ORIGINAL ARTICLE

Effect of storage temperatures, O₂ concentrations and variety on respiration of mangoes

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Abstract

The respiration rate of fruits and vegetables is an important indicator of senescence and ethylene production in fruits. Storage temperatures play a major role in the respiration rates of fruits and vegetables. Experiments were conducted to establish the influence of storage temperatures, O₂ concentrations and variety on the respiration of mangoes. The study was conducted on two varieties of mangoes namely, cvs 'Banganapalli' and 'Thothapuri'. Experiments were conducted on a single fruit, weighing approximately 500 g and kept in separate glass bottles stored at 12, 20, 28, and 40 °C. Respiration rates were calculated and presented as the rate of release of CO₂ or the rate of consumption of O₂. Respiration rates decreased with a decrease in temperature from 40 °C to 12 °C, and with a decrease in O₂ concentration from 21% to 1% in the micro-environment. The respiration rate was faster in 'Banganapalli' than in 'Thothapuri' as indicated by the CO₂ release rate. The rate of CO₂ release was very slow in mangoes stored at 12 °C in both the varieties and the rate decreased from 8.60 to 8.00 ml kg⁻¹ h⁻¹ in 'Banganapalli' variety and from 11.00 to 7.80 ml kg⁻¹ h⁻¹ in 'Thothapuri' variety. The respiration rates were faster at higher temperatures and remained low and stable at low temperatures. Using the respiration data, predictive models were developed for calculating the CO₂ release and O₂ consumption patterns.

Key words: mango; respiration rate; temperature; modified atmosphere packaging

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Abbreviations:

L* Luminosity (Black to white colour)
a* Green to red
b* Blue to yellow
TSS Total Soluble Solids

R² Coefficient of determination – it is the proportion of variability in experiment data. It provides a measure of how well future outcomes are likely to be predicted by the model. The coefficient of determination ranges from 0 to 1.

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INTRODUCTION

Increasing demand for fresh products and estimated post harvest losses of up to 50% have

given impetus to the development of technologies for prolonging fresh produce shelf life (Lee et al. 1995). A major factor contributing to post harvest losses is product respiration, which converts stored sugars or starch to energy in the presence of O₂ substrate, thus advancing ripening. Shelf life is directly proportional to the rate of senescence and inversely proportional to the respiration rate (Day 1990).

Respiration plays a central role in the overall metabolism of a plant and it is therefore often used as a general measure of metabolic rate (Kays 1991). Under proper storage conditions, respiration proceeds at relatively low and stable rates throughout the storage period. However, respiration may increase or decrease based upon changes in storage conditions and the physiological status of the produce (Kader 1992, Fennir et al. 2003). Reduced oxygen and increased carbon dioxide levels will reduce the rates of respiration and result in a slow ripening process (Mathooko 1996). Product temperature, an important factor that affects post harvest life has profound effect on the biological reactions. Low temperature storage is usually used to extend the storage life of fruit and vegetables. For every 10 °C reduction in temperature, the shelf life, in general, doubles (Nair and Singh 2003).

Mango is the second most important tropical fruit crop in the world. India is the largest producer of mangoes, accounting for 38.6% of world production from 2003 to 2005. During that period, India's mango crop averaged 10.79 million metric tons, followed by China and Thailand at 3.61 million metric tons (12.9%) and 1.73 million metric tons (6.2%), respectively (Evans 2008). Mango being a climateric fruit possesses a very short shelf life and reaches a respiration peak in ripening process on the 3rd or 4th day after harvesting at ambient temperatures (Narayana et al. 1996, Nair and Singh 2003). The shelf life of mango varies among its varieties depending on storage conditions. It ranges from 4 to 8 days at room temperature and 2 to 3 weeks in cold storage at 13 °C (Carrillo et al. 2000). Ueda (1999) reported the respiration rate of freshly harvested mango fruits was 35 percent slower at cold temperatures when compared with warm temperatures or around 35 °C. Nakamura et al. (2004), observed the change in respiration rate after 10 days of storage at 5, 10 and 15 °C under normal conditions. Usually after harvest the ripening process in mature green mango takes within 9 to 14 days in ambient conditions (Manzano et al. 1997, Herianus et al. 2003) with

good flavour, texture and colour characteristics. The ripening process of mango fruit involves a series of biochemical reactions or metabolic activities that cause chemical changes, increased respiration, ethylene production, changes in structural polysaccharides causing softening, degradation of chlorophyll and development of pigments by carotenoids biosynthesis, carbohydrates or starch conversion into sugars, changes in the organic acids, lipids, phenolics and volatile compounds, thus leading to ripening of fruit with a softening of texture to an acceptable quality (Herianus et al. 2003).

Spoilage of mango due to stem end Anthracnose limits its storage potential (Narayana et al. 1996). The modified atmosphere packaging (MAP) technique using a polyethylene perforated and non perforated sealed package coupled with low temperature at 14 °C for 3 weeks and then at 20 °C for 4 days when applied to Tommy Atkins mangoes showed no decay during storage in a non perforated pack until being opened, and then rotted rapidly. Data obtained on shelf life, weight loss, spoilage and retention of vitamin C indicated that a cool chamber was an ideal storage technique for the storage of mangoes (Pal 1998). Polyethylene wrapping reduces the rate of respiration by creating a modified atmosphere around the fruits and thereby retards senescence and ripening. The incidence of decay in perforated packages did not exceed 10–12% as compared to 20% decay in the control. A combination of MAP with effective decay controlling measures can extend the post harvest life of mango fruits (Rodov et al. 1997).

Studies related to the effect of MAP on mango varieties grown in India, and the O₂ concentrations on the respiration rate are meagre. Mango being a climateric fruit tends to ripen faster. In order to delay the ripening process the respiration rate of the fruits has to be minimized. As the respiration rate varies between fruits and their variety, it is essential to study the respiration rate of mangoes before designing a MAP storage unit. So the present study was conducted to find out the effect of storage temperatures, O₂ concentration and variety of mangoes on the respiration rate in order to design effective MA storage conditions.

MATERIALS AND METHOD

Mature, hard green mango fruits cv 'Banganapalli' and 'Thothapuri' of uniform size and shape were purchased from local market and immediately

transferred to the laboratory for the study. The mangoes 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 mangoes. A 12-mm-diameter hole was drilled in 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 storage study, a single mango of approximately 700 g of ‘Banganapalli’

and 500 g of ‘Thothapuri’ were placed in the bottles. The bottles were immediately brought to horizontal type refrigerated storage chambers (Industrial Laboratory Tools, India) with pre-set temperatures, 12 °C, 20 °C, 28 °C and 12 °C (with an accuracy of ± 1 °C) and the mangoes were allowed to equilibrate with the experimental temperatures. Then the lids were placed and the bottles were made air-tight using siliputin. The schematic representation of the experimental setup is in Fig. 1.

Fig. 1. Schematic representation of the experimental setup to study the respiration rate of mangoes

Gas samples of 1 ml were drawn using syringes. While drawing gas samples, care was exercised to discard about 0.5 ml gas 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, a molecular sieve and chromosob 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 interval for 24 h, 6 h interval for the next 24 h and at 24 h interval later, depending on the reducing rate of the O₂ gas in the microenvironment. The gas was analysed till the O₂ concentration in the bottles fell below 1%. All experiments were replicated three times.

The changes in O₂ and CO₂ concentration in the jar with time were measured. The rate of

respiration of mangoes was calculated using the following equation (Saltveit 1997):

$$RR = \frac{\left[\frac{C_1 - C_2}{100} \right] \times (V_1 - V_2) + \left[S \times W \times \frac{M}{100} \times 10^{-3} \right]}{W \times (T_1 - T_2)} \quad (4)$$

Where,

- RR = Respiration rate (O₂ consumption in ml kg⁻¹hr⁻¹ or CO₂ release in ml kg⁻¹hr⁻¹)
- C₁ = Initial concentration (ml) of CO₂ or O₂
- C₂ = Final concentration (ml) of CO₂ or O₂
- V₁ = Volume of the container (ml)
- V₂ = Volume of fruit (ml)
- W = Weight of the fruit (kg)
- M = Moisture present in the fruit (ml)
- T₁ = Initial period (hours)
- T₂ = Final period (hours)
- S = Solubility of gases (Table 1)

Table 1. Solubility of CO₂ and O₂ gases in water at different temperatures (Renault et al. 1994)

Temperature (°C)	Solubility (m ³ of gas/m ³ of water)	
	CO ₂	O ₂
40	0.01361	0.00051
28	0.01876	0.00072
20	0.02115	0.00074
12	0.02852	0.00093

Mangoes contain more than 75 to 80% water by weight. Therefore it became essential to take into account the solubility of the gases in water. For calculating the solubility, we used the procedure given by Renault et al. (1994).

Physio-chemical properties

To ascertain whether there were any quality changes in the mangoes 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 colour of the fruits was

measured at three locations (near the stem end, near the fruit end and in between these two ends) using a colour flux spectrophotometer (Hunterlab Inc., USA); textural properties such as the force and energy required to penetrate and the flux of fruits before penetration were measured using a texture analyser interfaced with a computer (TA exponent, USA); the pH of the pulp was measured using a digital pH meter with an accuracy of ± 0.01 (EI pH meter, model 111 E/101E, India); the TSS of the pulp was measured using a hand held refractometer (Erma, Atago, India); the titrable acidity and the vitamin C contents of the pulp were measured using gravimetric methods described by Srivastava and Kumar (1998) and the moisture content of the fruit was measured by drying 5 g samples in an air convection oven (Everflow Scientific Equipments, India) at 60 °C for 6 h. Table 2 lists the physico-chemical qualities of the mangoes used for the experiments. The values shown are the qualities measured before the start of the experiments.

The student-t test was performed for all the physico-chemical qualities to ascertain the significance of the changes before and after the experiments.

Table 2. Physico-chemical properties of Banganapalli and Thothapuri mangoes analysed before the start of the experiment

Characteristics			Banganapalli	Thothapuri
Colour	Full fruit	L*	51.7	52.9
		a*	−9.2	−3.4
		b*	30.6	34.3
	Fruit Pulp	L*	82.3	75.2
		a*	0.3	10.4
		b*	55.6	77.2
Texture	Flux (Distance traveled before penetration) (mm)		2.9	4.2
	Force required to penetrate the skin (kg)		2.3	2.1
Chemical properties	Moisture, %		78.0	76.7
	TSS, °B		11.1	11.7
	pH		4.1	3.7
	Acidity, %		0.2	0.4
	Vitamin C, mg 100 g ^{−1}		12.1	21.6

RESULTS AND DISCUSSION

The general respiration of fruits and vegetables is given by the general equation of the form in equation 1:

The O_2 concentration of the packed mangoes in the air-tight glass bottles decreased with time, while the CO_2 concentration increased.

Fig. 2 shows the changes in O_2 and CO_2 concentration with time in the jar, when 'Thothapuri' mangoes were packed and stored at 40 °C. Similar plots were obtained also for all other experimental conditions. 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 equation of the following form.

$$O_2 \text{ Concentration} = aO_2 * e^{-bO_2 * time} \quad (2)$$

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

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

The R^2 values of these equations were close to 1 (always greater than 0.99). Fig. 3 shows the best fitting line for the O_2 and CO_2 concentration changes with time.

Using the empirical models of equations 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 the predicted gas concentrations the rate of respiration of mangoes were calculated.

The rate of O_2 consumption and CO_2 release with time in mangoes were found to follow an empirical model of the form

$$\begin{aligned} O_2 \text{ consumption rate} &= AO_2 * e^{-BO_2 * time} \\ CO_2 \text{ release rate} &= aCO_2 * e^{-bCO_2 * time} \end{aligned} \quad (5)$$

Where,

A, a, B and b are the empirical constants.

Table 3 shows the empirical constants of predictive models of O_2 consumption and CO_2 release for all the experimental combinations.

Effect of temperature on the respiration rate of mangoes

Figs 4 and 5 shows the CO_2 consumption and O_2 release rate of the mangoes in air tight bottles at different temperatures. Respiration rates were low at lowered temperatures. Table 3 shows that the respiration rate of mangoes is 17 times faster when stored at 40 °C than the mangoes stored at 12 °C.

Mohammed and Brecht (2002) observed a 3 to 5 fold increase in CO_2 release as the mangoes were shifted from 5 °C to 20 °C.

Effect of variety on the respiration rate of mangoes

From Figs 6 and 7, it can be observed that there is only slight variation in the O_2 consumption rate and CO_2 release rate of both varieties of mangoes stored at 40 °C. But the effect of temperature on the respiration rate was not significant for both varieties. Similar trends were observed at other temperatures for both varieties of mangoes.

Even though, the 'Banganapalli' variety of mangoes showed a higher respiration rate than the 'Thothapuri' variety, it was found that there was no significant difference between the respiration rates of the two varieties at all temperatures at a confidence level of 99% ($P=0.01$) based on the Student's t-test. This may be due the cultivation environment; i.e. the mangoes that are used for the experiment were collected from same field and grown the same conditions.

Effect of O_2 concentration respiration rate of mangoes

Fig. 8 shows the change in the CO_2 release rate of 'Thothapuri' mangoes ($ml\ kg^{-1}\ h^{-1}$) at different O_2 concentrations when stored at 28 °C. This implies that at high O_2 concentrations, the respiration rate of the mangoes was also high. Fig., 8 shows the O_2 consumption of the 'Thothapuri' variety at 28 °C with respect to time. Similar changes were observed in all the other temperatures also.

Srinivasa et al. (2002) observed that on the 3rd day, the CO_2 and O_2 levels were 26.60% and 3.87% in chitosan-coated mangoes and 23.55% and 5.19% in polyethylene packed mangoes. The gas levels decreased to 21.50% and 5.21% in chitosan-coated mangoes and 18.35% and 6.65% in polyethylene packed mangoes. Similar trend of CO_2 and O_2 was observed by Dhalla and Hanson (1998) and Gonzalez-Aguilar et al. (1995).

Fig. 2. The CO₂ release and O₂ consumption with time when green Thothapuri mangoes 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 equation 2 and 3.

Fig. 3. Changes in the CO₂ release rate of Banganapalli when packed in air-tight glass bottles and stored at different temperatures

Table 3. The empirical constants a and b for Banganapalli and Thothapuri mangoes at different temperatures

Temp. (°C)	Banganapalli				Thothapuri			
	CO ₂		O ₂		CO ₂		O ₂	
	a _{co2}	b _{co2}	A _{o2}	B _{o2}	a _{co2}	b _{co2}	A _{o2}	B _{o2}
40	165.30	0.10	183.20	0.20	121.40	0.10	102.80	0.07
28	32.20	0.01	64.70	0.10	59.30	0.03	39.90	0.03
20	26.80	0.03	40.70	0.10	30.80	0.01	31.30	0.02
12	9.00	0.004	26.50	0.10	7.00	0.003	4.70	0.004

Fig. 4. Changes in the O₂ consumption rate of Thothapuri when packed in air-tight glass bottles and stored at different temperatures

Fig. 5. Changes in the O₂ consumption rate for Banganapalli and Thothapuri mangoes when packed in air-tight glass bottles and stored at 40 °C

Fig. 6. Changes in the CO₂ release rate for Banganapalli and Thothapuri mangoes when packed in air-tight glass bottles and stored at 40 °C

Fig. 7. Change in CO₂ release rate with respect to the availability of O₂ concentration in Thothapuri mangoes when stored at 28 °C in air tight glass bottles

Fig. 8. Change in O₂ consumption rate with respect to time in Thothapuri variety mangoes when stored at 28 °C in air tight glass bottles

Quality assessment

The physico-chemical qualities of the mango varieties were analysed before and after the study in order to ascertain whether there was any change during the period of the experiments. Mangoes stored at different temperatures had a skin luminosity of approximately 57.00. The green colour was lower in the 'Thothapuri' mangoes when compared to the 'Banganapalli' mangoes. The yellowness of the fruit increased slightly during storage in 'Banganapalli' while in 'Thothapuri' it remained the same when stored at a different temperature. The luminosity of

pulp colour of 'Banganapalli' mangoes increased during storage. The a* of 'Banganapalli' mango pulp was higher in mangoes at 40 °C followed by 20 and 12 °C, while it was found to be higher in 'Banganapalli' pulp. The b* remained the same for both the varieties after storage at different temperatures. The skin of 'Thothapuri' mangoes was harder than the 'Banganapalli' mangoes. The texture decreased when stored at different temperatures. The weight loss was found to be more in 'Banganapalli' mangoes stored at 40 °C, followed by mangoes stored at 20 °C, 28 and 12. But in 'Thothapuri' mangoes the

weight loss was seen more when stored at 20 °C followed by mangoes stored at 40 °C, 12 and 28. However, this was not significant. The moisture content of fresh 'Banganapalli' mangoes was 78.00%, which during storage increased by one percent in mangoes stored at 40 and 28 °C. The TSS, pH, vitamin C and acidity of the both the mango varieties remained the same when stored at different temperatures. The raw mangoes developed off-flavour when removed from the airtight bottles.

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. During the study, it was found that the temperature has no significant effect on the qualities of mangoes.

From the results of this study the following major conclusions can be drawn:

1. The CO₂ release and O₂ consumption rates were faster during the initial hours of packing. The CO₂ release rate was influenced by the O₂ concentration in the micro-environment.
2. The respiration rate was faster at higher temperatures (40 °C) but remained stable at a lower temperature (12 °C). This shows that the respiration rate was low at low temperatures, which in turn increases the shelf life of the mangoes. The respiration rates were not significantly different for the two varieties tested.
3. The data of CO₂ release and O₂ consumption was found to fit to predictive models of the form $y = a*(1-e^{-b*time})$ and $y = a*e^{-b*time}$, respectively. The rate of O₂ consumption and CO₂ release with time in mangoes were found to follow an empirical model of the form $y = a*e^{-b*x}$.
4. Mangoes can be best stored at 12 °C.

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