Respiratory behavior of turning stage mature tomato (*Solanum lycopersicum* L.) under closed system at different temperature

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Summary

The respiration rate and respiratory quotient of mature tomato (*Solanum lycopersicum* L. *cv. 'Himsona'*) fruits harvested at the turning stage were determined under closed system at 5, 10, 15, 20, 25 and 35 °C (ambient) temperatures. The rate of respiration was higher at the start of the experiment and gradually declined as the storage period prolonged, before becoming almost constant. The steady-state respiration rate for CO_2 evolution were observed to be 14.35, 15.04,19.95, 21.7 and 20.3 ml/kg-h at 10 °C, 15 °C, 20 °C, 25 °C and 35 °C, respectively. The RQ values for tomato varied from 0.55 to 1.10 with time under the experimental conditions. The respiration rate at steady state based on carbon dioxide evolution and oxygen consumption in closed condition decreased by about 46 % and 73 %, respectively relative to initial respiration rate values at normal air atmosphere. The results suggest that the respiration rate of tomato increased with temperature and decrease with storage time.

Keywords: tomato fruit, respiration rate, respiratory quotient

Introduction

Short postharvest life, high susceptibility to chilling, mechanical damage and pathogens limit tomatoes distribution to the domestic and supermarkets. 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 (Lee et al., 1991). Respiration of the produce and permeation of gas through the packaging films are the processes involved in creating a modified atmosphere inside a package that will extend shelf life of agricultural perishables (Mangaraj and Goswami, 2011). 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 (Lee et al., 1996). Temperature has been identified as the most important external factor influencing respiration. Biological reactions generally increase two or three-fold for every 10 ºC rise in temperature within the range of temperatures normally encountered in the distribution and marketing chain. Waghmare et al. (2013) found the respiration rate of fresh cut produce increased 4- to 5-fold higher with an increase in temperature from 10 to 30 °C. A few studies have been conducted on modeling to describe the effect of time and temperature on respiration rate of material such pomegranate fruit and arils (Caleb et al., 2012b), sliced mushroom (Iqbal et al., 2009), and shredded carrots (Iqbal et al., 2005).

Another important parameter associated with respiration is the respiration quotient (RQ). Very high values of the RQ or a sudden shift in RQ value indicate a shift in the respiration cycle to the anaerobic cycle (Saltveit, 1997). Thus, the accurate measurement of respiration is an important step in the successful design storage system for horticultural produce like tomato. Keeping in view the above, the study was undertaken to measure the respiratory behavior of mature tomato cv. '*Himsona*' under closed system at different temperatures.

Materials and methods

Fruit material

Tomato (*Solanum lycopersicum* L.) cv. '*Himsona*' fruits were harvested at turning stage from PFDC fruit farm of Central Institute of Agricultural Engineering, Bhopal for the study during the month of March, 2013. The tomatoes were graded manually to remove damaged, infested and non-uniform fruit. Uniform sized fruits having average weight of 95 g and diameter of 2.7 cm were selected for further experimentation.

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Headspace gas exchange measurement using closed system

Respiration rates measurement using flow through system is technically difficult, since it requires highly accurate analytical equipment (Cameron et al., 1989). A closed system is the convenient way of measuring the respiration of fresh produce (Hagger et al., 1992). Hence the respiration rate data was experimentally generated for different temperatures using the closed system method. The respiration rate measurement of tomatoes was done as per the method adopted by Singh (2011). A closed system is used to measure the respiration rate of tomatoes (Fig. 1). A known weight of mature tomatoes was filled into air tight glass container of known volume. The container was sealed carefully using vacuum grease. A single hole covered with silicon septum was made in container for measurement of gas concentrations. After packaging, container was kept at different temperature i.e. 5 °C, 10 °C, 15 °C, 20 °C, 25 °C and 35 °C (ambient temp) at 75 % RH in an Environmental chamber (Remi Laboratory Instruments, India; Model: CHM-10) and time was recorded (Fig 1). The O_2 and CO_2 concentrations in the headspace was measured and recorded after every 0.5 h directly by piercing syringe inside closed glass chamber through septum by a Headspace gas analyser (Systec Instruments Ltd, UK; Model: Gaspace Advance).

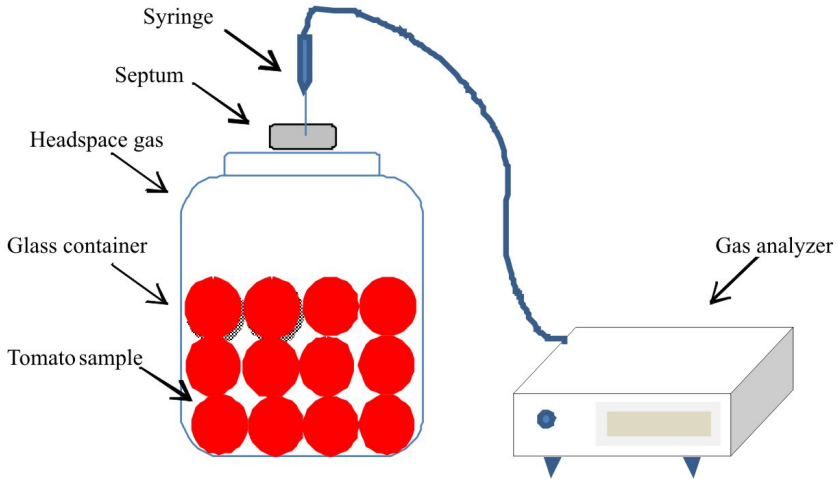


Fig. 1. A closed system for respiration rate measurement of the mature tomato

Measurement of rates of respiration

Respiration rates in terms of O_2 consumption(R_{O2}), CO_2 evolution(R_{CO2}) and respiratory quotient (RQ) were determined according to the Equations 1 and 2 below (Fonseca et al., 2002; Singh et al., 2012):

$$R_{O_2} = \frac{(p_{O_2}^{\ in} - p_{O_2}^{\ f})V_V}{100 \times W \times (t^f - t^{in})} \quad \text{and;} \quad R_{CO_2} = \frac{(p_{CO_2}^{\ f} - p_{CO_2}^{\ in})V_V}{100 \times W \times (t^f - t^{in})} \qquad (1)$$

where

P_{O2} *and* P_{CO2} = partial pressure of oxygen and carbon-dioxide gas, %
Vv = Void volume, ml
W = weight of the sample, kg
T = time, h
Superscript *in* and *f* = initial and final

$$\text{and} \qquad RQ = R_{CO_2} / R_{O_2} \tag{2}$$

where

RQ = respiratory quotient, dimensionless
R_{O2} = Respiration rate of oxygen gas, ml/kg-h
R_{CO2} = Respiration rate of carbon-dioxide gas, ml/kg-h

Weight of fruits taken during the experiment and its corresponding free volume is shown in Table 1. Void volume of the respire-meter was the total volume of the respire-meter minus volume occupied by its content. The void volume of the respiration chamber (V_v) was determined by nitrogen injection method (Mangaraj and Goswami, 2011). For this a predetermined quantity (Q_n) of N_2 which could cause a measurable change in N_2 level of container's atmosphere was injected. The increase in N_2 level was determined by analyzing the gas sample on gas chromatograph. By incorporating these values in Eq. 3, the void volume of the respiration glass container was calculated (Mangaraj and Goswami, 2011).

$$V_v = \frac{Q_n \times 100}{(N_f - N_i)} \tag{3}$$

where

V_v is the void volume of the respiration glass container in cm^3, Q_n is the volume of N_2 injected into the respiration chamber in cm^3, N_i and N_f are the initial and final N_2 concentration in %.

Table 1. Free volume of glass chamber and corresponding weight of tomatoes for respiration rate measurement

Temperature increments ºC	Weight of fruits W (kg)	Void volume of glass chamber V_v (ml)
10±2	1.05	1750
15±2	1.15	1735
20±2	1.12	1734
25±2	1.18	1737
35±2 (Ambient)	1.10	1748

Results and discussion

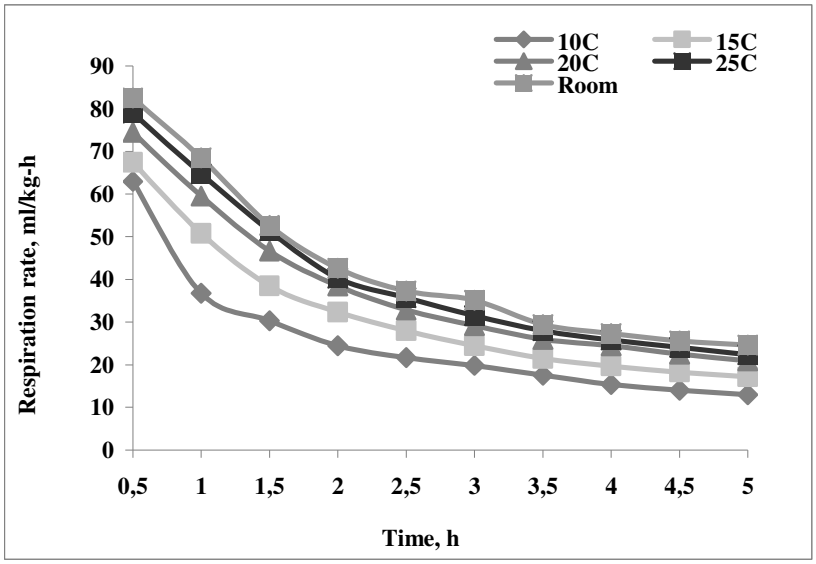
Rate of respiration

The O_2 concentration decreased and CO_2 increased with time inside the container at all the temperature (Table 2). The respiration data corresponding to the different temperature indicated that as the temperature increased the respiration progressed at a faster rate. The rate of respiration was higher at the start of the experiment and gradually declined as the storage period prolonged, before becoming almost constant (Fig. 2). The steady-state respiration rate for O_2 consumption was observed to be 12.95, 17.15, 21.0, 22.40 and 24.60 ml/kg-h at 10 °C, 15 °C, 20 °C, 25 °C and 35 °C (ambient), respectively. When compared to average initial R_{O2} values of 73.3 ml/kg-h at normal air atmosphere, there was almost 73 % decrease in R_{O2} values at steady state. Simillarly, the average respiration rate values (R_{CO2}) for all temperatures dropped from an initial value of 53.2 ml/kg-h to final steady-state value of 28.7 ml/kg-h i.e. about 46 % decrease in R_{CO2}.

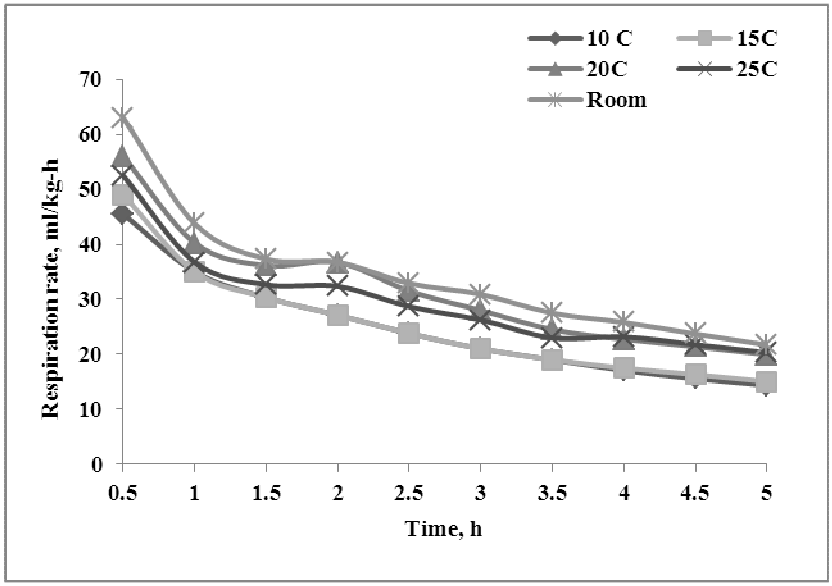
The increase in respiration rate was 32.4, 62.1, 72.9 and 89.9 % for O_2 and 4.88, 39.00, 41.4 and 51.2 % for CO_2 evolution at 15 °C, 20 °C, 25 °C and 35 °C (ambient) temperatures, respectively compared to those at 10 °C (Fig. 3). At all these temperatures, the CO_2 evolution rate remained lower than the O_2 consumption rate giving steady-state respiration quotient between 0.55 to 1.10.

Table 2. Headspace O_2 and CO_2 concentrations with time for tomato

Time (h)	Headspace O_2 concentration (%)					Headspace CO_2 concentration (%)				
	10 ºC	15 ºC	20 ºC	25 ºC	Ambient	10 ºC	15 ºC	20 ºC	25 ºC	Ambient
0.5	20.9	20.9	20.9	20.9	20.9	0.3	0.3	0.3	0.3	0.3
1.0	19.1	18.4	18.2	17.9	19.4	1.6	1.7	1.9	2.4	1.8
1.5	18.8	18.1	17.5	16.7	18.7	2.3	2.3	2.6	4.1	2.4
2.0	18.3	17.6	16.9	15.6	18.1	2.9	2.9	3.4	5.2	3.1
2.5	18.1	17.2	16.5	14.8	17.4	3.4	3.4	4.5	6.1	4.2
3.0	17.8	16.9	16.2	13.8	17.1	3.7	3.7	4.8	7.2	4.4
3.5	17.5	16.7	15.9	13.1	16.6	3.9	3.9	5.1	7.5	4.8
4.0	17.4	16.6	15.7	12.2	16.5	4.1	4.1	5.2	8.1	4.9
4.5	17.4	16.4	15.3	11.9	15.8	4.2	4.3	5.5	8.7	5.6
5.0	17.3	16.2	15.1	11.7	15.6	4.3	4.5	5.8	9.5	5.9



(a)



(b)

Fig. 2. Respiration rate in terms of O_2 depletion (a) and CO_2 evolution (b) for tomato cv. Himsona at 5, 10, 15, 20, 25 and 35 °C (Ambient) temperatures

The respiration rate R_{O2} and R_{CO2} at all temperature increments observed in this study is in agreement with the respiration range suggested by Patil et al., 2009,which is about 42-45 ml CO_2/kg-h. It should be noted that these values of R_{O2} and R_{CO2} during respiration rate that were, as previously mentioned calculated by using normal air rather than using the gas concentration values of modified atmosphere and for the reason, they are more than the respiration rate in previously modified atmosphere under identical temperature.

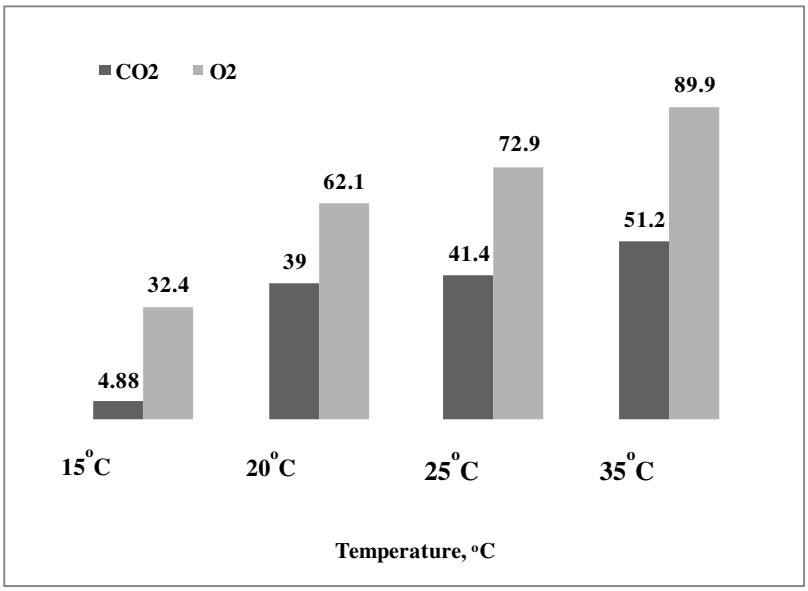


Fig. 3. Per cent increase in R_{O2} and R_{CO2} of tomato *cv. Himsona* at different temperature increments with respect to base temperature of 10 °C

Analysis of variance (Table 3) shows the effect of time and temperature on respiration rates. The Model F-value of 143.26 and 270.36 for R_{O2} and R_{CO2}, respectively implies the models are significant. There is only a 0.01 % chance that a "Model F-Value" this large could occur due to noise. Respiration rates both in terms of O_2 consumption and CO_2 evolution were found to be significantly affected by time and storage temperature at $p \leq 0.01$. The respiration value increased from 12.95 to 22.4 ml O_2/kg-h for tomatoes, as storage temperature was increased from 10 to 25 °C. It can also be observed from ANOVA that the effect of time on respiration rate was more pronounced than the storage temperature.

Table 3. Statistical analysis of oxygen (R_{O2}) and Carbon-dioxide (R_{CO2}) respiration rate

Variables	R_{O2}			R_{CO2}			
Source	SS	DF	F-value	SS	DF	F-value	P-value
Model	3.23	12		1.14	12		
Time	2.88	9	143.26	1.05	9	270.36	< 0.0001
Temperature	0.35	3	170.12	0.093	3	331.10	< 0.0001
Residual	0.051	27	62.71	0.0094	27	88.14	< 0.0001
Cor Total	3.28	39		1.15	39		
Mean	0.56			0.47			
SD	0.043			0.019			
CV	7.7			4.02			

SD: standard deviation; CV: co-variance; SS: sum of squares and DF: degree of freedom

Respiratory quotient

A change in the respiratory quotient at different temperature for tomato is shown in Fig 4. Respiratory quotient (RQ) depicts the ratio of the volume of carbon dioxide released to the volume of oxygen consumed by a body tissue of fruit in a given period (Deepak and Shashi, 2007). The ratio of carbon dioxide generation to oxygen consumption will be close to unity when substrate used in the metabolic process is carbohydrate and sufficient amount of oxygen is available. The respiratory quotient exhibited minor fluctuations during the initial stage of respiration rate experiments. The respiratory quotient stabilized as the experiment achieved steady state condition. It was observed that, the RQ indicated gradual decline in the early stage of experimentation for all the temperature except at 10 °C. The RQ values stabilized after 3 h for all the cases. These resulted phenomena may be due to the fact that at lower temperature reduces the metabolic activity consequently results in decreasing respiration rate. It was observed that higher temperature enhances the respiration rate and substrate (O_2) is dissolved at a faster rate resulting in production of more CO_2 leading to a faster accumulation of more CO_2 within the closed system and causing an increase in the respiratory quotient even at the early stage of experiment.

The RQ values for tomato varied between 0.55 to 1.10 with the time under the experimental conditions (Fig. 4). RQ value of less than unity indicated the O_2 consumption was always higher than the oxidative CO_2 production. This corresponds to some other produce reported by Fonseka et al. (2002) for fresh fruits and vegetables like apple, blueberry, cut broccoli and raspberry; Liu and Li (2004) for banana, and Toshitaka et al. (2004) for eggplant, asparagus, and broccoli.

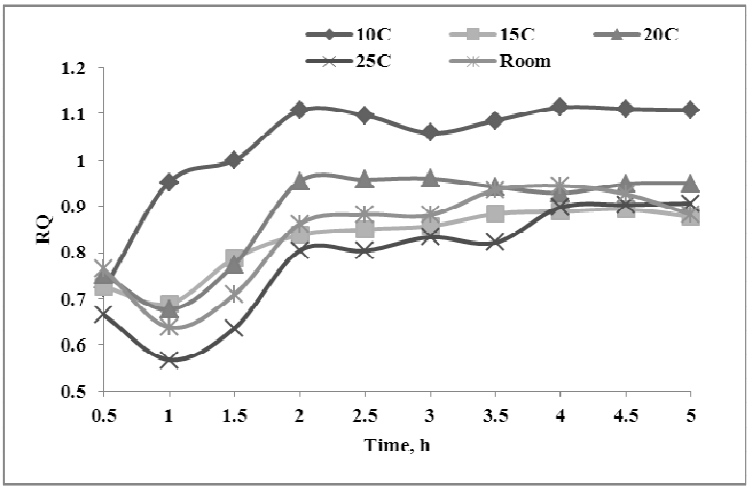


Fig. 4. Respiratory quotient (RQ) of tomato cv. Himsona at different temperature under closed system

Conclusions

Based on the experiments, it was concluded that the steady-state respiration rates were found to be decreasing with storage time. The respiration rates were also found to be increasing with increasing storage temperature. At all temperatures, the O_2 consumption rate remained higher than the CO_2 evolution rate giving steady-state respiration quotient values between 0.55-1.10 at different temperatures. RQ values varied initially up to 3 hours of storage period, and remained stable thereafter with the passage of time under the experimental conditions.

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