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Irradiation and Storage Temperature Influence the Physiological Changes and Shelf Life of Mango (*Mangifera indica* L.)

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Abstract: In spite of being the leading producer of mango in the world, India registers the highest post harvest losses and minuscule exports. The reasons for this paradox are manifold. However, issues related to quarantine, shelf life and quality are the major stumbling blocks to trade, both national and international Therefore, a balance between the required effective dose and tolerance of fruit to irradiation has to be investigated under various storage temperatures. The experiment was arranged with sixteen treatment combinations of irradiation doses (0.00kGy-0.60kGy) and similar to storage temperature (Ambient at 27±2°C and 60-70% RH, 9°C and 90% RH, 12°C and 90% RH and Control atmospheric (CA) storage (12°C, O_2 2%, CO_2 3% and RH 90%) from the year 2008-2010. The fruits were exposed to gamma radiation from the source of ^{60}Co. The data indicated that the fruits irradiated with 0.40kGy gamma rays recorded significantly minimum per cent reduction in physiological loss in weight, reduced ripening per cent, increased marketability of fruits and maximum average days to ripening and shelf life of fruits. Similar pattern were noticed when fruits kept at 9°C storage temperature and in combined effect of irradiation and storage conditions. Suggestions are made for maximizing storage potential by use of irradiation and adequate storage facilities for qualitative and hygiene produces.

Keywords: Alphonso Mango, Gamma Irradiation, Marketability, Ripening, Shelf Life, Storage Temperature

1. Introduction

Mangoes (*Mangifera indica* L.; family Anacardiacae) are still judged as luxuries and expensive items in the markets of many industrialized countries. Asia accounts for 77% of global mango production and the Americas and Africa account for 13 and 19%, respectively [14]. India is the global leader in mango production [28]. The high cost of mangoes in importing countries is due to high air freight charges. Mangoes are classified as climacteric fruits and ripen 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 the week [30] As fruit, it's also remain alive after harvesting it is necessary to restrain their respiration and metabolic activity in order to maintain cell life and optimize post harvest quality by delayed ripening and senescence. For overcome these metabolic activities, innovation in irradiation and cold storage is the new tools for the enhancement of physiological changes and health promoting components in most of climacteric fruits. Mango is susceptible to chilling injury and an optimum temperature of 12-13°C is generally recommended [7], [31]. Irradiation of fruits has been successfully shown to delay ripening in Papaya [16]. 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 contamination and at the same time preserves quality [9]. In spite of being the leading producer of mango in the world, India registers the highest post harvest losses and minuscule exports. The reasons for this paradox are manifold. However, issues related to quarantine, shelf life and quality are the major stumbling blocks to trade, both national and international [30]. Therefore, a balance between the required effective dose and tolerance of fruit to irradiation has to be investigated under various storage temperatures. So, irradiation can be used in combination with low temperature for to assess the effects of different doses of gamma irradiation and storage temperature on reduction the physiological loss in weight and ripening phenomena of fruit. The loss in weight of fruits is likely to reduce the marketability and quality of fruit drastically.

2. Materials and Methods

The experiment was at conducted at Department of Horticulture, Navinchandra Mafatlal College of Agriculture, Navsari agricultural University, Navsari, Gujarat from the year 2008-2010. Export grade mangoes of cv. Alphonso were harvested from 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. 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 250-350g. The selected fruits wash with chlorine water and after drying fruits packed in corrugated fibre board boxes cushioned (CFB) with tissue paper. The dimension of CFB box was 370 X 275 X 90mm 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 hours for pre-cooling treatment. The time gap between harvesting and pre-cooling was not more than 6 hours.

2.1. Irradiation Treatment

After pre-cooling, fruits transport to irradiation treatment in air conditioned vehicle. It was carried out at 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 1.33MeV. There were four irradiation doses *i.e.* I_1-0.00kGy (Unirradiated), I_2-0.20kGy, I_3-0.40kGy and I_4-0.60kGy. The time gap from pre-cooling to irradiation was not more than 9 hours. After irradiation, fruits immediately transported to cold storage of university in air conditioned vehicle.

2.2. Storage Conditions

The boxes were kept in cold storage at different temperature as per storage temperature treatments *viz*., Ambient at 27±2°C temperature and 65±5% relative humidity (S_1), 9°C temperature and 90% relative humidity (S_2), 12°C temperature and 90% relative humidity (S_1) and Control atmospheric storage at 12°C temperature, 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.

2.3. Measurement Protocols

2.3.1. Determination of Physiological Parameters

i. Physiological Loss in Weight (Per Cent)

Four fruits from each treatment were weighted on first day of treatment and subsequently their weight was recorded from forth day to at six day interval up to the end of shelf life. The Physiological loss in weight was expressed in percentage and calculated as follows. PLW %=W_1–W_2/ W_1 X 100, Where, W_1=initial weight and W_2=final weight [27]

ii. Ripening Per Cent

Ripening was measured by the number of fruits having change in colour from greenish to yellow and soft in texture were counted from four day of storage to at six day intervals up to the eating ripeness and expressed in percentage over total number of fruits taken for study.

2.3.2. Marketable Fruits Per Cent

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 per cent fruits has marketability.

2.3.3. Average Number of Days Taken to Ripening

The number of days taken by mango fruits in each treatment to attain eating ripeness by more than 80 per cent fruits of treatment was considered as days taken for ripening.

2.3.4. Shelf Life of Fruits

The number of days taken in each treatment to attain the maximum eating ripeness by all the fruits was computed considering the weighted mean. Each fruit was thoroughly scrutinized for any visible symptoms of spoilage and the end of shelf life was considered when the 90 per cent fruits were over ripened.

2.4. Statistical Analysis

Statistically the data obtained from 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 [15]. The data were subjected to appropriate transformation (arcsine) to meet the assumptions of normality.

3. Results and Discussion

3.1. 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 is evident from Table 1, that the minimum reduction in physiological loss in weight was recorded in the fruits exposed with 0.40kGy irradiation and stored at 9°C (I_3S_2) *i.e.* 0.932% at 6th day, 1.780% at 12th day, 2.760% at 18th day, 3.480% at 24th day, 4.730% at 30th day and 5.670% at 36th day of storage. The physiological loss of weight in fruits was possibly on account of loss of moisture through transpiration and utilization of some reserve food materials in the process of respiration [12]. 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 [18]. The delay in respiration rate as a result of irradiation is also reported by [19] in guava. Similar findings were also observed by [29], [17] [5] in mango. Lower physiological loss in weight was noted in 9°C and 12°C and in CA (12°C) storage temperature 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 [27]. The observations accordance with the results of [23] in mango; [14] in banana and [8] in guava.

Table 1. *Effect of Irradiation and storage conditions on physiological loss in weight of mango Cv. Alphonso during storage.*

	Physiological loss in weight (%) days after storage														
	4					**10**					**16**				
Source	**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	3.493	2.783	2.633	2.743	2.913	12.197	7.463	7.170	7.243	8.518	0.000	10.310	10.820	11.490	8.150
S_2	0.853	0.683	0.473	0.733	0.686	2.357	1.867	1.417	2.037	1.919	3.180	2.960	2.340	3.090	2.890
S_3	0.873	0.753	0.613	0.837	0.769	2.557	1.990	1.640	2.217	2.108	3.870	3.090	2.570	3.370	3.220
S_4	2.683	2.303	1.700	2.367	2.263	7.110	3.520	3.387	3.610	4.407	10.100	5.270)	5.220	5.470	6.510
Mean	1.976	1.630	1.355	1.670		6.055	3.710	3.403	3.777		4.290	5.410	5.250	5.850	
Source	I	S		I X S		I	S		I X S		I	S		I X S	
S. Em ±	0.0035	0.003		0.007		0.005	0.005		0.010		0.010	0.010		0.021	
CD ($P≤0.05$)	0.010	0.010		0.020		0.015	0.015		0.030		0.031	0.031		0.062	

Table 1. *Cont.*

	Physiological loss in weight (%) days after storage														
	22					**28**					**34**				
Source	**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	0.000	13.470	12.650	13.810	9.980	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
S_2	4.650	4.230	3.230	3.360	3.870	6.410	5.440	4.440	5.760	5.520	7.930	6.990	5.500	7.090	6.880
S_3	4.420	4.370	3.430	4.420	4.160	6.940	5.690	4.610	5.970	5.800	0.000)	7.230	5.510	7.520	5.060
S_4	13.320	7.320	6.940	7.990	8.890	0.000	9.300	9.200	5.490	5.990	0.000	0.000	0.000	0.000	0.000
Mean	5.600	7.350	6.850	7.100		3.340	5.110	4.560	4.300		1.980	3.550	2.750	3.650	
Source	I	S		I X S		I	S		I X S		I	S		I X S	
S. Em ±	0.005	0.005		0.010		0.005	0.005		0.011		0.005	0.005		0.010	
CD ($P≤0.05$)	0.16	0.16		0.031		0.016	0.016		0.033		0.015	0.015		0.030	

Where I=irradiation, S=Storage temperature, CA=Control atmospheric storage

3.2. Ripening Per Cent

The Table 2, indicated that irradiated fruits significantly delayed the ripening process over unirradiated fruits irrespective of storage condition and not fully ripen up to 30th day of storage at 9°C. The fruits exposed to gamma rays (0.40kGy) and stored at 9°C and 12°C were remained unripe (I_3S_2 and I_3S_3) on 30th day of storage, the gamma rays @ 0.40kGy (I_3) exposed fruits showed 50.10 and 52.00 per cent ripening, respectively at 9°C and 12°C (S_3) storage. Rest of the treatments has high ripening or discarded due to complete of their shelf life. The unirradiated mangoes had early ripeness whereas; gamma rays exposed mangoes had a significantly delayed ripening. The possible mechanisms that have been postulated include: a) irradiations results in decreased sensitivity to ripening action of ethylene and 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 [22]. Same findings noted by [26] and [6] in mango and [1] in banana. The lower and delayed ripening was noted at 9°C and 12°C and in CA (12°C) storage as compared to ambient temperature. The decrease of ripening per cent and increase in days for ripening at low temperature may be due to desirable inhibition of enzymatic activities leading reduction in the respiration and ethylene production. These results are supported by [11] in mango and [2] in banana. The minimum and delayed ripening in fruits due to exposed to gamma rays and stored at low temperature might be due to the joint balancing effect of irradiation and low temperature [26].

Table 2. *Effect of Irradiation and storage conditions on ripening of mango Cv. Alphonso during storage.*

	Ripening (%) days after storage														
	10					16					22				
Source	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	93.88	0.000	0.000	0.000	23.470	0.000*	71.630	69.900	72.920	53.610	0.00*	0.00*	0.00*	0.00*	0.00
S_2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00
S_3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00
S_4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	77.15	69.36	64.94	73.17	71.15
Mean	23.470	0.000	0.000	0.000		0.000	17.910	17.470	18.230		19.29	17.34	16.23	18.29	
Source	I	S		I X S		I	S		I X S		I	S		I X S	
S. Em ±	0.005	0.005		0.010		0.013	0.013		0.026		0.01	0.01		0.02	
CD (P≤0.05)	0.014	0.014		0.029		0.038	0.038		0.075		0.03	0.03		0.07	

Table 2. *Cont.*

	Ripening (%) days after storage									
	28					34				
Source	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	0.00*	0.00*	0.00*	0.00*	0.00
S_2	65.23	29.52	28.25	47.08	42.52	0.00*	86.06	84.13	97.76	66.98
S_3	74.66	33.08	28.93	57.90	48.65	0.00*	97.01	96.36	98.10	72.87
S_4	0.00*	0.00*	0.00*	0.00*	0.00	0.00*	0.00*	0.00*	0.00*	0.00
Mean	34.97	15.65	14.29	26.24		0.00	45.77	45.12	48.96	
Source	I	S		I X S		I	S		I X S	
S. Em ±	0.01	0.01		0.02		0.02	0.02		0.04	
CD (P≤0.05)	0.04	0.04		0.08		0.06	0.06		0.12	

Note: 1.-* indicate fruits completely discarded

2. Where I=irradiation, S=Storage temperature, CA=Control atmospheric storage

3.3. Marketable Fruits Per Cent

The marketable fruits percentage were influenced with the advancement of storage period and significantly affected by irradiation, storage temperature and their interaction (Table 3). During storage, few treatments had 100 per cent values for marketability and few had 0.00 per cent marketability due to induction of senescence. On 12th day of storage only unirradiated ambient stored fruits showed 98.53% marketability, rests are cent per cent marketable but up to 30th day of storage all treatments showed lover marketability compared to cent per cent in treatments I_2S_3 and I_3S_3. The gamma rays irradiated fruits stored at 9°C and 12°C and in CA (12°C) had significantly higher marketable fruits compared to unirradiated (0.00kGy) fruits. The possible reasons may be that irradiation maintains water content in the fruit and low temperature coupled with high humidity in cold storage maintains the health of the fruits. These results are in conformity with the findings of [27] and [5] with respect to irradiation and [10] with respect to low temperature in mango.

Table 3. *Effect of Irradiation and storage conditions on marketable fruits of mango Cv. Alphonso during storage.*

	Marketable fruits (%) days after storage									
	10					**16**				
Source	**I_1**	**I_2**	**I_3**	**I_4**	**Mean**	**I_1**	**I_2**	**I_3**	**I_4**	**Mean**
S_1	97.69	100	100	100	99.42	0.00	97.56	100	97.28	73.71
S_2	100	100	100	100	100	100	100	100	100	100
S_3	100	100	100	100	100	100	100	100	100	100
S_4	100	100	100	100	100	100	100	100	100	100
Mean	100	100	100	100		75.00	99.39	100	99.32	
Source	I		S	I X S		I	S		I X S	
S. Em ±	0.05		0.05	0.10		0.11	0.11		0.22	
CD (P≤0.05)	0.15		0.15	0.30		0.32	0.32		0.66	

Table 3. *Cont.*

	Marketable fruits (%) days after storage									
	22					28				
Source	I_1	I_2	I_3	I_4	Mean	I_1	I_2	I_3	I_4	Mean
S_1	0.00	88.82	89.37	86.00	66.05	0.00	0.00	0.00	0.00	0.00
S_2	100	100	100	100	100	84.57	95.97	100	94.11	93.66
S_3	100	100	100	100	100	98.47	100	100	100	99.62
S_4	94.07	100	100	96.22	97.57	59.49	71.08	84.34	69.32	71.06
Mean	73.52	97.20	97.34	95.55		60.63	141.76	71.08	65.86	
Source	I	S		I X S		I	S	I X S		
S. Em ±	0.11	0.11		0.22		0.08	0.08	0.16		
CD ($P \leq 0.05$)	0.32	0.32		0.64		0.24	0.24	0.48		

Note: Where I=irradiation, S=Storage temperature, CA=Control atmospheric storage

3.4. Average Number of Days Taken to Ripening

Significantly the maximum number of days (38.40) to ripening was recorded in fruits exposed to 0.40kGy gamma rays and stored at 9°C storage temperature (I_3S_2) followed by 37.41days when fruits exposed with 0.20kGy gamma rays and stored at same situations (I_2S_2). It can be observed that medium dose of irradiation and low temperature significantly enhanced the days taken to ripening of fruits and helped in extending the ripening process (Table 4).

3.5. Shelf Life of Fruits

The data on shelf life of fruits are presented in Table 4. It is cleared from the data that shelf life of fruits significantly influenced by irradiation, storage temperature and their interaction. Significantly the maximum shelf life (41.78 days) was recorded in fruits exposed to 0.40kGy gamma rays and stored at 9°C storage (I_3S_2) followed by I_2S_2 (40.46 days) when fruits exposed to 0.20kGy gamma rays and stored at same storage temperature. The minimum shelf life (14.11 days) was recorded in unirradiated fruits at ambient storage temperature (I_1S_1). The higher shelf life in irradiated fruits might be due to delaying the ripening process and senescence [16]. Same findings noted by [13] and [3] in mango; [32] in banana and [21] in guava. The fruits stored The shelf life increased in low temperature might be due to the delayed ripening as a result of inhibition of enzymatic activities and reducing the respiration and ethylene production [10]. The present findings confirmed with the findings of [4] in mango and [2] in banana. In combine the irradiated fruits stored at low temperature showed maximum shelf life compared to unirradiated fruits stored at ambient temperature which may be due to combined effect of irradiation and low temperature.

Table 4. *Effect of Irradiation and storage conditions on average days taken to ripening and shelf life of mango Cv. Alphonso.*

	Average days taken to ripening					Shelf life (days)				
Source	I_1	I_2	I_3	I_4	Mean	I_1	I_2	I_3	I_4	Mean
S_1	**12.00**	**21.18**	**21.90**	**20.92**	**18.99**	**14.13**	**24.16**	**24.80**	**24.10**	**21.79**
S_2	35.13	37.51	38.07	35.87	36.65	37.36	40.47	41.79	38.26	39.47
S_3	30.90	23.27	35.91	34.90	31.24	34.02	38.27	38.95	37.14	37.09
S_4	25.00	27.01	27.07	26.27	26.34	26.13	28.58	30.26	28.13	28.27
Mean	25.72	27.15	30.68	29.44		27.91	32.87	33.95	31.90	
Source	I	S	I X S			I	S		I X S	
S. Em ±	0.01	0.01	0.03			0.01	0.01		0.02	
CD ($P \leq 0.05$)	0.04	0.04	0.09			0.03	0.03		0.06	

4. Conclusion

The fruits of Alphonso mango subjected to 0.40kGy gamma rays irradiation subsequently stored at 9°C temperature delayed the ripening process which maintained lover percentage of physiological loss in weight and ripening per cent, higher percentage of marketable fruits, and increase the shelf life for longer period. This was followed by the fruits treated with 0.40kGy gamma irradiation subsequently stored at 12°C temperature.

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