Modeling of Respiration Rate of Fresh Date Fruits (Barhi Cultivar) Under Aerobic Conditions

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***Abstract*—There is a demand to utilize modified atmosphere packaging (MAP) for prolonging shelf life of fresh date fruits (*Barhi cultivar* at Khalal stage of maturity). Barhi fruits are good source of fiber, carbohydrates, minerals and vitamins and have a sweet taste and popular in marketing. Respiration of the produce with proper gas exchange through the packaging films can create a modified atmosphere inside a package that can be utilized to extend the shelf life of fresh dates at Khalal stage of maturity. Modeling of respiration rate is a crucial tool to design a proper modified atmosphere packaging system of fresh dates. The present study was conducted to determine the respiration rate of fresh Dates (*Barhi cultivar*) fruits in a closed system at temperatures 1, 5, 15 and 25 ℃, and to develop and test a mathematical model for predicting the respiration rate of the date fruits as a function of O_2 and CO_2 concentrations, time, and storage temperature.**

The respiration data corresponding to different temperatures indicated that rise in temperature increased the respiration rate. However, respiration rates were found to decrease with time in the range of temperatures examined. This could be attributed to the decrease in O_2 and proportional increase in CO_2 as the time progress. A mathematical model was developed based on the respiration data measured and calculated at different temperatures and time interval using the closed system method. The model showed good agreement with the experimentally data with R^2 values above 0.973.

***Index Terms*—dates, barhi, respiration rate, MAP, modeling, temperature, closed system.**

I. Introduction

The date palm (*Phoenix dactylifera* L.) is one of the oldest fruit trees in the world and has been closely associated with the sustenance and culture of the people in the Middle East since ancient times. The date fruit is a good source of fiber, carbohydrates, minerals and vitamins, and it has anti-mutagenic and anti-carcinogenic properties [1]-[5]. Fresh dates, such as Barhi cultivar, are popular and widely consumed at the Khalal stage of maturity (first edible stage, crunchy and sweet) during the date production season. One of the primary technical challenges in marketing fresh Barhi fruits at the Khalal stage of maturity is the preservation of quality for the longest possible period after harvesting and during the marketing process.

Proper packaging system should maintain the optimal storage, transport, and handling throughout the market chain for a specific commodity. Modified atmosphere packaging (MAP) has been considered to be beneficial in maintaining and extending the shelf life of several fresh produce. The MAP techniques relies on modification of the atmosphere inside a package, achieved by the natural interplay between two processes, the respiration of the product and the transfer of gases through the packaging [6], [7]. Nevertheless, accurate measurement of respiration rate and its modeling is an important aspect to the success of design and operational features of MAP [6].

Aerobic respiration of produce consists of oxidative breakdown of organic reserves to simpler molecules, including carbon dioxide (CO_2) and water, with release of energy. The process consumes oxygen (O_2) in a series of enzymatic reactions. Due to these metabolic processes in fruits, which continue even after harvest, the shelf life of the product is reduced. However, the rates of these metabolic processes are generally directly proportional to the storage temperature, thus increasing the shelf life to a certain level at lower temperatures.

Measurement of respiration rate of produce at a particular storage temperature and gas composition is time consuming and needs special equipment for gas analysis. However, it can be expressed with proper mathematical model of respiration rate. Experimental respiration rate can be measured by observing the concentration of O_2 consumptions or CO_2 evolution per unit time per unit weight of the produce at a specific temperature. 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. References [8]-[10] used closed systems to measure and model respiratory activity under various temperature and atmospheric conditions.

The present study was conducted with the specific objectives of: (a) determination of respiration rate of fresh dates (Barhi cultivar) using closed system at different temperatures, and: (b) to develop and test a suitable mathematical model to predict the respiration rate of the fruit as a function of O_2 and CO_2 concentrations and the storage temperature.

II. Materials and Methods

A. Materials

Fresh Dates fruits (Barhi cultivar) at Khalal stage of maturity were obtained from a local farm in AlKharj

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(south of Riyadh, Saudi Arabia). Fruits were washed to remove dust and any adhering dirt and then air dried to remove moisture on top of fruit surface. The fruits were weighed with a 4-digit sensitive balance, particle fruit was weighed and its true density was determined using a density kit (Metter Toledo PG 203-5 ,MonoBloc inside, weighing technology, Switzerland).

The physical properties of the date fruits were also determined in the laboratory prior to the respiration experiment. The moisture content was determined using the AOAC procedures [11]. The four linear dimensions, namely, length, major diameter, minor diameter and thickness, of the fruits were measured using a digital caliber with 0.1 mm accuracy. Initial fruit color was determined using LabScan XE spectrocolorimeter (Model No. LX16244, Hunter Associates Laboratory, Virginia). The physical parameters evaluated for the fruit samples are presented in Table I.

B. Closed System Respiration Experiments

Measurement of respiration rates using flow through system is technically difficult, since it requires highly accurate analytical equipment [9]. A closed system is the convenient way of measuring the respiration of fresh produce [12], [13]. Therefore, respiration rate of the fresh Dates fruits was examined using the closed system method. This system of measurement has been largely reported in the literature [6], [14]-[20]. At 1, 5, 15 and 25 ℃., three replicates (0.5 kg each sample) were used for all temperatures tested. The samples were placed into 2000 ml glass containers (conical flasks made airtight by closing with lids and sealed with silicon). Each container lid had two valves (inlet and outlet valves) for O_2/CO_2 gas analysis testing. The O_2 and CO_2 concentration (% v/v) was monitored over time with O_2/CO_2 gas analyzer (PBI Dansensor check point, Denmark). Gas readings were taken at constant intervals; at 25 ℃ the experimental time was 3 hrs, at 15 ℃ it was 6 hrs and at 5 and 1 ℃ it was 8 hrs. This time duration was based on the gas analysis that was monitored until the CO_2 concentration reach 18% (end of aerobic respiration) [12].

Mass of fruits taken during the experiment is shown in Table II. Free volume of respirometer was the total volume of respirometer minus volume occupied by its content. The free volume of the chamber was measured by water displacement method. All measurements were conducted in triplicate and the data are represented as mean and standard deviation.

C. Respiration Rate Modeling and Data Analysis

The experimental respiration data obtained from the closed system respirometer was utilized to calculate the experimental respiration rates by the difference in O_2 and CO_2 concentrations at different time intervals, mass of produce and free volume of chamber by using the following equations ([21]:

$$\mathbf{R}_{\mathbf{o_2}} = \left(\frac{(y_{o_2})_i - (y_{o_2})_t}{(t-t_i)}\right) * \frac{V_f}{W} \quad (1)$$

$$R_{co_2} = \left(\frac{(y_{co_2})_t - (y_{co_2})_i}{(t-t_i)}\right) * \frac{V_f}{W} \quad (2)$$

where:

R_{o_2} is the respiration rate, ml [O_2] kg $^{-1}$ h $^{-1}$,

R_{co_2} is the respiration rate, ml [CO_2] kg $^{-1}$ h $^{-1}$,

y_{co_2} and y_{o_2} are, respectively, the O_2 and CO_2 concentrations (volumetric fraction) in the gas mix at the initial time t_i (h) (or time zero) and at time t (h), V_f is the free volume inside the container (m^3) and,

W is the weight of the product (kg).

TABLE I. PHYSICAL PROPERTIES OF DATES FRUITS (BARHI CULTIVAR)

Property	Value*
Moisture content (w.b.), %	65.14±1.35
Fruit weight, g	13.79±1.59
Flesh fraction, %	93.64±1.10
Stone fraction, %	6.35±1.10
Fruit volume, ml	13.37±1.71
True density, kg/m^3	1034.17±0.04
Length, mm	33.21±0.16
Major diameter, mm	28.32±0.13
Minor diameter.mm	18.51±0.22
Thickness, mm	7.59±0.06
Hunter color parameters:	
L*	32.53±0.58
a*	2.01±0.44
b*	8.32±0.62
Hue	76.44±2.39
Chroma	8.57±0.67

*Values presented are average of 100 representative Barhi fruits and ± indicates the standard deviation.

TABLE II. FREE VOLUME OF RESPIROMETER AND WEIGHT OF DATES FRUITS TAKEN FOR GENERATING THE RESPIRATION DATA*

Storage Temperature, ℃	Fruit mass (kg)	Free volume of respirometer (ml)
1	0.504±0.003	1869.333±10.597
5	0.484±0.008	1884.867±35.501
15	0.500±0.002	1866.733±9.572
25	0.500±0.003	1870.867±6.825

*Values are average of three replications and ± indicates the standard deviation.

A regression analysis is often used to fit the gas concentration data versus time and the first derivative of the regression function obtained is used to calculate the respiration rate at that time [9], [12], [22]. The resultant regression equations for O_2 consumption and CO_2 evolution are shown in (3) and (4) to determine the values of the coefficients [19]:

$$y_{o_2} = 0.21 - [\frac{t}{at+b}] \quad (3)$$

$$y_{co_2} = \frac{t}{(at+b)} \quad (4)$$

The rate of change of gas concentration was determined from the first derivative of the regression functions as outlined in (5) and (6):

$$\frac{d\, y_{o_2}}{dt} = at(at+b)^{-2} - (at+b)^{-1} \quad (5)$$

$$\frac{d\,y_{co_2}}{dt} = -\,at(at+b)^{-2} + (at+b)^{-1} \quad (6)$$

At any given time, the respiration rate of the sample was then calculated by substituting the values of dy/dt obtained from (5) and (6) in (1) and (2), respectively. The temperature dependence of the model coefficients a and b were estimated by linear interpolation between the two temperatures.

By using the generated experimental respiration data, a nonlinear regression analysis is done to fit O_2 concentration and CO_2 concentration at different storage time periods.

III. Results and Discussion

The values of the physical properties of Dates fruits (Barhi cultivar) at Khalal stage of maturity are shown in Table I. The values of the properties indicate that the fruits were physically mature.

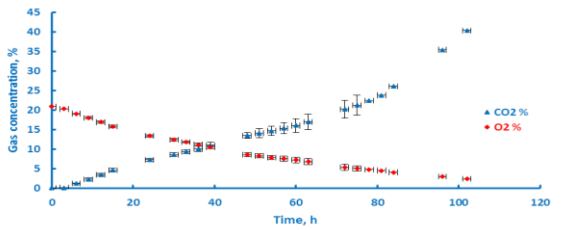

Figure 1. Experimental data for Barhi O_2 consumption and CO_2 evolution at 25 °C

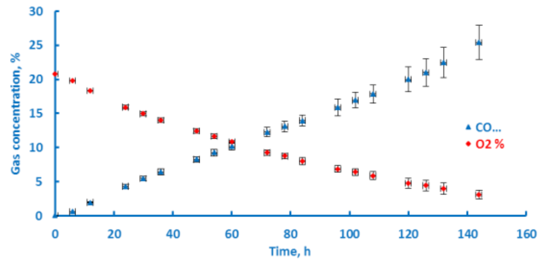

Figure 2. Experimental data for Barhi O_2 consumption and CO_2 evolution at 15 °C

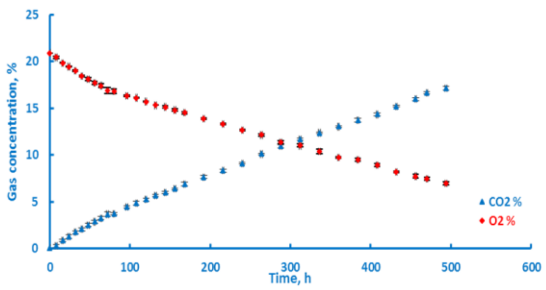

Figure 3. Experimental data for Barhi O_2 consumption and CO_2 evolution at 5 °C.

Fig. 1 to Fig. 4 illustrate the changes in O_2 and CO_2 concentrations with time inside the closed respirometer containing the fruits at different storage temperatures. The O_2 concentration in the respirometer decreased with an increase in CO_2 concentration with the storage period in which the rate being higher at the higher storage temperature. In addition, for each temperature, the respiration rate tends to slow down as time progressed. The same trend was reported by [19], [23]. This could be attributed to the decreasing O_2 and increasing CO_2 concentration in the gaseous environment with time.

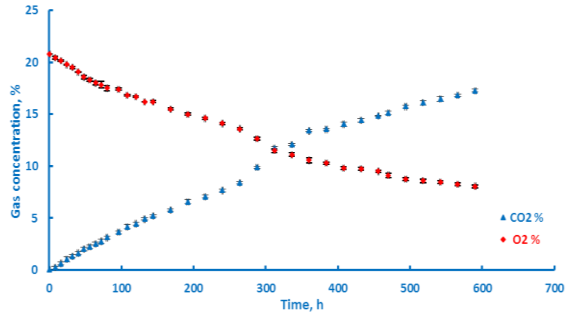

Figure 4. Experimental data for Barhi O_2 consumption and CO_2 evolution at 1 °C.

In addition, the gas concentrations reached their upper limit (CO_2 > 17%) after 590 and 494 h at 1 and 5 ℃, respectively. While the same gas concentration was achieved within 96 and 63 h for experiments at 15 and 25 ℃, respectively. This trend verifies that the temperature is the most important factor influencing respiration behavior of fruits [6].

The initial respiration rates recorded for RO_2 at 1, 5, 15 and 25 ℃ were 1.699, 2.185, 6.226 and 7.488 ml kg $^{-1}$ h $^{-1}$, respectively; while the initial respiration rates recorded for RCO_2 at 1, 5, 15 and 25 ℃ were 0.941, 1.109, 3.549 and 1.289 ml kg $^{-1}$ h $^{-1}$, respectively. Temperature showed a significant effect on respiration rates of dates fruits. Both O_2 consumption and CO_2 production rates increased with temperature in the temperature range tested.

Changes in value of respiration quotient with temperature were shown in Fig. 5. The respiratory quotient (the ratio of CO_2 production rate to O_2 consumption rate) value compared favorably to normal limits of 0.7–1.3 [24] and ranged from 1.03 ±0.17 to 1.29 ±0.33. It did not show a clear dependence on temperature, showing that the respiration quotient pattern was independent of the temperature range tested.

The respiratory quotient (RQ) (the ratio of CO_2 evolved to the O_2 consumed) was found to vary with time for all the temperature levels studied. The average RQ tends to slight increase as the temperature increased starting from 5 ℃ as indicated in Fig. 2. A similar temperature dependence of RQ has reported for mangoes [25].

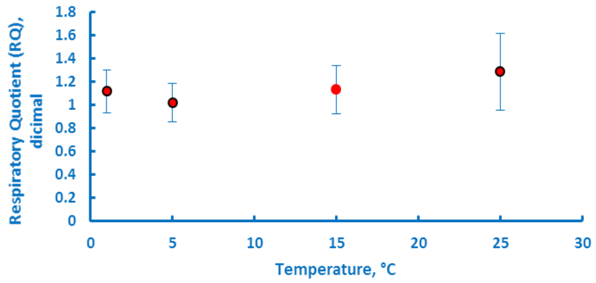

Figure 5. Changes in value of respiratory quotient with temperature.

D. Estimation of Model Parameters

The regression coefficients a and b of (2) and (3), and correlation coefficients (R^2) at different storage temperatures are shown in Table III. Those regression functions described the experimental data very well ($R^2 >$ 0.973) for dates. It can be inferred from the values of the regression coefficients a and b as shown in Table III that both the parameters were influenced by the storage temperature. It can be noticed that coefficient b was more influenced by temperature than that of coefficient a. The values of a and b obtained in this study are similar to the ranges of respiration parameters reported for apples [22].

For other temperatures, the value of a and b can be determined by linear interpolation within the range studied. The corresponding values of a and b when substituted in (4) and (5) estimate dy_{O2}/dt and dy_{CO2}/dt, respectively. The respiration rates at a given temperature can then be determined using (1) and (2).

TABLE III. VALUES OF REGRESSION COEFFICIENTS FOR THE MODEL.

T ℃	Respiration rate	Regression coefficients		R^2
		a	b	
1	O_2 consumption	3.694 (0.111)	2280 (35.341)	0.993
	CO_2 evolution	1.428 (0.242)	2453.333 (104.887)	0.993
5	O_2 consumption	3.689 (0.044)	1847 (25.71)	0.991
	CO_2 evolution	1.587 (0.18)	2154.667 (49.652)	0.998
15	O_2 consumption	2.639 (0.323)	427.967 (28.188)	0.999
	CO_2 evolution	-0.068 (0.461)	601.367 24.666	0.998
25	O_2 consumption	2.908 (0.663)	262.067 21.374	0.997
	CO_2 evolution	-2.318 0.177	506.367 57.455	0.983

IV. CONCLUSION

Respiration rates determined by closed system method were found to vary inversely with increase in storage temperature in the range of 1–25 ℃ for the Barhi dates studied. This could be attributed to the diminishing concentrations of O_2 and proportional increase in CO_2 concentrations in the respirometer as the storage time progresses. The relationship between the concentration of O_2 and CO_2 concentrations in the storage space with storage time was expressed as a regression function at the different temperatures examined with R^2 values >0.973.

The model exhibited a trend, which was in good agreement with the experimentally determined respiration rate. The results demonstrate that the model applied well to predict the respiration rate of dates (Barhi cultivar) in the temperature range studied.

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