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Influence of Storage Temperatures, O_2 Concentrations and Variety on Respiration of Tomatoes

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Abstract: Respiration is an index of physiological activity of fruits and vegetables. Information on respiration of fruits and vegetables are essential to determine the rate of maturity, shelf life and for the design of effective Modified Atmosphere Packaging (MAP) or Storage (MAS). Experiments were conducted to determine the influence of storage temperatures, O_2 concentrations and variety on the respiration of tomatoes. The study was conducted on two varieties of tomatoes namely, local variety of India (PKM) and hybrid (5005). The tomatoes were placed in separate air-tight glass bottles stored at 12, 20, 28, and 40°C. Respiration rates were calculated and presented as the rate of release of CO_2 or the rate of consumption of O_2. Respiration rates decreased with a decrease in temperature from 40°C to 12°C, and with a decrease in O_2 concentration from 21% to 1% in the micro-environment. The respiration rate as indicated by the release of CO_2 by a local variety of tomato in India, for example was 111.8 ml kg^{-1} h^{-1} at 40°C and decreased to 5.7 ml kg^{-1} h^{-1} at 12°C, when the O_2 concentration was 17.47%. As the O_2 concentrations in the micro-environment decreased from 19.5 to 10.0%, the rate of release of CO_2 decreased from 106.1 to 53.6 ml $kg^{-1}h^{-1}$, when hybrid variety was stored at 40°C. Using the respiration data, predictive models were developed for calculating the CO_2 release rate and O_2 consumption rates. There was no significant difference in the respiration rates between the two varieties of tomatoes. It was observed that there was no change or only marginal changes in the physico-chemical properties of both varieties of tomatoes during the period of study.

Key words: Tomatoes · Respiration Rate · Temperature · MAP

INTRODUCTION

Fruits and vegetables are living commodities and continue to respire even after harvest. Respiration involves the uptake of oxygen, the release of carbon dioxide and breakdown of stored reserves. Respiration provides energy for metabolism, growth and maturation. The storage life of commodities varies inversely with the respiration rate[8]. This is because respiration supplies compounds that determine the rate of metabolic processes directly related to quality parameters like firmness, sugar content, aroma and other parameters. Respiration behavior is one of the most important indexes as it provides a window through which physiological activities of fruits and vegetables can be known [1, 2].

Respiration is affected by a wide range of environmental factors that include light, chemical stress (e.g. fumigants), radiation stress, water stress, growth regulators, and pathogen attack. The most important post harvest factors are temperature, atmospheric gas composition, and physical stress. Temperature has a profound effect on the rate of biological reactions like metabolism and respiration. Over a temperature range of 0 to 30°C for most crops, increased temperatures caused an exponential rise in respiration. The Van't Hoff Rule states that the velocity of a biological reaction increases 2 to 3- fold for every 10°C rise in temperature.

Tomato (*Lycopersicon esculentum* Mill.) is the primary model for climacteric fruit ripening for a combination of scientific and agricultural reasons. Ripening of climacteric fruit is accompanied by a peak in respiration that is needed to trigger several processes that is associated with ripening, such as the dramatic changes in color, texture, flavor, and aroma of the fruit. Tomatoes show a less steep incline of respiration as a function of O_2, which is probably due to the relatively impermeable skin of tomato. Shelf life of tomatoes is short and subject to quick decay [3] at temperatures greater than 20°C.

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Modified Atmosphere Packaging (MAP) or storage (MAS) is techniques of altering the gaseous composition of micro environment to delay the respiration rates thereby increasing the shelf life of fruits and vegetables. [4] Observed that aerobic respiration was reduced by decreasing the available O_2 but only to a critical level, below which anaerobic respiration sets in. [5] Found tomatoes stored at 20°C with 5% O_2 and 5 to 15% CO_2 gas environments were safe for 45 days without any off flavor than tomatoes stored under ambient temperatures. On the contrary, [6] found tomatoes held at 12.8°C and 3% O_2 combined with 0% CO_2 had better quality than those stored under ambient air. [7] Reported that average respiration rate for the tomatoes var. *santa clara* of various stages of maturity ranged from 40 to 120 mg kg^{-1} h^{-1} evolved CO_2.

Under tropical conditions, quality and storage life of tomato fruits can be extended and ripening delayed by MAP better than by low temperature storage owing to fruit susceptibility to chilling injury [8]. Tomatoes packed in various films at either 13 or 20°C found to have delayed over ripening for 60 d in MAP storage [9]. But, [10] reported that cooling tomatoes to 10°C nearly doubles the time to ripeness, in addition to this, with partially or completely sealing the fruit for up to 5 days to allow a build up of MAP further extends this period with minimal disease incidence. In MA packages, steady state oxygen and CO_2 were achieved when the rates of O_2 consumption and CO_2 release by the product were equal to the rates of O_2 and CO_2 flow through the barrier [11, 12]. An important problem in the commercial application of MA for fruits and vegetables was the effect of MA was different for the same cultivars grown in different locations or under different cultural practices or different seasons. [13] found that the optimum condition for MA or CA storage were influenced by factors such as type of commodity, crop cultivation methods, cultivars, growing conditions, maturity, quality, temperature, relative humidity and storage duration. The information about the rates of respiration as affected by different physical parameters is essential for an effective design of MA storages or packages [14]. So the present study was conducted to know the influence of storage temperatures, O_2 concentration and variety of tomatoes on the respiration rate in order to design effective MA storage conditions.

MATERIALS AND METHOD

Mature, green tomatoes *cv* local variety of India (PKM) and hybrid (5005) of uniform size and shape were harvested from nearby fields and immediately transported to the laboratory for the study. The tomatoes were packed and the experiments started within 12 h of harvesting.

Respiration Rate: Glass bottles of 3.45 l capacity with metal lids were used for packing tomatoes. A 12-mm-diameter hole was drilled on the lid through which a rubber septum was tightly inserted. This rubber septum served for inserting needles to draw gas samples from the bottles. For 12°C storage study, 1000 g of tomatoes were placed in the bottles while for 20 and 28°C, 500 g of tomatoes were placed and for 40°C, 250 g of tomatoes were placed. The bottles were immediately brought to the storage chambers (Industrial Laboratory Tools, India) with pre-set temperatures (with an accuracy of ± 1°C) and the tomatoes were allowed to equilibrate with the experimental temperatures. Then the lids were placed and the bottles were made air-tight by using siliputin. Plate 1 shows the set up of the study.

Gas samples of 1 ml were drawn using syringes. While drawing gas samples, care was exercised to throw about 0.5 ml gas out to make sure the drawn gas sample was a true representative of the micro-environment gas. The gas samples were analysed using a gas chromatograph (nucon - 5765, AIMIL Ltd, India). The gas chromatograph was equipped with a thermal conductivity detector, and molecular sieve and chromo sob 102 columns arranged in series. The injector, detector and oven temperatures were maintained at 80, 80 and 60°C, respectively.

Gas samples were drawn immediately after the sealing and at 3 h intervals for 24 h, 6 h interval for the next 24 h and at 24 h interval later on depending on the reducing rate of the gases. The gas was analyzed till the O_2 concentration in the bottles fell below 1%. All experiments were replicated three times.

Physico-Chemical Properties: In order to ascertain whether there was any quality changes in the tomatoes during the study the following physico-chemical properties were measured before and at the end of each experiment: the weight loss was measured using an electronic balance; the color of the fruits were measured at three locations (near the stem end, fruit end and in between these two ends) using a color flux spectrophotometer (Hunterlab Inc., USA); the textural properties like the force and energy required to penetrate and the flux of fruits before penetration were measured using a texture analyzer interfaced with a computer (TA exponent, UK); the pH of the pulp was measured using a digital pH meter with an accuracy

Table 1: Physico-chemical properties of local variety and hybrid tomatoes analysed before the start of the experiment.

	Characteristics		Local variety	Hybrid
Colour	Full fruit	L*	55.6	67.1
		a*	-9.6	-5.5
		b*	34.1	32.6
		L*	52.6	61.1
		a*	-13.7	-7
	Fruit Pulp	b*	44.4	42
Texture	Flux (Distance traveled before penetration)(mm)		2.8	2.4
	Force required to penetrate the skin (Kg)		1	0.9
Chemical properties	Moisture, %		92.67	92.33
	TSS, oB		5.13	5.2
	pH		4.27	4.34
	Acidity, %		0.21	0.17
	Vitamin C, mg/100g		15.76	22.61

of ± 0.01 (EI pH meter, model 111 E/101E); TSS of the pulp was measured using hand held refract meter (Erma, Atago, India); the titrable acidity and the vitamin C contents of the pulp were measured using gravimetric methods[15] and the moisture content of the fruit were measured by drying 5 g samples in air convection oven (Everflow Scientific Equipments, India) at 60°C for 6 h. Table 1 lists the physico-chemical qualities of the tomatoes used for the experiments. The values shown are the qualities measured before the start of the experiments.

RESULTS AND DISCUSSION

Due to the respiration of the packed tomatoes the O_2 concentration in the air-tight glass bottles decreased with time, while the CO_2 concentration increased. The respiration of fruits and vegetables is given by the general eqn. of the form in eqn. 1.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 673kcal \quad (1)$$

We have, however, measured only the changes in O_2 and CO_2 concentrations in the jar with time. Figure 1 shows the changes in O_2 and CO_2 concentrations with time in a jar, when 250 g of green local variety tomatoes in India were packed and stored at 40°C. Similar plots were obtained for all other experimental conditions also.

The measured data of all three replicates were pooled together in the figure. The rate of decrease of O_2 was found to follow an exponential pattern and observed to fit to an empirical eqn of the following form.

$$O_2consumed = aO_2 * e^{-bO_2*time} \quad (2)$$

Similarly the changes in the CO_2 concentration with time was found to fit to an empirical model of the following form.

Table 2: Solubility of CO_2 and O_2 gases in water at different temperatures19

	Solubility (m^3 of gas/ m^3 of water)	
Temperature (°C)	CO_2	O_2
40	0.01361	0.00051
28	0.01876	0.00072
0	0.02115	0.00074
12	0.02852	0.00093

Table 3: The empirical constants a and b for local variety and hybrid tomatoes at different temperatures

	Local variety				Hybrid			
	CO_2		O_2		CO_2		O_2	
Temp. (°C)	ACO_2	BCO_2	AO_2	BO_2	ACO_2	BCO_2	AO_2	BO_2
40	122.65	0.03	116.21	0.04	115.24	0.02	89.03	0.03
28	49.29	0.04	30.39	0.03	44.74	0.02	43.43	0.03
20	10.9	0.01	8.15	0.01	25.86	0.01	24.87	0.02
12	6.11	0.01	2.52	0.01	6.5	0.01	8.87	0.02

$$CO_2 released = aCO_2 * (1 - e^{-bCO_2 * time}) \quad (3)$$

The R^2 values of these eqns were close to 1 (always greater than 0.99). Figure 1 shows the best fitting line for the O_2 and CO_2 concentration changes with time.

Using the empirical models of eqns 2 and 3, the O_2 and CO_2 concentrations were predicted from 0 to 30 h with an increment of 3 h for all experimental combinations. Using these predicted gas concentrations the rate of respiration was calculated using the following eqn^{-1} [16].

$$RR = \frac{\left[\frac{\text{C1-C2}}{100}\right] \text{x} (V_1 - V_2) + \left[\text{S x W x } \frac{M}{100} \times 10^{-3}\right]}{\text{W x } (T_1 - T_2)} \quad (4)$$

Where

RR RR = Respiration rate (O_2 consumption in ml $kg^{-1}hr^{-1}$or O_2 release in ml $kg^{-1}hr^{-1}$)

C_1 = Initial concentration (ml) of CO_2 or O_2
C_2 = Final concentration (ml) of CO_2 or O_2
V_1 = Volume of the container (ml)
V_2 = Volume of fruit (ml)
W = Weight of the fruit (kg)
M = Moisture present in the fruit (ml)
T_1 = Initial period (hours)
T_2 = Final period (hours)
S = Solubility of gases (Table 2)

Tomatoes contained more than 90% of water by weight. Therefore it became essential to include solubility of gases in water. For calculating the solubility, we have used the procedure given by [17]. Table 2 shows the solubility of CO_2 and O_2 gas in water at different temperatures.

The respiration rates of tomatoes with time as calculated using eqn 4, were found to follow an empirical model of the form,

$$O_2 \text{ consumption rate} = AO_2 * e^{-BO_2 * time}$$
$$CO_2 \text{ release rate} = ACO_2 * e^{-BCO2 * time} \quad (5)$$

Where, A and B are the empirical constants and are given in Table 3.

Effect of Temperature on the Respiration Rate of Tomatoes: From the table 3, it can be noted that the constants of ‘A’ was higher at 40°C than the other temperatures. This shows that the respiration rate decreased as the temperature decreased.

From 2 and 3 shows the CO_2 consumption and O_2 release rate of the local variety and hybrid tomatoes in air tight bottles at different temperatures. This shows that the constants of ‘A’ were higher at 40°C than the other temperatures. Respiration rate was decreased with decreased temperatures.

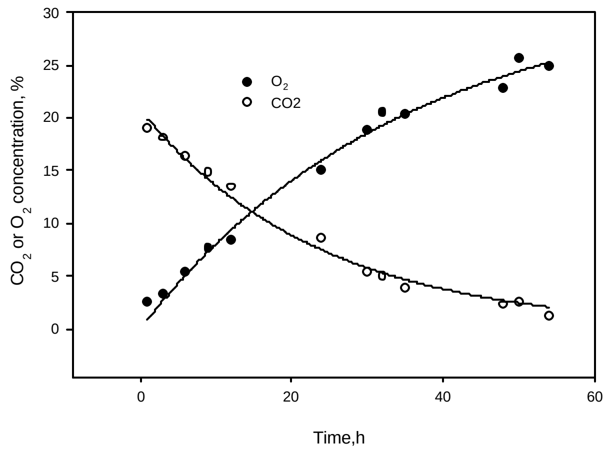

Fig. 1: The CO_2 release and O_2 consumption with time when 250 g of green local variety tomatoes were packed in 3.45 l air-tight glass bottle and stored at 40°C. Symbols represent the data and the lines represent the values predicted by eqns 2 and 3.

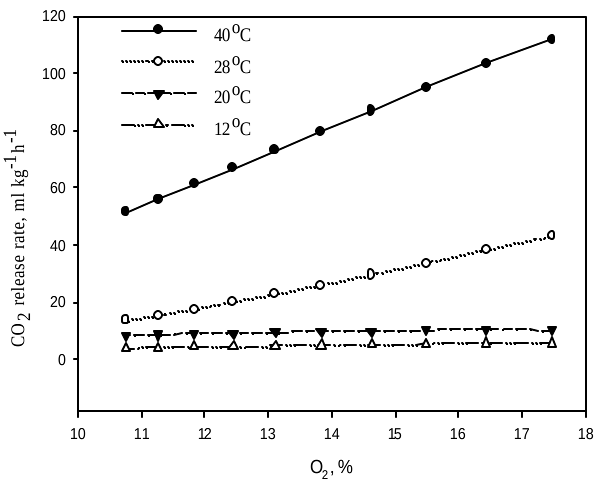

Fig. 2: Changes in the CO_2 release rate of local tomato variety of India when packed in air-tight glass bottles and stored at different temperatures

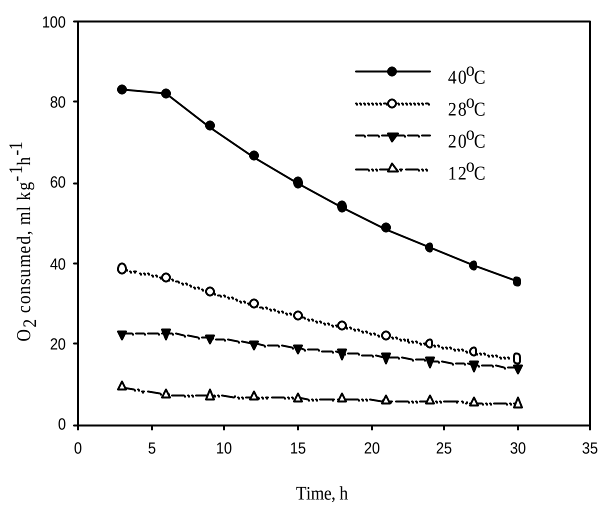

Fig. 3: Changes in the O_2 consumption rate of hybrid variety when packed in air-tight glass bottles and stored at different temperatures

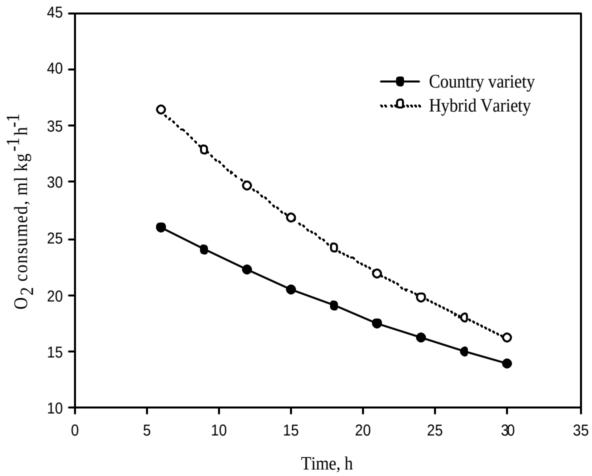

Fig. 4: Changes in the O_2 consumption rate for local variety and hybrid variety of green tomatoes when packed in air-tight glass bottles and stored at 28°C.

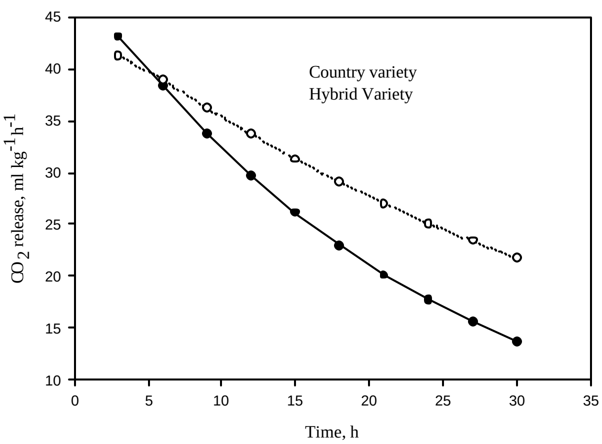

Fig. 5: Changes in the CO_2 release rate for local and hybrid variety of green tomatoes when packed in air-tight glass bottles and stored at 28°C

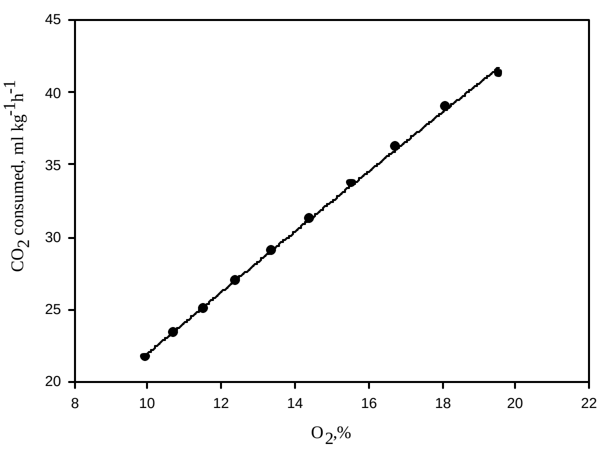

Fig. 6: Change in CO_2 release rate with respect to the availability of O_2 concentration in hybrid tomatoes when stored at 28°C in air tight glass bottles

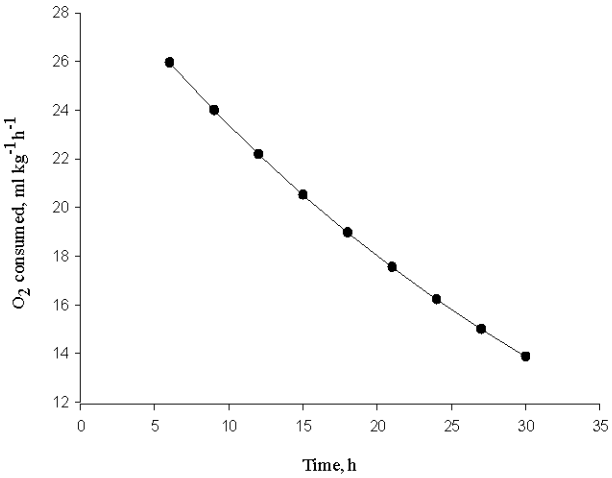

Fig. 7: Change in O_2 consumption rate with respectto time in local variety tomatoes when stored at 28°C in air tight glass bottles

It was found that there was no significant difference between the respiration rates of two varieties of tomatoes at all temperatures at a confidence level of 99% (P=0.05) based n the students -‘t’ test.

Difference in respiration rate due to temperature diminished towards the end of the storage period. Respiration declined rapidly at 24°C, but very slowly at 16°C [18]. Gustafson [19] found that respiration rates decreased rapidly initially and slowed down later on. At low temperature, the shelf life of the tomatoes was long [20] due to the decreased respiration rate.

Effect of Variety on the Respiration Rate of Tomatoes: From Fig 4 and 5, it can be observed that there is slight change in the respiration rate of both varieties at 28°C. But the effect of temperature on the respiration rate was not significant for both varieties.

Similar trends were observed at other temperatures for local and hybrid variety of tomatoes. Reduced O_2 and increased CO_2 levels on fruit varies with gas concentration, exposure time and variety of the fruit but it generally reduces respiration rate, softening of fruits and inhibits the effect of ethylene [21].

Effect of O_2 Concentration on Respiration Rate of Tomatoes: Figure 6 shows the change in CO_2 release (ml kg^{-1} h^{-1}) with respect to O_2 concentration by hybrid tomatoes when stored at 28°C. This implies that when the O_2 concentration was more, the respiration rate of the tomatoes was also higher; *i.e.* the CO_2 release rate was higher. Figure 7 shows the O_2 consumption of the local variety tomatoes at 28°C with respect to time. Similar changes were observed in all the other temperatures also. The results of the study were in line with the report given by [21, 22]. They reported that the CO_2 evolution and the O_2 consumption rates decreased with increasing storage time. The effects were more pronounced at higher O_2 concentration levels than at lower levels. Higher levels of CO_2 concentration in the atmosphere reduced the respiration rate.

[23] observed a general decrease in respiration during the post harvest ripening of tomatoes. The tomatoes harvested at the mature green stage showed a typical climacteric pattern in respiration rates. Fruits that had already ripened on plant showed declining rates of respiration. [7] found that mature green tomato obtained from local market had higher mean respiration rate of 90 mg kg^{-1} h^{-1} than the tomatoes obtained from the commercial growers (60 mg kg^{-1}h^{-1}). They explained that this might be due to lesser mechanical injury and fruits attached peduncle that provide a barrier to gaseous exchange. [24, 19] found that there was uniform rise in respiration as the fruits advance from mature green and respiration rate was 30% at the climacteric stage and declined later on.

Quality Assessment: The physico-chemical qualities of the tomato varieties were analyzed before and after the study in order to ascertain whether there was any change in the qualities during the period of experiments. The luminosity (indicated by L*) of the both the varieties changed slightly but remained the same in the tomato pulp. The a* which shows the intensity of green, in fruit and pulp decreased slightly during storage at different temperature in both the variety. The b* which indicates the yellowness, in both the varieties of tomato and in pulp remained the same when storage at all temperature.

The texture, pH and moisture content of the both the varieties of tomatoes remained the same when stored at different temperatures. The weight loss was minimum in local variety tomatoes, but in hybrid tomatoes, the weight loss was seen more in tomatoes stored at 28°C followed by 40°C. Only slight variation was found in the acid and TSS content of stored tomatoes, except in hybrid tomatoes stored at 40°C, which decreased to 3.97°B. The vitamin C content of local variety tomatoes decreased during storage as the temperature decreased but in hybrid tomatoes it increased.

The student-t test was performed for all the measured physico-chemical qualities to ascertain the significance of the changes before and after the experiments. It was found that there were no significant changes in the qualities before and after the experiments.

CONCLUSION

From the Results of this Study the Following Major Conclusions Can Be Drawn: The CO_2 release and O_2 consumption rates were faster during the initial hours of packing. The CO_2 release rate was influenced by the O_2 concentration inside the air-tight glass bottles. The respiration rate was faster at higher temperatures (40°C) but remained stable at lower temperature (12°C). This shows that the respiration rate was low at low temperature, which in turn increases the shelf life of the tomatoes. The respiration rates were not significantly different for the two varieties tested. The data of CO_2 release and O_2 consumption was found to fit to a predictive model of the form $y = a*(1-e^{-b*time})$ and $y = a*e^{-b*time}$, respectively. The rate of O_2 consumption and CO_2 release with time in tomatoes were found to follow an empirical model of the form $y = a*e^{-b*x}$.

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