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Research Article

Neural Network Modeling of Respiration Rate of Litchi

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Abstract

Litchi is one of the most environmentally sensitive tropical fruits crop. It is popular export cultivar due to its attractive red color and high fruits quality. Pericarp browning, desiccations, loss of quality and post harvest decay have been identified as major problems restricting expansion of the industries in litchi exporting countries. Modified atmosphere packaging (MAP) has been considered to be beneficial to maintain high humidity essential for prevention of water loss and browning of litchi pericarp. Accurate measurement of respiration rate and its modeling is an important aspect to the success of design and operational features of techniques like modified atmosphere storage. The respiration data generated at temperatures 0-30 ^oC in the step of 5 for litchi using the closed system method was used for modeling respiration rate using neural network technique. Here O_2, CO_2, temperature and time are considered as independent parameters and respiration rate as the dependent parameters. To establish a specific relationship between these parameter using neural network modeling three layers are taken i.e. input layer, output layer and a hidden layer. In this method first of all the experimental values are coded in between -1 to +1. Then by use of mathematical formulations in MATLAB programming the out put response (respiration rate) with respect to O_2 and CO_2 was found out at any specific temperature. This respiration rate provides the basis for modeling of modified atmospheric packaging system. In the MATLAB program using neural network the respiration rate can be obtained by giving the storage period and concentration of O_2 and CO_2 at specified temperature. The relative deviation at different storage temperature was found out and it is in good agreement with that of experimental values.

Key words: Litchi, fruits, Respiration, temperature

INTRODUCTION

Litchi is a non-climacteric fruit and its shelf life at room temperature is less then 72 hours (Kadam and Deshpande, 1995). Litchi is a popular export fruit due to its attractive red color, excellent aroma and high fruit quality.

Litchi is an excellent source of ascorbic acid containing about 44 mg/100 g pulp (Chadha and Rajkot, 1969). Most Indian varieties range in sugar content from 10-13%. The carbohydrate and protein content of the litchi varies from 13-15% and 0.8-

1.5%, respectively (Kadam and Deshpande, 1995). Pericarp browning, desiccation, loss of quality and post harvest decay have been identified as major problems restricting expansion of the industries in litchi exporting countries (Sivakumar and Korsten, 2006). The fruit litchi (*cv. shahi*) is a small fruit, with shape index of 1.21 (Singh and Babita, 2002). This is the most popular cultivar grown in India. Besides, having high quality, it has a distinct rose-like aroma and hence is called 'Rose Scented' (Singh and Babita, 2002). This cultivar occupies a major area under litchi in India. Modified atmosphere packaging (MAP) has been considered to be beneficial to maintain high humidity essential for prevention of water loss and browning of litchi pericarp (Tian, et al, 2005; Mangaraj and Goswami, 2009a; Mangaraj and Goswami, 2011a).

In the storage and transportation process of fresh fruits and vegetables, respiration rate control plays major role in prolonging the self-life of the product. The lowering of O_2 gas concentration and elevating the CO_2 gas concentration surrounding the produce are usually effective for respiration depression. Aerobic respiration consists of oxidative breakdown of organic reserves to simpler molecules, including CO2 and water, with release of energy. Due to these metabolic processes in fruits, which continue even after harvest the self-life of the product is reduced. These metabolic processes were found to be reduced at low temperature and under MA conditions thus increasing the shelf life to a certain level (Mangaraj and Goswami, 2008; Mangaraj and Goswami, 2009b).

Various mathematical models have been developed to correlate the respiration rate with different storage parameters such as gas composition *i.e.* O_2 and CO_2 and temperature. Yang and Chinned (1988) used a quadratic function to correlate the respiration rates of tomato with O_2 and CO_2 concentrations and storage time. The effect of temperature on respiration rate was not considered in their models. The models adequately predicted the respiration rate of tomatoes stored in a controlled atmosphere. They have suggested an enzyme kinetics theory for modelling of respiration rate. Cameron *et al*. (1989) used an empirical approach to measure the respiration rate as a function of O_2 concentration by observing the rate of O_2 depletion in a closed system. Talasila *et al*. (1992) developed a non-linear empirical model for predicting the respiration rate of strawberry as a function of temperature, O_2 and CO_2 concentration. Most of the models have not incorporated one or other independent factors such as O_2, CO_2, temperature and time hence, are not flexible enough to predict the respiration rate at various storage conditions. Hence by considering all these factors a specified relationship was established between all these four parameters using Neural Network (NN). So the independent parameters are O_2, CO_2, temperature and time on which respiration rate depends (Das, 2005; Mangaraj et al., 2009). Hence the dependent parameters considered are respiration rate with respect to O_2 and CO_2.

Neural network is a simplified model of animal nervous system. The nervous system consists of nerve cells or neurons. These are connected by treelike nerve fibers called dendrites. These dendrites receives electrochemical signal from several neurons through 'synaptic joints' and pass them to the neurons, the output channel of which is called axon. An axon is connected to the other dendrites again through synaptic joints. A single neuron can have many synaptic inputs and synaptic outputs. A neuron receives inputs through dendrites, sums them and produces an output only when the sum is greater than a threshold or bias value of the neuron. Speed of learning or pattern recognition is characterized by the repeated electrochemical potential transmittance through the synapses, area of synaptic junctions and threshold electrochemical potential of the neurons (Das, 2005; Hopfiled, 1982; Brown et al., 2004; Yang et al., 2008; Strukov et al., 2008).

To get a better fit form regression analysis the relationship between a set of independent variables X and the dependent variables Y can be obtained by using the method of neural network. This is an algorithm based on the way animal brain recognizes a pattern or relationship from the impressions it receives through nerve cells located at different parts of the body. Neural network 'learns' directly from the pairs of input X and output Y data and develops a relationship between them but does not yield any mathematical equation relating the variables. After learning the network is able to find the correct output from input data set that has not been previously used during the 'learning'.

MATERIALS AND METHODS

Determination of Respiration Rate

Fresh mature litchi (cv. Shahi) was obtained from Baruipur farm (India). Fruits were washed to remove adhering dirt, and used for the study. Care was taken to ensure that the fruits were of uniform size and weight (Mangaraj and Goswami, 2009c). The respiration rate data was experimentally generated for different temperatures using the closed system method (Menon Rekha and Goswami, 2008; Bhande et al., 2008; Mangaraj and Goswami, 2011a &b). Gas analysis was done till aerobic respiration persisted (Hagger et al., 1992). Changes in the O_2 and CO_2 concentration for a certain period of time at a particular temperature were measured and used to estimate respiration rates. Storage gas sample of about 1ml was taken periodically with an airtight syringe and was analyzed quantitatively for O_2 and CO_2 concentrations using gas chromatograph (GC model 100, Knaur, Germany). The sampling intervals were different for different storage temperatures. The experimental respiration data obtained from the closed system respirometer was used to calculate the experimental respiration rate using the following equations as given by Kays (1991).

$$R_{O2} = \left[\frac{(Y_{O2})_t - (Y_{O2})_{t+1}}{\Delta t}\right]\frac{V_f}{W}$$

$$R_{CO2} = \left[\frac{(Z_{CO2})_{t+1} - (Z_{CO2})_t}{\Delta t}\right]\frac{V_f}{W}$$

where, R_{O2} is the respiration rate, ml $[O_2]$ $kg^{-1}h^{-1}$, R_{CO2} is the respiration rate, ml $[CO_2]$ $kg^{-1}h^{-1}$, Y_{O2} and Z_{CO2} are the gas concentrations for O_2 and CO_2, respectively in decimal, t is the storage time in h, Δt is the time difference between two gas measurements, V_f is the free volume of the respiration chamber in ml and W is the weight of the fruit in kg.

Two different approaches were attempted to model the respiration rate based on the experimental data as outlined below.

Modelling of Respiration Rate by Application of Neural Network

Neural network consists of developing a set of interconnected elements called neurons; the connections are largely parallel .A layer of neuron acts as input and another as output Number of neurons in the input layer is equal to number of independent variables and the number in the output layer the number of dependent variables. Between the input and output layers a hidden layer is usually made less than two times the number of neurons in input layer .The network thus created is called as ‘ Feed forward back propagation network’.

Weights of interconnected lines between ‘input to hidden’ and ‘hidden to output’ layer neurons and the ‘threshold’ or bias values of the hidden and output layer neurons are altered during the learning or training of network so that a given input data fed to the input layer neurons will lead to specific target output through output layer neurons. Typically several input and target data pairs are used during learning. After the appropriate learning, network establishes values of appropriate ‘weights’ of interconnecting lines and the threshold or bias values of hidden and output layer neurons. A ‘trained’ neural network gives higher degree of fit between actual and predicted values of response than that is possible from second degree regression equation.

Process Modeling

In Neural networking it is convenient to handle the input and output data sets by coding them .We did the coding of input data sets for developing the regression equation. In the present case, coding of the input data sets (i.e., X_1, X_2, X_3,….) was carried out within range -1 and +1, while the output data sets (i.e., Y_1, Y_2, Y_3…….) between 0 and +1. If X_{max} and X_{min} represent respectively the maximum and minimum values of an input variable X, and x is its coded value such that the coded value of X_{max} is +1 and that of X_{min} is -1, the relationship between X and x can be expressed by the following equations.

$$X_M = \left(\frac{X_{max} + X_{min}}{2}\right)$$

$$X_D = X_{max} - X_M$$

$$x = \left(\frac{X - X_M}{X_D}\right)$$

$$X = x.X_D + X_M$$

These equations were used for developing the relationship between actual (Y) and coded y values of dependent variables such that the coded value of Y_{max} is +1 and that of Y_{min} is 0. A new parameter is introduce i.e. Y_{mins} representing pseudo-minimum of actual minimum Y_{min}, which is expressed as,

$$Y_{minps} = Y_{min} - (Y_{max} - Y_{min})$$

The relationship between Y and y will be expressed as,

$$Y_M = \left(\frac{Y_{max} + Y_{minps}}{2}\right)$$

$$Y_D = Y_{max} - Y_M$$

$$y = \left(\frac{Y - Y_M}{Y_D}\right)$$

$$Y = yY_D + Y_M$$

The neural network modeling was done for one input, one hidden and one-output layer neurons. Connecting lines between the neurons represent the synaptic joints and the weights associated with these lines represent electrochemical potential conductance of the joints. Each of the neurons in the hidden and output layer has been shown with a bias or threshold value. When the input received by a neuron in the hidden or output layer exceeds its threshold value, an output is produced (Fig. 1). In the feed forward back propagation network, computational sequence follows (for prediction of dependent variables) from input to hidden and then hidden to output layer. Error value computed the actual and predicted values of dependent variable) is propagated backward (from output to hidden layer and then from hidden to input layer) in such a way that the new values of weight of connecting links and the biases at hidden and output layer is established. When this forward and backward computations are repeatedly carried out for some of the input and output data pair for a large number of time, the resulting weights of synaptic joints and the biases are able to give the correct values of output from an input data set fixed within the range of the input data previously used for the training of network.

Hence experiments were carried out and a set of data containing (i) values of independent parameters (X_1, X_2, X_3……) and (ii) the corresponding values of responses ($Y1_1$, Y_2, Y_3,….) were obtained. It has been observed that these data can be related by using regression equations. It has been observed that one of the measures of the degree of fitness between the actual and predicted values of response is relative deviation percent 'R_d'. Increasing the degree of regression equation can increase the value of R_d. Thus a second degree (e.g., $y=b_0+b_1x_1+b_2x_2+b_3x_1^2+b_4x_2^2+\ldots$) equation would give a better fit than a fast degree (i.e. $y = b_0 + b_1x_1 + b_2x_2 + \ldots..$), a third degree (i.e. $= b_0 + b_1x_1 + b_2x_2 + b_3x_1^2 + b_4x_2^2 + b_5x_1^3 + b_6x_2^3 + \ldots\ldots$), would give a better fit than a second degree and so on. Number of constants used in the regression equation however, increase with the increase in the degree of the equation (Das, 2005; Hopfiled, 1982).

Neural Network's methodology

- Neural Network is an algorithm based on the way animal brain recognizes a pattern or relationship from the impressions, it receives through nerve cells located at different parts of the body
- Neural network 'learns' directly from the pairs of input X and output Y data and develops a relationship between them
- After the learning the network is able to find the correct output from input data set
- A layer of neuron acts as input and another as output. Number of neurons in the input layer is equal to number of independent variables and number of neurons in the output layer is equal to number of dependent variables
- Between the input and output layers a hidden layer is usually made less than two times the number of neurons in input layer
- The network thus created is called as ' Feed forward back propagation network'

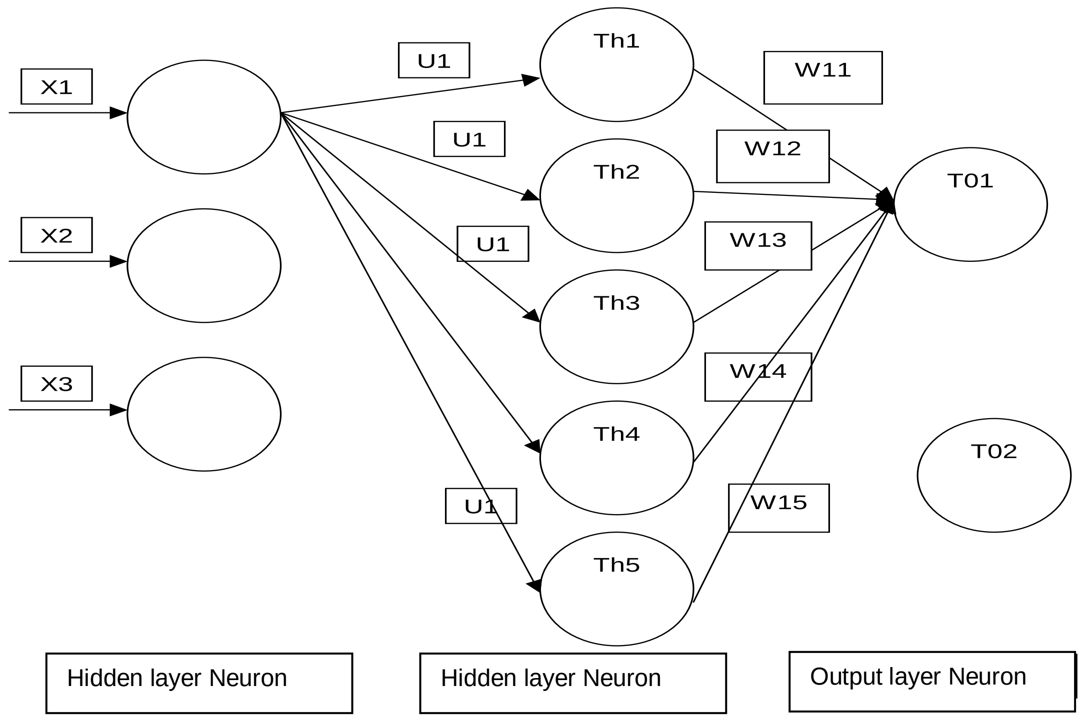

Fig. 1: Diagrammatic representation of Neural Network

Coding and models in Neural Network

- nx is the number of independent variable
- Coding of the parameters in the range -1 and +1
- ny is the number of independent variable
- Coding of the parameters in the range 0 and +1
- A single output data set is represented by a row matrix 'y' of size (1*ny)
- u = Weight of synaptic joints between the input and hidden layer neuron and its size is (nx*nh),

Where

  - nx is the number of independent variable
  - nh is number of hidden layer neurons

- The element of u matrix is lies between -1 and +1which are formed by method of random number generation.
- Th = The biases or threshold values of hidden layer neurons

  It is a vector or column matrix of size (nh*1).
- The elements of matrix are assumed to lie between -1 and +1 and formed by method of random number generation.
- w = The weights of synaptic joint between hidden and output layer neuron and its size is (nh*ny)

  Here, ny is the number of neurons in the output layer.
- The values of w matrix are assumed to lie between +1 and -1 and formed by method of random number number generation.

- To is the bias or threshold values of the output layer neurons which is a vector or column matrix of size (ny*1).
- Initial values of To matrix is fixed between +1 and -1.
- yh = computed output values of hidden layer neurons.
- yo = computed output values of output layer neurons.
- eh = Back propagation error at the hidden layer neuron.
- eo =Back propagation error at the output layer neurons.
- The back propagation error eo and eh are used for updating the values u, w, Th and To in the next computation cycle.
- This process is called as ‘training’ where the network ‘learns’ to relate a given input output data pair.
- This type of learning method is known as the ‘gradient descent method’ of learning.

Output yh of hidden layer neuron is

$$yh = \frac{1}{1+\exp[-(u'*x'+Th)]}$$

Where u' and x‘ are the transpose of matrices u and x

- The size of yh matrix = (nh*1).
- Output yo at the output layer neuron is

$$yo = \frac{1}{1+\exp[-(w'*yh+To)]}$$

- Since the size of matrix w is (nh*ny) and that of yh is (nh*1), size of yo matrix will be (ny*1).
- Computed value of error eo at the output layer neuron is

$$eo = (y'-yo)_o * yo_o * (w*eo)$$

Here y' is the transpose of the matrix y

- eo is a scalar product of matrices (y'-yo), yo and (1-yo).
- The size of matrix eo = (ny*1).
- Computed value of error eh at the hidden layer neuron is

$$eh = yh_o * (1-yh)_o * (w*eo)$$

- Matrixes yh and (1-yh) form scalar product whereas, (w*eo) is a vector product.
- Size of the matrix eh = (nh*1).
- New values of bias or threshold parameter To_{new} of output layer neurons for the next computation cycle is

$$To_{new} = L*eo+To$$

- L is the learning rate the value of which lies between 0.6 and 0.9
- New values bias or threshold parameter Th_{new} of hidden layer neurons for next computation cycle is

$$Th_{new} = L*eh+Th$$

- Values of weights u_{new} of lines joining the input and hidden layer neurons is

$$u_{new} = x'*L*eh'+u$$

- Values of weights w_{new} of lines joining the hidden and output layer neuron for next computation cycle is given by,

$$w_{new} = L*yh*eo'+w$$

- A single computation cycle carries out this procedure for all the data pairs.
- Establishment of final values of u, w, Th and To by large number of computation cycles for getting the values of yo for all input data.
- Conversion of coded values of yo to real values. By this method relative deviation percent between the actual and estimated values of dependent variable will reduce gradually with the completion of computation cycles.

Steps in Neural Network

i. In this method, the initially assumed values or weight of synaptic joints between the input and hidden layer neurons (u), those between hidden and output layer neurons (w), bias or threshold values of hidden layer neurons (Th) and those of output layer neurons (To) are obtained through random number (lying between 0 and +1) generation.

ii. In NN at a given time, only one out of n sets of input-output data is utilized. Hence a single input dataset is represented by a row matrix ‘x’ of size (1*nx) and a single output datasets is represented by a row matrix ‘y’ of size (1*ny).

iii. For starting the NN calculation, the values of first set of input data or row matrix (x), the output dataset or row matrix (y), which may combinable to be called as the ‘input-output data pairs’, the assumed values (matrix) of u, w, Th and To (obtained through random number generation) are used to find out the values (matrix) of yh, yo, eo and eh by using the above equations.

iv. Then taking the value of the learning rate parameter L as 0.6, the new values of u, w, Th and To are calculated as u_{new}, w_{new}, Th_{new} and To_{new} respectively.

v. The new values of u, w, Th and To as obtained above (by using the first set of input-output data pairs and initially assumed values of u, w, Th and To, to find the values of yh, yo, eo and eh and then taking the learning rate parameter ‘L’) are to be used for the second set of input-output data pairs.

vi. Like this the new values of u, w, Th and To obtained by using the second set of input-out data pairs are to be used for third set of input-output data pairs and so on. It must be emphasized that these network parameters depend on the initially assumed values for u, w, Th and To that were obtained through random number generation.

vii. A single computation cycle carries out this procedure on all the input-out data pairs (experimental input-output data pairs). After a large number of computation cycles (say N=5000), final values of u, w, Th and To will give the final values of ‘yo’ for all the input data sets.

viii. It should be noted that the ‘yo’ are the coded values, which lies between 0 and +1. These coded values are then converted to their real values by using the above appropriate equations. The relative deviation percent between the actual (i.e.Y_1 and Y_2) and estimated values of dependent variables will reduce gradually with the completion of each of the computation cycles.

RESULTS AND DISCUSSION

Initially assumed values of u, w, Th and To were obtained through random number generation. A single computation cycle carries out this procedure for all the data pairs. After a large number of computation cycles, final values of u, w, Th and To are established. By taking these values the output parameter yo for all input data are calculated. Here yo is the coded value, which lies in the range of 0 and +1. Finally these coded values are then converted to real values. The final values of u, w, Th, To at 5, 10 and 15°C are presented as follows:

Final values of u, w, Th, To at 5 °C:

$$u = \begin{pmatrix} 0.88 & 0.92 & 0.02 & 0.19 & 0.94 \\ 0.12 & 0.45 & 0.30 & 0.52 & 0.25 \\ 0.68 & 0.30 & 0.43 & 0.63 & 0.26 \end{pmatrix}_{3\times5}$$

$$w = \begin{pmatrix} 0.12 & 0.84 \\ 0.94 & 0.22 \\ 0.13 & 0.31 \\ 0.52 & 0.01 \\ 0.93 & 0.42 \end{pmatrix}_{5\times2}$$

$$Th = \begin{pmatrix} 0.82 \\ 0.40 \\ 0.39 \\ 0.58 \\ 0.38 \end{pmatrix}_{5\times1}$$

$$To = \begin{pmatrix} 0.66 \\ 0.38 \end{pmatrix}_{2\times1}$$

Final values of u, w, Th, To at 10 °C:

$$u = \begin{pmatrix} 0.95 & 0.49 & 0.46 & 0.44 & 0.92 \\ 0.23 & 0.89 & 0.02 & 0.62 & 0.74 \\ 0.76 & 0.82 & 0.79 & 0.18 & 0.61 \end{pmatrix}_{3\times5}$$

$$w = \begin{pmatrix} 0.41 & 0.06 \\ 0.94 & 0.35 \\ 0.92 & 0.81 \\ 0.41 & 0.01 \\ 0.89 & 0.14 \end{pmatrix}_{5\times2}$$

$$Th = \begin{pmatrix} 0.20 \\ 0.20 \\ 0.60 \\ 0.27 \\ 0.20 \end{pmatrix}_{5\times1}$$

$$To = \begin{pmatrix} 0.02 \\ 0.65 \end{pmatrix}_{2\times1}$$

Final values of u, w, Th, To at 15 °C:

$$u = \begin{pmatrix} 0.20 & 0.25 & 0.95 & 0.59 & 0.62 \\ 0.41 & 0.31 & 0.97 & 0.69 & 0.91 \\ 0.66 & 0.68 & 0.19 & 0.24 & 0.78 \end{pmatrix}_{3\times5}$$

$$w = \begin{pmatrix} 0.42 & 0.34 \\ 0.78 & 0.20 \\ 0.65 & 0.09 \\ 0.54 & 0.13 \\ 0.77 & 0.15 \end{pmatrix}_{5\times2}$$

$$Th = \begin{pmatrix} 0.27 \\ 0.71 \\ 0.14 \\ 0.79 \\ 0.81 \end{pmatrix}_{5\times1}$$

$$To = \begin{pmatrix} 0.40 \\ 0.09 \end{pmatrix}_{2\times1}$$

Using the final values of u, w, Th, To at 5, 10 and 15°C the neural network calculated the respiration profile of litchi fruit. The respiration rate of litchi calculated by the Neural Network models and obtained thorough the experiments were compared as shown in Fig. 2. The mean relative deviation moduli between the respiration rates of Litchi at 12 ºC predicted by Neural Network model and that obtained through experiments were 8-11% for O_2 consumption and CO_2 evolution. The results indicate that Neural Network model have good fit for predicting the respiration rate for O_2 consumption and CO_2 evolution,

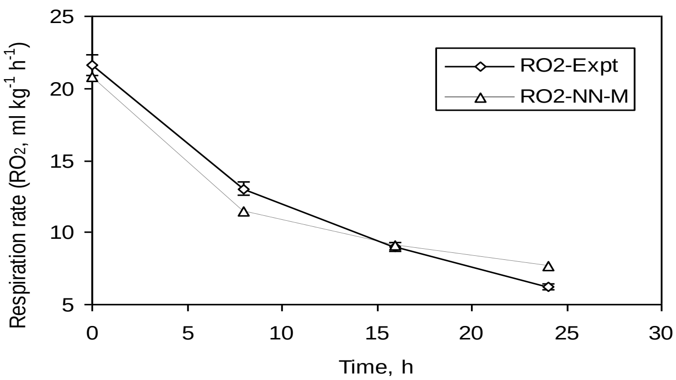

Fig. 2 **Experimentally estimated and predicted respiration rates for Litchi at 12ºC —◊— is for experimental respiration rate; ···Δ··· is for respiration rate predicted by NN**

CONCLUSIONS

When the number of variables are more than two the neural network establishes an easy accessible method for establishing the relationship between the dependent and independent variable. In the MATLAB program at any specified temperature, by giving the storage period and concentration of O_2 and concentration of CO_2, the respiration rate for O_2 and CO_2 can be obtained. The mean relative deviation percentage between the respiration rates predicted by NN and obtained through experimental data at 12°C were 8-11 percent for O_2 consumption and CO_2 evolution respectively which implies it is in very good agreement with that of experimental values.

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