academicJournals

Vol. 9(5), pp. 562-571, 30 January, 2014
DOI: 10.5897/AJAR2013.8240
ISSN 1991-637X ©2014 Academic Journals
http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Optimization of irradiation and storage temperature for delaying ripening process and maintaining quality of Alphonso mango fruit (*Mangifera indica* L.)

M. K. Yadav[1]* and N. L. Patel[2]

[1]Department of Horticulture, N. M. College of Agriculture, Navsari Agricultural University, Dandi Road, Navsari-396450, India.
[2]ASPEE College of Horticulture and Forestry, Navsari Agricultural University, Dandi Road, Navsari -396450, India.

Accepted 9 January, 2014

Alphonso mango fruit has high nutritional values, pleasant flavor, delicious taste as well as beautiful appearance and hence is known as the king of mango verities. The experiment was arranged from the 2008 and 2010 with 16 treatment combinations of irradiation dose (that is, 0.00, 0.20, 0.40, and 0.60 kGy) and stored at different storage temperatures viz., ambient at 27 ± 2°C and 60 to 70% RH, 9°C and 90% RH, 12°C and 90% RH, and Control atmospheric storage (12°C, O_2 2%, CO_2 3% and RH 90%). The fruits were exposed to gamma radiation from the source of ^{60}Co. The two years collective data indicated that, the significantly minimum percent reduction in physiological loss in weight, reduced ripening percent, increased marketability of fruits, maximum total soluble solids, total and reducing sugars, and ascorbic acid content and minimum acidity were noted in 0.40 kGy gamma rays irradiated fruits stored at 12°C as compared to the other irradiated or unirradiated fruits stored at ambient condition and other storage environment. Suggestions were made for maximizing maintained physiological changes and quality by use of irradiation and adequate storage facilities for hygiene produce.

Key words: Alphonso mango, irradiation, marketability, ripening, quality, storage temperature.

INTRODUCTION

Asia accounts for 77% of global mango production and the Americas and Africa account for 13 and 19%, respectively (Pereira et al., 2010). India is the global leader in mango production (Tharanathan et al., 2006).The significant mission of any post harvest skill is to be raising the method by which decline of produce is controlled as much as possible during the stage between collect and consumption. Mango (*Mangifera indica* L., family Anacardiacae) is a tropical fruit and classified as climacteric fruit and ripens rapidly after harvest. Mango is generally harvested when physiologically mature and is allow ripening under suitable conditions of temperature and humidity. Therefore, if freshly harvested fruit is allowed to ripen at normal ambient conditions, ripening processes increase rapidly within few days, and quality point of view, it is not good. Mango is susceptible to chilling injury and an optimum temperature of 12 to 13°C is generally recommended (Gomez-Lim, 1993, Yimyong et al., 2011).

Irradiation is a physical process for the treatment of foods akin to conventional process like heating or freezing. It prevents food poisoning, reduces wastage to

*Corresponding author- manoj_bioversity@hotmail.com, Tel: +919377310884.

contamination, and at the same time preserves quality (Mahindru, 2009). However, issues related to quarantine and quality are the major stumbling blocks to trade, both national and international (Yadav et al., 2010). Therefore, the new knowledge is critical because it is important to maintain a balance between the optimum doses required to achieve safety and the minimum change in the sweetness of the fruit. In view of the aforementioned fact, it becomes quite clear that, investigation for mango fruit is very important for not only increase the soluble solids but also to control the conversion of starch into sugars for long time. The loss in sweetness of fruits is likely to reduce the marketability and quality of fruit drastically. Alphonso mangoes from India have captured sizeable Indian market and have very good export potential, but the protocol for their irradiation and post harvest storage yet needed to be standardized. In this paper the results of studies for standardization protocol of irradiation and storage are presented and discussed.

MATERIALS AND METHODS

Fruits and irradiation treatment

The experiment was set from 2008 to 2010 at Department of horticulture, N. M. College of Agriculture, Navsari Agricultural University, Navsari, Gujarat. Export grade mangoes of cv. Alphonso were harvested from the University orchard. The selected mangoes from class I as per the quality parameters specified and described in "post harvest manual for mangoes" published by Agricultural Production and Export Development Authority (Anonymous, 2007). These fruits sorted by uniformity in size, maturity, and freedom from defects. The fruits were kept in plastic crates with cushioned material and transported to cold storage of Post Harvest Technology Unit, Navsari Agricultural University, Navsari (Gujarat) India. Than after, fruits were again sorted to remove those with spotty and having bad appearance. The individual fruit weight was from 250 to 350 g. The selected fruits were washed with chlorine water and after drying, the fruits were packed in corrugated Fiber board boxes cushioned (CFB) with tissue paper. The dimension of CFB box was 370 × 275 × 90 mm and gross weight of box with fruits was 3.0 kg. One box having nine fruits for each treatment and each treatment replicated thrice as per experimental design. The packed boxes kept in cold storage at 12°C for 8 h for pre-cooling treatment. The time gap between harvesting and pre-cooling was not more than 6 h.

After pre-cooling, fruits were transported to irradiation treatment in air conditioned vehicle. It was carried out at ISOMED plant, Board of Radiation and Isotope Technology, Bhabha Atomic Research Centre, Mumbai (India). The fruits were exposed to gamma radiation for different doses from the source radio isotope ^{60}Co with energy 1.33 MeV. There were four irradiation doses that is, I_1 -0.00 kGy (Unirradiated), I_2 -0.20 kGy, I_3 -0.40 kGy, and I_4 -0.60 kGy. The time gap from pre-cooling to irradiation was not more than 9 h. After irradiation, fruits immediately transported to cold storage of university in air conditioned vehicle.

Storage conditions

The boxes were kept in storage at different temperature as per s torage temperature treatments viz., ambient at 27 ± 2°C and 65 ± 5% relative humidity (S_1), 9°C and 90% relative humidity (S_2), 12°C and 90% relative humidity (S_1) and Control atmospheric storage at 12°C, O_2 2%, CO_2 3%, and 90% relative humidity (S_1). Post harvest biochemical changes of these fruits were studied by measuring the total soluble solids, sugars, acidity and ascorbic acid content of fruits.

Measurement protocols

Determination of physiological parameters

Physiological loss in weight (PLW) (%): Four fruits from each treatment were weighted on 1st day of treatment and subsequently their weight was recorded from 4 to 6 day interval up to the end of shelf life. The PLW was expressed in percentage and calculated as follows;

$$\text{PLW \%} = \frac{W_1 - W_2}{W_1} \times 100$$

where, W_1 = initial weight and W_2 =final weight (Shankar et al., 2009).

Ripening percent: Ripening was measured by the 10 number of fruits having change in colour from greenish to yellow and soft in texture were counted from the 4th day of storage to the 6th day intervals up to the eating ripeness and expressed in percentage over total number of fruits taken for study.

Marketable fruits percent: The number of good quality and visibly sound fruits that can be marketed were counted and expressed as percentage over the total number of fruits at prescribed interval up to 90% fruits has marketability.

Quality parameters

Total soluble solids were tested by using a digital hand refractometer PAL-1 (Atago, Japan). Sugar's percentage was determined by titrimetric method of Lane and Eynon described by Rangana (1986). The method is based on the principle that, invert sugar or reducing sugar reduced the copper in the Fehling's solution to red insoluble cuprous oxide. Non-reducing sugars were calculated by subtracting reducing sugar from total sugars. Method for titrable acidity by Rangana (1986) was adopted for estimation of titrable acidity. Ascorbic acid (mg/100 g) determination by the 2, 6-dichloroindophenol titrimetric method described by Rangana (1986) was adopted for estimation of the ascorbic acid content of fruits.

Statistical analysis

Two years thrice replicated data obtained from the experiment was analyzed using ANOVA for completely randomizes deign with factorial concept. Significance differences among treatments were compared using the Fisher's analysis of variance at the 5% probability level, technique as described by Panse and Sukhatme (1967). The data were subjected to appropriate transformation (arcsine) to meet the assumptions of normality.

RESULTS AND DISCUSSION

Physiological loss in weight

The data indicated that, the physiological loss in weight of fruits increased with the advancement of storage period and significantly influenced by irradiation and storage temperature. It was evident from the Table 1 that, the shelf life of fruits exposed with 0.40 and 0.60 kGy irradiation and stored at 9°C was extended more than 34 days. The minimum reduction in PLW was recorded in the fruits exposed with 0.40 kGy irradiation and stored at 9°C (I_3S_2) that is, 5.50% at 34th day, 4.45% at 28th day, 3.23% at 22th day, 2.35% at 16th day, 1.43% at 10th day, and 0.53% at 4th day of storage. The physiological loss in weight of fruits was possibly on account of loss of moisture through transpiration and utilization of some reserve food materials in the process of respiration (Mayer et al., 1960).

The physiological loss in weight of mango fruit was significantly influenced by the various exposed dose of gamma rays and different storage temperature. The irradiation significantly reduced physiological loss in weight during storage period over control which might be attributed to reduction in utilization of reserve food material in the process of respiration (Purohit et al., 2004). The delay in respiration rate as a result of irradiation was also reported by Singh and Pal (2009) in guava (*Psidium guajava* L.). Similar findings were also observed by Prasadini et al*.* (2008) and by El-Salhy et al*.* (2006) in mango.

Similarly, in the different storage conditions, the highest physiological loss in weight was observed in fruits subjected to ambient temperature and this was largely due to water loss through lenticles of fruits, which permit free water vapor movement (Salahddin and Kedar, 2006). Lower physiological loss in weight was noted in temperatures which might be due to lesser water vapour deficit compared to ambient condition and the low temperature which had slowed down the metabolic activities like respiration and transpiration (Mane and Patel, 2010). The observation accordance with the results in mango (Waskar and Masalkar, 1997), in banana (Nagaraju and Reddy, 1995), and in guava (Gutierrez et al,. 2002). The significantly minimum reduction in physiological loss in weight of mango fruits subjected to irradiation and stored at various temperatures that is, at 9 and 12°C and in CA (12°C) might be due to the mutual complementary effect of irradiation and low temperature.

Ripening percent

Irradiated fruits significantly delayed the ripening process over unirradiated fruits irrespective of storage condition (Table 2) and not fully ripe up to 34th day of storage at 9°C. Rest of the treatments had more ripening and the other was discarded due to the lost of their shelf life. The fruits exposed to gamma rays (0.20 and 0.40 kGy) and stored at 9°C were showed at 86.21 and 84.23% ripening, respectively at 9°C (S_3) on 34 days of storage. Rest of the treatments had high ripening or discarded due to complete of their shelf life. Ripening percentage is a physiological process which designates the period from harvest until the fruits attain the stage of maximum consumer acceptability. The unirradiated mangoes had early ripeness whereas, gamma rays exposed mangoes that had a significantly delayed in ripening. The possible mechanisms that have been postulated include:

a) Irradiations results in decreased sensitivity to ripening action of ethylene.
b) Alteration in carbohydrates metabolism by regulating certain key enzymes, which interfere with production of ATP which is required for various synthetic processes during ripening (Udipi and Ghurge, 2010). Same findings were noted by Farzana (2005) in mango and by Aina et al. (1999) in banana. The decrease of ripening percent and increase in days for ripening at low temperature may be due to desirable inhibition of enzymatic activities leading to reduction in the respiration and ethylene production. These results were supported by Mann and Singh (1975) in mango and by Deka et al. (2006) in banana. The minimum and delayed ripening in fruits due to exposed to gamma rays and storage temperature at 9 and 12°C and in CA (12°C) storage compared to fruits unirradiated and kept at ambient temperature in present study might be due to the joint balancing effect of irradiation and low temperature.

Marketable fruits percent

During storage, few treatments had 100% values for marketability and few had 0.00% marketability due to induction of senescence (Table 3). Irradiation significantly influenced the marketable fruit compared to unirradiated fruits at all conditions of the storage.

The highest marketable fruit (96.46%) was recorded in fruits exposed to 0.40 kGy gamma irradiation and kept at 12°C storage (I_3S_3) at 34 day of storage, and the rest of treatments had lower marketability or discarded due to the end of their shelf life. The marketable fruit was significantly influenced by various doses of gamma irradiation and storage temperatures. The possible reasons might be that, irradiation maintained water content in the fruit and low temperature coupled with high humidity in cold storage maintained the health of the fruits. These results were in conformity with the findings of El-Salhy et al*.* (2006) with respect to irradiation and Mane and Patel (2010) with respect to low temperature in mango.

Total soluble solids

The data revealed that, total soluble solids in fruits were significantly affected by irradiation, storage temperature, and their interaction. It was evident from the data presented in Table 4 that significantly, the maximum total

Table 1. Optimization of irradiation and storage temperature for maintaining physiological loss in weight of Alphonso mango.

Source	Physiological loss in weight days after storage (%)														
	4					10					16				
	I_1	I_2	I_3	I_4	Mean	I_1	I_2	I_3	I_4	Mean	I_1	I_2	I_3	I_4	Mean
S_1	3.54	2.82	2.68	2.79	2.95	12.21	7.47	7.18	7.26	8.53	0.00 (1.65)	10.31 (18.72)	10.83 (19.20)	11.50 (19.81)	8.16 (14.84)
S_2	0.89	0.73	0.53	0.78	0.73	2.36	1.87	1.43	2.05	1.93	3.19 (10.28)	2.97 (9.91)	2.35 (8.82)	3.10 (10.13)	4.30 (9.79)
S_3	0.92	0.80	0.66	0.88	0.81	2.56	2.00	1.65	2.23	2.11	3.88 (11.34)	3.10 (10.13)	2.58 (9.23)	3.38 (10.58)	3.24 (10.32)
S_4	2.73	2.34	1.74	2.40	2.30	7.12	3.52	3.39	3.62	4.41	10.11 (18.53)	5.28 (13.27)	5.23 (13.20)	5.48 (13.52)	6.54 (14.63)
Mean	2.02	1.67	1.40	1.71		6.06	3.72	3.41	3.79		4.30 (10.45)	5.42 (13.01)	5.25 (12.62)	5.87 (13.52)	
Source	I		S		I X S	I		S		I X S	I		S		I X S
S. Em ±	0.002		0.004		0.004	0.003		0.003		0.006	0.005		0.005		0.011
CD (P≤0.05)	0.005		0.016		0.011	0.009		0.009		0.017	0.016		0.016		0.031

Source	22					28					34				
	I_1	I_2	I_3	I_4	Mean	I_1	I_2	I_3	I_4	Mean	I_1	I_2	I_3	I_4	Mean
S_1	0.00 (1.65)	13.49 (21.54)	12.66 (20.84)	13.83 (21.83)	9.10 (16.46)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)
S_2	4.66 (12.45)	4.24 (11.87)	3.23 (10.35)	4.37 (12.05)	4.12 (11.68)	6.43 (14.68)	5.47 (13.52)	4.45 (12.16)	5.78 (13.90)	5.53 (13.57)	7.74 (16.36)	7.00 (15.33)	5.50 (13.56)	7.10 (15.44)	6.84 (15.17)
S_3	4.83 (12.68)	4.38 (12.07)	3.43 (10.67)	4.63 (12.42)	4.32 (11.96)	6.95 (15.27)	5.70 (13.80)	4.62 (12.41)	5.99 (14.15)	5.82 (13.91)	0.00 (1.65)	7.23 (15.59)	5.72 (13.83)	7.52 (15.91)	5.12 (11.74)
S_4	13.33 (21.40)	7.33 (15.69)	6.96 (15.28)	8.00 (16.42)	8.91 (17.20)	0.00 (1.65)	9.31 (17.75)	9.21 (17.65)	9.51 (17.95)	7.01 (13.75)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)
Mean	5.70 (12.05)	7.36 (15.29)	6.61 (14.53)	7.42 (15.43)		3.350 (8.31)	5.12 (11.78)	4.57 (10.97)	5.32 (11.92)		1.94 (5.33)	3.56 (8.55)	2.81 (7.67)	3.66 (8.66)	
Source	I		S		I X S	I		S		I X S	I		S		I X S
S. Em ±	0.004		0.004		0.009	0.004		0.005		0.009	0.003		0.003		0.006
CD (P≤0.05)	0.013		0.013		0.026	0.013		0.014		0.026	0.009		0.010		0.019

Figure in parenthesis indicates ARC SINE transformed value. Where, I= Irradiation, S= Storage temperature.

soluble solids (17.69%) were recorded in fruits exposed to treatment I_3 (0.40 kGy) followed by treatment I_2 (0.20 kGy). The minimum total soluble solids (16.60%) were observed in treatment I_1(0.00 kGy). The higher total soluble solids in medium and lower dose irradiated fruits indicating

Table 2. Optimization of irradiation and storage temperature for maintaining ripening of Alphonso mango.

Source	Ripening days after storage (%)														
	4					10					16				
	I_1	I_2	I_3	I_4	Mean	I_1	I_2	I_3	I_4	Mean	I_1	I_2	I_3	I_4	Mean
S_1	0.00	0.00	0.00	0.00	0.00	93.96 (75.73)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	23.49 (20.17)	0.00* (1.65)	71.68 (57.82)	69.95 (56.73)	72.96 (58.64)	53.57 (43.7)
S_2	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)
S_3	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)
S_4	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)
Mean	8.36 (10.12)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)		23.49 (20.17)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)		0.00 (1.65)	17.95 (15.69)	17.49 (15.42)	18.12 (15.90)	
Source	I		S		I X S	I		S		I X S	I		S		I X S
S. Em ±	0.003		0.003		0.004	0.007		0.007		0.002	0.010		0.010		0.019
CD (P≤0.05)	0.010		0.010		0.014	0.021		0.021		0.007	0.028		0.029		0.055
Source	22					28					34				
	I_1	I_2	I_3	I_4	Mean	I_1	I_2	I_3	I_4	Mean	I_1	I_2	I_3	I_4	Mean
S_1	0.00* (1.65)	0.00* (1.65)	0.00* (1.65)	0.00* (1.65)	0.00 (1.65)	0.00* (1.65)	0.00* (1.65)	0.00* (1.65)	0.008 (1.65)	0.00 (1.65)	0.00* (1.65)	0.00* (1.65)	0.00* (1.65)	0.00* (1.65)	0.00 (1.65)
S_2	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	65.38 (53.94)	29.98 (33.18)	28.39 (32.19)	47.16 (43.35)	42.73 (40.66)	0.00* (1.65)	86.21 (68.29)	84.23 (66.65)	97.81 (81.56)	66.91 (54.47)
S_3	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	74.75 (59.81)	33.16 (35.14)	28.98 (32.55)	57.47 (49.56)	48.59 (44.27)	0.00* (1.65)	97.08 (80.25)	96.40 (79.08)	98.16 (82.31)	72.91 (60.75)
S_4	77.30 (61. 52)	69.53 (56.47)	65.00 (53.71)	73.26 (58.84)	71.27 (57.63)	0.00* (1.65)	0.00* (1.65)	0.00* (1.65)	0.00* (1.65)	0.00 (1.65)	0.00* (1.65)	0.00* (1.65)	0.00* (1.65)	0.00* (1.65)	0.00 (1.65)
Mean	19.33 (16.62)	17.38 (15.36)	16.25 (14.67)	18.32 (15.95)		35.03 (29.26)	15.79 (17.91)	14.34 (17.01)	26.16 (24.06)		0.00 (1.65)	45.82 (37.90)	45.16 (37.23)	48.99 (41.74)	
Source	I		S		I X S	I		S		I X S	I		S		I X S
S. Em ±	0.01		0.02		0.02	0.09		0.04		0.02	0.03		0.03		0.06
CD (P≤0.05)	0.03		0.06		0.06	0.27		0.14		0.05	0.09		0.09		0.17

Figure in parenthesis indicates ARC SINE transformed value 2 * indicate fruits completely discarded Where, I = irradiation, S = storage temperature.

the induction of ripening process due to irradiation (Sudto et al. 2005). These results were in accordance with the findings of El-Salhy et al. (2006) in mango, Wall (2007) in banana, Singh and Pal (2007) in guava, and Silva et al.(2010) in Caja (*Spondias sp.*) fruit. Under various storage

Table 3. Optimization of irradiation and storage temperature for maintaining marketing of Alphonso mango.

Source	Marketable fruits days after storage (%)														
	4					10					16				
	I_1	I_2	I_3	I_4	Mean	I_1	I_2	I_3	I_4	Mean	I_1	I_2	I_3	I_4	Mean
S_1	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	8.36 (1.65)	97.66 (81.19)	100 (88.31)	100 (88.31)	100 (88.31)	99.41 (86.53)	0.00 (1.65)	100 (88.31)	100 (88.31)	100 (88.31)	75.00 (60.90)
S_2	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	100 (88.31)	100 (88.31)	100 (88.31)	100 (88.31)	100 (88.31)	100 (88.31)	100 (88.31)	100 (88.31)	100 (88.31)	100 (88.31)
S_3	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	100 (88.31)	100 (88.31)	100 (88.31)	100 (88.31)	100 (88.31)	100 (88.31)	100 (88.31)	100 (88.31)	100 (88.31)	100 (88.31)
S_4	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	100 (88.31)	100 (88.31)	100 (88.31)	100 (88.31)	100 (88.31)	100 (88.31)	100 (88.31)	100 (88.31)	100 (88.31)	100 (88.31)
Mean	8.36 (10.12)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)		99.41 (86.53)	100 (88.31)	100 (88.31)	100 (88.31)		75.00 (60.90)	100 (88.31)	100 (88.31)	100 (88.31)	
Source	I		S		I X S	I		S		I X S	I		S		I X S
S. Em ±	0.003		0.003		0.004	0.03		0.03		0.07	0.02		0.02		0.03
CD (P≤0.05)	0.010		0.010		0.014	0.10		0.10		0.20	0.05		0.05		0.10

Source	22					28					34				
	I_1	I_2	I_3	I_4	Mean	I_1	I_2	I_3	I_4	Mean	I_1	I_2	I_3	I_4	Mean
S_1	0.00 (1.65)	88.80 (70.43)	89.33 (70.91)	85.96 (67.97)	66.02 (52.74)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)
S_2	100 (88.31)	100 (88.31)	100 (88.31)	100 (88.31)	100 (88.31)	84.54 (66.82)	95.94 (78.36)	100 (88.31)	94.00 (75.80)	93.62 (77.32)	0.00 (1.65)	70.45 (57.05)	74.22 (59.46)	69.11 (56.21)	53.45 (43.59)
S_3	100 (88.31)	100 (88.31)	100 (88.31)	100 (88.31)	100 (88.31)	98.44 (82.83)	100 (88.31)	100 (88.31)	100 (88.31)	99.61 (86.94)	74.16 (59.42)	94.13 (75.94)	96.46 (79.12)	92.00 (73.54)	89.19 (72.00)
S_4	94.04 (78.85)	100 (88.31)	100 (88.31)	96.17 (78.70)	97.55 (82.79)	59.41 (50.41)	70.89 (57.32)	84.23 (66.57)	69.27 (56.31)	70.95 (57.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)	0.00 (1.65)
Mean	73.51 (63.53)	97.20 (83.84)	97.33 (83.56)	95.53 (80.82)		60.60 (50.43)	66.71 (56.41)	71.06 (61.21)	65.82 (55.52)		18.54 (16.10)	41.15 (34.07)	42.67 (35.47)	40.28 (33.26)	
Source	I		S		I X S	I		S		I X S	I		S		I X S
S. Em ±	0.003		0.003		0.004	0.03		0.03		0.07	0.02		0.02		0.03
CD (P≤0.05)	0.010		0.010		0.014	0.10		0.10		0.20	0.05		0.05		0.10

Figure in parenthesis indicates ARC SINE transformed value, I = irradiation, S= storage temperature.

conditions, the maximum total soluble solids (18.04%) were recorded by fruits stored under treatment S_3 (12°C) followed by treatment S_4 (CA at 12°C). The minimum total soluble solids (16.62%) were observed under treatment S_1 (9C). The total soluble solids in fruits at ripening were

Table 4. Optimization of irradiation and storage temperature for maintaining quality of Alphonso mango.

Source	TSS (%)					Total sugars (%)					Reducing sugars (%)				
	I_1	I_2	I_3	I_4	Mean	I_1	I_2	I_3	I_4	Mean	I_1	I_2	I_3	I_4	Mean
S_1	15.86	17.13	17.36	16.14	16.62	13.12	13.76	13.87	13.48	13.56	3.45	3.93	4.12	3.67	3.79
S_2	16.12	17.27	17.36	16.57	16.83	13.52	14.15	14.47	13.81	13.99	3.92	4.39	4.68	4.17	4.29
S_3	17.62	18.27	18.46	17.82	18.04	14.21	14.97	15.12	14.36	14.67	4.58	5.13	5.20	4.88	4.95
S_4	16.83	17.44	17.57	17.34	17.30	13.68	14.05	14.61	13.95	14.07	4.00	4.52	4.97	4.42	4.48
Mean	16.60	17.53	17.69	16.96		13.63	14.24	14.52	13.90		3.99	4.49	4.74	4.291	
Source	I		S		I X S	I		S		I X S	I		S		I X S
S. Em ±	0.009		0.009		0.017	0.007		0.007		0.014	0.004		0.004		0.009
CD (P≤0.05)	0.026		0.025		0.049	0.021		0.021		0.041	0.013		0.013		0.026
Source	Non-reducing sugars (%)					Acidity (%)					Reducing sugars (%)				
	I_1	I_2	I_3	I_4	Mean	I_1	I_2	I_3	I_4	Mean	I_1	I_2	I_3	I_4	Mean
S_1	9.67	9.82	9.74	9.80	9.76	0.262	0.215	0.193	0.244	0.228	9.12	9.20	9.45	9.12	9.23
S_2	9.60	9.76	9.79	9.79	9.63	0.240	0.194	0.182	0.230	0.211	9.14	9.41	9.53	9.23	9.33
S_3	9.63	9.84	9.91	9.47	9.71	0.182	0.162	0.145	0.169	0.164	9.12	10.24	10.58	9.98	9.98
S_4	9.68	9.53	9.64	9.52	9.59	0.220	0.179	0.171	0.215	0.196	9.20	9.78	9.87	9.41	9.57
Mean	9.64	9.74	9.77	9.61		0.226	0.187	0.172	0.214		9.15	9.66	9.86	9.43	
Source	I		S		I X S	I		S		I X S	I		S		I X S
S. Em ±	0.005		0.005		0.011	0.0003		0.0003		0.0006	0.005		0.005		0.010
CD at 5 %	0.016		0.016		0.031	0.0008		0.0008		0.0017	0.015		0.015		0.029

Where, I = irradiation, S = storage temperature.

significantly higher in fruits stored at lower temperature storage as compared to minimum at ambient temperature (Table 4).This might be that, the accumulation of total soluble substances due to desired ripening. These findings were also in accordance with the findings of Roy and Joshi (1989) in mango, Plaza et al. (1992) in papaya, and Hussein et al., (1998) in guava. Jointly the maximum total soluble solids (17.36%) were recorded in fruits exposed to gamma rays at 0.40 kGy and stored at 12°C (I_3S_3).The minimum total soluble solids (15.86%) were recorded in unirradiated ambient stored (I_1S_1) fruits at the time of full ripening (Table 4). The maximum total soluble solids was recorded in fruits exposed to various dose of irradiation and stored at 12 and 9°C and in CA (12°C) storage compared to unirradiated fruits stored at ambient temperature in present study might be due to the beneficial effects of irradiation dose and storage temperature.

Sugars (percent)

Effect of irradiation

The data revealed that, total sugar percent of fruits was significantly affected by irradiation, storage temperature and their interaction. It was evident from the data presented in Table 4 that significantly the maximum total sugars (14.52%) were observed in fruits exposed to treatment I_3 (0.40 kGy). The minimum total sugars (13.63%) were observed in treatment I_1 (0.00 kGy). The maximum reducing sugar percent (4.95) was observed in fruits exposed to treatment I_3 (0.40kGy) whereas, minimum reducing sugars (3.795%) were observed in treatment I_1 (0.00 kGy). The maximum non-reducing sugars (9.77%) were observed in fruits exposed to treatment I_4 (0.60 kGy) followed by treatment I_2 (0.20 kGy) compared to minimum (9.61) in unirradiated. The higher rate of increase in sugars content in irradiated fruits might be due to maintained ripening and corresponding greater conversion of starch into sugars. Irradiation might also accelerate the rate of gluconeogenesis (Wall, 2007). Similar findings had been observed by Beyers and Thomas (1979) in mango and Kovacs et al. (1994) in apple.

Effect of storage temperature

It was cleared from the data presented in Table 4 that significantly maximum total sugar (14.61%) was recorded by fruits stored under treatment S_3 (12°C), and minimum (13.56%) were under treatment S_1. The maximum reducing sugar percent (4.95) was recorded in fruits stored under treatment S_3 (12^0C). The minimum reducing sugars (3.79%) were observed under ambient temperature (S_1). The maximum non-reducing sugar (9.71%) was recorded in fruits stored under treatment S_3 (12°C) compared to minimum (9.63%) were observed under at 9°C (S_4). The increase in the total and reducing sugars were maintained till the end of shelf life in storage temperature at 12 and 9°C and in CA (12°C) storage might be due to suppression in the respiration rate and enzyme activities and therefore, the conversion of starch into sugars might had been at slower rate and reaching maximum at the end of storage. Same trend of results were noticed by Narayana and Singh (2000) in mango and Purwoko et al. (2002) in banana.

Combined effect of irradiation and storage temperature

Results obtained during experimentation indicating (Table 4) significantly that, the maximum total sugars (15.12%) were recorded in fruits exposed to gamma rays at the dose of 0.40 kGy and stored at 12°C (I_3S_3. The minimum total sugar (13.12%) was recorded in unirradiated ambient stored (I_1S_1) fruits at the time of complete ripening. The maximum reducing sugar (5.20%) was recorded in fruits exposed to gamma rays at the dose of 0.40 kGy and stored at 12°C (I_3S_3). Results obtained during experimentation indicating that, maximum non-reducing sugar (9.91%) was recorded in fruits exposed to gamma rays at the dose of 0.40 kGy and stored at 12°C (I_3S_3) whereas, minimum non-reducing sugar (9.67%) was recorded in unirradiated ambient (I_1S_1) stored fruits at the time of full ripening. The maximum total and reducing sugar were recorded in fruits exposed to various doses of irradiation and storage temperature of 12 and 9°C and in CA (12°C) storage compared to unirradiated fruits stored at ambient temperature in present study which might be due to the beneficial effects of irradiation dose and storage temperature. The total and reducing sugars increased during storage but the non-reducing sugars did not exhibit same pattern during storage, since it represented a product of subtraction of reducing sugars from total sugars.

Titrable acidity

The data revealed that, acidity fruits was significantly affected by irradiation, storage temperature and their interaction. It was evident from the Table 4 that, significantly minimum acidity (0.172%) was observed in fruits exposed to treatment I_3 (0.40 kGy) compared to maximum (0.226%) was observed in treatment I_1 (0.00 kGy). The reduction in acidity by irradiation reflects a possible decrease in organic acids (Wall, 2007). These results were in accordance with the findings of Upadhyay (1992) and El-Salhy et al. (2006) in mango and Sornsrivichai at el. (1990) in apple. Under storage conditions it is cleared from the Table 4 that, significantly the minimum acidity (0.164%) was recorded in fruits stored under treatment S_3 (12°C). The maximum acidity (0.228%) was observed under treatment S_1 (ambient temperature). The lower acidity at low temperature might be due to utilization of acids in the process of respiration during ripening and reduced supply of sugars (Mane and Patel 2010). Same findings noted by Plaza et al. (1992) in papaya and Singh and Pal (2007) in guava. Combined results obtained during experimentation indicating that, significantly the minimum acidity (0.145%) was recorded from fruits exposed to gamma rays at the dose of 0.40 kGy and stored at 12°C (I_3S_3) whereas, maximum acidity (0.262%) was recorded in unirradiated ambient stored (I_1S_1) fruits at the time of full ripening. The minimum acidity was recorded in fruits exposed to various dose of irradiation and stored at 12 and 9°C and in CA (12°C) storage as compared to unirradiated fruits stored at ambient temperature in present study might be due to the beneficial effects of irradiation dose and storage temperature.

Ascorbic acid

Significantly the maximum ascorbic acid (9.86 mg/100g pulp) was observed in fruits exposed to 0.40 kGy (I_3), and the minimum ascorbic acid (9.15 mg/100 g pulp) was observed in treatment I_1 (0.00 kGy) (Table 4). The higher ascorbic acid due to irradiation was in accordance with the findings of Dhakar et al. (1966) in mango and Bhushan and Thomas (1990) in apple. Significantly the maximum ascorbic acid (9.98mg/100g pulp) was recorded in fruits stored under treatment S_3 (12°C) as compared to minimum (9.23 mg/100 g pulp) was observed under treatment S_1. Also, significantly the maximum ascorbic acid was recorded in fruits stored at 12 and 9°C temperature and in CA (12°C) storage whereas, minimum ascorbic was recorded under ambient temperature stored fruits (Table 4). Same findings was noted by Ray and Joshi (1989) in mango and Plaza et al. (1992) in papaya.

RESULTS

Results obtained (Table 4) during the experimentation indicates that, significantly the maximum ascorbic acid (10.58 mg/100 g pulp) was recorded in fruits exposed to gamma rays at 0.40 kGy and stored at 12°C (I_3S_3) whereas, minimum ascorbic acid (9.12 mg/100 g pulp) was recorded in unirradiated ambient stored (I_1S_1) fruits at the time of complete ripening. The fruits of Alphonso mango subjected to 0.40 kGy gamma rays irradiation subsequently stored at 9°C delayed the ripening process which maintained lower percentage of physiological loss in weight and ripening percentage, higher percentage of marketable fruits, and increase the shelf life for longer period. The data also indicated that, the maximum total soluble solids, total, and reducing sugars, ascorbic acid, and minimum acidity were noted in 0.40 kGy gamma rays irradiated fruits were stored at 12°C as compared to unirradiated fruits stored at ambient condition at ripening stage.

ACKNOWLEDGEMENTS

Thanks are due to Dr. R. Chander, Dr. L. N. Bandi, Dr. A. Shrivastva, and Shri Jyotis, ISOMED (Board of Radiation and Isotope Technology) Sir Bhabha Atomic Research Centre, Mumbai(India) for providing necessary facility for irradiation.

REFERENCES

Aina JO, Adesiji OF, Ferris SRB (1999). Effect of gamma irradiation on post harvest ripening of plantain fruit (*Musa paradisiaca* L.). J Sci Food. Agric. 79(5):653-656.

Anonymous (2007). Post harvest manual for mangoes. APEDA, Ministry of Agriculture, Govt of India.

Beyers M, Thomas AC (1979). Gamma irradiation of subtropical fruits 4. Changes in certain nutrients present in mangoes, papayas and litchis during canning, freezing and gamma irradiation. J Agric Food Chem. 27(1):48-51.

Bhushan B, Thomas P (1990). Quality of apples following gamma irradiation and cold storage. Int. J. Food Sci. Nut. 49(66):485-492.

Deka BC, Choudhury A, Bhattacharyya KH, Begum, Neog M (2006). Postharvest treatment for shelf life extension of banana under different storage environments. Acta Hort. 2:841-849.

Dhakar SD, Savagraon KA, Srirangarajan AN, Sreenivasan A (1966). Irradiation of mangoes. I. Radiation- induced delay in ripening of Alphonso mangoes. J Food Sci. 31(6):863-869.

El-Salhy FTA, Khafagy SAA, Haggay LF (2006). The changes that occur in mango fruits treated by irradiation and hot water during cold storage. J. Appl .Res. 2(11):864-868.

Farzana P (2005). Post harvest technology of mango fruits, its development, physiology, pathology and marketing in Pakistan. Digital VerlagGmbH Pub Germany.

Gomez-Lim MR (1993). Mango fruit ripening: Physiological and Molecular biology. Acta Hort. 341:484-496.

Gutierrez AO, Nieto AD, Martinez D, Dominguez AMT, Delgadillo S, Qutierrez AJG (2002). Low temperature plastic film, maturity stage and shelf life of guava fruits. Revista Chapingo Serie Hort. 8(2):283-301.

Hussein AM, Sabrou MB, Zaghloul AE (1998). Post harvest physical and biochemical changes of common and late types of seedy guava fruits during storage. Alexandria J. Agric. Res. 43(3):187-204.

Kovacs E, Djediro GA, Sass P (1994). Metabolism of source in apples (*Malus domestica* Borkh) as a function of ripeness, cultivar, radiation dose and storage time. Acta Hort. 60:235-242.

Mahindru SN (2009) Food preservation and irradiation. APH publishing corporation, New Delhi.

Mane SR, Patel BN (2010). Effect of maturity indices, postharvest treatments and storage temperatures on physiological changes of mango (*Mangifera indica* L) cv Kesar. In: National seminar on precision farming in horticulture during, CoHF, Jhalawar, India, P. 291.

Mann SS, Singh RN (1975). Studies on cold storage of mango fruits (*Mangifera indica* L.) cv. Langra. Indian J. Hort. 32(1):7-14.

Mayer BS, Anderson DS, Bhing RH (1960). Introduction to plant physiology. D Van Nastrand Co Ltd, London.

Nagaraju CG, Reddy TV (1995). Deferral of banana fruit ripening by cool chamber storage. Adv. Hort. Sci. 9(4):162-166.

Narayana CK, Singh BP (2000). Effect of chilling temperature on ripening behavior of mango. Haryana J. Hort Sci. 29(3-4):168-170.

Panse VG, Sukhatme PV (1967). Statistical Methods for Agricultural workers. ICAR, New Delhi.

Pereira T, Tijskens LMM, Vanoli M, Rizzolo A, Eccherzerbini P, Torricelli A, Spinelli L, Filgueiras H (2010). Assessing the harvest maturity of Brazilian mangoes. In EW Hevett et al. (Eds) Proc IS on Post Harvest Pacifica 2009. Acta Hort*,* P. 880.

Plaza J, L-de la Alique R, Calvo L, Moure J (1992). Control of modifications in quality of the papaya fruit during cold storage in polyethylene bags. In Rodriguez J H (eds) Proceeding of a conference held in Granada, Spain, pp. 19-27.

Prasadini PP, Khan MA, Reddy PG (2008). Effect of irradiation on shelf life and microbiological quality of mangoes (*Mangifera indica* L.). J. Res. ANGRU. 36(4):14-23.

Purohit AK, Rawat TS, Kumar A (2004). Shelf life and quality of ber fruit cv. Umran in response to post harvest application of ultra violate radiation and paclobutrazole. Pl Foods for Human Nut. 58(3):1-7.

Purwoko BS, Susanto S, Kodir KA, Novita T, Harran S (2002). Studies on the physiology of polyamines and ethylene during ripening of banana and papaya fruits. Acta Hort. 575(2):651-657.

Rangana S (1986). Manual of analysis of fruits and vegetable products. Tata McGraw Hill Publishing Co Ltd New Delhi.

Roy SK, Joshi GD (1989). An approach to integrated post harvest handling of mango. Acta Hort. 231:469-661.

Salahddin ME, Kedar AA (1980). Post harvest physiology and storage behaviour of pomegranate fruits. Sci. Hort. 24:287-298.

Shankar V, Veeragavathatham D, Kannan M (2009). Effect of organic farming practices on post harvest storage life and organoleptic quality of yellow onion (*Allium cepa* L.). Indian J. Agric. Sci. 79(8):608-614.

Silva JM, Correia LCSA, DeMoura NP, Maciel MIS, Villar HP (2010). Use of technology radiation as a method of reducing the microorganism and conservation postharvest of caja during storage. In 10th International Working Conference on Stored Product Protection, Cidade University, Brazil, pp. 573-577.

Singh SP, Pal PK (2007). Post harvest fruit fly disinfestations strategies in rainy season guava crop. Acta Hort. 375:591-596.

Singh SP, Pal RK (2009). Ionizing radiation treatment to improve postharvest life and maintain quality of fresh guava fruit. Radiation Phy. Chem. 78:135-140.

Singh SP, Pal RK (2009). Ionizing radiation treatment to improve postharvest life and maintain quality of fresh guava fruit. Radiation Phy. Chem. 78:135-140.

Sornsrivichai J, Jampanil R, Gomolmanee S, Tuntawiroon O, Boonthan K (1990). Post harvest colouration improvement of Anna apple by white fluorescent light. Acta Hort. 279:501-509.

Sudto T, Uthariaratanakij A, Jitareerat R, Photchanachai S, Vongcheeree S (2005). Effect of gamma irradiation on ripening process of Morn-Thong durian. In International symposium on new frontier irradiated food and non-food products, Bangkok, Thailand.

Tharanathan RN,Yashoda HM, Prabha TN (2006). Mango (*Mangifera indica* L) the king of fruits – An overview. Food Rev Int. 22:95-123.

Udipi SA, Ghurge PS (2010). Applications of food irradiation. In: Udipi SA, Ghugre PS (ed) Food irradiation, Agrotech Publishing Academy, Udaipur, pp. 40-71.

Upadhyay PI (1992). Effect of gamma irradiation and hot water treatment on the shelf life of mango (*Mangifera indica* L) var Red. In Asian Inst Tech, Bangkok.

Wall MM (2007). Post harvest quality and ripening of Dwarf Brazillian bananas (*Musa Sp)* after x-ray irradiation quarantine treatment. HortSci. 42(1):130-134.

Waskar DP, Masalkar SD (1997). Effect of hydrocooling and bavistin dip on the shelf life and quality of mango during storage under various environments. Acta Hort. 455:687-695.

Yadav MK, Patel NL, Hazarika Ankita, Chaudhary PM (2010). Physiological changes in Kesar mango as influenced by treatment and storage. The Hort. J. 23(1):16-17.

Yimyong S, Datsenka TU, Handa AK, Sereypheap K (2011). Hot water treatment delays ripening associated metabolic shift in ‘Okrong’ mango fruit during storage. J. Am. Soc. Hort Sci. 136(6):441-451.