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GAMMA IRRADIATION WITH MODIFIED ATMOSPHERE PACKAGING EXTEND SHELF LIFE OF MANGOES CV. HIMSAGAR

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Abstract

Irradiation technology has been in use to prolong shelf life and reduces postharvest losses of agricultural produce in many parts of the world as a safe and commercial option for its high efficacy and safety. The research was carried out at the Postharvest Laboratory of Horticulture Division, BINA during the period from June to July 2021 following completely randomized design (CRD) with three replications of 8 fruits per replication. The preharvest bagged and unbagged mangoes (cv. Himsagor) were collected from Bagha Upazila of Rajshai District. Different doses of gamma irradiation (0, 200, 400, and 600 Gy) were applied, and the irradiated mangoes were wrapped in polypropylene (PP) bags of 35µ thickness along with a control treatment to evaluate shelf life and quality at ambient condition. Parameters investigated were colour, texture, TSS, weight loss, disease incidence, disease severity, and vitamin C content during the period of storage. In terms of combined effect of preharvest bagging and gamma irradiation at the 12th day after storage, the minimum weight loss (3.92%), disease incidence (11.00%) and disease severity (8.61%) were found from pre-harvest bagged mangoes when irradiated @ 400 Gy and wrapped in PP bags. In contrast, the maximum weight loss (18.18%), disease incidence (80.00%) and disease severity (74.67%) were found from the preharvest non-bagged and non-irradiated mangoes that were not wrapped. The findings would greatly contribute in reducing postharvest loss of mangoes and maintain their quality during marketing at ambient condition.

Key words: Mango, Gamma irradiation, MAP, Pre-harvest bagging

Introduction

Mango (*Mangifera indica* L.; family Anacardiaceae) is known as the king of the fruits due to its excellent flavour, delicious taste and high nutritive values (Ullah *et al.*, 2010) that make the crop valued for both food and nutritional security especially for developing countries like Bangladesh where the nutritional security is still a challenge. The fruit is an excellent source of vitamin A and C and rich in carbohydrates, minerals (potassium and phosphorus), phenolic compounds and dietary antioxidants (FAO, 2002). Its yellow-orange characteristic color was attributed to the presence of carotenoids (Venkateswarlu and Reddy, 2014). Fifty per cent of the world's mango output comes from India, occupying the first place among the mango producing countries and the present world's major mango producing lands include India, Bangladesh, Pakistan, China, Myanmar, Thailand, Philippines, Indonesia, Brazil, Mexico, Nigeria and Egypt (Sarker, 2022).

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In Bangladesh, it occupies an area of 116 thousand hectares of land with an annual production of 1215 thousand metric tons (BBS, 2022). Mango grows in almost all parts of Bangladesh but commercial and good quality mangoes are grown in the North-Western districts of the country. The leading mango growing districts of the country are Rajshahi, Chapainawabgonj and Satkhira. Mangoes are classified as climacteric fruits and ripen rapidly after harvest. Mango is generally harvested at physiological mature (mature-hard) and is allowed to ripen under suitable conditions of temperature and humidity. Therefore, if freshly harvested fruit is allowed to ripen at normal ambient conditions, ripening process increases rapidly within a week (Yadev, *et al.*, 2013). Mango is highly perishable and the estimated postharvest loss of mango in Bangladesh is 32% (Hassan *et al*., 2021). There are various options for reducing postharvest loss and improving shelf life of perishables like low temperature storage, use of heat treatments and sanitizers, use of ethylene scavengers and ethylene inhibiting compounds, MA and CA storage, and irradiation like gamma, x-ray and e-beam. Gamma rays have been reported to be safe and proven technology and, the source is available at the BINA HQ. Since other irradiation sources are not available at the moment, the already proven gamma irradiation has been included in the present investigation. The food irradiation process does not present any enhanced toxicological, microbiological, or nutritional hazard beyond those brought about by conventional food processing techniques (Diehl, 1995) and food is safe and wholesome for consumption after irradiation up to a dose of 10000 Gy. (Kim and Vanee. 2004). Irradiation of fruits has been successfully shown to delay ripening (Pimentel and Walder, 2004) and it prevents food poisoning, reduces wastage to contamination and at the same time preserves quality (Mahindru, 2009). 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 quality of the fruit. In view of the above fact, it becomes quite clear that investigation for mango fruit is very important not only to reduce the rate of ripening but also to control weight loss. MAP aids in increasing the shelf-life of commodities from many days to many weeks as compared to conventional storage system and reduces physiological injury, disorder, weight loss, fungal growth and pathological deterioration (Kargual *et al.*, 2020). Modified atmosphere contains higher in CO_2 and lower in O_2; and it also rely on the characteristics of the commodity and the packaging film (Mahajan *et al*. 2007). The relative humidity for storage of fruits and vegetable is kept high (>90%) to avoid physiological loss in their weight and ultimate shriveling. The Himsagor variety of mango is famous for its excellent table fruit quality. This is a leading commercial mango cultivar of Bangladesh and is taking position in the export market. So, irradiation can be used in combination with MAP to assess the effects of different doses of gamma irradiation and MAP on reduction of the physiological loss in weight and ripening phenomena of fruit. The present study was undertaken to determine suitable doses of gamma irradiation to extend shelf life of mangoes and to examine their physico-chemical properties.

Materials and Methods

Experimental materials

A commercially important mango variety, namely Himsagor, was used for conducting the present experiment. Experimental preharvest bagged and un bagged export grade mangoes were collected from a commercial mango grower in Bagha, Rajshahi. The fruits were sorted by uniformity in size, shape, maturity and freedom from defects. The individual preharvesh bagged mango average length, breadth, TSS, Texture and colour is 10.5 cm, 8.1 cm 7 Brix, 6.7 and yellowish green (RHS 149A) and pre harvesh unbagged mango average length, breadth, TSS, Texture and colour is 8.8 cm, 7.1 cm 8.2 %Brix, 7.5 and deep green (RHS 137A). A total 384 export graded mangoes were used for setting up the experiment, of which 48 mangoes ware used as control (0 Gy), whereas 336 were used for imposing 3 different doses of gamma irradiation (200, 400, and 600 Gy).

Experimental location

The experiment was conducted at the Postharvest Laboratory, Horticulture Division, Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh. The experiment was conducted during the period from June-July 2021. The average temperature and humidity of the Postharvest Lab were 29.5 ^{o}C and 81.0% respectively.

Experimental treatments and design

Preharvest bagged and un-bagged mangoes were treated with gamma irradiation (0, 200, 400 and 600 Gy) through ^{60}Co gamma irradiator (CG-5000) located at Gamma Irradiation Room, Electronics Section, Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh. BINA having the research mandate for peaceful use of nuclear technique in agricultural fields, an irradiation source of Gamma Chamber (CG-5000) for exposing experimental samples was commissioned by Board of Radiation and Isotope Technology (BRIT), Mumbai, India in 2013. The equipment is calibrated by the Board of Radiation and Isotope Technology (BRIT) for ensuring the delivery of required dose of gamma radiation to the experimental samples by the inbuilt PLC (Programmable Logic Controller) system. During irradiation, the mangoes were packed in polyethylene bags and placed in the irradiation chamber and exposed to gamma irradiation for different periods of time. The critical dose rate (CDR) at the time of irradiation was 2380 Gy hr^{-1}. The treatment periods were 5 min 03 s, 10 min 05 s, 15 min 08 s for 200 Gy, 400 Gy, and 600 Gy dose of gamma irradiation, respectively. The non-irradiated mangoes were kept as control (0 Gy). The irradiated mangoes were wrapped in PP bags of 35μ thickness along with a control treatment (unwrapped) and kept in corrugated fiberboard boxes for observation. The experiment was laid out in completely randomized design (CRD) with three replications of 8 fruits per replication. The temperature and relative humidity of the storage room ranged from 28.5-30.0 ^{o}C and 76-86%, respectively during entire period of investigation (June-July 2021).

Parameters investigated

Physiological weight loss: For assessment of physiological weight loss, each mango of each replication of each treatment was separately weighed using digital electronic balance at different days of observations (1, 3, 6, 9, 12 days after irradiation). The cumulative percentage weight loss was calculated based on initial bulb weight (Nouri and Toofnaian, 2001). Weight loss was calculated using the following formula:

$$\text{PLW (\%)} = \frac{\text{Initial weight of sample (wi)} - \text{Final weight of sample (wF)}}{\text{Initial weight of sample (Wi)}} \times 100$$

Colour: The changes in colour of mango were determined using a numerical rating scale of 1-6, where 1 = green, 2 = Breaker, 3 = Up to 25% yellow, 4 = 25- <50% yellow, 5 = 50- <75% yellow and 6 = 75- 100% yellow (Hassan, 2006).

Firmness: Firmness of mango was determined by hand feeling using a numerical rating scale of 1-5, where, 1=mature hard, 2=sprung, 3=between sprung and eating ripe, 4=eating ripe and 5=over ripe (Hassan, 2006).

Disease incidence (DI) and disease severity: Diseases incidence means percentage of fruits infected with disease. This is measured by calculating the percentage of fruits infected in each replication of each treatment. The diseased fruits were identified symptomatically. Disease severity represents the percent diseased portion of the infected mango fruit. The infected fruit of each replication of each treatment were selected to determine percent fruit area infected, and was measured based on eye estimation (Hassan, 2006).

Total soluble solids (TSS): TSS was assessed from the randomly selected mango (kept for destructive sampling) at the 1, 4, 8, and 12 days after irradiation. Mango pulps were crushed by mortar and pestle and juice was extracted by passing through a cheese cloth. Then, TSS was recorded using a Refractometer (0-32% BRIX, ERMA) by taking a drop of juice on the prism and expressed as % Brix.

Vitamin C (Ascorbic acid): It was determined by titration method (Ranganna, 1979). The Vitamin C (ascorbic acid) content of the sample was calculated by following formula:

$$\text{Vitamin C (Ascorbic acid)content (mg/100g)} = \frac{\text{Titre} \times \text{Dye factor} \times \text{Volume made up (ml)}}{\text{Aliquot volume (ml)} \times \text{Weight of sample}} \times 100$$

Estimation of shelf life: Shelf life of mango was calculated by counting the days required to ripe fully as to retaining optimum marketing and eating qualities (Hassan, 2006).

Statistical analysis

The experiment was laid out in a completely randomized design (CRD) with 3 replications. Data were analyzed using analysis of variance by Statistix 10 (version 10.0 Analytical software USA). Statistically significant differences among the different doses were identified by LSD at a 5% level of significance.

Results and Discussion

The results obtained from the present experiment are presented and discussed in the following:

Physiological weight loss

Results showed that weight loss increased with storage period, and was significantly influenced by preharvest bagging, MAP and irradiation. Minimum weight losses (main effects) were found in preharvest bagged mangoes (8.80%), PP bag-wrapped mangoes (6.0%) and gamma irradiated mangoes (8.6%) respectively (Table 1). In case of combined effect, the minimum weight loss (3.92%) was found in pre-harvest bagged mangoes irradiated @ 400 Gy and wrapped in PP bags (35 µM), whereas maximum weight loss (18.18%) was found in the non-bagged, unwrapped and non-irradiated mangoes at the 12th days after irradiation (Table 1). Yadav *et al.* (2017) reported that minimum reduction in physiological loss in weight was recorded in the fruits exposed with 400 Gy irradiation and stored at 9°C. 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). Similar results were found in onion where weight loss was greatly reduced due to the application of gamma irradiation (Akhther *et al*., 2022). The delay in respiration rate as a result of irradiation is also reported in guava (Roy *et al.*, 1989). MAP also reduces weight losses, chilling injury and maintains the colour of commodity (Mahajan and Goswami, 2001; Bodbodak and Moshfeghifar, 2016). On 18^{th} date of storage, PWL for packaged mangoes were only 3.93% (Ayele *et al.*, 2012). Higher relative humidity and modified atmosphere created within the package were possible causes for significant reduction of PWL for packaged mango fruits. Faster air movement around fruits may result in higher water loss (Wills *et al.*, 1998). The result agrees with reports of many researchers (Cocozza *et al*., 2004; and Alye, 2005).

Disease incidence and severity

Disease incidence (DI) of mangoes increased with the duration of storage irrespective of treatments, and was significantly influenced due to preharvest bagging, MAP and gamma irradiation. Disease started to appear at 6 DAI for all the treatments (Table 1). Minimum DI (main effects) were recorded in preharvest bagged mangoes (32.00%), PP bag-wrapped mangoes (43.3%) and irradiated mangoes (32.10%) at the 12 days after irradiation. In terms of combined effects, the minimum DI (11.00%) was found preharvest bagged mangoes when irradiated @ 400 Gy and wrapped in PP bags and the maximum DI (80%) was found pre-harvest bagged, unwrapped and non-irradiated mangoes. Similarly, disease severity (DS) of mangoes increased with the advancement of storage period, and was significantly influenced by preharvest bagging, postharvest wrapping and irradiation.

Firmness and peel colour

Firmness was significantly influenced (main effects) by preharvest bagging, PP-bag wrapping and irradiation. Results revealed that better firmness (eating stage) was retained in preharvest bagged mangoes (wrapped in PP bags and mangoes treated with @ 400 Gy) than those of control fruits at 12 days after irradiation (Table 1). In case of combined effects, suitable firmness (eating stage) was retained in the bagged mangoes irradiated @ 400 Gy and wrapped in PP bags. In contrast, poor firmness (over ripe) was recorded in the non-bagged, unwrapped and non-irradiated mangoes (Table 1). Packaged mango fruits needed higher force to penetrate indicating that they were firmer than non-packaged ones. The effect of polyethylene bag in delaying loss of firmness could be due to modified atmosphere created within the packaging free space which may show influence to reduced rate of respiration (Zagory and Kader, 1988). Similar effect of polyethylene packaging was observed on banana fruits (Zeweter, 2008). Significant variations were observed in respect of peel colour among the fruits subjected to various pre and postharvest treatments. The most attractive colour (50-75% yellow) was found in the preharvest bagged mangoes irradiated @ 400 Gy and wrapped in PP bags (35 μM) at 12 days after irradiation (Table 2).

TSS and vitamin C

In case of TSS, there was no significantly difference among the treatments (Table 2). However, maximum TSS was found in preharvest un-bagged mangoes (17.4% Brix), PP bag-wrapped mangoes (18.0%) and mangoes treated with @ 200 Gy (17.8% Brix). It is noted that higher TSS non-bagged control fruit and lower in black polythene bagged fruit were reported by Hossain *et al*. (2020). The result is in agreement with the finding of Signes *et al.* (2007). Vitamin C contents decreased with storage period and not significantly influenced by pre harvest bagging, postharvest PP bag wrapping, gamma irradiation, and by their interactions. Maximum Vitamin C (22.7 mg/100g) was found in preharvest un-bagged mangoes treated witht @ 400 Gy and wrapped in PP bags (35μM) and minimum (16.8 mg/100 g) was found pre harvest unwrapped non-irradiated mangoes at 12 days after irradiation, respectively (Table 2). Similar results were reported by Hossain *et al.* (2020). The bagging led to lower content of chemical components such as vitamin C, phenols and organic acids in most of peach varieties (Lima *et al.*, 2013). The bagged fruits showed highest content of vitamin C, sucrose, glucose and fructose over non-bagged control in Zill mango (Hongxia *et al*., 2009) and date palm (Harhash and Al-Obeed, 2010).

Shelf life

The shelf life of mangoes was significantly influenced by postharvest PP bag wrapping and irradiation, and due to their interaction. Shelf life was calculated on basis of DS (≤10%). Preharvest bagging did not produce any significant impacts on shelf life (Fig. 1). The main effect of postharvest PP bag wrapping caused significant effects, and wrapping had significantly longer shelf life than unwrapping of fruits. The main effect of radiation caused significant effects on shelf life, and longest shelf life was recorded in 400 Gy

Table 1. Effects of bagging, radiation dose and PP bags (35 µM) on physiological weight loss, disease incidence and severity, and texture of Himsagor mangoes

Treatments	% Physiological weight loss				%DI			%DS			Firmness			
Pre-harvest bagging	3DAI	6DAI	9DAI	12DAI	6DAI	9DAI	12DAI	6DAI	9DAI	12DAI	3DAI	6DAI	9DAI	12DAI
B_0	2.9	4.8	8.5	11.3	15.0	36.7	58.3	1.7	21.9	38.7	1.2	2.4	3.4	4.0
B_1	1.7	3.2	6.4	8.8	3.5	25.0	32.0	0.2	11.7	29.9	1.1	2.4	3.4	3.9
LSD	1.1	1.4	1.4	1.5	6.8	13.0	13.0	0.7	5.1	9.7	0.2	0.2	0.3	0.2
L. of significance	*	*	**	**	**	**	**	**	**	NS	NS	NS	NS	NS
Postharvest bagging (PP bag- 35 µM)														
P_0	3.1	5.4	10.7	14.2	16.8	36.9	47.0	1.7	23.3	43.7	1.3	3.4	4.2	4.4
P_1	1.5	2.6	4.2	6.0b	1.7	24.8	43.3	0.2	10.3	24.9	1.0	1.4	2.7	3.5
LSD	1.1	1.5	1.4	1.5	6.8	13.0		0.7	5.1	9.8	0.16	0.2	0.3	0.2
L. of significance	**	**	**	**	**	NS	ND	**	**	**	**	**	**	**
Radiation dose														
T_0	2.6	4.7	8.8	12.1	12.1	43.8	66.4	1.1	21.6	54.5	1.1	2.6	3.8	4.4
T_1	2.6	4.0	7.2	9.7	11.1	29.4	36.4	0.8	16.1	27.2	1.3	2.3	3.2	3.9
T_2	1.7	3.3	6.6	8.6	6.7	24.3	32.1	1.0	14.0	23.5	1.1	2.3	3.3	3.7
T_3	2.4	4.1	7.1	10.0	7.1	25.9	45.7	0.8	15.4	31.9	1.2	2.4	3.5	4.0
LSD	1.5	2.0	2.0	2.1	9.6	18.	18.3	1.0	7.3	13.8	0.2	0.3	0.4	0.3
L. of significance	NS	NS	NS	*	NS	NS	**	NS	NS	**	NS	NS	*	**
Pre-harvest bagging × Potharvest bagging × Radiation dose														
$B_0 \times P_0 \times T_0$	3.4	6.7	14.3	18.2	40.0	66.7	80.0	4.0	44.1	74.7	1.4	3.8	4.9	5.0
$B_0 \times P_1 \times T_0$	2.5	3.5	5.4	7.3e	0.0	33.3	80.0	0.0	11.8	45.0	1.0	1.6	3.0	4.2
$B_1 \times P_0 \times T_0$	2.2	4.7	10.6	16.5	8.3	36.1	47.2	0.0	16.0	58.3	1.0	3.7	4.3	4.6
$B_1 \times P_1 \times T_0$	2.1	3.8	4.8	6.3	0.0	39.0	58.3	0.0	14.6	39.9	1.0	1.6	2.9	3.9
$B_0 \times P_0 \times T_1$	3.6	6.2	12.4	15.9	33.3	46.7	60.0	3.3	32.5	32.0	1.7	3.4	4.0	4.4
$B_0 \times P_1 \times T_1$	2.6	3.3	5.0	6.4	0.0	26.7	46.7	0.0	9.6	27.0	1.0	1.0	2.0	3.2
$B_1 \times P_0 \times T_1$	2.9	4.4	7.7	11.0	11.1	22.2	19.4	0.0	12.9	38.1	1.3	3.3	4.0	4.2
$B_1 \times P_1 \times T_1$	1.1	1.9	3.6	5.5	0.0d	22.2	19.4	0.0	9.2	11.8	1.0	1.4	2.8	3.6
$B_0 \times P_0 \times T_2$	2.6	4.8	11.0	14.3	13.3	40.0	40.0	2.5	26.3	37.3	1.2	3.6	3.9	4.2
$B_0 \times P_1 \times T_2$	1.3	2.6	4.6	6.3	13.3	26.7	46.7	1.4	12.0	22.0	1.1	1.3	2.8	3.2
$B_1 \times P_0 \times T_2$	2.6	4.3	7.9	9.7d	0.0	19.4	30.6	0.0	12.6	26.1	1.1	3.1	3.9	4.1
$B_1 \times P_1 \times T_2$	0.4	1.6	3.0	3.9	0.0	11.1	11.1	0.0	4.8	8.6f	1.0	1.3	2.4	3.1
$B_0 \times P_0 \times T_3$	6.0	8.7	10.9	15.3	20.0	33.3	60.0	2.0	29.5	41.7	1.1	3.6	4.2	4.4
$B_0 \times P_1 \times T_3$	1.1	2.6	4.4	7.0	0.0	20.0	53.3	0.0	9.6	29.7	1.1	1.3	2.8	3.4
$B_1 \times P_0 \times T_3$	1.7	3.4	10.5	12.8	8.3	30.6	38.9	1.2	12.0	41.2	1.7	3.1	4.3	4.4
$B_1 \times P_1 \times T_3$	0.9	1.6	2.8	5.0	0.0	19.4	30.6	0.0	10.3	15.1	1.0	1.3	2.8	3.6
L. of significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

B_0= Pre harvest un-bagged; B_1= Pre harvest bagged mango; P_0= Unwrapped in PP bags; P_1= Wrapped in PP bags; T_0= 0 Gy; T_1= 200Gy; T_2= 400Gy & T_3= 600Gy

Table 2. Effects of bagging, radiation dose and PP bags (35 µM) on TSS, vitamin C and peel colour of Himsagor mangoes

Treatments	TSS (%Brix)				Vitamin C (mg/100gm)				Peel Colour			
Pre-harvest bagging	1DAI	4DAI	8DAI	12DAI	1DAI	4DAI	8DAI	12DAI	3DAI	6DAI	9DAI	12DAI
B_0	8.1	13.6	16.4	17.4	41.1	37.0	27.6	20.2	1.0	1.4	2.2	2.8
B_1	7.0	12.7	15.1	17.0	39.8	37.1	31.5	20.3	2.1	2.6	3.6	4.1
LSD	0.5	0.9	0.9	0.6	2.2	2.1	1.0	0.6	0.1	0.4	0.3	0.3
L. of significance	**	NS	**	NS	NS	NS	**	NS	**	**	**	**
Postharvest bagging (PP bags 35 µM)												
P_0	7.6	13.9	17.3	16.5	40.3	36.8	28.7	18.7	1.6	3.7	3.7	4.1
P_1	7.5	12.6	14.3	18.0	40.6	37.3	30.4	21.8	1.6	1.7	2.1	2.8
LSD	0.5	0.9	0.9		2.2	2.1	1.0	0.6	0.1	0.4	0.3	0.3
L. of significance	NS	**	**	**	NS	NS	**	**	NS	*	**	**
Radiation dose												
T_0	8.2	15.1	16.1	16.3	39.9	36.4	28.5	19.3	1.5	2.1	2.9	3.3
T_1	6.8	12.6	15.8	17.8	41.9	38.6	30.4a	20.4	1.6	2.0	2.6	3.3
T_2	7.4	13.2	16.4	17.6	39.7	36.4	29.9	20.8	1.6	1.8	2.9	3.8
T_3	7.9	11.7	14.8	17.3	40.2	36.7	29.4	20.5	1.6	2.0	3.3	3.5
LSD	0.7	1.3	1.3	0.9	3.1	3.0	1.4	0.9	0.1	0.6	0.4	0.4
L. of significance	**	**	NS	**	NS	NS	NS	**	NS	NS	NS	*
Pre-harvest bagging × Potharvest bagging ×Radiation dose												
$B_0 \times P_0 \times T_0$	9.3	15.5	17.7	16.8	41.8	37.1	24.3	16.8	1.1	1.6	3.0	3.1
$B_0 \times P_1 \times T_0$	9.7	13.0	15.3	16.6	40.6	37.2	26.8	21.6	1.0	1.2	1.7	2.2
$B_1 \times P_0 \times T_0$	7.2	16.8	16.1	14.2	37.8	35.0	30.2	18.2	2.0	3.1	4.9	4.9
$B_1 \times P_1 \times T_0$	6.7	15.2	15.4	17.3	39.5	36.4	32.6	20.6	2.0	2.3	2.0	2.9
$B_0 \times P_0 \times T_1$	6.1	12.1	18.1	16.3	38.8	35.3	27.7	18.5	1.0	1.7	2.6	2.8
$B_0 \times P_1 \times T_1$	7.2	11.8	14.7	18.2	43.8	39.8	28.7	22.4	1.0	1.0	1.3	2.1
$B_1 \times P_0 \times T_1$	6.7	14.3	17.6	17.5	43.0	40.2	31.3	19.5	2.2	3.2	4.2	5.0
$B_1 \times P_1 \times T_1$	7.0	12.4	12.6	18.6	41.9	39.2	34.0	21.4	2.0	2.1	2.3	3.1
$B_0 \times P_0 \times T_2$	7.5	16.6	17.8	17.6	41.9	36.4	28.1	18.2	1.0	1.7	3.1	4.0
$B_0 \times P_1 \times T_2$	7.6	14.6	15.2	18.9	41.3	37.4	28.6	22.7	1.0	1.0	1.7	2.9
$B_1 \times P_0 \times T_2$	7.0	11.1	17.3	15.6	36.3	34.	30.5	20.0	2.0	2.4	4.3	4.8
$B_1 \times P_1 \times T_2$	7.2	10.4	15.4	18.5	39.3	36.8	32.3	22.4	2.3	2.1	2.6	3.3
$B_0 \times P_0 \times T_3$	9.4	11.9	17.3	16.7	40.2	35.7	28.7	19.0	1.0	1.5	3.0	3.0
$B_0 \times P_1 \times T_3$	8.1	13.2	15.4	17.8	40.3	36.6	27.8	22.4	1.0	1.0	1.6	2.1
$B_1 \times P_0 \times T_3$	7.2	12.5	16.2	16.6	42.7	39.7	29.1	19.4	2.3	3.0	4.7	4.9
$B_1 \times P_1 \times T_3$	6.7	9.10	10.	18.0	37.7	35.0	32.2	21.2	2.1	2.4	3.9	4.1
L. of significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

B_0= Pre harvest un-bagged; B_1 = Pre harvest bagged mango; P_0 = Unwrapped in PP bags; P_1= Wrapped in PP bags; T_0= 0 Gy; T_1= 200Gy; T_2= 400Gy & T_3= 600Gy

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irradiated mangoes (Fig. 1). Similar dose of gamma irradiation has been recommended for exporting mango from India (APEDA 2007). In case of combined effect, the longest shelf life (13.17 days) was found with 400 Gy irradiated, preharvest bagged mangoes when wrapped in PP bags (postharvest), while the shortest shelf life (6.5 days) was found in control fruits. Shelf life of fruits was significantly influenced by irradiation and extended shelf life in in the case of irradiated fruits might be due to delayed ripening process and senescence (Pimental *et al.*, 2004). Similar findings were also noted in mango (Moreno *et al.*, 2006), banana (Zaman *et al.*, 2007) and in guava (Singh, *et al.*, 2008). The maximum shelf life (41.78 days) was recorded in fruits exposed to 400 Gy gamma rays and stored at 9°C storage and the minimum shelf life (14.11 days) was recorded in non-irradiated fruits at ambient storage temperature (Yadav *et al.*, 2017). The greater storability of the bagged fruits was might be due to the reduced level of disease both in terms of incidence and severity. The bagging modified the microenvironment near fruit especially in respect to air temperature and humidity (Yang *et al.*, 2009). The shelf life increased at ambient room temperature might be due to the delayed ripening as a result of inhibition of enzymatic activities and reducing the respiration and ethylene production (Mane *et al.*, 2010). The storage of fresh fruits and vegetables in plastic films restrict the transmission of respiratory gases for the accumulation of carbon dioxide and depletion of oxygen around the crop, which may increase their shelf life.

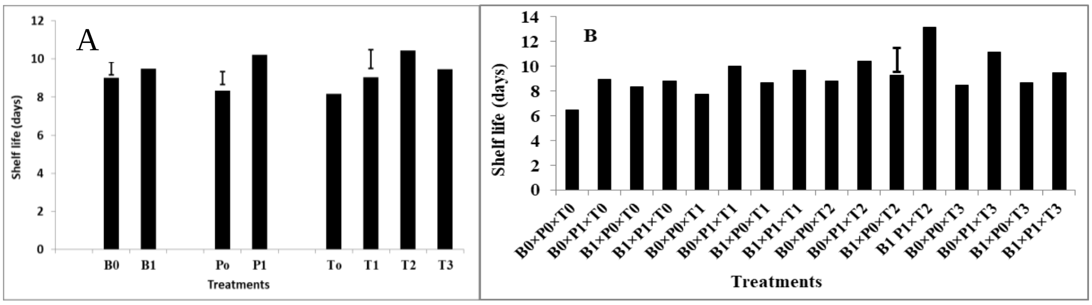

Fig. 1: Graph showing shelf life of the irradiated and non-irradiated mangoes (A: Main effects of preharvest bagging, MAP and gamma irradiation; B: Combined effects of preharvest bagging, MAP and gamma irradiation). B_0= Pre harvest un-bagged; B_1 = Pre harvest bagged mango; P_0 = Unwrapped in PP bags; P_1= Wrapped in PP bags; T_0= 0 Gy; T_1= 200 Gy; T_2= 400 Gy and T_3= 600 Gy The vertical bar represents LSDs at the 5% level of significance.

Conclusion

The fruits of Himsagor mango subjected to 400 Gy gamma rays irradiation subsequently wrapped in PP bags and stored at ambient temperature (24-25 ^{o}C) delayed the ripening process, reduced weight loss, disease incidence and disease severity, and prolonged shelf life of mangoes. The above dose was found to retain the optimal eating and nutritional quality of fruits. Furthermore, irradiation technology is safe and modern commercial method of extending shelf life and reducing postharvest loss of perishables. Further studies may be suggested to carry out for further refinement of the technology.

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