Pak. J. Bot., 42(3): 2077-2084, 2010.

STORAGE OF RIPE MANGO (*MANGIFERA INDICA* L.) CV. ALPHONSO IN CONTROLLED ATMOSPHERE WITH ELEVATED CO_2

HAMEED ULLAH[1], SAEED AHMAD[2*], A.K. THOMPSON[3], WAQAR AHMAD[2] AND M. AZHER NAWAZ[2]

[1]*Citrus Research Station, Sahiwal, Pakistan*
[2]*Institute of Horticultural Sciences, University of Agriculture, Faisalabad-38040, Pakistan*
[3]*Post harvest Technology, Silsoe College, Cranfield University, MK40, 4DT UK*
[*]*Corresponding author E-mail: sandhu100hasan@yahoo.com*

Abstract

Alphonso cultivar of mango (*Mangifera indica* L.) is an important fruit of Pakistan which has strong export potential. Fresh mango fruits normally have a short storage life of 10 to 12 days at ambient temperature and can suffer low temperature injury (chilling injury) during refrigerated storage, which severely hinders it from reaching the ultimate consumers in suitable edible form so causes high economic losses. Controlled atmosphere (CA) storage was studied to determine its feasibility and optimum storage conditions for mango fruit cv. Alphonso in order to extend its shelf life without detrimental affects on its quality. Fully ripe mangoes were stored at 3% O_2 with elevated CO_2 levels i.e., 0, 3, 6, 9, 12 and 15 %, and compared with fruit stored at 21% O_2 and 0% CO_2 at 10°C as a control. Fruits were removed from Controlled Atmosphere (CA) three weeks after storage and different quality parameters were measured chemically and by sensory evaluations. It was found that the rate of weight loss decreased with an increase of CO_2 in the storage atmosphere. Fruits stored in controlled atmosphere storage showed better retention of freshness, colour, firmness, TSS and flavour as compared to the fruits stored in the air. Panellists preferred the treatment in which fruits were stored at 3% O_2 with 6% CO_2 than other treatments. Fruits held in the air were highly unacceptable due to off flavour and fermentation. It was concluded that the controlled atmosphere storage is feasible for extending the shelf life of mangoes cv. Alphonso while 3% O_2 with 6% CO_2 proved to be the optimal atmospheric conditions for storage.

Introduction

Mango (*Mangifera indica* L.) is known as king of the fruits due to its excellent flavour, delicious taste and high nutritive values. The Alphonso cultivar is especially preferred for export to many countries from India and Pakistan. Mango industry of Pakistan faces several challenges, especially in postharvest management (Amin *et al.*, 2008) instead of this it is ranking 4th in case of mango export (Maqbool *et al.*, 2007). Maintenance of fruit quality for a specific period of time before its consumption is important factor in the post harvest life of the fruit. The physiological changes may occur in harvested fruit due to unfavorable atmospheric conditions especially fluctuation in temperature and humidity. Fresh mango fruits have a short storage life of 10 to 12 days at room temperature and can also suffer low temperature injury (chilling injury) during refrigerated storage (Lakshminarayana, 1973). Therefore, it is necessary to develop improved methods of mango storage in fresh state that can enhance its shelf life without any detrimental effect on the quality. Various methods of extending the storage life of mangoes have been tested but little research has been conducted on controlled atmosphere (CA) techniques, particularly on cv. Alphonso. CA storage has been shown to be beneficial technique in reducing the rate of physiological and biochemical changes, ethylene sensitivity and incidence of decay development of perishable fruit products (Medlicott & Jeger, 1987) and as a result of it senescence is delayed. CA storage has proved to be very successful in commercial use with apples and pears and its implementation for other commodities is increasing. The response of mangoes to CA condition reported in the literature has been shown to vary. Nakamura *et al.,* (2004) reported that CA storage having 5-10% CO_2 is effective to suppress the respiration rate of ripe mango. Lalel *et al.,* (2003) found that CA comprised of 2% O_2 and 2% CO_2 is better for maintaining the aromatic compounds of ripen fruit. Similarly Mitra & Baldwin (2005) stated that low temperature, hypobaric and CA storage can keep the mango fruit for about two to four weeks however, they suggested further research in this area. Lalel *et al*., (2005) reported that CA treatments reduced respiration rate, de-greening of the skin and fruit softening of mangoes but yellowness of the skin, total soluble solids (TSS),TSS/acid ratio, total sugars content and taste of the ripe fruit were maintained. In another research Lalel & Singh (2006) recommended that shelf life of Delat R2E2 mangoes can be increased up to 38 days with out any fermentation by storing them in 6% CO_2 and 3% O_2. Different varieties of mangoes showed different responses to CA storage (Rattanapanone, 2001). Therefore, it is essential to evaluate the response of mango “Alphonso” variety before implementation of CA techniques. Keeping export potential of Alphonso and beneficial aspects of CA technology an experiment was carried out to determine optimum CA storage conditions for mango cv. Alphonso.

Materials and Methods

The mango cv. Alphonso used in this experiment were harvested in India. They were held at ambient conditions of 25 to 30°C from harvest to shipment. The shipment was made by air and they were received after seven days of harvest at Silsoe, UK. A wide range of CO_2 concentrations were selected for studying the storage behaviour of Alphonso mangoes under CA conditions. It was subjectively estimated that the Alphonso mangoes were almost fully ripe on arrival at Silsoe College, UK. The mangoes were carefully selected to maintain uniformty and placed in airtight plastic boxes each with a capacity of 35 litres. Nine mangoes (2.75 -3.0 Kg) of each treatment were placed in each airtight box. Each treatment was replicated four times. Two hundred and sixteen (216) mangoes were stored at 3% O_2 with 0, 3, 6, 9, 12 and 15% levels of CO_2 and compared with fruit (36 mangoes) stored at 21% O_2 and 0% CO_2 as a control at 10°C. The required concentrations were checked by Gas Chromatograph Carlo-Erba (Model GC-8000) fitted with a flame ionization detector. Fruit was allocated at random to the different controlled atmosphere containers so that each container contained similar amounts of fruit.

The controlled atmosphere system consisted of gas tight plastic containers (Model C217, Mailbox International Ltd, Cheshire, UK) each of 75 liters capacity. Each container had one inlet and one outlet tube. The tips of the outlets were immersed in water to prevent hack flow into the container. The inlets tubes were separately connected to a gas distributor (Mercury, UK) by PVC tubing of 6.5 mm internal diameter. The gas distributor was connected to a computer programmed gas blender (Singal Instrument Co. Ltd. Surrey, UK 850 series) which was connected to cylinders of compressed O_2, CO_2 and a nitrogen generator (Bolton 75-72). The gas output from the gas blender and controlled atmosphere storage containers was analyzed daily using an Oxystate 2.0, Fruit Store Analyzer fitted with an Infra Red Gas Analyzer and a paramagnetic Oxygen Analyzer (David Bishop Instrument Sussex, UK type 770).

An additional control treatment (36 mangoes) was added by placing some fruit on a shelf in normal air at the same temperature in the same room. Two hundred and eighty eight (288) total mango fruits were used in this experiment. All of the fruit were stored at 10^{o}C with 80-85% Relative humidity for three weeks, after which the mangoes were removed from the storage and subjected to analysis for different quality parameters and sensory evaluations. Samples of mangoes were also analysed at the start of the experiment. The peel colour was measured using a colorimeter (Model CR-200/CR-200b; Milton Keynes, UK), and CIE system, where a negative a* values corresponds to the degree of greenness, and a positive b* value corresponds to the degree of yellowness. Fruit firmness was measured in Newtons (N) using an lnstron Universal Testing Machine (Model 2211; Instron, High Wycombe, UK) with an 8 mm cylindrical probe. Only peel firmness data are presented in this paper since pulp firmness values were similar to peel firmness data. Total soluble solids contents (SSC) were measured using a digital refractometer (Model PR-1; Atago Co. Ltd., Tokyo, Japan). Acidity was measured by means of an acid base titration method using a juice sample (10 ml juice + 10 ml distilled water) and 0.1N Sodium hydroxide (NaOH) with phenolphthalein colour indicator. For the sensory evaluation tests, a panel of eight assessors was selected from the University. The tests involved individuals in isolated tasting conditions under a standard light source. Judges were asked to assess pulp flavour, sweetness, off flavour, astringency and acceptance, each on a five point scale where: 1= low; 2= moderate; 3= good/high; 4= very good/high; 5= excellent/high.

The scores marked by panelists were collected and an average was calculated for each parameter. All results were analyzed as a randomized blocks with 4 replications. Where there was statistical significance at P=0.05 or above in the ‘f test’ at test’ at $P=0.05$ was carried out.

Results and Discussion

Weight Loss (%): Changing the CO_2 in the storage atmosphere showed that in a statistically significant effect on weight loss of mangoes. Control fruit stored in the open air exhibited the higher weight loss as compared to control fruit in the boxes. Mangoes stored in air showed higher weight loss than those stored in different compositions of atmospheric gases. A positive correlation between weight loss and CO_2 while negative correlation between weight loss and O_2 was observed (Table 1). The higher weight loss in the control as compared to those kept in air in closed CA boxes could be due to higher transpiration rates probably due to the lower humidity surrounding the fruits. These findings confirm those reported by Lakshminarayana & Subramanayam (1970) who showed that weight loss of fruits kept in open crates were higher than those kept in closed containers. The lower weight loss in fruits held in air in the closed box in the current investigations could be due to combination of a build up of humidity and lower metabolic activity and respiration. It is well documented that CA treatments reduced respiration of fruits due to this reason weight loss of fruits decreased while in open climate higher respirations increased the weight loss of fruit Lalel *et al.*, (2005).

Table 1. Quality parameters of mangoes cv. Alphonso stored under CA conditions at 10°C for three weeks.

Gases	Weight loss (%)	Peel colour values		Firmness (N)
		a (greenness)	b (yellowness)	
3% O_2 + 0% CO_2	3.11	-2.4	53.5	1.61
3% O_2 + 3% CO_2	3.01	-1.8	52.3	1.72
3% O_2 + 6% CO_2	2.56	-0.6	54.0	1.96
3% O_2 + 9% CO_2	2.31	-2.7	52.4	1.97
3% O_2 + 12% CO_2	2.05	-6.3	50.4	2.10
3% O_2 + 15% CO_2	1.98	-8.8	49.3	2.26
21% O_2 + 0% CO_2	3.41	-4.6	50.9	1.59
Control open air	3.90	-3.7	51.9	1.53
LSD (p=0.05)	0.33	2.33	2.81	0.19
CV%	12	21	5	10
Initial reading	-	-7.4	47.8	2.3

Peel Colour: Non significant differences in peel colour were related for various treatments held in 3% O_2 with 12% CO_2. There was a trend to delay de-greening in fruits kept in the higher CO_2 levels. Those stored in 12 and 15% CO_2 had similar levels of greenness to the initial levels. There was some indication that storage in 0 to 9% CO_2 with 3% O_2 resulted in more de-greening than fruit stored in air. Fruit held in 3% O_2 with 0 to 9% CO_2 showed lower greenness than other fruit and were statistically at par with each other (Table 1). Fruit held in 3% O_2 showed less loss of yellowness (b*) and were not statistically at par with those held in 0, 3 and 9% CO_2 atmospheres. Fruit held in 3% O_2 with 15% CO_2 showed lower yellowness as compared to other fruit and were statistically similar to those held in 12% CO_2 atmosphere and with those held in either of the control treatments (Table 1). The more yellow and less green colour of fruit in CA treatment than control conformed the finding of Srinivasa *et al.*, (2002) where they reported that the yellow colour of mangoes is due to the chlorophyll and carotenoid synthesis but their synthesis remained inhibited with an increase of CO_2 but these were not in line with the findings of Rattanapanone *et al.*, (2001) who reported that CA treatments did not affect the skin colour of mangoes during storage.

Fruit firmness (N): Treatments exhibited the significant variation for fruit firmness. Elevated CO_2 in the storage atmosphere resulted in a significant increase in fruit firmness compared with the fruit stored in air or in an atmosphere with reduced CO_2 levels. Fruit held in either of the control treatments were shown to be softer than the fruit of other treatments. Fruit held in 3% O_2 with 12 or15% CO_2 showed higher fruit firmness than those held in air, and in 3% O_2 while 0 or 3% CO_2 showed significantly lower fruit firmness (Table 1). Regarding the firmness, mangoes stored in CA represented the excellent results by retaining the maximum firmness as compared to air. The current investigations confirm the view that CA conditions delay fruit ripening and softening (Kader, 1986). A positive correlation was noted between rate firmness and CO_2 and same was for O_2. In another work, the rate of Kiwifruit softening during storage at 0°C for 24 weeks was significantly reduced in fruits exposed to 2% O_2 with 5% CO_2 relative to those kept in air (Arpaia *et al.*, 1985).

Total soluble solids (TSS) % age: Maximum TSS values were obtained from the mangoes stored in 3% O_2 with 6% CO_2 followed by mangoes stored in 3% O_2 with 9% CO_2. Whereas, control fruits showed minimum TSS contents. Mangoes stored in CA can be divided into two groups: those kept in 0, 3, 12 or 15% CO_2 gave 19.2 to 19.3% TSS while those in 6 or 9% CO_2 represented 20.1 to 20.4% TSS (Fig. 1). The lower TSS contents in mangoes kept in an atmosphere containing 1% O_2 could be attributed to fermentative decarboxylation of the fruit. These findings are in line with those reported by Lakshminarayana & Subramanayam (1970). Goodenough & Thomas (1981) found that CA condition slowed down the losses in sugars and organic acids in tomatoes during storage at 12.5°C for up to 2 months. In the current work, the lower TSS for control fruit held in air and for those held in higher O_2 (5%) with lower CO_2 concentration suggests the onset of senescence.

Acidity (%): Statistical analysis showed highly significant differences for acidic contents between different CO_2 levels (p=0.05). Fruit held in 3% O_2 with 6% CO_2 showed significantly lower acidity, followed by those held in 3% O_2 with 9% CO_2 as compared to those kept in either of the control treatments or in other combinations of atmospheric gases. Fruit stored in 9% CO_2 or lower exhibited markedly less citric acid than control and similar to the levels measured initially in fruit. Fruit kept in 12 and 15% CO_2 had increased acid contents as compared to initial levels and had similar levels to controls (Fig. 2). The higher acidic content in mangoes stored under high CO_2 composition could be attributed to the conversion of CO_2 to HCO_3 (carbonic acid) which might occur due to the accumulation of higher concentrations of CO_2 in fruit tissue. The results of the current investigations regarding titratable acidity confirmed the findings of Williams & Patterson (1964) who reported that an increase in CO_2 in the storage atmosphere leads to an increase in citric acid in fruit. Higher acidity in fruits kept in air and lower CO_2 could be due to their internal breakdown or advanced senescent stage.

Sensory evaluations: Fruit kept in 3% O_2 with 6 or 9% CO_2 showed higher flavour scores as compared to those kept in air and other combinations of atmospheric gases. All fruit (except those stored in 3% O_2 with 6% CO_2) attained lower flavour scores than those given at the beginning of the experiment (Fig. 3). Generally the CA exhibited better flavour than the fruits stored in air. Over all some improvements in flavour and acceptability were noted (Fig. 3) as CO_2 levels were increased up to 6% and then a general trend of reduction in flavour at CO_2 levels above 6%. However there was no indication of an increase in off-odour in fruits stored at higher CO_2 levels. These observations are supported by the findings of Lalel & Singh (2006) where they found increased aroma volatile compounds in mango fruits which were held at 6% CO_2 than those which were held at 8% CO_2. Fruit held in 3% O_2 with 6 or 9% CO_2 showed higher ratings for sweetness compared with those held in other treatments. Other treatments, including control in air, were statistically at par with each other (Fig. 3). It could be due to the fact that all fruits were initially ripe, and starch to sugar conversion was completed. The results are in line with the findings of Rattanapanone *et al.*, (2001).

Fruit held in 3% O_2 with 6 to 15% CO_2 showed lower ratings for off-odour development compared with other treatments including control. Fruit held in 3% O_2 with 6% CO_2 were highly acceptable to the taste panelists followed by those held in 3% O_2 with 9% CO_2. Control fruit held in air were highly unacceptable to the taste panelists and occupied the lowest position in acceptability rating and those held in 3% O_2 with 3, 12 and 15% CO_2 occupied an intermediate position. The current investigations produced substantial evidence regarding the sensory evaluation that mangoes held in optimal CA conditions result in better retention of flavour and sweetness. These observations are in accordance with those reported by Noomhorm & Tiasuwan (1995) and Hatton & Reeder (1967). More over similar results were also reported by Freezer *et al.*, (2002) where they found longest shelf life by sensory evaluation of mango fruit which were stored under gas mixture.

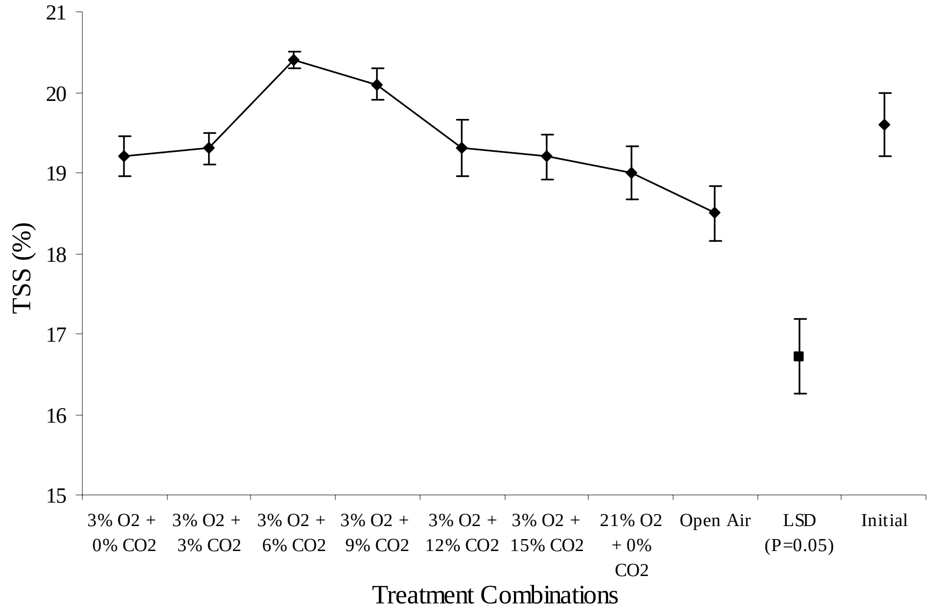

Fig. 1. Effect of different CO_2 concentrations on TSS (%) of Alphonso mangoes stored in 3% O_2 at 10°C for three weeks (Vertical bars present standard error of means).

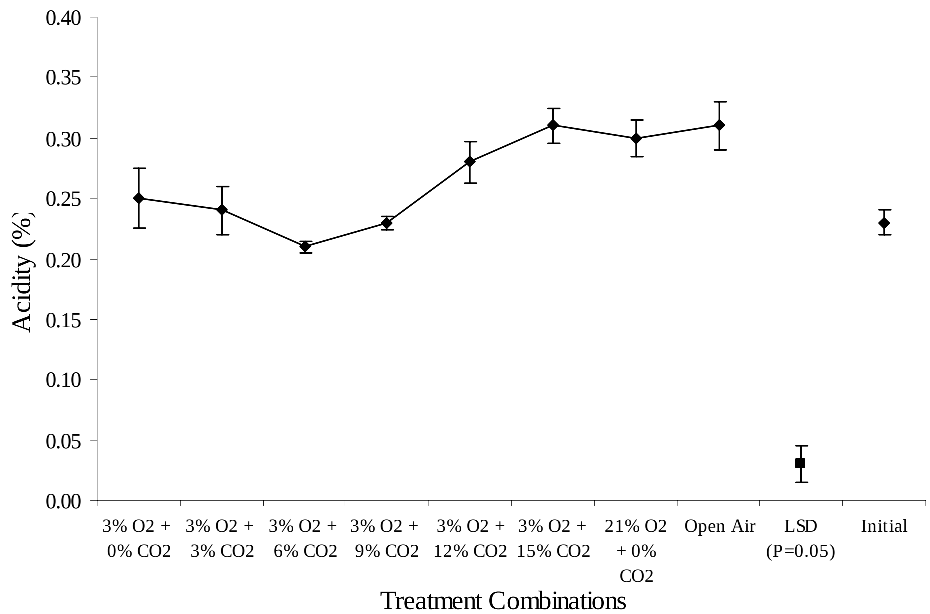

Fig. 2. Effect of different CO_2 concentrations on acidity (%) of Alphonso mangoes stored in 3% O_2 at 10°C for three weeks(Vertical bars present standard error of means).

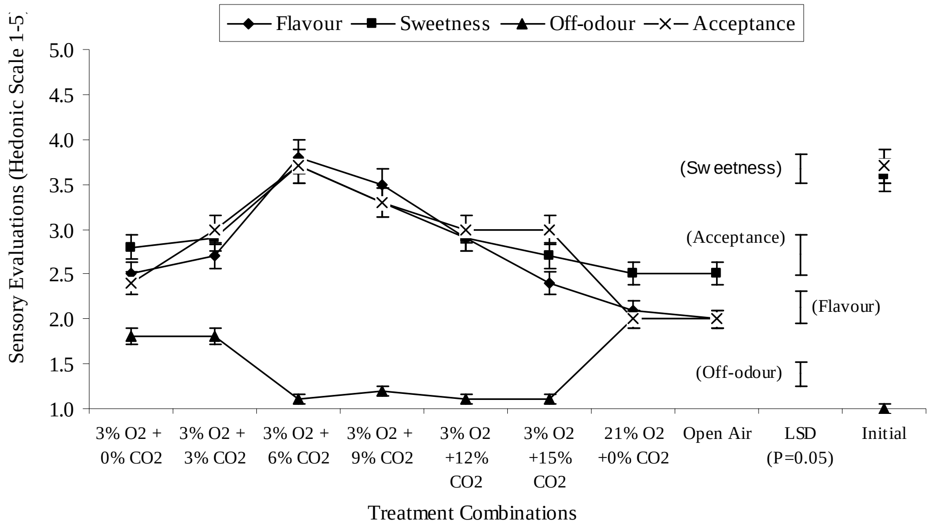

Fig. 3. Effect of different CO_2 concentrations on sensory characteristics of Alphonso mangoes stored in 3% O_2 at 10°C for three weeks (Vertical bars present standard error of means).

Conclusion

It is concluded that the controlled atmosphere (CA) storage is feasible for extending the shelf life of ripe mangoes cv. Alphonso, and a sensory evaluation also confirmed that CA storage results in better retention of flavour and sweetness. The treatment of 3% O_2 with 6% CO_2 emerged as optimal atmospheric conditions for the storage of fully mature mangoes cv. Alphonso. CA storage shall have important commercial as well as social implications for Pakistan mango industry as ripe mangoes could be reached to the ultimate consumers with in extended period and improve incomes for farmers.

Acknowledgements

The authors are grateful to the ARP-II project for providing the funds for these projects. We also thank Mr. Allan Hilton of Cranfield University, UK for technical assistance

References

Amin, M., A.U. Malik, M.S. Mazhar, I.U. Din, M.S. Khalid and S. Ahmad. 2008. Mango Fruit desapping in relation to time of harvest. *Pak. J. Bot*., 40(4):1587-1593.

Arpaia, M.L., F.G. Mitchel, A.A. Kader and G. Mayer. 1985. Effect of 2% O_2 and various concentrations of CO_2 with or without ethylene on the storage performance of Kiwifruit. *J. Am. Soc. Hort. Sci.*, 110: 200-203.

Goodenough, P.W. and T.H. Thomas. 1980. Comparative physiology of field grown tomatoes during ripening on the plant or retard ripening in controlled atmosphere. *Ann. Appl. Biol.*, 94: 445-451.

Hatton, T.T and W. F. Reeder. 1967. Controlled atmosphere storage of Keitt mangoes. *Proceedings of Caribbean Region of the Am. Soc. Hort. Sci.*, 10: 114-119.

Kader, A. A. 1986. Biochemical and physiological basis for effects of CA and MA on fruits and vegetables. *Food Technol.,* 40:99-104.

Lakshminarayana, S. 1973. Respiration and ripening patterns in the life cycle of mango fruit. *J. Hort. Sci.,* 48: 227-233.

Lakshminarayana, S. and H. Subramanyam. 1970. Carbon dioxide injury and fermentative decarboxylation in mango fruit at low temperature storage. *J. Food Sci. Technol.,* 7: 148-152.

Lalel, H.J.D. and Z. Singh. 2006. Controlled atmosphere storage of "Delta R2E2" mangoes fruit affects production of aroma volatile compounds*. J. Hort. Sci. Biotechnol*., 81(3):449-457.

Lalel, H.J.D., Z. Singh and S.C. Tan. 2003. Elevated levels of CO_2 in Controlled atmosphere storage affects shelf life, fruit quality and aroma volatiles of Mango. *Proceeding XXVI International Horticultural Congress: Issues and Advances in Postharvest Horticulture, Toronto, Canada*. 09 May 2005.

Lalel, H.J.D., Z. Singh and S.C. Tan. 2005. Controlled atmosphere storage affects fruit ripening and quality of 'Delta R2E2' mango*. J. Hort. Sci. Biotechnol*., 80 (5): 551-556.

Maqbool, M., A.U. Malik and J.A. Jabbar. 2007. Sap dynamics and its management in commercial mago cultivars of Pakistan. *Pak. J. Bot.,* 39(5):1565-1574.

Medlicott, A. P. and M.J. Jeger. 1987. The development and application of postharvest treatments to manipulate ripening of mangoes. In: *Mangoes - a review*. (Ed.): RT Prinsley and G Tucker, Commonwealth Science Council, pp.56-77.

Mitera, S. and E.A. Baldwin. 2005. Mango. *In:* Post harvest Physiology and Storage of Tropical and Sub Tropical Fruit. (Ed.): S. Mitra. CABI, West Bangal, India. pp. 85-123.

Nakamura, N., D. V.S. Rao, T. Shina and Y. Nawa. 2004. Respiration properties of tree-ripe mango under CA condition. *JARQ*, 38(4): 221-226.

Noomhorm, A. and N. Tiasuwan.1995. Controlled atmosphere storage of mango fruit, *Mangifera indica* L cv. Rad. *J. Food Process. Preserv.,* 19: 271-281.

Srinivasa, P., R. Baskaran, M. Ramesh, K.H. Prasanth and R. Tharanthan. 2002. Storage of studies of mango packed using biodegradable chitosan film. *J. European Food. Res. Tecnol.,* 215(6): 504-508.

Tattanapanone, N., Y. Lee, T. Wu and A.E. Watada. 2001. Quality and microbial changes of fresh-cut mango cubes held in controlled atmosphere. *HortSci.,* 36(6): 1091-1095.

Williams, M.W. and M.E. Patterson. 1964. Non-volatile organic acids and core breakdown of 'Bertlett' pears. *J. Agric. Food Chem.,* 12: 80-83.

(Received for publication 15 August 2009)