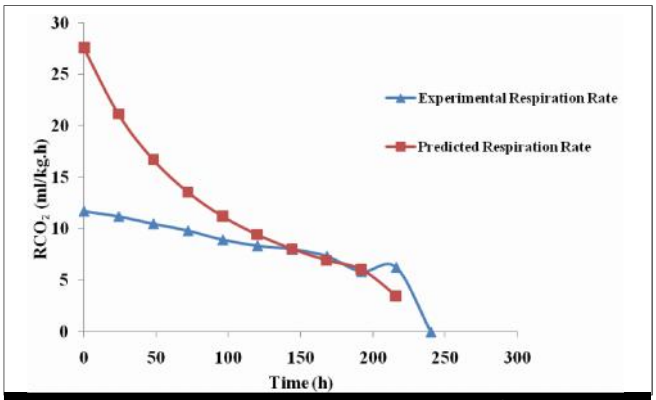

Fig. 6 : Measured and predicted respiration rates of carbon dioxide for moringa pods at 21°C

and substantial genetic diversity found in the crop. The individual crop respiration rate changes due to maturity, cultivar, growing and handling conditions.

Vegetables include a great diversity of plant organs (roots, tubers, seeds, bulbs, fruits, sprouts, stems and leaves) that have different metabolic activities and consequently different respiration rates. Even different varieties of the same product can exhibit different respiration rates (Fidler and North, 1967; Gran and Beaudry, 1992; Song *et al.*, 1992).

Alban *et al.* (1940) stated that respiration rate changes because of cultivar, maturity difference, production environment and preharvest crop management practices.

Parameter estimation for the model :

The values of the coefficients a and b determined for

Table 1 : Values of constants 'a', 'b' and regression coefficients (R^2) for local moringa pods at different storage temperatures

Storage temperature (^{0}C)	O_2			CO_2		
	a	b	R^2	a	b	R^2
14	1.9079	829.0554	0.9946	2.048	937.0084	0.9995
28	2.9835	90.7301	0.9953	1.7593	225.7574	0.9983

Eqs. (3) and (4) for different temperatures with the corresponding R^2 values are given in Table 1. The experimental data fitted well with the regression equation with R^2 values >0.99. From the values of the regression coefficients a and b in the Table 1, it can be inferred that both the parameters were influenced by the storage temperature and that coefficient b was more influenced by temperature than coefficient a. For any unknown temperature, the value of a and b can be determined by linear interpolation of the known values. The respiration rates for the given temperature can then be determined using Eqs. (1) and (2).

Verification of the models :

The model parameter estimated was then verified by comparing predicted and experimental respiratory rates at 21°C and shown in Fig. 5 and 6. The model based on regression analysis gave the best fit for RO_2 with an mean relative deviation modulus of 12.68 %. However, for RCO_2, its mean relative deviation modulus value was poorer at 28.66 %.

Conclusion :

The suitability of model for predicting the respiration rate of moringa pods was investigated using experimental data generated using a closed system method at different temperatures. The model was verified for goodness of fit at 21°C and the model based on enzymatic kinetics.

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