EFFECT OF GAMMA IRRADIATION AND PACKAGING ON QUALITY AND SHELF LIFE OF MANGO

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JUNE, 2020

EFFECT OF GAMMA IRRADIATION AND PACKAGING ON QUALITY AND SHELF LIFE OF MANGO

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A Thesis
Submitted to the Faculty of Agriculture
Sher-e-Bangla Agricultural University, Dhaka
in partial fulfilment of the requirements
for the degree of

MASTER OF SCIENCE
IN
HORTICULTURE
SEMESTER: JANUARY-JUNE, 2020

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This is to certify that the thesis entitled, **"EFFECT OF GAMMA IRRADIATION AND PACKAGING ON QUALITY AND SHELF LIFE OF MANGO"** *submitted to the Department of Horticulture, Faculty of Agriculture, Sher-e-Bangla Agricultural university, Dhaka, in partial fulfillment of the requirement for the degree of* **MASTER OF SCIENCE IN HORTICULTURE** *embodies the results of a piece of bona fide research work carried out by* **MD. ATIQUR RAHMAN SHAON,** *bearing Registration No.* **12-04891** *under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma, elsewhere in the country or abroad.*

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ACKNOWLEDGEMENT

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EFFECT OF GAMMA IRRADIATION AND PACKAGING ON QUALITY AND SHELF LIFE OF MANGO

ABSTRACT

Mango is a highly perishable fruit that has a short shelf life. The irradiation technology plays an important role in controlling the food spoilage by microorganism, and also enhances the shelf life. The irradiation treatment was carried out at Institute of Food and Radiation Biology, Bangladesh Atomic Energy Research Establishment, Ganakbari, Savar, Dhaka, while the parameters were studied at Postharvest Laboratory of Department of Horticulture, Sher-e-Bangla Agricultural University. Mango fruits were treated with gamma irradiation of different doses i.e. Ra_0: 0.00kGy, Ra_1: 0.30kGy, Ra_2: 0.50kGy, Ra_3: 0.70kGy, Ra_4: 1.00kGy; and stored in two postharvest packaging i.e., non-packaging (P_0) and packaging (P_1) with low-density polyethylene (LDPE). Results revealed that 0.70kGy irradiated fruits reduced percentage of weight loss, disease severity, delay ripening, prevented moisture loss (%) and maintained better quality in terms of titratable acidity (TA), total soluble solids (TSS), p^H, ascorbic acid content, β-carotene content, and prolonged shelf life compared to other gamma irradiation treatment. Perforated LDPE bag (P_1) also increase the shelf life of mango and maintain better quality as irradiation. Therefore, 0.70kGy irradiated fruit stored in perforated LDPE polybag can be considered the most effective treatment in maintaining better quality and extending the shelf life of mangoes.

LIST OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

(Cont'd)

LIST OF PLATES

PLATE	TITLE	PAGE NO.
1.	Application of postharvest treatment	31
2	Chemical analysis of mango pulp	32
3	Comparison of black spot severity (%) among treatment combination	61
4	Comparison of disease severity (%) among the treatment combination	65

LIST OF APPENDICES

List of Abbreviations of Technical Symbols and Terms

Full Word	Abbreviation/ Symbol
Food & Drug Administration	FDA
Adenosine Triphosphate	ATP
Analysis of Variance	ANOVA
International Consultative Group of Food Irradiation	ICGFI
And Others	*et al.*
Institute of Food and Radiation Biology	IFRB
Low Density Poly Ethylene	LDPE
Physiological Loss of Weight	PLW
Coefficient of Variation	CV
Total Soluble Solid	TSS
Complete Randomized Design	CRD
Titratable Acidity	TA
Days After Storage	DAS
Modified Atmosphere Packaging	MAP
Relative Humidity	RH
Food and Agriculture Organization	FAO
Degree of Freedom	DF
High Density Polyethylene	HDPE
Journal	*J.*
Least Significant Difference	LSD
Negative Logarithm of Hydrogen Ion Conc.	pH
World Health Organization	WHO
Percentage of Disease Incidence	% DI
Sher-E-Bangla Agricultural University	SAU
That is	i.e.
Percentage of Disease Severity	%DS

CHAPTER I
INTRODUCTION

Mango (*Mangifera indica* L.) is one of the most important fruits of Bangladesh and acknowledged as the "king of fruits". It belongs to the family Anacardiaceae. Bangladesh is the world's eighth largest mango producing country and it accounts for about 4% of the world total mango production (Rahman and Khatun, 2018). It is recognized as one of the choicest and well accepted fruits all over the world due to its luscious taste, attractive color and exemplary nutritive value. It plays an important role in balancing the human diet by providing about 64-86 calories per 100 grams of ripe fruits (Rathore *et al.*, 2007). It is a good source of vital protective nutrients like vitamins A, B, and C, niacin, and also rich in minerals including calcium, potassium and iron (Amin and Hanif, 2002).

It is an important tropical fruit, however it is susceptible to a number of biotic and abiotic stresses that leads to rapid deterioration and postharvest losses. The postharvest loss in terms of quality and quantity of fruits occur all stages in the postharvest system from harvesting to consumption. Mango showed highly prominent postharvest loss because of its high perishability and climacteric pattern of respiration. Anthracnose (*Colletotrichum gloeosporioides*) and stem-end rot (*Diplodia natalensis*) are the major postharvest diseases of mango fruits, which cause black spots on fruits skin during ripening and storage. Many scientists estimated that 20-30 per cent losses in fruits and vegetables are due to post harvest diseases (Yadav *et al.*, 2013). Tahir *et al*. (2002) reported that in mango, postharvest losses lie in the range of 25-40% from harvesting to consumption while it is 51.88% in case of Bangladesh stage (Molla *et al.*, 2010). It is not only a serious problem of Amrapali growers and traders in Bangladesh, but also the improvement of the shelf life and reduction of the postharvest losses of mango fruit has become an international issue. Therefore, it is necessary to explore the ways and means to prolong the shelf life of the fruit while keeping the quality high.

Gamma radiation has been used as a post-harvest food preservation process for many years. Irradiation has proved to be effective for controlling post-harvest losses and extending the shelf life by delaying the ripening and senescence of climacteric fruits (Mostafavi *et al.*, 2010). Internationally, World Health Organization (WHO), the Food & Agriculture Organization (FAO), and the International Atomic Energy Agency in Vienna have considered food irradiation as a safe and efficient technology (El-Samahy *et al.*, 2000). Akram and Kwon, (2010) reported that irradiation is considered a safe and well proven process that has found numerous applications in food processing and preservation. Ferrier (2010) explained that higher doses of irradiation may cause damage to the living tissues of food. Therefore, the level of damage, its effect on human health and the acceptance of irradiated foods by consumers are a debatable topic. Generally, the low doses are used for fresh fruits and vegetables with exception of fresh spinach and lettuce.

The FDA (Food and Drug Administration) restricts the maximum level of irradiation for fresh fruits and vegetables to 1.0kGy. In mango, it fulfils three purposes, (a) control of insect infestation, (b) delays ripening and (c) reduces microbial load (CAC, 1983). Gamma ray treatment with dose range between 0.25 and 1kGy is used for inducing delayed ripening in fresh fruits and vegetables (ICGFI,1999). Low doses of irradiation (up to 1kGy) significantly extend the shelf- life of fruits by inhibiting ripening processes and by inactivating the spoilage microorganisms (Fan, 2012). Mahto, R., Das, M. (2013) studied the feasibility of low dose gamma radiation on Dushehri (0.3-0.7kGy) and Fazli (0.5-0.7kGy). They showed that low dose gamma radiation useful in delaying ripening, reducing weight loss, and extension of shelf life by a minimum of 3 and 4 days in case of Dushehri and Fazli respectively. Wrapping fruit by packaging material helps to extend shelf life by reducing weight loss, decay and chilling injury. MAP (Modified atmosphere packaging) is a unique technique used for enhancing the storage and shelf life of fresh or processed fruits, vegetables and other perishable commodities (Parry, 1993). Osman and Abu-Goukh (2008) reported that use of polythene film liners sealed or perforated,

significantly delay ripening, maintain quality and extend shelf-life of fruits. Vachon *et al.* (2003) reported that irradiation used in combination with MAP or edible coatings proved to be effective in maintaining the safety of fruits and vegetables and extending their shelf life

Therefore, the present study was done to fulfill the following objectives:

i. To determine the effect of Radiation on the shelf life and quality of mango.
ii. To determine the effect Packaging on the shelf life and quality of mango.
iii. To study the physico-chemical changes during the storage of mango.

CHAPTER II
REVIEW OF LITERATURE

Fruits are living entities and still perform metabolic reactions and sustain physiological processes for a substantial time during their post-harvest period. The respiration and transpiration losses are made up by replenishing water, photosynthates (sucrose, amino acid) and minerals from the flow of cell sap, while the fruits are attached to the plant. After harvest since the source of water, photosynthates and minerals are stop, fruits enter "deterioration" or "perishable" phase (Salunkhe and Desai, 1984).

Mango holds a very short shelf life as it is highly perishable and as well as climacteric fruit and reach to respiration peak of ripening process on 3rd or 4th day after harvesting at ambient temperature (Narain *et al*., 1998). The shelf life of mango depends on storage conditions among its varieties. It extends from four to eight days at ambient temperature and 2-3 weeks in cold storage at 13ºC (Carrillo *et al*., 2000). The ripening process in mature green mango takes 9-12 days after harvesting. The ripening process of mango fruit involves a series of biochemical reactions thus cause ripening of fruit with softening of texture to admissible quality (Herianus *et al*., 2003). The uncontrolled ripening results in softness, cracking and deterioration in pulp along side losses in taste and aroma. It invites various sorts of infections too. Obviously, the consumer is forced to buy fresh lot frequently and traders and growers incur huge amount of cash losses.

Post-harvest losses of fresh produce are enormous in tropics and are estimated to 25 to 40% due to improper storage, transport and packaging. Fruits when detached from the mother plant undergo rapid physiological changes resulting in their ripening and deterioration. One among the objectives of post-harvest research is to know the causes of economic spoilage of such perishables and suggest remedies to prolong their

storage life, that understanding the post-harvest changes of the fruits may be a pre-requisite.

Therefore, an attempt has been made in this chapter to compile the literature pertaining to the effect gamma radiation and packaging material on the shelf life and storage quality of mangoes and some other stuffs under the following headings:

2.1 EFFECT OF GAMMA IRRADIATION ON QUALITY ATTRIBUTES AND SHELF LIFE OF MANGO.

Gamma rays are normally emitted from the radioisotopes of cobalt-60 and cesium-137, while high-energy electrons and X-rays are produced by machine sources.

Arvanitoyannis (2010) reported that these types of radiation are selected for the irradiation of food for the following reasons:

(a) They produce the desired food preservative effects;

(b) They do not induce radioactivity in foodstuffs or packaging materials;

(c) They are available in quantities and at costs that allow the commercial use of the irradiation process.

(Akram and Kwon, 2010) reported that irradiation is considered a safe and well proven process that has found numerous applications in food processing and preservation.

Ferrier (2010) explained that higher doses of irradiation may cause damage to the living tissues of food. Therefore, the level of damage, its effect on human health and the acceptance of irradiated foods by consumers are a debatable topic. Generally, the low doses are used for fresh fruits and vegetables with exception of fresh spinach and lettuce. The FDA restricts the maximum level of irradiation for fresh fruits and vegetables to 1.0kGy

WHO (1999) reported that the joint FAO/IAEA/WHO expert committee on food irradiation has concluded that irradiated foods are safe for consumption and are nutritionally adequate and wholesome.

Fan and Sokorai (2008) studied the production of furan, a possible carcinogen, in different fresh-cut fruits on gamma irradiation of 5kGy. They showed that irradiation produced low levels of furan in grape and pine apple, while in other fruits furan levels were not detectable. Considering the low levels and high volatility of furan, they concluded that radiation-induced furan is not a significant concern for fresh-cut produce. It is estimated that postharvest losses of fruits and vegetables can amount to as much as 40% at various points in the distribution system between production and consumption.

(Lacroix and Vigneault, 2007) found that food irradiation offers potential as a viable sanitary and phytosanitary treatment for food and agricultural products. Disease-causing pathogens can be easily controlled by the use of this technology. In addition, food irradiation technology can also be used in combination with other technologies to maintain the quality of the fresh fruits and vegetables

Moreno *et al*. (2006) reported that the textural characteristics of the mangoes affected when it exposed to gamma ray doses above 1.00kGy. Mangoes exposed to 1.5 and 3.1kGy were softer and fewer firm throughout the storage. Only the fruits irradiated at 3.1kGy were unacceptable to the sensory panelists in terms of overall quality, texture, and aroma. Therefore, 1.0kGy was the recommended dose for "Tommy Atkins" mangoes to take care of the general fruit quality attributes.

Moreira *et al*. (2007) concluded that Irradiation at doses above 1.1kGy affected the texture of the blueberries and therefore the fruits became considerably softer and fewer acceptable throughout the storage. Blueberries when exposed to 3.2kGy were found unacceptable by the sensory panelists.

Weight loss is an essential index of ripening. With the advancement of ripening, the weight of the fruits and vegetables reduces because of the conversion of starch to sugar. Manzano *et al*. (1997) observed that 6.2% fresh weight loss of

6

mango occurred when stored at 25°C temperature for 20 days. Yadav *et al.* (2017) reported that the fruits irradiated with 0.40kGy gamma rays recorded significantly minimum per cent reduction in physiological loss in weight (0.932% at 6th day, 1.780% at 12th day, 2.760% at 18th day). The irradiation significantly reduced the physiological loss in weight during storage period over control due to reduction in utilization of reserve food material in the process of respiration (Purohit *et al.*, 2004). Sing *et al.* (2016) showed that weight loss in tomatoes treated with 0.5, 0.75, 1.0 and 1.5kGy was lower than that of the control during 21 days of storage. Weight loss in tomatoes at dose of 1.5kGy was 9.95% and 16.29% as compared to 11.7% and 18.42% in unirradiated tomatoes after 14 days and 21 days of storage. The reduced weight loss observed is due to the effect of gamma-irradiation on the respiration rate and in delaying the onset of climacteric, ripening process and senescence (Dong *et al.* 1994). Alphanose. Reddy and Raju (1988) conducted an experiment on mango fruit cv. Alphanose. They stated an average 3.96% weight loss in "Alphonso" mango stored at ambient temperature for 5 days compared with 3.9% and 3.7% weight loss in "Tommy Atkins" or "Palmer" mangoes from the study conducted by Cecilia et al., stored at 20^{0}C for 5 days. Hossain *et al.* (2014) conducted an experiment on guava and reported that gamma ray dose 1kGy was the most effective in reducing weight loss (1.58 %) at 15 days of storage under room temperature condition than the control sample (5.60%). With the advancement of storage period, weight loss increased significantly in both room temperature and refrigerated condition; however, weight loss was significantly higher in unirradiated samples than irradiated samples throughout the entire storage period. Among irradiation treatments, dose of 1.2kGy was significantly effective in reducing the weight loss under both the storage conditions (Sharma and Rastogi, 2016).

Abbasi *et al.* (2015) concluded that the moisture content of green mango normally is nearly 85.54%. Shahajahan *et al.* (1994) reported that the moisture content of pulp of mature hard 'Fazli' mango was 79.95% but found it as 91% and in ripe mango 78-86%. Absar *et al.* (1993) reported that moisture content at the early stage of development varied from 87.4% to 90.1%, gradually decreased

as the maturity advanced and at ripening stage it varied from 71.22 to 79.4%. Samad *et al*. (1975) studied the fruits of ten varieties of mango, the moisture percentage was the highest (87.55%) in Ranibhog where as it was the lowest 78.96% in misribhog. This trait for the different varieties under consideration ranged from 78.96 to 87.55%. Mollah and Siddique (1973) conducted an experiment with 12 varieties of mango and found that moisture content of the pulp of all the varieties of mango ranged from 81.03 to 87.12%. Respiration is one the main metabolic determinants of tomato quality if this process is not controlled, postharvest quality significantly deteriorates. It is generally accepted that the loss of postharvest quality is proportional to the respiration rate during storage. Bu *et al*. (2013) reported that radiation doses reduced the rate of respiration compared to control. Paul *et al*. (2005) conducted an experiment and showed that guava fruits treated with the three radiation doses 0.30kGy; 0.40 kGy and 0.50kGy contain 72.7%-75.7% Moisture, 10-26mg Ascorbic acid and 0.003-0. 001mg Beta-carotene per 100gm respectively and were found acceptable till 21-26 days at room temperature whereas in the case of control the fruits stored at room temperature spoiled within 3-6 days. Boynton *et al*. (2005) revealed that respiration rate decreases with irradiation doses, greater reductions of respiration rate occurred at higher dose level, because of reduced metabolic activities of irradiated samples.

Mahto, R., Das, M. (2013) studied the feasibility of low dose gamma radiation on Dushehri (0.3-0.7kGy) and Fazli (0.5-0.7kGy). They showed that low dose gamma radiation useful in delaying ripening and extension of shelf life by a minimum of 3 and 4 days in case of Dushehri and Fazli respectively. The peel of the control fruit of 'Dushehri' turned yellowish green during the initial 4 d and complete yellow on the 7th d, in comparison to the irradiated fruit that were green on 4th d and yellowish-green on 7th d of the storage. Similarly, the peel of the irradiated fruit of 'Fazli' was also greener than that of the controls throughout the storage period. Irradiation also induced lighter pulp color in the fruit of both cultivars. The control fruit of 'Dushehri' and 'Fazli' were over ripe on the 7th and 14th d respectively. In comparison, the low dose treated fruit, particularly

those treated with 0.7kGy had firmer flesh and looked more acceptable. Andrew *et al*. (1988) reported that irradiated mango fruits were significantly greener than the non- irradiated fruits. Fruit irradiated at dose 1kGy were greener than control fruits.

Udipi *et al*., (2010) reported that 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. Same findings were noted by Yadav *et al*. (2014) in mango. Hossain *et al*. (2014) found that guava showed delayed ripening at 1.0kGy irradiation treatment which was 19th day whereas the control sample was ripened on 14 days.

Sing *et al*. (2016) showed that Gamma irradiation doses at 0.75 to 1.0kGy was effective in reducing rotting and enhancing the shelf life of tomatoes. Gamma irradiation treatment resulted in significant decrease in microbial load and decay of tomatoes under both ambient and refrigerated conditions. Mahto, R., Das, M. (2013) reported that when Dushehri mangoes were treated with gamma radiation dose(0.00kGy, 0.5kGy,0.7kGy and 1.00kGy), the disease incidence percentage was (25,5%,5%,0%) respectively at 7th day of storage, whereas in case of Fazli the disease incidence percentage was (30%, 25%, 20%, 15%) respectively at 15th day of storage at ambient temperature.

Efficacy of gamma irradiation on minimizing decay of fruits and vegetables could also be associated to its ability of penetration deep into tissues and destroying spoilage microorganism harbored in wounds or inside host tissues, thus preventing or minimizing the decay process by inhibiting the expansion of those microbes (Barkai-Golan,2001). Previously, significantly reduced rotting (decay) has been reported in strawberries treated with 2.0 and 2.5kGy, stored for 2 weeks (Silva *et al*., 2009) and in peach

(*Prunus persica*) exposed to gamma irradiation doses ranging 1.0-2.0kGy (Hussain *et al*., 2008). Majeed *et al*. (2014) also found that non-radiated strawberry fruit samples showed maximum decay (94.5 %) and weight loss (58 %) at 9th day of storage; however, irradiation significantly reduced these two quality parameters especially at higher doses which corresponded to lower weight loss and fruit decay. Dhakar *et al*. (1966) showed the Percentages of spoiled fruits during storage at room temperatures after irradiation by different doses (12-200 krads). Mangoes irradiated by 12 (0.12kGy) and 75 (0.75kGy) krads show minimum spoilage on the 19th day of storage (60%, compared with 100% for the controls), whereas fruits irradiated by more than 100 (1kGy) krads spoil much earlier. Gamma irradiation (doses of 0.75 and 1kGy) reduced lesion size caused by *Colletotrichum gloeosporioides* and anthracnose incidence in papaya fruit (*Carica papaya*). These doses inhibited *Colletotrichum gloeosporioides* conidial germination. The fruits were stored at 25∘C/80% RH for 7 days (Cia *et al*., 2007).

Shahbaz *et al*. (2014), who reported that TSS of the pomegranate juice was not affected at different irradiation doses (0.4, 1 and 2kGy). Sadoughi *et al*. (2012) also found that there was no significant change in the TSS of onion puree as a consequence of γ-irradiation. Kim and Yook (2009) reported that exposure to radiation doses up to 3kGy did not affect the TSS content of kiwi fruits at week 0, but irradiated fruits showed a decrease in the TSS content with increasing irradiation dose during storage. On the other hand, Moreno *et al*. (2006) reported that irradiated fruits showed a decrease in the TSS (°Brix) content over a period of time, suggesting a delay of ripening induced by irradiation. Tai (2008) had stated that the TSS difference depends on the days after fruit set or density and temperature storage. The rise in TSS was the outcome of conversion of carbohydrates into simple sugars through a complex mechanism during storage. Lodh *et al*. (1974) analyzed eight sorts of mango where TSS ranged from 15.40% (Totapuri) to 21.40% (Bombay green). On the other hand, Palaniswamy *et al*. (1974) observed 11.8-26.8% TSS in South Indian mango cultivars. Prasad (1977) found the utmost total soluble solids (21.5%) in

Alphanso and minimum (16.41) in Banglora mango varieties. Mollah and Siddique (1973) reported that TSS of mango cultivars Fazli and Langra were 7.70 to 14.8% and 12.15 to 18.00%, respectively. Increase within the percentage of total soluble solids during storage was recorded in mango (19.68) by Srivastava (1967). He also found that total soluble solids increased while the acidity of the fruit generally decreased.

Jana *et al*. (1998) studied the 20 mango sorts of West Bengal, India and located that variety Daudia had the highest titratable acids (0.58%). They also administered an experiment with 21 mango cultivars and qualitative analysis was performed. They narrated that titratable acidity of mango varieties differed 23 greatly. it had been the utmost (0.59%) in Himsagar and therefore the minimum (0.14%) in Jahangir. Consistent with Hossain *et al*. (1999) titratable acidity was decreased during storage and ripening. Medlicott *et al*. (2000) also observed similar results. consistent with them acidity was reduced during later growth stage on attainment of maturity and ripening. Naresh *et al*. (2015) conducted an experiment to see the effect of γ-irradiation on TA of different cultivars of mango juice samples. He reported that TA in all cultivars of control mango juice ranged from 0.42 to 0.55 (% citric acid), the lowest TA was found in Banginapalli and highest was in Neelam cultivars, respectively. The TA was remained unchanged up to 0.5 kGy but a slight decrease was observed at 1 and 3kGy irradiation doses in all the mango juices studied except Raspuri and Totapuri cultivars. He also reported that the pH of the control (0kGy) mango juices ranged between 3.88 and 4.52, with the lowest in Neelam and highest in Raspuri cultivars, respectively. He also found that pH was unaffected up to 1kGy but at a higher dose of 3kGy a significant increase in pH was noted in all the cultivars, except Raspuri and Totapuri cultivars. Yadav *et al*. (2013) reported that the acidity% of fruits was significantly affected by irradiation, storage temperature and their interaction. From their experiment the lowest acidity (0.2375%) was observed in fruits exposed to (0.40kGy) on 33 day of storage, while the highest acidity (0.2754 %) was observed in treatment (0.00kGy) on

27 day of storage. The reduction in acidity by irradiation, indicate a possible decrease in organic acids into sugars under enzymatic activities (Wall 2007). Bashir and Abu-Goukh (2003) also found that during fruit ripening, titratable acidity was reported to increase up to the climacteric peak and declined afterwards in papaya, mango and guava. The retention of acidity is an indication of delay in ripening due to effect of gamma radiation. Tovar *et al*. (2000) and Saeed *et al*. (2010) stated that pH was increased during ripening of mango fruits. Dadzie *et al*. (1997) concluded that the increase in pH (decline in acidity) could be due to utilization of acids as respiration substrates.

Youssef *et al*. (2002) reported an increase in acidity values of mango pulp at irradiation doses of 0–2kGy. This was also the case in the work of Harder *et al*. (2009), who reported an increase in acidity values of nectar of kiwi fruit irradiated with 0.5kGy. Besides the decrease in acid content of fruits with the increase in storage period could be attributed to the use of organic acids in respiratory process by the fruit cells and conversion of acids into total sugars.

Absar *et al*. (1993) studied ten varieties of mango at different stages of maturity. At ripe stage the highest vitamin C was obtained in Fonia (28.85) preceded by Ashwina (22.36), Langra (22.0), Fazli (20.40), Himsagar (15.24), Jalibanda (12.60), Kanchamitha (10.81), Khirsapat (10.65) and Gopalbhog (8.66 mg/l00g). Losses of ascorbic acid are common in various fresh fruits during storage. A sharp reduction in ascorbic acid was observed in fresh-cut and whole Ataulfo mango during storage for 5 days (Robles-Sánchez *et al*., 2009).The decrease in ascorbic acid during storage is due to conversion of ascorbic acid to dehydroascorbic acid due to the action of ascorbic acid oxidase (Mapson, 1970; Singh *et al*., 2005).Yadav *et al*. (2013) reported that the ascorbic acid content of fruits was significantly affected by irradiation and storage conditions and their interaction. He found highest ascorbic acid (9.662 mg/100 g pulp), when the kesar mangoes exposed to 0.40kGy after 33 day of storage, while the lowest ascorbic acid content

(8.848 mg/ 100 g pulp) was observed in unirradiated fruits (0.00kGy) on 27 day of storage. The similar findings mean higher ascorbic acid content at higher dose of irradiations were found by Bhushan and Thomas (1990) in apple. Dhakar *et al*. (1966) also found that ascorbic acid values are higher for irradiated Alphonso mangoes than for other treatments and compare with those for controls. Since reduction of ascorbic acid is associated with ripening, the delay in ripening due to irradiation is reflected in the higher values of ascorbic acid. Hossain *et al*. (2014) treated guava fruits with chemical (0.2% and 0.3% citric acid and potassium sorbate) and radiation (0.5kGy and 1.0kGy) at room and low temperature (4°C) and stated that ascorbic acid was much higher in citric acid (0.2 and 0.3%), potassium sorbate (0.2 and 0.3%) and radiation (0.5 and 1.0kGy) treated guava during storage as compared to control under both temperature. Rubio *et al*. (2001) studied the effects of irradiation (0.50, 0.75, and 1.00kGy) on the vitamin C content of lettuce (*Lactuca sativa*), cabbage (*Brassica oleracea*), and celery (*Apium graveolens*). There was a marked difference in the natural total ascorbic acid content of the vegetables studied with cabbage showing the highest. Irradiation did not decrease these initial concentrations, and in the case of cabbage, it actually increased them. For lettuce, cabbage, and celery the initial ascorbic acid content was 2.357, 3.085, and 0.549mg/100g, respectively and after irradiation was 2.036, 5.018, and 0.616 mg/100 g, respectively irradiated with 1.00kGy.

Jakhar *et al*. (2016) stated that the β-carotene content of mango fruits significantly increased with the advancement of storage period, likely due to the breakdown of chlorophyll and increase in carotenoids content by chlorophyllase enzyme during the storage.

 Harvesting stages and storage period had significant effect on β-carotene content of mango fruits. β-carotene content was increased with the advancement of storage concluded by Azad *et al*. (2009). It was the minimum after harvest and was maximum at last edible stage. Minimum β-carotene was

recorded in the fruits harvested first. The amount of βcarotene increased gradually with the delay in harvest and being highest at last harvest. Similar trend was noted in all periods of storage. The findings of the study by Azad *et al.* (2009) conformed to those of Absar *et al.* (1993) and Mondal *et al.* (1995).

Kalt (2005) reported that harvest stage can significantly affect carotenoid content, with later harvests of riper fruit generally leading to higher carotenoid content. the main carotenoids in fruits and vegetables, α- and β-carotene and lycopene tend to increase with ripening, and, as many carotenoid-containing fruits and vegetables are harvested before full maturity.

In fruits the rise in carotenoids with ripening are often highly significant. β- and δ- carotene increased significantly with ripening in tomatoes and apricots (Carillo-Lopez and Yahia, 2010 and Campbell *et al.,* 2013) β-carotene in tomatoes increased 1.8-fold during ripening on the vine, due to conversion from lycopene by lycopene-β-cyclase (Bravo *et al.*, 2013).

Studies had shown that post-harvest application of UV light, gamma irradiation used as a disinfestation treatment, can significantly decrease pro-vitamin A carotenoids.

Kumar *et al.* (2014) conducted an experiment to look at the individual and combined effect of two different electromagnetic energies, i.e., gamma ray viz 0.1, 0.5 and 1kGy and static magnetic field (50mT for 1 h) and their combination (0.5kGy + 50mT) on the shelf life of tomato and evaluates the biochemical attributes that influence the fruit ripening and fruit quality. They reported that gamma ray exposed fruits at 0.5 and 1kGy showed an extended shelf life due to delayed fruit ripening and reduced lycopene synthesis and ethylene production. Ethylene production was highest in control (1.7 nmol g-1 fw h-1) but decreased significantly within the gamma radiated fruits with least ethylene production within the 1kGy treated fruits.

Maxie *et al*. (1996) suggested that at higher dose of gamma ray (1kGy) the ethylene production reduces and therefore the ripening process get delayed with in the irradiated fruits.

Christian *et al*. (1990) reported that ripening response to ethylene was expected to be mediated by increase/decrease in enzyme activity of ACC synthase. The low dose of gamma ray didn't inhibit ACC synthase thus, no effect on ethylene production in treated fruits was observed. But at 1kGy dose of gamma irradiation the activity of ethylene-forming enzyme (ACC synthase) was significantly inhibited.

Gunes *et al*. (2000) stated that irradiation of fresh apple slices increased the respiration rate and decreased ethylene production in a dose- dependent manner above 1.2kGy.

Pimentel *et al*. (2004) reported that the higher shelf life in irradiated fruits might be due to delaying the ripening process and senescence. Similar findings were stated by Moreno *et al*. (2006) and Dhaker *et al*. (1966) in mango; Zaman *et al*. (2007) in banana and Sing *et al*. (2008) in guava.

Panou *et al*. (2019) conducted an experiment on effect of gamma-irradiation on sensory characteristics, physicochemical, parameters, and shelf life of *Camarosa* strawberries stored under refrigeration. Results revealed that gamma irradiation at 0.5kGy prolonged the shelf life of *Camarosa* strawberries by 3 days (shelf life of 10 days) compared to control samples (shelf life of 7 days), while irradiation at 1.0kGy accelerated the degradation of strawberries. Irradiation at 0.5kGy and 1.0kGy reduced also fungal decay by 31% and 43%, respectively. Based primarily on sensory and physicochemical data, the use of gamma irradiation at a dose of 0.5kGy in combination with refrigeration was found as a suitable approach for a considerable shelf life extension of strawberries.

2.2 EFFECT OF PACKAGING MATERIAL ON QUALITY ATTRIBUTES AND SHELF LIFE OF MANGO.

Kader (1994) reported that Packaging of 'Tommy Atkins' mango in perforated polyethylene bag delayed normal ripening, reduced weight loss and prevent fruit shriveling. Moreover, the postharvest life of mangoes can be extended by the combination of MAP with effective decay-controlling measures (Rodov *et al*., 1997).

Yahia (2006) who reported that mango fruit color development was delayed by using MA packaging. Development of color could be less due to the slowing down of various metabolic activities which are responsible for chlorophyll breakdown (Doreyappa-Gowda and Huddar, 2001)

MAP is a unique technique used for extending the storage and shelf life of fresh or processed fruits, vegetables and other perishable commodities (Parry, 1993).

Dhoot *et al*. (1984) conducted experiment on the shelf life of guava fruits with polythene packaging and chemical treatments and reported that the polythene packaging was highly effective in checking weight loss (2.21-2.37% as against 33.18% with no polythene).

Osman and Abu-Goukh (2008) studied on effect of polyethylene lining and GA3 on quality and shelf life of banana fruits in which use of polyethylene film liners sealed or perforated, significantly delay fruit ripening, maintain quality and extend shelf life of bananas and GA3 (100 ppm) treatment either by dipping the tip of the fruit only or whole fruit, resulted in delay of ripening and thereby increased the shelf life of banana fruits.

Hofinan *et al*. (1997) carried out an experiment to look the effect of packaging on mango (*Mangifera indica* l.) in addition to improve the fruit first-class of late maturing cultivars. They reported that less disease incidence was carried out in case of treated fruits as compared to nontreated fruits. Non-treated fruits were attacked by anthracnose (*Colletotrichum gloeosporioides*) which cause black sunken spots at the surface of the fruits. In case of packaging technique, fruits

packed in one-of-a-kind packaging materials (like corrugated fiber board carton, plastic crate, perforate and nonperforated polyethylene bag) had the maximum shelf life, lower physiological loss in weight and less disease incidence than without package. among the different packaging materials, fruits packed in corrugated fiber board carton had the maximum shelf life (13.02 days), decrease physiological loss in weight (4.11%) and much less disease occurrence (1.12%) without excessive deterioration as compared to others. percentage of dry matter (% DM) was higher, and days to ripen shorter. Fruit-mass, flesh color, overall soluble solids, acidity and eating quality had been generally no longer affected by packaging. those outcomes suggest that packaging can improve fruit quality through reduction in disease, and this gain outweighs the negative effects of bagging on skin shade within the 'keitt' cultivar.

Molla *et al*. (2011) carried out an experiment to increase the shelf life and maintaining the quality of mango (Mangifera indica) fruits. There were two factors. Factor A: postharvest treatments with six levels (1. untreated (control), 2. washing with chlorine, 3. dipping (5 minutes) in calcium chloride (CaCl2), 4. dipping (5 minutes) in bavistin and rinse in clean water, 5. hot water treatment and 6. tap water wash) and factor B: packaging technique with five levels (1. without packaging (control), 2. perforated poly bag (0.5%), 3. non- perforated poly bag, 4. plastic crate and 5. corrugated fiber board carton). The fruits treated with chlorine wash, tap water wash, hot water treatment, dipping in calcium chloride and bavistin were significant difference on chemical parameter (total sugar content, vitamin-C, total titratable acidity and total soluble solid) of mango. Treated fruits performed less disease incidence compared to without treated fruits. Non-treated fruits were attacked by the sunken black spots on the surface of the fruits as well as anthracnose (*Colletotrichum gloeosporioides*). In case of packaging technique, fruits packed in different packaging materials (like corrugated fiber board carton, plastic crate, perforate and non-perforated polyethylene bag) had the maximum shelf life, lower physiological loss in weight and less disease incidence, disease severity, black spot than without package.

Hailu *et al.* (2014) carried out an experiment to evaluate the effect of packaging materials on the shelf life and quality of three banana cultivars with four packaging materials, namely, LDPE perforated polythene bag, HDPE perforated polyethylene bag, dried banana leaf, teff straw and no packaging materials (control) were used. They found that banana remained marketable for 36 days in the high- density polyethylene and low-density perforated polyethylene bags, and for 18 days in banana leaf and teff straw packaging treatments while the unpackaged fruits remained marketable for 15 days only. Fruits that were not packaged lost their weight by 24.0 % whereas fruits packaged in banana leaf and teff straw became unmarketable with final weight loss of 19.8 % and 20.9 %, respectively. Packaged fruits remained well until 36th days of storage with final weight loss of only 8.2 % and 9.20 %, respectively. Decay loss for unpackaged banana fruits was16 % at the end of date 15, whereas the decay loss of fruits packaged using HDPE and LDPE perforated polyethylene bags were 43.0 % and 41.2 %, respectively at the end of the 36th day of the experiment. It can, thus, be concluded that packaging of banana fruits in HDPE and LDPE perforated polyethylene bags resulted in longer shelf life and improved quality of the produce.

Kaur *et al.* (2014) conducted an experiment to study the effect of perforated and non-perforated films on the quality and storage life of guava fruits and fruits were packed in different packaging material, viz. LDPE, HDPE, PP plastic film with or without perforation. After two weeks of storage results revealed that fruits packed in LDPE perforated films maintained higher organoleptic rating (8.30), lower PLW (0.910%), desirable firmness, minimum spoilage and better quality as compared to other treatments. The study revealed that guava fruits packed in perforated LDPE polythene film can be stored for 14 days as compared to unpacked control fruits which had storage life of 7 days.

Kader *et al.* (1989) reported that Proper packaging techniques are required for tomato fruit to avoid quality deterioration primarily due to bruising, decay and softening. 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.

Gonzalez *et al*. (1990) also concluded that modified atmosphere packaging with polythene bags delayed ripening and reduced weight loss. Rana *et al*., (2002) observed that fruits of kinnow in polyethylene bags had the lowest physiological weight loss than fruits packed in paper lining. There was no fruit decay up to 28 days of storage. Wavhal and Athale (1989), Shrivarma and Thimmaraju (1989) also reviewed that weight loss of mango was reduced when the fruits were packaged in polythene bag.

Ashenafi *et al*. (2018) reported that packaging had a significant effect on physiological weight loss, decay percentage, color score, overall acceptability and marketability on tomato fruits. Lowest physiological weight loss (24.57%) was recorded from perforate polyethylene bag. Moreover, the lowest (0.00%) decay percentage and the highest (60%) marketability were recorded from perforated polyethylene bag on 9 days of storage. Color and overall acceptability score of tomato fruit was also maximum on perforated polyethylene bag and the lowest was obtained from control treatment at the end of storage. Thus, it can be concluded that packaging of tomato fruits in perforated polyethylene bags resulted in extending storage-life with better-quality of the produce in samara area.

The increase in TSS with the advancement of storage period might be due to conversion of reserved starch and other polysaccharides into soluble form of sugar (Gohlani and Bisen, 2012). Yamashita *et al*. (2002) who also reported high SSC in control fruits of atemoyas may be due to accelerated ripening in nonwrapped fruits because of their higher respiration rates. Hence fruits packed in LDPE packaging may have recorded lower soluble solids as compared to fruits which were kept in environment with greater respiration.

Bagged fruit had low TSS value as compared to unbagged fruit due to low respiration and delayed ripening in bagged fruit. Due to low respiration rate, ripening was delayed which further delayed the conversion of carbohydrates into

sugars thereby showing a decreased TSS value. Low acidity percentage in bagged fruit could be due to least conversion of starch into sugars which can be attributed to slower ripening in bagged fruit. These results are in accordance with the findings of Kelany *et al*., (2010) who reported that fruit stored in MAP bags exhibited lower titratable acidity as compared to control fruit. Decrease in acidity percentage during extended storage has been reported by Kelany *et al*. (2010), which could be due to the substantial loss of organic acids during prolonged storage (Brecht and Yahia, 2009). Echeverria and Valich (1989) also reported that decrease in acidity could be ascribed to the utilization of organic acids as respiratory substrate during storage.

Mango ripening produces an increase in β-carotene content, which is more significant at room temperature, and may be due to an increase in mevalonic acid and geraniol syntheses, which lead to higher levels of total carotenes (Mitra and Baldwin, 1997). LDPE packaging delay ripening process and hence carotenoid contents increased gradually during storage. LDPE packaging delayed ripening and carotenoids synthesis during ripening (Ali *et al*., 2015).

During ripening of green mango fruit chlorophyll is degenerated due to various metabolic activities which leads to development of yellow color linked with carotenoids development (Doreyappa-Gowda and Huddar, 2001).

Yahia (2006) who reported that color development of mango fruit was delayed by using MA packaging. Less color development could be due to the slowing down of various metabolic activities responsible for chlorophyll breakdown (Doreyappa-Gowda and Huddar, 2001). Similarly, fruit color development was retarded under modified atmosphere storage (Miller *et al*., 1986; Yantarasri *et al*., (1995).

Galvis *et al*. (2005) concluded that MAP treatment increased fruit shelf-life by delaying the ripening process and reduced fruit weight loss and increased ascorbic acid content compared to control. Similar result was found by (Nakasone and Paull, 1998) who stated that mango is a climacteric fruit and

modified atmosphere storage using plastic bags or wrapping has shown some delay in ripening

Rodov *et al*. (1997) performed an experiment on 'Modified atmosphere packaging of Tommy Atkin mango in perforated film'. Results revealed that packaging 'Tommy Atkin' mango in perforated polythene film delayed fruit spoilage and allowed normal ripening together with a weight reduction and prevention of fruit shrivelling.

Miller *et al*. (1986) stated that plastic packaging was found to be advantageous in reducing respiration rate, delaying ripening and increasing the shelf life of mango. Ben- Yehoshua (1985) also reported that storing individual climacteric fruit in LDPE bags delayed ripening and softening, and hence improved marketability.

Gill *et al*. (2015) performed an experiment to examine the effect of LDPE (Low density polyethylene) packaging on quality of Dashehari mango fruits under low temperature storage. Physiological mature fruits were subjected to LDPE packaging with different perforation levels (0, 0.05 and 0.1%) and were placed at 12±1oC for 4 weeks. The control fruits were packed in corrugated fiber board boxes. After four weeks of storage, minimum PLW (2.03 %) was registered in LDPE packaged fruits while maximum PLW (9.86 %) was recorded in control fruits. This treatment also retained maximum fruits firmness (5.8 lbf) after three weeks of storage. At the end of storage, fruits kept in LDPE packaging resulted in highest (0.41%) juice acidity while control fruits had lowest (0.18%) acidity. Similarly, control fruits developed maximum sensory quality rating of 8.5 till two weeks of storage and then showed declining trend. Maximum β-carotene content (3.32 mg/100g of pulp) was recorded in control fruits at 3rd week of storage. In conclusions, LDPE packaging (0.1 % perforation) of Dashehari mango fruits was effective in maintaining quality characteristics up to three weeks under low temperature storage.

Azene *et al*. (2014) conducted an experiment to assess the effects of packaging materials and storage environments on shelf life of papaya fruit (*Carica papaya*

L.). A factorial combination of five packaging materials and two storage environments using randomized complete block design with three replications were used. The papaya fruits were evaluated for weight loss, percentage marketability, firmness, total soluble solids, pH, titratable acidity, ascorbic acid, reducing sugar and total sugar content. The packaged and cooled fruits remained firmer than unpackaged and evaporatively cooled fruits. Higher chemical compositions were recorded in the control fruits stored under ambient conditions during the earlier times of storage. Packaging and cooling maintained the chemical quality of papaya fruits better than the control sample fruits towards the end of storage periods.

Mango is a very popular fruit because of its wide range of adaptability, high nutritive value and richness in variety, but Postharvest losses and deterioration of nutritional quality are the most important problems in tropical and sub-tropical regions of the world. From the above reviews it is evident that many research works have been done on mango by applying radiation and using packaging materials as a postharvest technology to improve the fruit quality, but Very little information is present in Bangladesh regarding the use of radiation in fruits as a postharvest treatment on physiochemical changes, shelf life and diseases during storage and ripening. From this point of view, this research has been done so that we can find out the proper postharvest treatments to extend shelf life of the mango varieties of Bangladesh.

CHAPTER III
MATERIALS AND METHODS

3.1 Experimental location:

This experiment was conducted from June to July 2019 in the postharvest Laboratory of Horticulture Department at Sher-e-Bangla Agricultural University, Dhaka-1207, Bangladesh, while the gamma irradiation treatment was carried out at Institute of Food and Radiation Biology, Atomic Energy Establishment Ganakbari, Savar, Dhaka.

3.2 Experimental materials:

Mature, green mangoes (cv. Amrapali) were collected from a renowned orchard of Thakurgaon district, Bangladesh. Uniform sized, free from diseases, undamaged fruits were selected and transferred to the central laboratory, Sher-e-Bangla Agricultural University as early as possible with careful handling to avoid injury.

3.3 Treatments of the experiment:

The experiment consisted of two factors:

Factor A: Postharvest Gamma-radiation

i. $Ra_0 = 0.00kGy$

ii. $Ra_1 = 0.30kGy$

iii. $Ra_2 = 0.50kGy$

iv. $Ra_3 = 0.70kGy$

v. $Ra_4 = 1.00kGy$

Factor B: Postharvest packaging

i. $P_0 =$ Non packaging

ii. $P_1 =$ Perforated LDPE (Low Density Poly Ethylene) bag

3.4 Experimental Design:

The two factor experiment was laid out in a completely randomized design (CRD) with three replications. The postharvest irradiation and packaging material were assigned randomly in each replication. Under each replication, five fruits were collected for physical and destructive analysis. A total number of $10\times5\times3= 150$ matured, uniform sized, undamaged healthy fruits were harvested. The skin adherences, dots and latex were cleaned by gently wiping the fruits with moist and clean towel. There were 5×2 treatments combinations. Each treatment combination comprised of 15 fruits.

3.5 Application of Gamma irradiation:

Gamma irradiation treatment was applied by using Cobalt-60 gamma cell (Model: GSCIE -11, Serial no. 021601) (Plate 1). Before applying the treatments fruits were washed, surface sanitized with ozonized water for 20 minutes (Plate 1). Then the fruits were air dried and poured into LDPE perforated plastic bag and sealed tightly. The sealed plastic bags were labeled by indicating the name of the product. The fruits were exposed to different radiation doses (0.30kGy, 0.50kGy, 0.70kGy and 1.00kGy) and the dose rate was 7.16kGy/h. The dose rate was determined by Fricke dosimetry.

3.6 Storage condition:

The irradiated and unirradiated fruits were stored at 25 $(\pm 2)^0$ C with relative humidity 80-85% until the end of shelf life.

3.7 Parameters studied

In this experiment the following parameters were studied:

3.7.1 Physical parameters

1. Weight loss (%)

2. Ripening (%)

3. Moisture content (%)

3.7.2 Chemical parameters

1. TSS (Total soluble solid)

2. TA (Titratable acidity)

3. Vitamin C

4. p^H

5. β-carotene content

3.7.3 Microbial characters

1. Disease severity (%)
2. Browning/ black spot severity (%)

3.7.4 Shelf life

1. Duration (Days)

3.8 Observation and Data collection:

During the entire postharvest storage period the experimental fruits were keenly observed every day to find out any kind of special change. Physical observations (weight loss %, ripening %, moisture content %, browning/black spot % and disease severity %) were recorded at an interval of 3 days during storage influenced by different gamma irradiation doses and postharvest packaging. For estimating chemical analysis total soluble solids (TSS), titratable acidity (TA), β-carotene, ascorbic acid and pH of each samples were drawn at the end of shelf life.

3.9 Methods of studying parameters listed earlier

3.9.1 Physical parameters

3.9.1.1 Estimation of total weight loss

The fruits of each treatment were individually weight by using electric balance and kept for storage. Percent total weight loss was calculated at an interval of 3 days during storage by using the following formula:

Weight loss (%) = $\frac{IW - FW}{FW} \times 100$

Where,

IW = Initial fruit weights (g) and

FW= Final fruit weight (g)

3.9.1.2 Ripening percent

The ripening of fruit was judged on the basis of visual observations of change in color from greenish to yellow and by feeling softness in texture and flavor. The number of fruits having change in color from greenish to yellow were measured by using numerical rating scale of 1-5, where 1 = green, 2 = one-quarter-yellow (< 25%), 3 = two-quarter fruit skin yellow (<50%), 4 = three quarter yellow (<75%), 5 = fully yellow (75-100%). The ripen fruits were counted and expressed as percentage over total number of fruits.

3.9.1.3 Estimation of moisture content

Fifty gram of fruit pulp was weighed in a porcelain crucible (which was previously cleaned, dried and weighed) from each treatment and replications. The crucible was placed in electric oven at 80°C for 72 hours until the weight became constant. It was then cooled in desiccators and weighed again. Percent moisture content was calculated by using the formula:

Moisture content (%) = $\frac{IW - DW}{IW} \times 100$

Where,

IW = Initial weight of fruit pulp (g) and

FW= Dry weight of fruit pulp (g)

3.9.3 Chemical parameters

3.9.3.1 TSS (Total soluble solids content)

Total soluble solids content of mango pulp was estimated by using hand refractometer. A drop of mango juice squeezed from the fruit pulp on the prism of the refractometer. In each treatment three readings were taken and their average value was considered. The results were expressed as percentage.

3.9.3.2 TA (Titratable acidity)

The acidity of fruit was estimated by titrating the fruit pulp extract with 0.1 N sodium hydroxide using phenolphthalein as indicator (Rangana, 2004). From mango fruit 5 gram of fruit pulp was chopped, blended by mortar and pestle Then the juice was filtered by sieve in a beaker. The volume was made up to 50 ml by adding distilled water, then 2 drops phenolphthalein indicator was added. From this 10 ml solution was taken in a conical flask and titrated against 0.1N NaOH until a pink color was obtained. The reading was taken for 3 times. The acid content of the mango sample was calculated using the following formula:

$$TA\% = \frac{(\text{Titrate} \times \text{Normality of alkali} \times \text{volume made up} \times \text{equivalent wt.of acid} \times 100)}{(\text{volume of sample taken for estimation} \times \text{wt.of sample taken} \times 1000)}$$

0.1N NaOH solution preparation:

4.0 g of sodium hydroxide was added in water. Then the volume made up to 1 liter

Phenolphthalein indicator preparation:

To prepare phenolphthalein indicator 0.5g phenolphthalein was weighted. 50% ethanol was prepared by adding 50 ml ethanol and 50 ml distilled water. Then 0.5 g phenolphthalein was dissolved in 50% ethyl alcohol solution.

3.9.3.3 Ascorbic acid content:

Ascorbic acid content (ascorbic acid) was estimated by using 2,6-Dichlorophenol indophenol (DCPIP) visual titration method (Rangana, 2004).

5gm mango fruit sample was blended, juice was filtered by sieve. Volume was made up to 100 ml by adding oxalic acid.10 ml from solution was taken in conical flask and titrated against DCPIP (Standard dye) to a pink end point which should persist for at least 15 seconds. Ascorbic acid content in terms of mg/100 g pulp weight was calculated using the following formula:

**Ascorbic acid (mg/100g)

$$= \frac{\text{Titrate value} \times \text{die factor} \times \text{volume made up} \times 100}{\text{Aliquot of extract taken for estimation} \times \text{wt.of sample taken for estimation}}$$

5% Oxalic acid solution preparation:

It was prepared by dissolving 50g oxalic acid powder in 1000 ml distilled water.

Standard ascorbic acid solution:

10 mg of L-ascorbic acid was dissolved with 100 ml of 5% oxalic acid solution. Then 10 ml of this solution was taken in a volumetric flask with 90 ml of 5% oxalic acid solution to prepare standard ascorbic acid solution.

Dye solution preparation:

It was prepared by dissolving 260 mg of the sodium salt of 2,6-dichlorophenol indophenol in approximately 1000 ml of hot distilled water containing 210 mg of sodium bicarbonate.

Standardization of dye solution:

Ten milliliters (10 ml) of standard ascorbic acid solution was taken in a conical flask and 5 ml of oxalic acid was added to it. A micro burette was filed with the dye solution. The content of the conical flask was titrated with dye solution. The content of conical flask was titrated with dye till the pink colored end point appeared. The milliliters of dye solution required to complete the titration was recorded. Dye factor was calculated using the following formula:

Dye factor = 0.5/ titrate value

3.9.3.4 p^H:

pH was measured using a phs-25 p^H meter (Plate 2). An electrolytic cell comprise of two electrodes (calomel electrode and glass electrode) was standardized with buffer solution of p^H 4. Then the electrodes were dipped into the test sample. A voltage corresponding to the p^H of the solution was identified by the instrument. For preparing sample solution of fruits, mangoes were chopped into small pieces and ground into a fine paste by mortar and pestle. The mango juice was transferred into a test tube and the p^H of the paste was determined by inserting the electrodes into the paste and stabilized readings were recorded.

3.9.3.5 β-carotene content:

β-carotene in mango pulp was determined according to the method of (Nagata and Yamashita, 1992). One gram of pulp was mixed with 10 ml of acetone: hexane mixture (4:6) and vortex for 5 minutes. The mixture was filtered and absorbance was measured at 453nm, 505nm and 663nm wave length. The calculation was done by following method:

β-carotene (mg/100gm) = 0.216 A663-0.304 A505+0.452 A453

3.9.4 Microbial characters

3.9.4.1 Assessment of percentage of browning or black spots and disease severity:

The percentage of fruit skin browning or black spots and disease severity was recorded from 6th day of storage as visual symptom like black sunken lesions of *Colletotrichum gloeosporioides* or mycelial development (Gray mold disease) on the surface of fruit caused by *Botrytis cinerea* was visible. Fruits were stored till >25% fruit skin considered commercially unacceptable. All the infected fruits were selected to determine percent of fruit area infected.

These parameters were taken by eye estimation, for this visual scoring of mango skin was done on the basis of brown/black spot severity and disease severity. In browning or black spots 0= no browning/blackspots, 1=1-10% browning/black spots, 2=>10-20% browning/ black spots, 3= >20-30% browning/ black spots,

4=>30-40% browning/black spots, 5= >40% browning/black spots. In case of disease severity 0= no disease, 1=1-10% disease, 2=>10-20% disease, 3=>20-30% disease, 4=>30-40% disease, 5=>40% disease.

3.9. Shelf life

Shelf life of fruits were calculated from daily estimation of disease severity on the same fruits from each replication and considered as ended when the fruits had little or no commercial viability (disease severity more than 25%) as estimated by Rashid *et al.* (2015)

3.10 Statistical analysis

The collected data were statistically analyzed by STATISTIX 10 software. The significance of difference between the pairs of means was compared by least significant difference (LSD) test at the 1% level of probability (Gomez and Gomez, 1984).

A. Collection of mangoes from orchard

B. Cleaning of mangoes by ozone water

C. Cobalt-60 gamma cell
   (Model: GSCIE -11, Serial no. 021601)

D. Mangoes are irradiated by gamma ray

Plate 1: Application of postharvest treatment

E. Titration for TA and Ascorbic acid
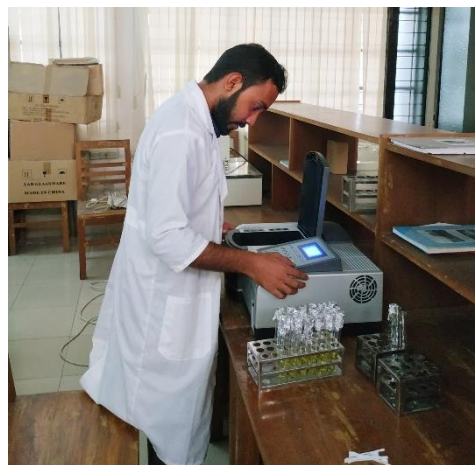
F. Estimation of Beta-carotene

G. Weighted for misture determination
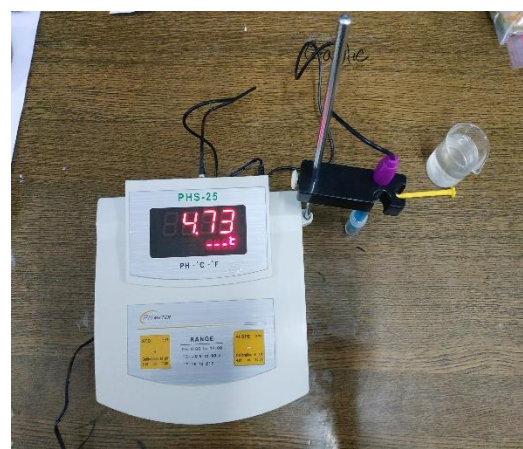
H. Determination of p^H

Plate 2: Chemical analysis of mango pulp

CHAPTER IV
RESULTS AND DISCUSSION

This chapter accounts for the presentation of the results acquired from the present study. The results of the study on physico-chemical changes during postharvest losses of "Amrapali" mango variety are represented and discussed from Table 1 to Table 11 and Figure 1 to Figure 22 in this chapter. These results are explained under the following headings:

4.1 Weight loss (%)

Physiological loss in weight of mango fruits as influenced by irradiation doses and postharvest packaging were recorded periodically at 3rd, 6th, 9th, 12th and 15th days during the storage. The weight loss percent calculating for each irradiation doses and postharvest packaging showed significant difference (Table 1, Appendix I).

The maximum weight loss (4.84%, 8.94%, 14.28%, 18.33% and 21.82% at 3rd, 6th, 9th, 12th and 15th day of storage, respectively), was found in Ra_0 (unirradiated fruit) followed by Ra_4 (1.00kGy irradiation), Ra_1 (0.30kGy irradiation) and minimum (2.40%, 5.40%, 7.01%, 8.90% and 10.55% at 3rd, 6th, 9th, 12th and 15th day of storage, respectively) was found in Ra_3 (0.70kGy irradiation) (Figure 1). 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. 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 Roy *et al*. (1989) in guava. Similar findings were also observed by Yadav *et al*. (2017), Prasadini *et al*. (2008), Yimyong *et al*. (2011) in mango. However, increase in weight loss when mango fruit irradiated to 1.00kGy was attributed to the severe membrane degradation at higher irradiation dose reported by Hayashi *et al*. (1992), Mitsuhashi *et al*. (1998).

It was found that the maximum loss in weight (4.74%, 9.87%, 13.63%, 17.29% and 19.70% at 3rd, 6th, 9th, 12th and 15th day of storage, respectively), was found in P_0 (non-packaging fruit) and the minimum (1.87%, 4.10%, 7.01%, 9.80% and 12.17% at 3rd, 6th, 9th, 12th and 15th days after harvest, respectively) was found in P_1 (perforated LDPE packaging fruit) (Figure 2). Minimum weight loss in perforated LDPE packed fruits could be due to lesser availability of oxygen for respiration, which retarded the rate of respiration and thereby lowering the moisture loss due to transpiration (Nath *et al*., 2012). The present findings were in agreement with the previous findings of Singh *et al*. (2013), Ashenafi *et al*. (2018), Rana *et al*. (2002) who found that LDPE packaging reduced PLW in mango fruits.

Figure 1: Effect of different doses of gamma irradiation on weight loss (%) of mango at different days after storage (LSD$_{0.01}$ = 0.39, 0.87, 0.77, 0.88, 1.14 at 3, 6, 9, 12 & 15 days after storage, respectively)

Ra$_0$ = 0.00kGy, Ra$_1$ = 0.30kGy, Ra$_2$ = 0.50kGy, Ra$_3$ = 0.70kGy, Ra$_4$ = 1.00kGy
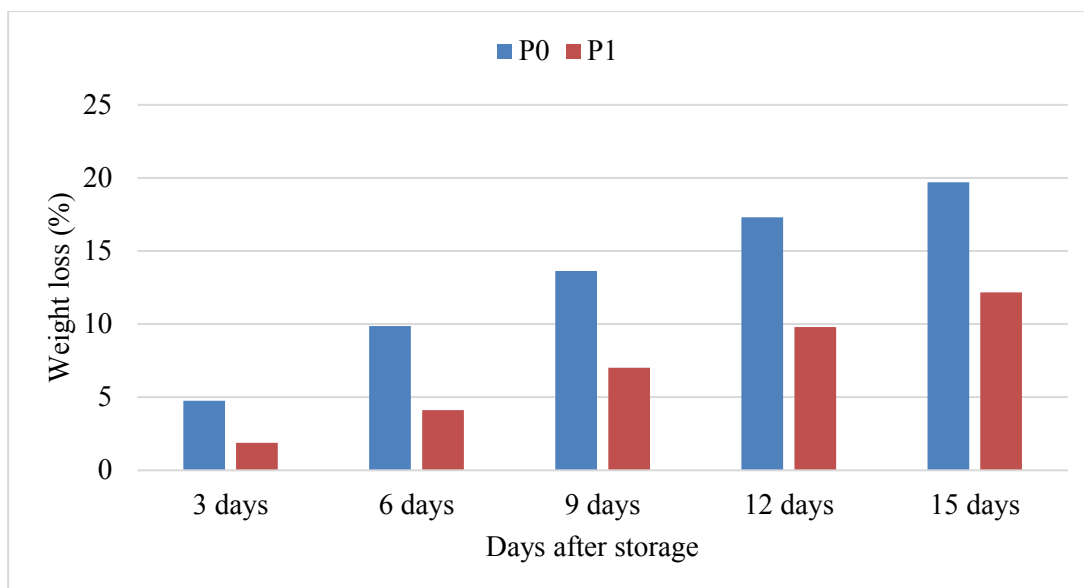
Figure 2: Effect of postharvest packaging on weight loss (%) of mango at different days after storage (LSD$_{0.01}$ = 0.24, 0.55, 0.48, 0.56, & 0.72 at 3, 6, 9, 12 & 15 days after storage, respectively)

P$_0$ = Non-packaging, P$_1$ = Packaging

The combined effect of irradiation doses and postharvest packaging using perforated LDPE bags on total weight loss was statistically significant at 3rd, 6th, 9th, 12th and 15th Days after storage (Appendix I). The highest rate of weight loss (6.51%, 11.57%, 16.72%, 21.61% and 26.11% at 3rd, 6th, 9th, 12th and 15th DAS) was observed in Ra$_0$P$_0$ (unirradiated fruits without packaging) combination and lowest (1.00%, 2.78%, 3.76%, 5.03% and 6.16% at 3rd, 6th, 9th, 12th and 15th DAS) rate was recorded in Ra$_3$P$_1$ (0.70 kGy irradiated fruits stored in perforated LDPE bag) combination (Table 1).

Table 1. Combined effect of gamma irradiation and postharvest packaging on weight loss (%) of mango at different days after storage (DAS)

Treatments	Weight loss (%)				
	3 DAS	**6 DAS**	**9 DAS**	**12 DAS**	**15 DAS**
Ra_0P_0	6.51 a^z	11.57 a	16.72 a	21.61 a	26.11 a
Ra_0P_1	3.16 d	6.31 c	11.83 cd	15.05 d	17.53 d
Ra_1P_0	4.85 b	10.47 a	14.48 b	18.89 b	21.58 b
Ra_1P_1	1.35 f	2.95 d	4.65 f	8.34 f	11.15 f
Ra_2P_0	4.22 c	8.90 b	12.58 c	15.81 d	16.73 d
Ra_2P_1	1.25 f	2.84 d	3.91 f	6.01 g	8.04 g
Ra_3P_0	3.81 c	8.02 b	10.25 e	12.78 e	14.93 e
Ra_3P_1	1.00 f	2.78 d	3.76 f	5.03 g	6.16 h
Ra_4P_0	4.33 bc	10.42 a	14.12 b	17.40 c	19.16 c
Ra_4P_1	2.60 e	5.65 c	10.93 de	14.56 d	18.00 cd
LSD (0.01)	0.553	1.236	1.090	1.2534	1.625
CV (%)	7.11	7.52	4.49	3.94	4.34

Ra_0 = 0.00kGy, Ra_1 = 0.30kGy, Ra_2 = 0.50kGy, Ra_3 = 0.70kGy, Ra_4 = 1.00kGy, P_0 = Non-packaging, P_1 = Packaging. ^{z} Means with different letters significantly differ at LSD‟ s test at P ≤ 0.01; CV: Coefficient of Variation; LSD: Least Significant Difference.

4.2 Ripening (%) of mango

The Figure 3, indicated that irradiated fruits significantly delayed the ripening process over unirradiated fruits irrespective of storage condition and not fully ripen up to 12th day of storage. The maximum (29.00%, 55.35%, 79.65%, and 95.33% at 3rd, 6th, 9th and 12th DAS) value was recorded from Ra_0 (0.00kGy irradiated fruits) and minimum (0.00%, 18.50%, 29.16 % and 45.83% at 3rd, 6th, 9th and 12th DAS) value was obtained from Ra_3 (0.70kGy irradiated fruits) (Figure 17). The unirradiated mangoes had early ripeness whereas; gamma rays exposed mangoes had a significantly delayed ripening. The decrease of ripening

percent and increase in days for ripening may be due to desirable inhibition of enzymatic activities leading reduction in the respiration and ethylene production. So, 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. The present findings are in the agreement of the findings noted in mango by (Yadav *et al*., 2014 & Farzana *et al*., 2005).

The ripening percentage was influenced with the advancement of storage period and significantly affected by postharvest packaging (Figure 4, Appendix II). The maximum (11.73%, 36.80%, 53.40% and 69.06% at 3rd, 6th, 9th and 12th DAS) value of ripening was found in P_0 (Non-packaging fruit) and minimum (7.53%, 26.66%, 40.80% and 58.04% at 3rd, 6th, 9th and 12th DAS) value was recorded in P_1 (Fruits packed in perforated LDPE polybag). Stored fruits in perforated polythene helps to reduce respiration rate which in turns reduce the rate of ethylene synthesis, hence delay the ripening period. These results are supported by (Ali *et al*., 2015; Galvis *et al.,* 2005).
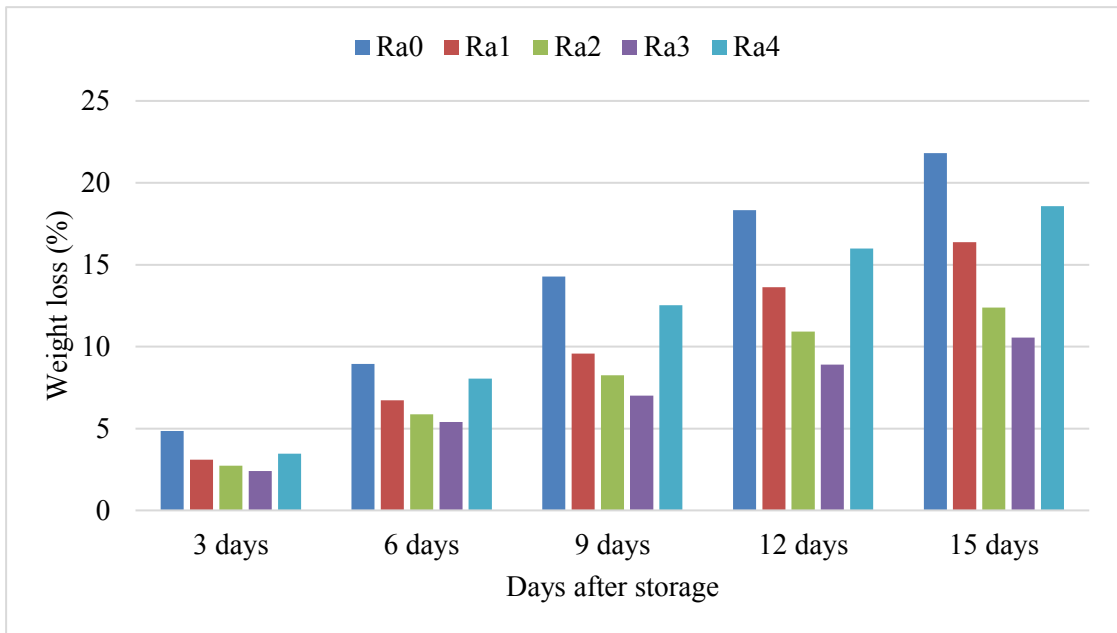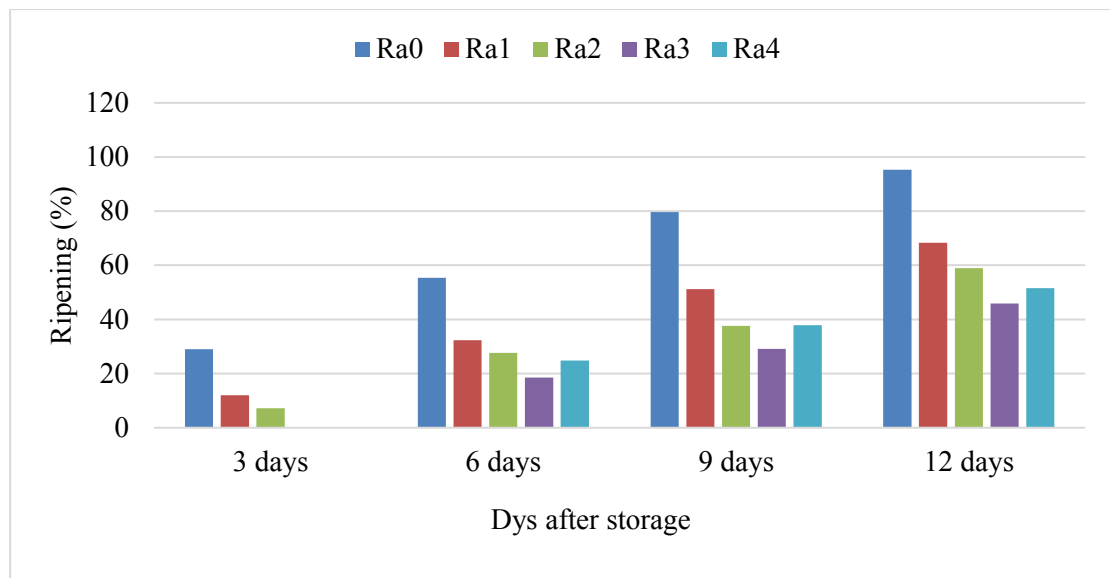

Figure 3: Effect of different doses of gamma irradiation on ripening (%) of mango at different days after storge (LSD$_{0.01}$ = 1.18, 2.49, 2.46 & 3.01 at 3, 6, 9 & 12 days after storage, respectively)

Ra$_0$ = 0.00kGy, Ra$_1$ = 0.30kGy, Ra$_2$ = 0.50kGy, Ra$_3$ = 0.70kGy, Ra$_4$ = 1.00kGy
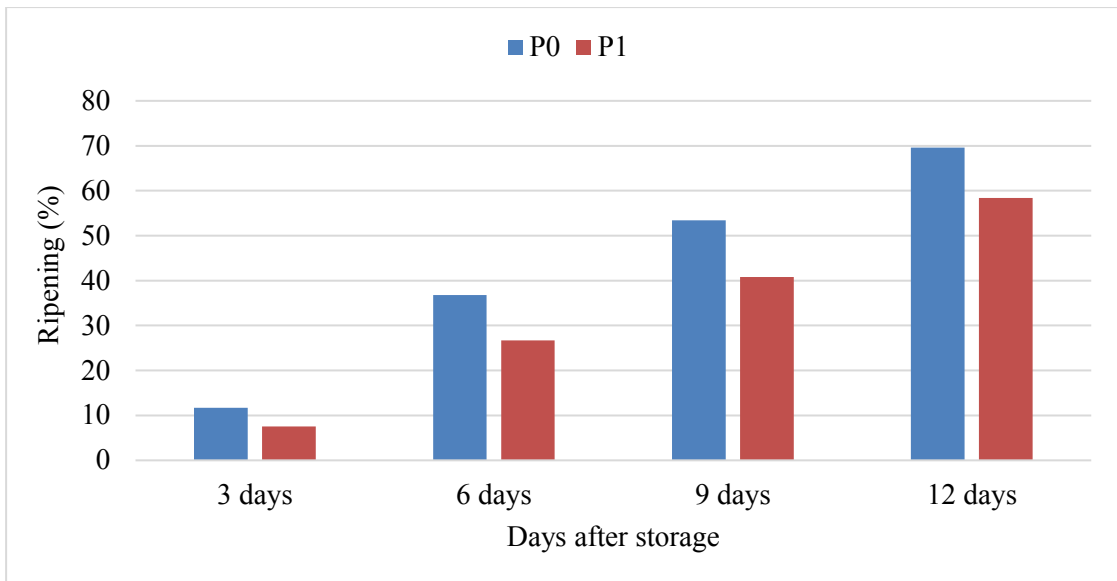
Figure 4: Effect of postharvest packaging on ripening (%) of mango at different days after storage (LSD$_{0.01}$ = 0.74, 1.57, 1.55 & 1.90 at 3, 6, 9 & 12 days after storage, respectively)

P$_0$ = Non-packaging, P$_1$ = Packaging

The combined effect of irradiation doses and postharvest packaging using perforated LDPE bags on ripening (%) was statistically significant at 3rd, 6th, 9th and 12th Days after storage (Table 2, Appendix II). Highest ripening (%) (35.00%, 69.00%, 92.66% and 100% at 3rd, 6th, 9th and 12th DAS) was observed in Ra$_0$P$_0$ (0.00kGy irradiated fruit without packaging) combination and lowest value (0.00%, 15.66%, 23.33%, and 42.33% at 3rd, 6th, 9th and 12th DAS) was found in Ra$_3$P$_1$ (0.70kGy irradiated fruit stored in perforated LDPE polybag) combination followed by Ra$_4$P$_1$ (1.00kGy irradiated fruit stored in perforated LDPE polybag, where the value was (0.00%, 21.66%, 34.33% and 47.67% at 3rd, 6th, 9th and 12th DAS) (Table 9)

Table 2. Combined effect of gamma irradiation and postharvest packaging on ripening (%) of mango at different days after storage

Treatments	Ripening (%)			
	3 DAS	**6 DAS**	**9 DAS**	**12 DAS**
Ra_0P_0	35.00 a^z	69.00 a	92.66 a	100.00 a
Ra_0P_1	23.00 b	41.66 b	66.66 b	90.67 b
Ra_1P_0	14.33 c	36.33 c	56.00 c	76.67 c
Ra_1P_1	9.66 d	28.33 d	46.33 d	60.00 e
Ra_2P_0	9.33 d	29.33 d	42.00 e	66.67 d
Ra_2P_1	5.00 e	26.00 d	33.33 f	51.33 fg
Ra_3P_0	0.00 f	21.33 e	35.00 f	49.33 g
Ra_3P_1	0.00 f	15.66 f	23.33 g	42.33 h
Ra_4P_0	0.00 f	28.00 d	41.33 e	55.33 f
Ra_4P_1	0.00 f	21.66 e	34.33 f	47.67 g
LSD (0.01)	1.674	3.529	3.480	4.25
CV (%)	7.39	4.73	3.14	2.83

Ra_0 = 0.00kGy, Ra_1 = 0.30kGy, Ra_2 = 0.50kGy, Ra_3 = 0.70kGy, Ra_4 = 1.00kGy, P_0 = Non-packaging, P_1 = Packaging. ^{z} Means with different letters significantly differ at LSD‟ s test at P ≤ 0.01; CV: Coefficient of Variation; LSD: Least Significant Difference

4.3 Moisture content (%) of mango pulp

Significant variation was observed in respect of moisture content (%) of mango pulp between irradiation doses and postharvest packaging of mangoes at the end of shelf life (Table 3, Appendix III). The maximum (84.02%) moisture content was noticed in Ra_3 (0.70kGy irradiated treated fruits) followed by Ra_2 (0.50kGy irradiated fruits) where moisture content was 80.302%, which is statistically similar with Ra_1 (0.30kGy irradiated fruits). The minimum (77.27%) moisture content was found in Ra_0 (unirradiated fruits) (Figure 5). The above findings were in partial agreement with the findings of Paul *et al*. (2005). Absar *et al*.

(1993) reported that moisture content at the early stage of development varied from 87.4% to 90.1%, gradually decreased as the maturity advanced and at ripening stage it varied from 71.22 to 79.4%.

It was recorded that highest moisture content 81.697% was found in P_1 when mango fruits were stored in perforated LDPE bags and minimum 78.676% moisture was found in non-packaging mango at the end of shelf life (Figure 6). Fruits wrapping with packaging films creates microclimate retards loss of moisture content (Grierson, 1969). The reduction in percent moisture content was due to transpiration and starch hydrolysis. Total decrease was probably more than the increase in water due to osmotic withdrawal of water from peel to pulp and complete failure of starch to CO_2.

Figure 5: Effect of different doses of gamma irradiation on moisture content (%) of mango pulp at the end of shelf life ($LSD_{0.01} = 0.85$ at the end of shelf life)

$Ra_0 = 0.00kGy$, $Ra_1 = 0.30kGy$, $Ra_2 = 0.50kGy$, $Ra_3 = 0.70kGy$, $Ra_4 = 1.00kGy$
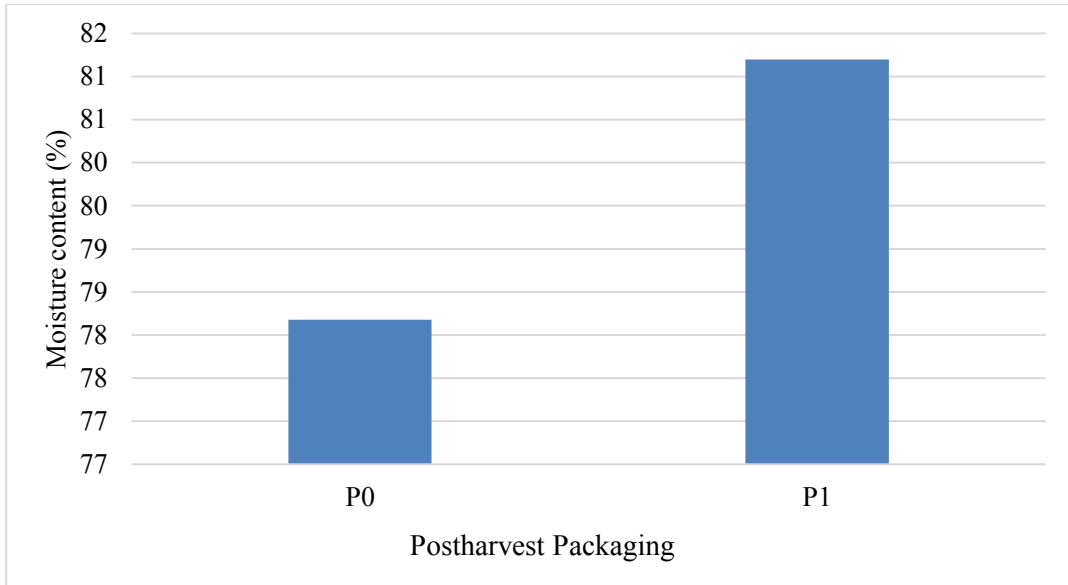
Figure 6: Effect of postharvest packaging on moisture content (%) of mango pulp at the end of shelf life (LSD$_{0.01}$ = 0.54 at the end of shelf life)

P$_0$ = Non-packaging, P$_1$ = Packaging

The combined effect of gamma irradiation doses and postharvest packaging in respect of moisture content in mango pulp was found to be statistically significant at the end of shelf life. The maximum moisture content (85.77%) was found in Ra$_3$P$_1$ (0.70kGy irradiated fruits stored in perforated LDPE bag) combination and minimum moisture content (75.60%) was recorded in Ra$_0$P$_0$ (unirradiated fruits without packaging) combination (Table 3).

Table 3. Combined effect of gamma irradiation and postharvest packaging on moisture content (%) of mango pulp at the end of shelf life

Treatments	Moisture content (%) of mango pulp
Ra_0P_0	75.60 g^z
Ra_0P_1	80.94 cd
Ra_1P_0	78.08 f
Ra_1P_1	81.87 bc
Ra_2P_0	80.25 de
Ra_2P_1	80.35 de
Ra_3P_0	82.28 b
Ra_3P_1	85.77 a
Ra_4P_0	77.17 f
Ra_4P_1	79.55 e
LSD (0.01)	1.214
CV (%)	0.64

Ra_0 = 0.00kGy, Ra_1 = 0.30kGy, Ra_2 = 0.50kGy, Ra_3 = 0.70kGy, Ra_4 = 1.00kGy, P_0 = Non-packaging, P_1 = Packaging. ^{z} Means with different letters significantly differ at LSD" s test at P ≤ 0.01; CV: Coefficient of Variation; LSD: Least Significant Difference.

4.4 Total soluble solids (TSS) content

Significant variation in TSS content of mango pulp was found during storage due to gamma irradiation doses and postharvest packaging (Table 4, Appendix III). The fruits irradiated with 0.50kGy (Ra_2) maintained the lowest TSS value (15.50%) followed by 0.700kGy (Ra_3) irradiated fruit (16.33%), while unirradiated control fruits (Ra_0) maintained the highest TSS value (18.67%) (Figure 7).

Postharvest packaging showed significant variation as the highest value (18.00%) was recorded in non-packaging fruits ($P_0$0 and lowest value (16.20%) was recorded in fruits stored perforated LDPE bags (P_1) (Figure 8).
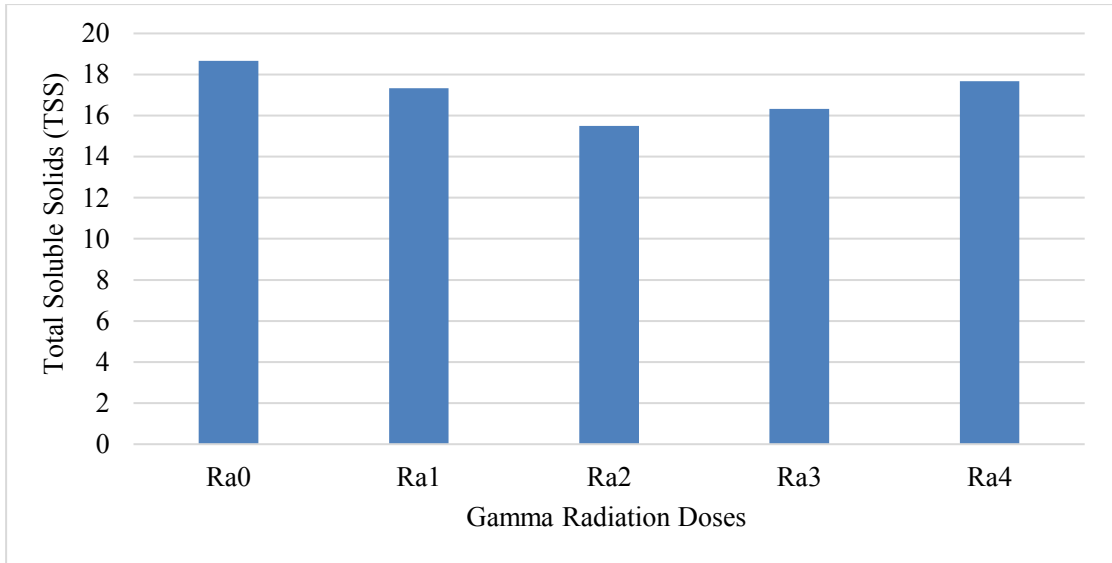
Figure 7: Effect of different doses of gamma irradiation on TSS% of mango pulp at the end of shelf life ($LSD_{0.01} = 0.61$ at the end of shelf life)

$Ra_0 = 0.00kGy$, $Ra_1 = 0.30kGy$, $Ra_2 = 0.50kGy$, $Ra_3 = 0.70kGy$, $Ra_4 = 1.00kGy$

Figure 8: Effect of postharvest packaging on TSS (%) of mango pulp at the end of shelf life ($LSD_{0.01} = 0.38$ at the end of shelf life)

P_0 = Non-packaging, P_1 = Packaging

The combined effect of gamma irradiation doses and postharvest packaging using perforated LDPE bags on total soluble solids was statistically significant at the end of shelf life (Appendix III). The maximum TSS value (20.333%) was reported in Ra_0P_0 [unirradiated fruits without packaging) combination, followed by (18.667%) Ra_1P_0 (0.30kGy irradiated fruit without packaging) which is statistically similar (18.00%) with Ra_4P_0 (1.00kGy irradiated fruit without packaging) combination and minimum TSS value (15.00%) was recorded in Ra_2P_1 (0.50kGy irradiated fruits stored in perforated LDPE bag) combination which is statistically similar with Ra_3P_1 (0.70kGy irradiated fruits stored in perforated LDPE bag), where the value was (15.67%) ((Table 4).

Total soluble solids (TSS) consist of sugars, non-organic matter, proteins, organic acids, etc. Irradiated fruits showed a decrease in the TSS content with increasing irradiation dose during storage. Similar findings were reported by Kim and Yook (2009). Slow increment in TSS of fruits in perforated plastic package during storage could be due to production of higher. levels of CO_2, which may lead to less physiological processes, slow ripening and reduce the respiration rate of fruits resulting slower conversion of starch to soluble sugar (Mosie *et al*., 2019).

Table 4. Combined effect of gamma irradiation and postharvest packaging on TSS (%) of mango pulp at the end of shelf life

Treatments	TSS (%) of mango pulp
Ra_0P_0	20.33 a^z
Ra_0P_1	17.00 d
Ra_1P_0	18.67 b
Ra_1P_1	16.00 e
Ra_2P_0	16.00 e
Ra_2P_1	15.00 f
Ra_3P_0	17.00 d
Ra_3P_1	15.67 ef
Ra_4P_0	18.00 bc
Ra_4P_1	17.33 cd
LSD (0.01)	0.8700
CV (%)	2.16

Ra_0 = 0.00kGy, Ra_1 = 0.30kGy, Ra_2 = 0.50kGy, Ra_3 = 0.70kGy, Ra_4 = 1.00kGy, P_0 = Non-packaging, P_1 = Packaging. ^{z} Means with different letters significantly differ at LSD‟ s test at P ≤ 0.01; CV: Coefficient of Variation; LSD: Least Significant Difference.

4.5 Titratable acidity (TA)

The present investigation showed that application of gamma irradiation dose had significant effect on titratable acidity of mango pulp (Figure 9, Appendix III). The maximum value (0.36%) of titratable acidity for mango fruits was recorded for 0.70kGy irradiated fruit (Ra_3) followed by 0.50kGy irradiated fruit (Ra_2), the value was 0.30% and the minimum (0.22%) value was recorded in case of 0.00 kGy (Ra_0, unirradiated fruit) (Figure 9). The retention of acidity is an indication of delay in ripening due to effect of gamma irradiation (Tovar *et al*., 2000)

Statistically significant difference was found for titratable acidity due to postharvest packaging of mangoes (Figure 10, Appendix III). Titratable acidity (TA) content was found to be the maximum (0.32%) when mangoes were stored in perforated polybags (LDPE) rather than the non-packaging mangoes, the value was 0.26% (Figure 10).
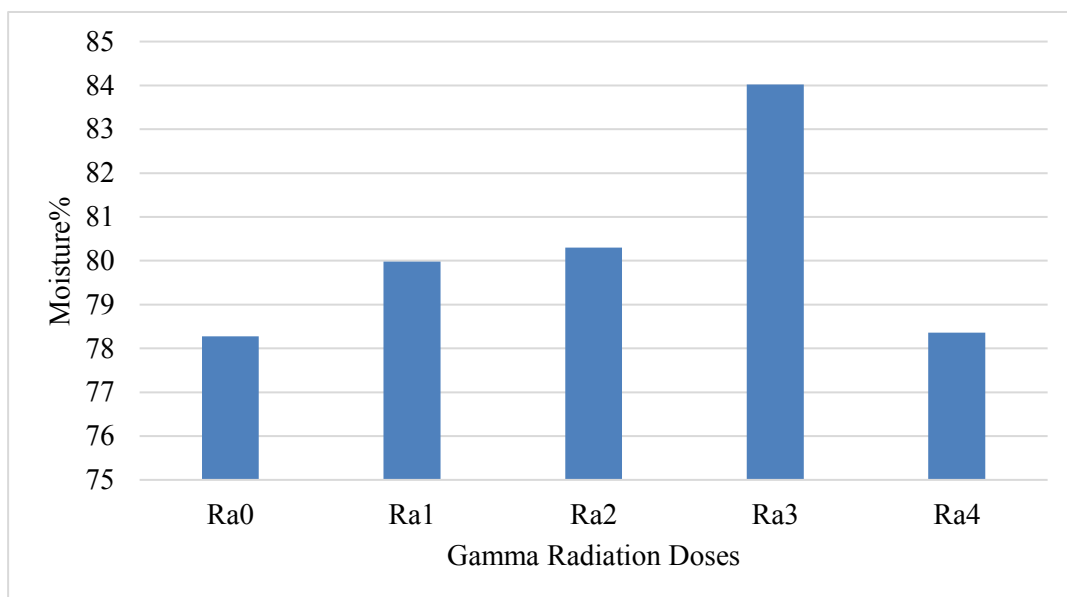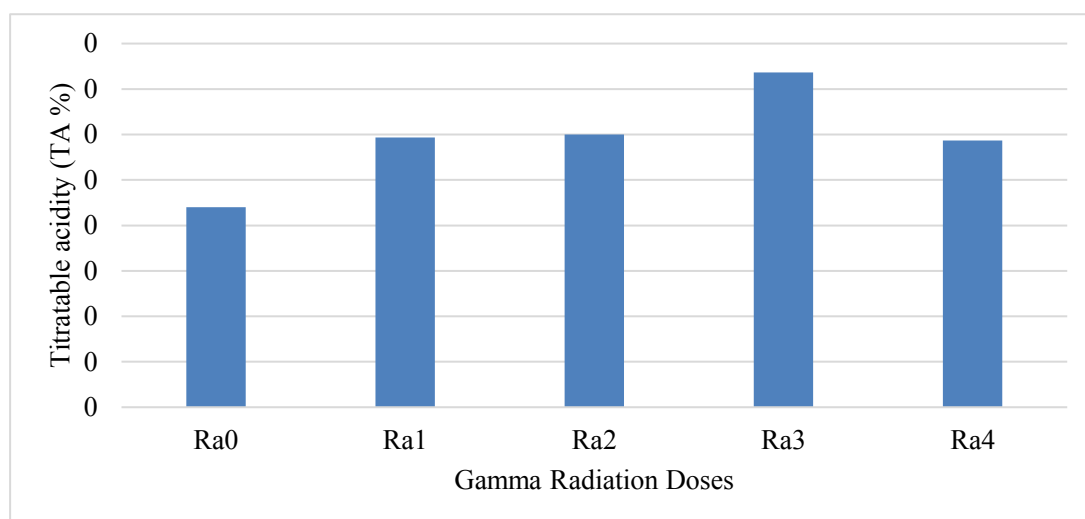

Figure 9: Effect of different doses of gamma irradiation on TA (%) of mango pulp at the end of shelf life ($LSD_{0.01} = 0.018$ at the end of shelf life)

$Ra_0 = 0.00kGy$, $Ra_1 = 0.30kGy$, $Ra_2 = 0.50kGy$, $Ra_3 = 0.70kGy$, $Ra_4 = 1.00kGy$

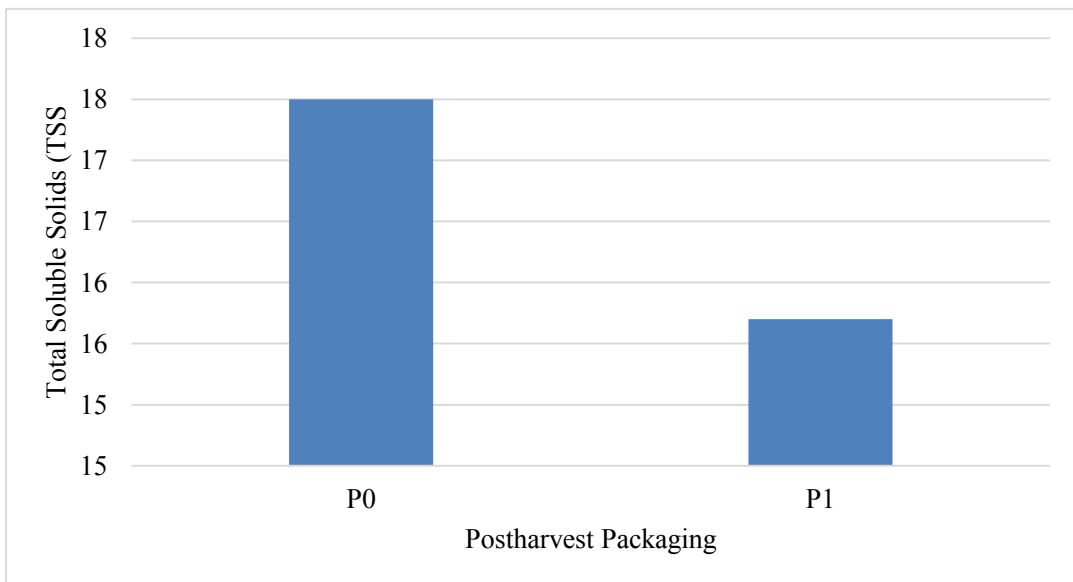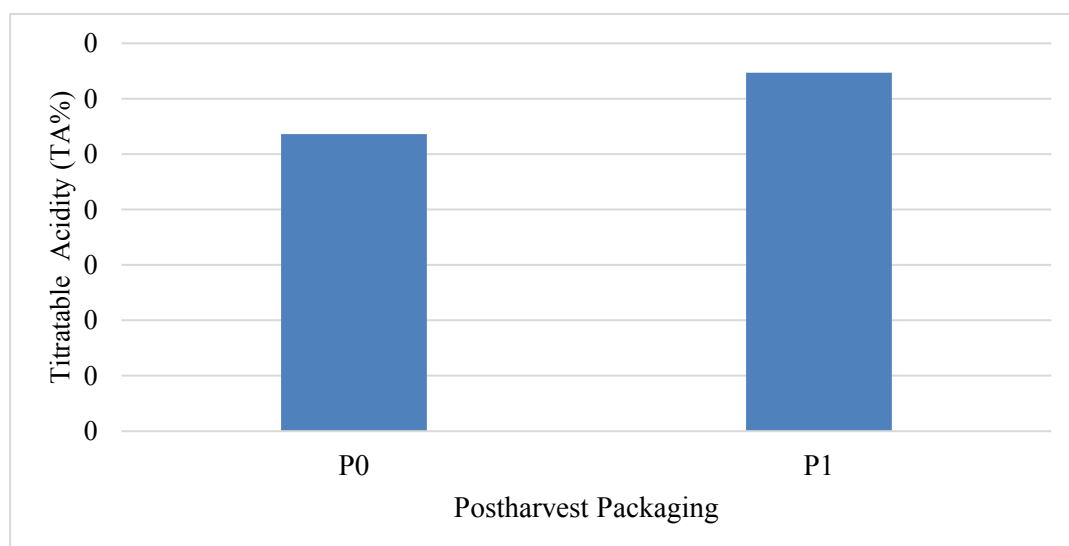**Figure 10: Effect of postharvest packaging on TA (%) of mango pulp at the end of shelf life** ($LSD_{0.01} = 0.051$ at the end of shelf life)

P_0 = Non-packaging, P_1 = Packaging

The combination between irradiation doses and postharvest packaging had highly significant effect on the titratable acidity of mango fruits (Table 5, Appendix III). The highest TA value (0.41%) was reported in Ra_3P_1 (0.70kGy irradiated fruits stored in perforated LDPE polybags) combination, followed by Ra_2P_1 (0.50kGy irradiated fruit stored in perforated LDPE polybags) which is statistically similar with Ra_3P_0 (0.70kGy irradiated fruit without packaging) combination and lowest TA value (0.19%) was found in Ra_0P_0 (0.00kGy irradiated fruits without packaging) combination (Table 5).

Youssef *et al*. (2002) reported an increase in acidity values of mango pulp at irradiation doses of 0–2kGy. This was also the case in the work of Harder *et al*. (2009), who reported an increase in acidity values of nectar of kiwi fruit irradiated with 0.5kGy. Besides the decrease in acid content of fruits with the increase in storage period could be attributed to the use of organic acids in respiratory process by the fruit cells and conversion of acids into total sugars. So, it may be concluded that interaction effect of irradiation doses and postharvest packaging reduced respiration rate, delayed ripening process which in turns slowed down the conversion rate of acids into sugar. For this, reason titratable acidity percent reduction was slower in the treated fruits than the control.

Table 5. Combined effect of gamma irradiation and postharvest packaging on TA (%) of mango pulp at the end of shelf life

Treatments	TA (%) of mango pulp
Ra_0P_0	0.19 g^z
Ra_0P_1	0.25 f
Ra_1P_0	0.28 de
Ra_1P_1	0.31 c
Ra_2P_0	0.26 ef
Ra_2P_1	0.34 b
Ra_3P_0	0.32 bc
Ra_3P_1	0.41 a
Ra_4P_0	0.28 de
Ra_4P_1	0.30 cd
LSD (0.01)	0.026
CV (%)	3.76

Ra_0 = 0.00kGy, Ra_1 = 0.30kGy, Ra_2 = 0.50kGy, Ra_3 = 0.70kGy, Ra_4 = 1.00kGy, P_0 = Non-packaging, P_1 = Packaging. ^{z} Means with different letters significantly differ at LSD" s test at P ≤ 0.01; CV: Coefficient of Variation; LSD: Least Significant Difference.

4.6 Ascorbic acid content (mg/100g):

Fruits are the natural source of ascorbic acid and degradation of vitamin c is verry much responsive because of its oxidation compared to other nutrient during food processing, preservation and storage. As the fruits proceed towards ripening process, the level of acid gradually decreased. In general, a gradual decline was observed both treated and untreated controlled mango fruits. The significant variation was found in gamma irradiation doses and postharvest packaging (Table 6, Appendix III).

It was revealed that gamma irradiation doses showed significant variation. The highest value (31.05 mg/100g) was recorded in both Ra_2 (0.50kGy irradiated

fruit) and Ra_3 (0.70kGy irradiated fruit) which were statistically similar and lowest value (22.44 mg/100g) was reported in Ra_0 (0.00kGy irradiated fruit) (Figure 11). Dhakar *et al*. (1966) also found that ascorbic acid values are higher for irradiated Alphonso mangoes than for other treatments and compare with those for controls. Since reduction of ascorbic acid is associated with ripening, the delay in ripening due to irradiation is reflected in the higher values of ascorbic acid. The present findings are compatible with the findings reported by Sing *et al*. (2005), Yadav *et al*. (2013), Hossain *et al*. (2014).

Figure 11: Effect of different doses of gamma irradiation on ascorbic acid content of mango pulp at the end of shelf life ($LSD_{0.01} = 1.22$ at the end of shelf life)

$Ra_0 = 0.00kGy$, $Ra_1 = 0.30kGy$, $Ra_2 = 0.50kGy$, $Ra_3 = 0.70kGy$, $Ra_4 = 1.00kGy$

It was seen that postharvest packaging showed significant variation in respect of ascorbic acid content of mango fruit at the end of shelf life. Fruits that were stored in P_1 (Perforated LDPE polybag) revealed the highest value (30.21 mg/100g) and minimum value (25.03) was found in P_0 (non-packaging mango) (Figure 12). Packed fruits maintain and showed higher ascorbic acid content than the control. This might be due to reduced rate of respiration and inside the package that retards respiration and depletion of acids. Furthermore, the reduction in internal O_2 and ethylene concentration might explain the

maintenance of higher value of vitamin c in packed fruits although there is delay in respiration and ripening (Kader *et al.*, 1985)
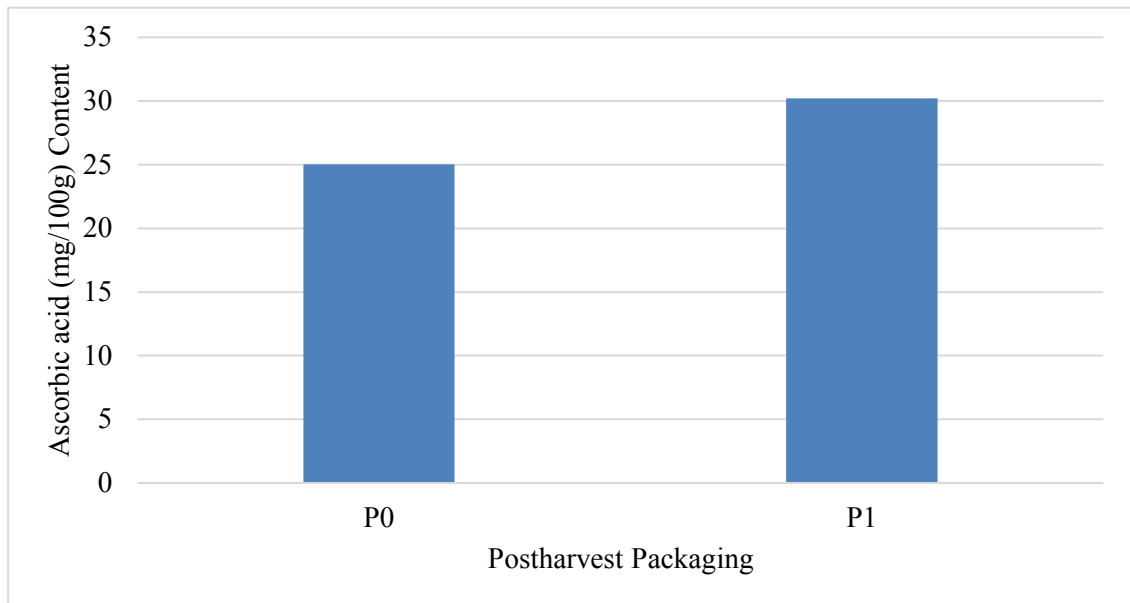
Figure 12: Effect of postharvest packaging on ascorbic acid content of mango pulp at the end of shelf life (LSD$_{0.01}$ = 0.77 at the end of shelf life)

P$_0$ = Non-packaging, P$_1$ = Packaging

The combined effect of irradiation doses and postharvest packaging had highly significant effect on the ascorbic acid content of mango fruits (Table 6, Appendix III). The highest value (34.36 mg/100g) of ascorbic acid was recorded in Ra$_2$P$_1$ (0.50kGy irradiated fruit stored in perforated LDPE polybag) combination and Ra$_3$P$_1$ (0.70kGy irradiated fruits stored in perforated LDPE polybags) combination which are statistically similar and lowest value (20.48 mg/100g) was recorded in Ra$_0$P$_0$ (0.00KGy irradiated fruits without packaging) combination (Table 6).

Variation in ascorbic acid retention in different treatments might be due to different levels of oxidation as affected by irradiation doses and plastic permeability to environmental oxygen. Lower loss of ascorbic acid content might be due to low O$_2$ permeability, which reduces respiration rate. During storage, higher temperature and oxygen favor activities of oxidizing enzymes

like ascorbic acid oxidase, peroxidase, catalase and polyphenol oxidase to act on substrates of respiration, including acids, and hasten loss of ascorbic acid of the fruits (Yoshida *et al.*, 1984).

Table 6. Combined effect of gamma irradiation and postharvest packaging on Ascorbic acid (mg/100g) content of mango pulp at the end of shelf life

Treatments	Ascorbic acid (mg/100g)
Ra_0P_0	20.48 e^z
Ra_0P_1	24.40 d
Ra_1P_0	22.15 e
Ra_1P_1	26.98 c
Ra_2P_0	27.73 c
Ra_2P_1	34.36 a
Ra_3P_0	27.73 c
Ra_3P_1	34.36 a
Ra_4P_0	27.06 c
Ra_4P_1	30.96 b
LSD (0.01)	1.726
CV (%)	2.66

Ra_0 = 0.00kGy, Ra_1 = 0.30kGy, Ra_2 = 0.50kGy, Ra_3 = 0.70kGy, Ra_4 = 1.00kGy, P_0 = Non-packaging, P_1 = Packaging. ^{z} Means with different letters significantly differ at LSD" s test at P ≤ 0.01; CV: Coefficient of Variation; LSD: Least Significant Difference.

4.7 p^H

Variations in pH of mangoes under different gamma irradiation doses and postharvest packaging were observed during successive days of storage (Table 7, Appendix IV). The pH value of irradiated fruits showed significant differences. The highest (5.56) pH value was recorded in Ra_0 (0.00kGy or

unirradiated fruits) followed by Ra_1 or 0.30kGy irradiated fruit (5.52) and they were statistically nonsignificant. The lowest (4.74) value was found in Ra_4 (1.00 kGy irradiated fruits). Ra_3 (0.70kGy irradiated fruits) also showed lower pH value and that was 5.12 (Figure 13).

It was seen that postharvest packaging showed significant variation in respect of p^H of mango fruit at the end of shelf life (Figure 14, Appendix IV). The minimum p^H value (5.06) was recorded in fruits stored in P_1 (Perforated LDPE polybag) than the p^H value (5.41) of non-packaging mangoes (P_0).
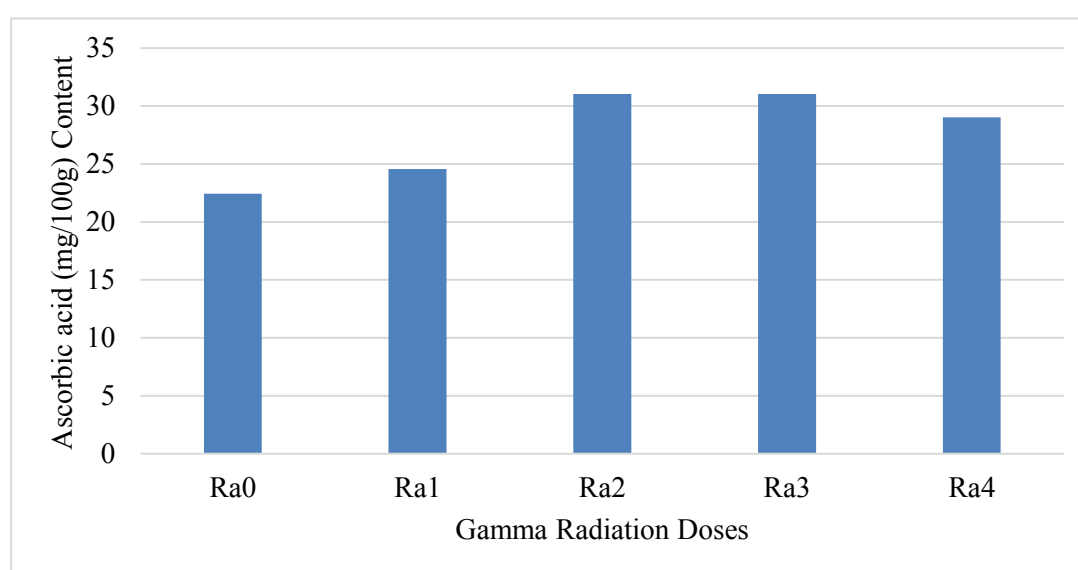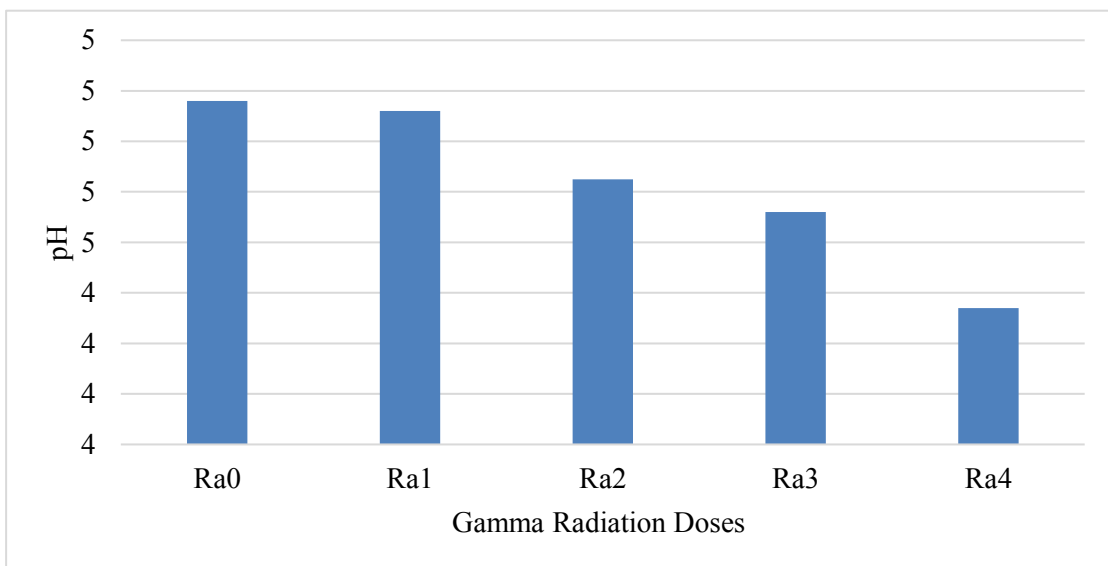

Figure 13: Effect of different doses of gamma irradiation on P^H of mango pulp at the end of shelf life (LSD$_{0.01}$ = 0.081 at the end of shelf life)

Ra_0 = 0.00kGy, Ra_1 = 0.30kGy, Ra_2 = 0.50kGy, Ra_3 = 0.70kGy, Ra_4 = 1.00kGy
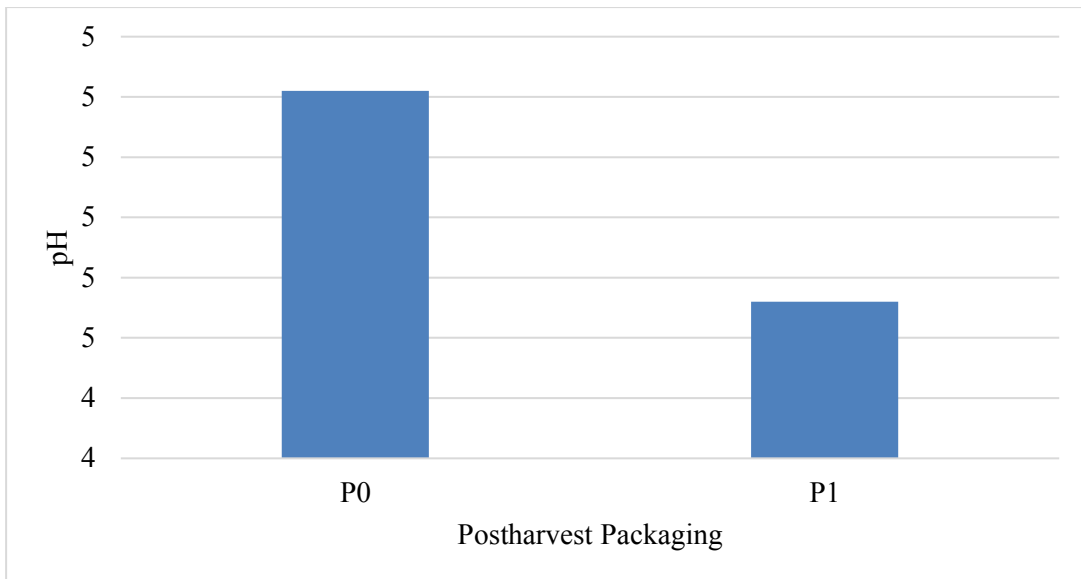
Figure 14: Effect of postharvest packaging on P^H of mango pulp at the end of shelf life (LSD$_{0.01}$ = 0.051 at the end of shelf life)

P_0 = Non-packaging, P_1 = Packaging

The combined effect of irradiation doses and postharvest packaging also showed significant result (Table 7). The maximum (5.84) p^H value was recorded from Ra_0P_0 (0.00kGy irradiated fruits without packaging) combination and minimum (4.60) value was recorded in Ra_4P_1 (1.00kGy irradiated fruit stored in perforated LDPE polybag) combination followed by Ra_4P_0 (1.00kGy irradiated fruits stored without packaging) combination where p^H value was 4.89 which is statistically similar with the p^H value (4.93) of Ra_3P_1 (0.70kGy irradiated fruit stored in perforated LDPE polybag) combination.

The p^H value was affected by variety, maturity stage of mango, their storage condition and so on. The p^H value continuously increasing during the entire period of storage as acidity get lower day by day due to advancement of ripening. It was due to the general catabolization of organic acids and their conversion into sugar. The results showed that gamma irradiation significantly reduced the increase of fruit juice p^H. The result also indicated that lower p^H values of packed fruits than non-packed fruit could be explained by reduced respiration rate in the package. Reduced O_2 and increased CO_2 which could delay the rate of respiration

in the package, delay ripening process and keep pH values low. The results are in agreement with the findings of (Mathooko, 2003)

Table 7. Combined effect of gamma irradiation and postharvest packaging on p^H of mango pulp at the end of shelf life

Treatments	p^H
Ra_0P_0	5.84 a^z
Ra_0P_1	5.27 d
Ra_1P_0	5.62 b
Ra_1P_1	5.41 c
Ra_2P_0	5.40 c
Ra_2P_1	5.10 e
Ra_3P_0	5.32 cd
Ra_3P_1	4.93 f
Ra_4P_0	4.89 f
Ra_4P_1	4.60 g
LSD (0.01)	0.115
CV (%)	0.94

Ra_0 = 0.00kGy, Ra_1 = 0.30kGy, Ra_2 = 0.50kGy, Ra_3 = 0.70kGy, Ra_4 = 1.00kGy, P_0 = Non-packaging, P_1 = Packaging. ^{z} Means with different letters significantly differ at LSD‟ s test at P ≤ 0.01; CV: Coefficient of Variation; LSD: Least Significant Difference.

4.8 β-carotene content of mango pulp (mg/100g)

Carotenoids are isoprenoid compounds biosynthesized by the tail to tail connection of two C-20 geranylgeranyl diphosphate molecules, which constructs the parent C-40 carbon skeleton from which all individual variations are made. The carotenoids of fruits are usually fat-soluble and are associated with lipid portions of human tissues, cells, and membranes. β-carotene of mango pulp showed significant variation incase of gamma irradiation and postharvest

packaging (Table 8, Appendix IV). β-carotene content was found to be the highest (5.14 mg/100g) at the end of shelf life in case of Ra_3 (0.70kGy irradiated fruit) followed by Ra_2 (0.50kGy irradiated fruit), where the value was (4.82 mg/100g) and the lowest value (4.26 mg/100g) was recorded in Ra_0 (unirradiated fruit) (Figure 15).

Postharvest packaging had statistical impact on β-carotene content of mango (Appendix IV). β-carotene content was found to be maximum (4.74 mg/100g) when mangoes were stored in perforated polybags (LDPE) and minimum (4.59 mg/100g) in non-packaging mangoes (Figure 16).
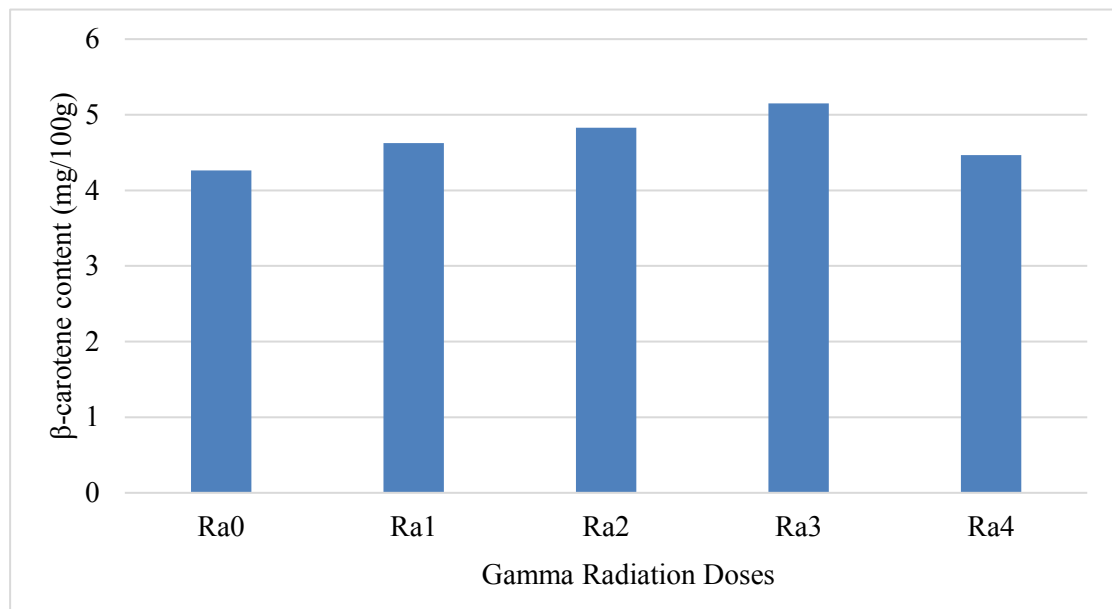
Figure 15: Effect of different doses of gamma irradiation on β-carotene content of mango pulp at the end of shelf life ($LSD_{0.01} = 0.04$ at the end of shelf life)

$Ra_0 = 0.00kGy$, $Ra_1 = 0.30kGy$, $Ra_2 = 0.50kGy$, $Ra_3 = 0.70kGy$, $Ra_4 = 1.00kGy$
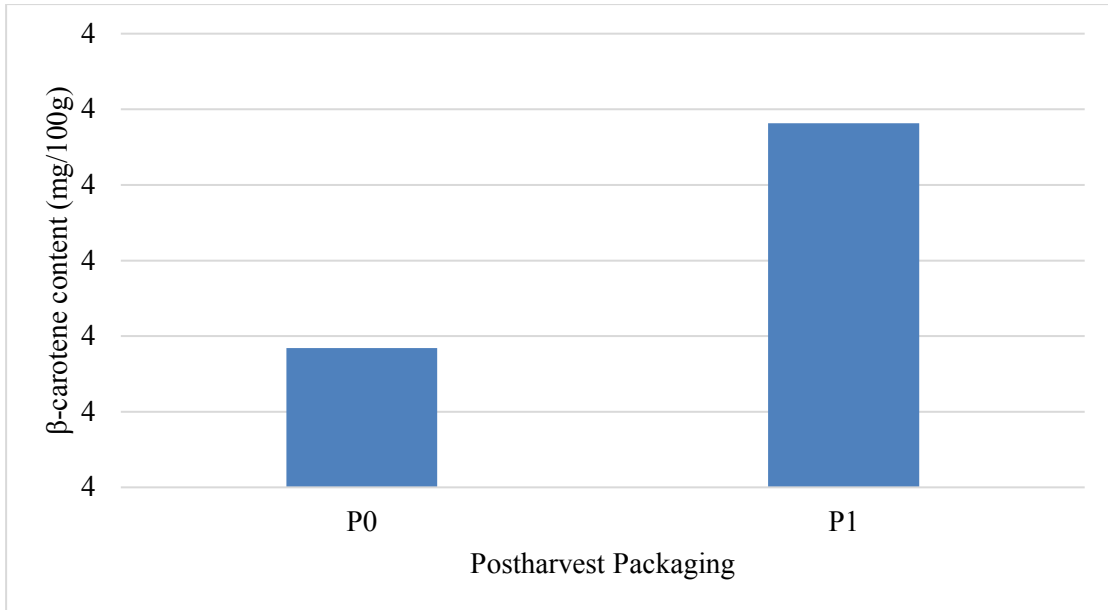
Figure 16: Effect of postharvest packaging on β-carotene of mango pulp at the end of shelf life (LSD$_{0.01}$ = 0.02 at the end of shelf life)

P$_0$ = Non-packaging, P$_1$ = Packaging

The combined effect of gamma irradiation and postharvest packaging using perforated LDPE bags on β-carotene content was significant at the end of shelf life (Appendix IV). The maximum (5.23 mg/100g) β-carotene content was recorded from Ra$_3$P$_1$ (0.70kGy irradiated fruit stored in perforated LDPE polybag) combination followed by Ra$_3$P$_0$ or 0.70kGy irradiated fruit stored without packaging (5.06 mg/100g) and minimum (4.19 mg/100g)) value was recorded in Ra$_0$P$_0$ (0.00kGy irradiated fruit stored without packaging).

significant increase in β-carotene content was found with increase of storage period. This occurred due to breakdown of chlorophyll and increase in carotenoid content by chlorophyllase enzyme during the storage. Similar findings were found by (Kays, 1999). Irradiated fruit showed higher level of carotene content than the unirradiated fruit, though chlorophyll disappearance in the skin was delayed in comparison with unirradiated fruits. The present findings are in agreement with the findings of Pablo *et al*. (1971). But irradiation dose higher than 1.00kGy resulted in a decrease of the total carotenoid content as reported by Jerome *et al*. (2019).

Table 8. Combined effect of gamma irradiation and postharvest packaging on β-carotene of mango pulp at the end of shelf life

Treatments	β-carotene content (mg/100g)
Ra_0P_0	4.19 h^z
Ra_0P_1	4.33 g
Ra_1P_0	4.59 e
Ra_1P_1	4.66 d
Ra_2P_0	4.71 d
Ra_2P_1	4.94 c
Ra_3P_0	5.06 b
Ra_3P_1	5.23 a
Ra_4P_0	4.40 f
Ra_4P_1	4.53 e
LSD (0.01)	0.0576
CV (%)	0.53

Ra_0 = 0.00kGy, Ra_1 = 0.30kGy, Ra_2 = 0.50kGy, Ra_3 = 0.70kGy, Ra_4 = 1.00kGy, P_0 = Non-packaging, P_1 = Packaging. ^{z} Means with different letters significantly differ at LSD" s test at P ≤ 0.01; CV: Coefficient of Variation; LSD: Least Significant Difference.

4.9 Brown/Black spot severity

Browning or black spots decreased quality of mangoes. Various irradiation doses and postharvest packaging adopted in the study showed significant variation in relation to browning or black spots on skin (Table 9, Appendix V). The maximum (13.16%, 23.28%, 32.35, and 47.66% at 6th, 9th, 12th and 15th DAS) value was noticed from Ra_0 (0.00kGy irradiated fruits) followed by Ra_4 (1.00 kGy irradiated fruit) which showed a value of (6.66%, 14.05%, 24.17% and 44.16% at 6th, 9th, 12th and 15th DAS). On the contrary, lowest (2.00%, 6.66%, 11.00 % and 18.16% at 6th, 9th, 12th and 15th DAS) value was obtained from Ra_3 (0.70kGy irradiated fruits) (Figure 17). Mainly black spots were recorded in unirradiated fruit. But 1.00kGy irradiated fruit showed solid dark brown to black region on the surface of the mango. Higher irradiation dose causes the cell damage of the fruit, softening the tissue and cause skin bronzing or blackening. Fruits irradiated with 1.00kGy were damaged to a greater extent as reported by (Andrew *et al.*, 1988)

Postharvest packaging also showed significant variation in respect of black/brown spot severity of mango skin (Appendix V). The highest (8.13%, 16.12%, 24.07% and 36.4% at 6th, 9th, 12th and 15th DAS) value of black spots was found in P_0 (Non-packaging fruit) and lowest (6.00%, 11.40%, 18.00% and 28.00 at 6th, 9th, 12th and 15th DAS) value was recorded in P_1 (Fruits packed in LDPE polybag) (Figure 18).

The present investigation showed that irradiation dose highly influenced mango skin appearance. It was recorded that lower was the irradiation dose higher the rate of change in skin appearance. Higher was the irradiation dose, slower was the rate of change occurred on the skin except the 1.00kGy irradiation dose because it caused the damage of the fruit skin. The color of fruit skin is altering due to unmasking of preformed pigments by degradation of chlorophyll and biosynthesis of carotenoids and anthocyanins and their accumulation in vacuoles (Tucker and Grierson, 1987; Lizada, 1993).
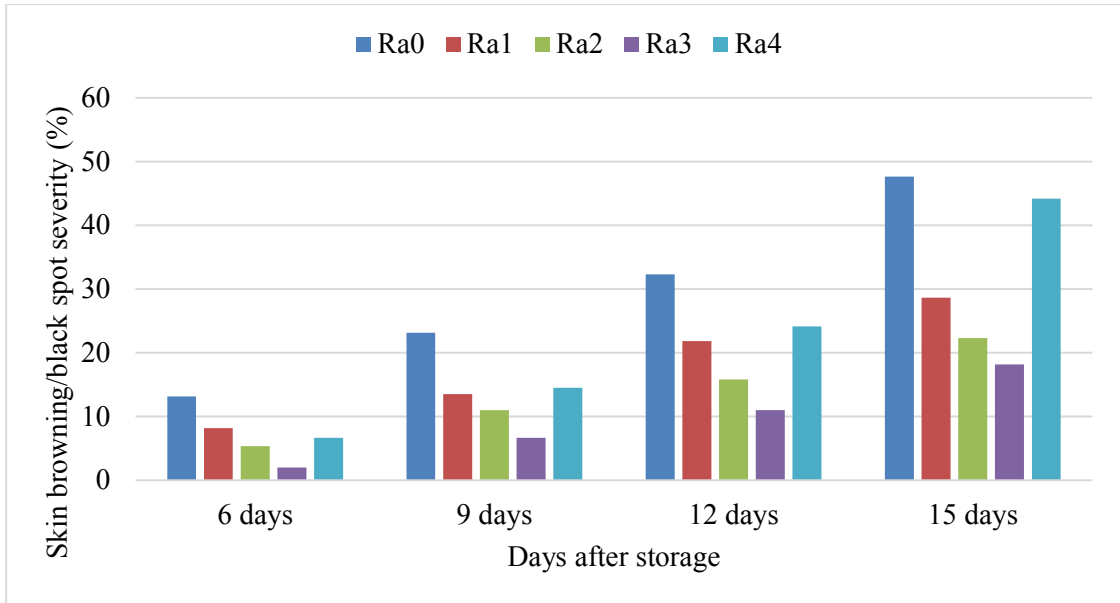
Figure 17: Effect of different doses of gamma irradiation on browning/black spot severity (%) of mango at different days after storge (LSD$_{0.01}$= 1.40, 1.78, 2.92 & 3.88 at 6, 9, 12 & 15 days after storage, respectively)

Ra$_0$ = 0.00kGy, Ra$_1$ = 0.30kGy, Ra$_2$ = 0.50kGy, Ra$_3$ = 0.70kGy, Ra$_4$ = 1.00kGy
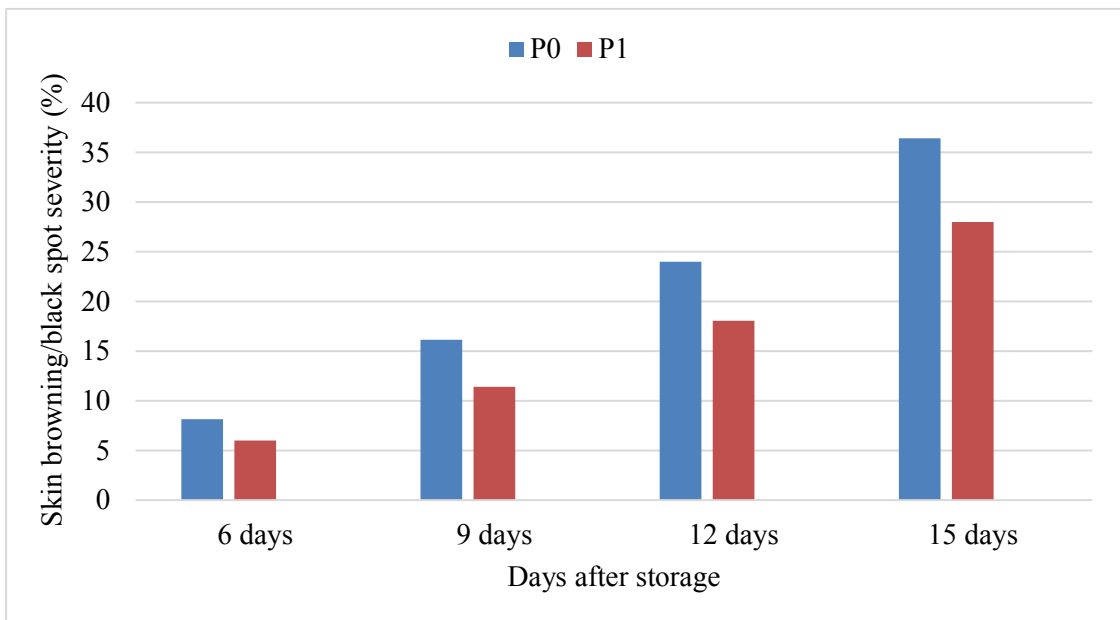
Figure 18: Effect of postharvest packaging on browning or black spot severity (%) of mango at different days after storage (LSD$_{0.01}$ = 0.88, 1.13, 1.85 & 2.45 at 6, 9, 12 7 15 days after storage)

P$_0$ = Non-packaging, P$_1$ = Packaging

The combined effect of irradiation doses and postharvest packaging using perforated LDPE bags on black or brown spot severity (%) was statistically significant at 6th, 9th, 12th and 15th Days after storage (Appendix V). Highest black spot severity (%) (16.005%, 29.00%, 40% and 58.33% at 6th, 9th, 12th and 15th DAS) was recorded in Ra_0P_0 (0.00kGy irradiated fruit without packaging) combination and lowest value (1.33%, 4.33%, 9.00%, and 14.64% at 6th, 9th, 12th and 15th DAS) was recorded in Ra_3P_1 (0.70kGy irradiated fruit stored in perforated LDPE polybag) combination (Table 9, Plate 3)

Table 9. Combined effect of gamma irradiation and postharvest packaging on browning or black spot severity (%) of mango at different days after storage (DAS)

Treatments	Brown/Black spot severity (%)			
	6 DAS	**9 DAS**	**12 DAS**	**15 DAS**
Ra_0P_0	16.00 a^z	29.00 a	40.00 a	58.33 a
Ra_0P_1	10.33 b	17.33 b	22.66 bc	37.00 c
Ra_1P_0	8.66 bc	14.66 cd	23.00 bc	30.66 d
Ra_1P_1	7.66 cd	12.33 d	20.66 cd	26.66 de
Ra_2P_0	6.33 d	12.33 d	17.33 de	24.66 ef
Ra_2P_1	4.33 e	9.66 e	14.33 ef	20.00 fg
Ra_3P_0	2.66 ef	9.00 e	13.00 fg	21.66 ef
Ra_3P_1	1.33 f	4.33 f	9.00 g	14.66 g
Ra_4P_0	7.00 cd	15.66 bc	26.66 b	46.66 b
Ra_4P_1	6.33 d	13.33 cd	21.66 c	41.66 bc
LSD (0.01)	1.987	2.530	4.143	5.487
CV (%)	11.96	7.82	8.38	7.25

Ra_0 = 0.00kGy, Ra_1 = 0.30kGy, Ra_2 = 0.50kGy, Ra_3 = 0.70kGy, Ra_4 = 1.00kGy, P_0 = Non-packaging, P_1 = Packaging. ^{z} Means with different letters significantly differ at LSD" s test at P ≤ 0.01; CV: Coefficient of Variation; LSD: Least Significant Difference

A. Black spot severity % at 6 days
   after storage (Ra$_0$P$_0$)

B. Black spot severity % at 15 days
   after storage (Ra$_0$P$_0$)

C. Black spot severity % at 6 days
   after storage (Ra$_3$P$_1$)

D. Black spot severity % at 15 days
   after storage (Ra$_3$P$_1$)

Plate 3: Comparison of black spot severity (%) among treatment combination

4.10 Disease severity (%)

The data on disease severity (%) of mango (at 6th, 9th, 12th and 15th DAS) significantly influenced by irradiation, postharvest packaging and their interaction (Table 10, Appendix VI). The maximum (12.16%, 18.66%, 25.83%, and 37.50% at 6th, 9th, 12th and 15th DAS) value was recorded from Ra_0 (0.00 kGy irradiated fruits). On the contrary, minimum (0.00%, 3.16%, 9.83% and 16.66% at 6th, 9th, 12th and 15th DAS) value was obtained from Ra_3 (0.70kGy irradiated fruits) followed by Ra_2 (0.50kGy irradiated fruit) in which data recorded (3.66%, 7.83%, 13.33% and 23.66% at 6th, 9th, 12th and 15th DAS) (Figure 19).

It was seen that highest disease severity (%) (7.66%, 13.06%, 20.26% and 31.13% at 6th, 9th, 12th and 15th DAS) was recorded in P_0 (Non-packaging fruit), while the lowest value (4.13%, 9.00%, 15.33% and 24.66% at 6th, 9th, 12th and 15th DAS) was recorded when fruit stored in perforated LDPE polybag (P_1) (Figure 20).

From the above discussion it is revealed that severity of disease on mango fruits increased with the advancement of time. Fungal diseases account for one of the main reasons of loss during commercialization of tropical fruits. Mangoes irradiated by 12 (0.12kGy) and 75 (0.75kGy) krads show minimum spoilage, whereas fruits irradiated by more than 100 (1kGy) krads spoil much earlier as reported by (Dhakar *et al*., 1966). Gamma irradiation (doses of 0.75 and 1 kGy) reduced lesion size caused by *Colletotrichum gloeosporioides* and anthracnose incidence in papaya fruit (*Carica papaya*). These doses inhibited *Colletotrichum gloeosporioides* conidial germination, reduced mycelial growth and lesion size, hence reduced the disease severity (%). Present findings are in conformity with the findings of (Cia *et al*., 2007). Irradiation brings about changes in the pathogens that make critical system e.g. nucleic acid, active proteins, more susceptible to irradiation effect. The reduction of disease severity will also reduce the production of lytic and toxic compound by the pathogen, aiding the retention of fruit quality. Higher the level of

irradiation dose lower will be the percentage of disease severity. But in case of this study 1.00kGy irradiation dose cause higher disease severity (%). Specially at higher dose level irradiation will accelerate the degradation of the fruit earlier by damaging tissues and cause increment of respiration rate and softening the fruits. similar findings were found by Andreas *et al.* (2019)
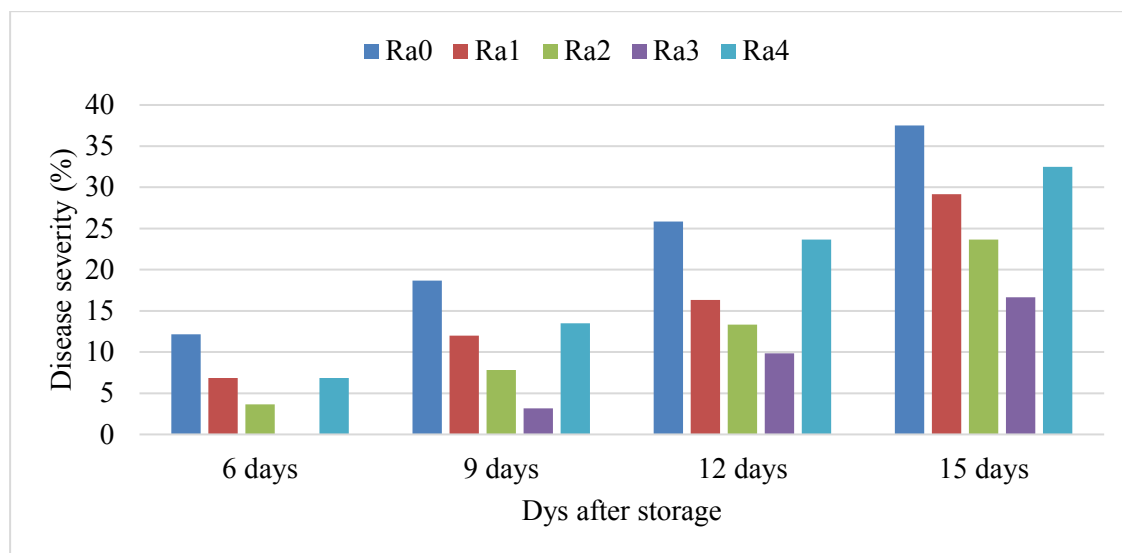
Figure 19: Effect of different doses of gamma irradiation on disease severity (%) of mango at different days after storge (LSD$_{0.01}$ = 1.23, 2.52, 3.95 & 4.04 at 6, 9, 12 & 15 days after storage)

Ra$_0$ = 0.00kGy, Ra$_1$ = 0.30kGy, Ra$_2$ = 0.50kGy, Ra$_3$ = 0.70kGy, Ra$_4$ = 1.00kGy
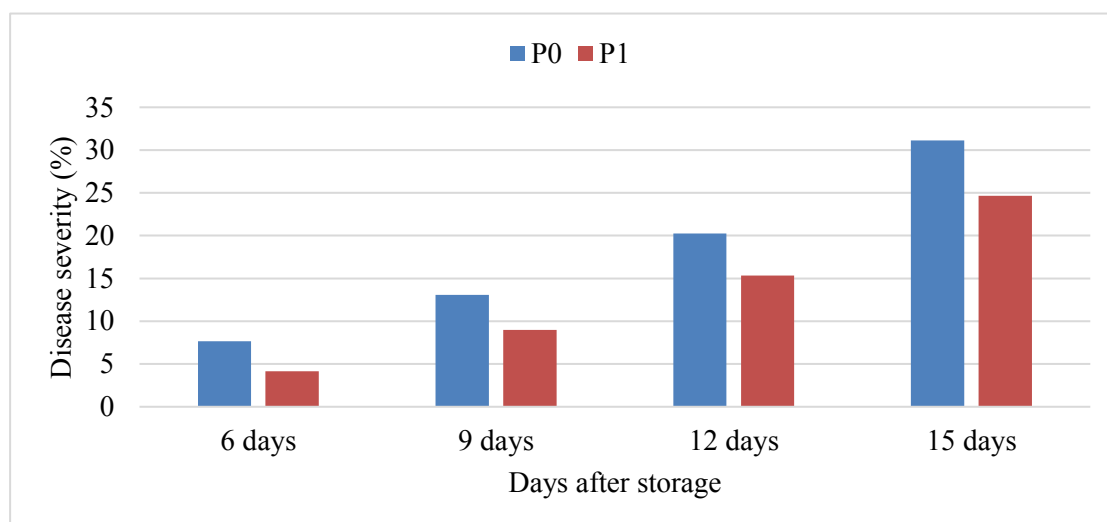
Figure 20: Effect of postharvest packaging on disease severity (%) of mango at different days after storage (LSD$_{0.01}$ = 0.78, 1.59, 2.50 & 2.55 at 6, 9, 12 & 15 days after storage)

P$_0$ = Non-packaging, P$_1$ = Packaging

The combined effects of postharvest gamma irradiation and packaging on disease severity (%) were statistically significant (Table10). The maximum (%) value of disease severity(15.00%, 22.33%, 33.33% and 43.33% at 6th, 9th, 12th and 15th DAS) was recorded in Ra_0P_0 (0.00kGy irradiated fruit without packaging) combination and lowest value (0.00%, 2.00%, 8.33%, and 13.33% at 3rd, 6th, 9th and 12th DAS) was found in Ra_3P_1 (0.70kGy irradiated fruit stored in perforated LDPE polybag) combination followed by Ra_3P_0 (0.70kGy irradiated fruit without packaging) combination, where the value were (0.00%, 4.33%, 11.33% and 20.00% at 6th, 9th, 12th and 15th DAS) (Plate 4).

Table 10. Combined effect of gamma irradiation and postharvest packaging on disease severity (%) of mango at different days after storage

Treatments	Disease severity (%)			
	6 DAS	**9 DAS**	**12 DAS**	**15 DAS**
Ra_0P_0	15.00 a^z	22.33 a	33.33 a	43.33 a
Ra_0P_1	9.33 b	15.00 bc	18.33 cd	31.66 bc
Ra_1P_0	8.66 b	13.33 bcd	16.66 de	30.00 cd
Ra_1P_1	5.00 c	10.66 d	16.00 de	28.33 cd
Ra_2P_0	5.33 c	10.00 d	15.00 de	25.66 de
Ra_2P_1	2.00 d	5.66 e	11.66 ef	21.66 e
Ra_3P_0	0.00 e	4.33 ef	11.33 ef	20.00 e
Ra_3P_1	0.00 e	2.00 f	8.33 f	13.33 f
Ra_4P_0	9.33 b	15.33 b	25.00 b	36.66 b
Ra_4P_1	4.33 c	11.66 cd	22.33 bc	28.33 cd
LSD (0.01)	1.745	3.564	5.596	5.723
CV (%)	12.59	13.75	13.38	8.73

Ra_0 = 0.00kGy, Ra_1 = 0.30kGy, Ra_2 = 0.50kGy, Ra_3 = 0.70kGy, Ra_4 = 1.00kGy, P_0 = Non-packaging, P_1 = Packaging. ^{z}Means with different letters significantly differ at LSD" s test at P ≤ 0.01; CV: Coefficient of Variation; LSD: Least Significant Difference

A. Disease severity % at 6 days
   After storage (Ra_0P_0)

B. Disease severity % at 15 days after
   storage (Ra_0P_0)

C. Disease severity % at 6 days
   After storage (Ra_3P_1)

D. Disease severity % at 15 days after
   storage (Ra_3P_1)

Plate 4: Comparison of disease severity (%) among the treatment combination

4.11 Shelf life (Days)

shelf life is the basic quality index of fruit and it is the most important parameter in loss of biochemical reaction of fruit. This shelf life period begins from the time of harvesting and extends up to the start of rotting of fruit. The data on shelf life of fruits were significantly influenced by irradiation, packaging and their interaction (Table 11, Appendix VII). Significantly the maximum shelf life (17.50 days) was recorded in fruits exposed to 0.70kGy gamma rays (Ra_3) followed by Ra_2 (15.33 days) when fruits exposed to 0.50kGy irradiation. The minimum shelf life (10.66 days) was recorded in unirradiated fruits (Ra_0) (Figure 21). This finding is similar with Mahto & Das, (2013). They studied the feasibility of low dose gamma irradiation on Dushehri (0.3-0.7kGy) and Fazli (0.5-0.7kGy). They showed that low dose gamma irradiation useful in delaying ripening and extension of shelf life by a minimum of 3 and 4 days in case of Dushehri and Fazli respectively. The higher shelf life in irradiated fruits might be due to delayed ripening as a result of inhibition of enzymatic activities and reducing the respiration and ethylene production. Same findings noted by Moreno *et al*. (2006) and Dhaker *et al*. (1966) in mango; Zaman *et al*. (2007) in banana and Sing *et al*. (2008) in guava.

Postharvest packaging had significant influence on shelf life of mango (Appendix VII). Shelf life was found to be the highest (14.80 days) when mangoes were stored in perforated polybags (LDPE) than the non-packaging mangoes (12.93 days) (Figure 22). 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. The present findings confirmed with the findings of Kaur *et al*. (2014); *Hailu et al. (2014)*.
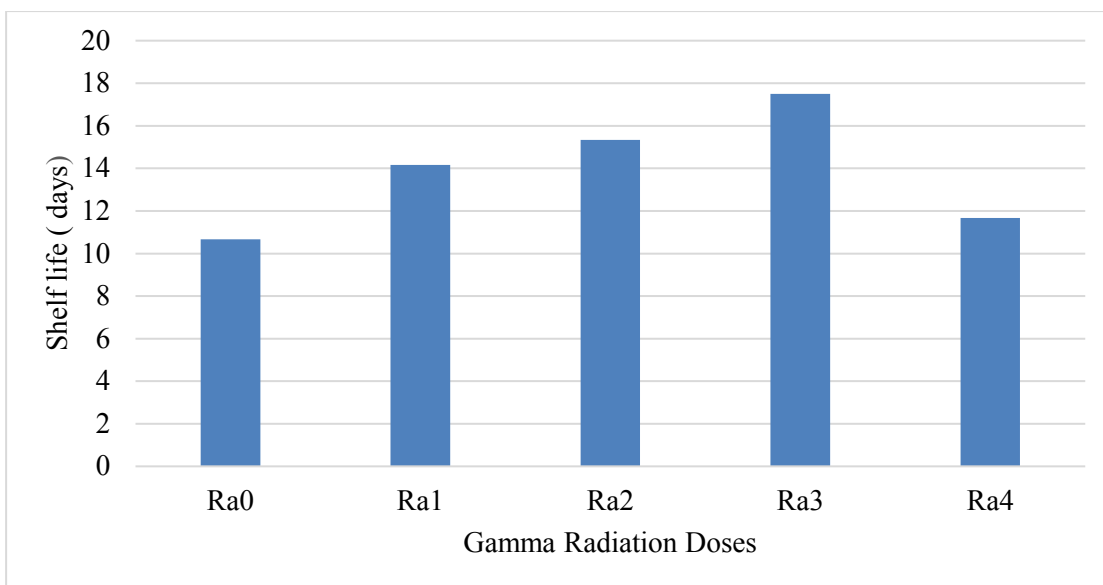
Figure 21: Effect of different doses of gamma irradiation on shelf life of mango (LSD$_{0.01}$ = 0.70)

Ra$_0$ = 0.00kGy, Ra$_1$ = 0.30kGy, Ra$_2$ = 0.50kGy, Ra$_3$ = 0.70kGy, Ra$_4$ = 1.00kGy
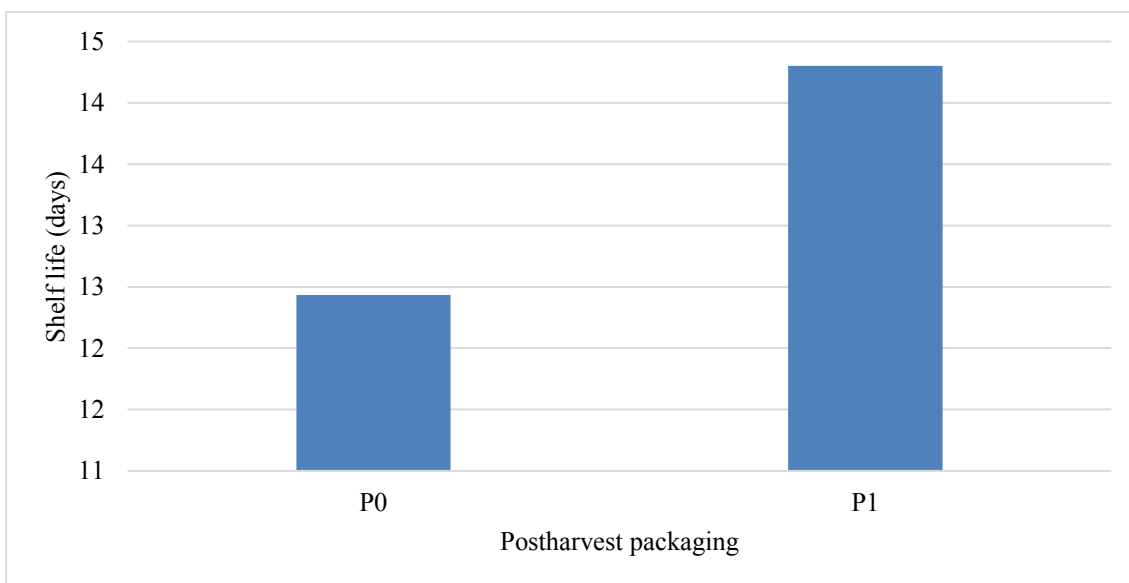
Figure 22: Effect of postharvest packaging on shelf life of mango (LSD$_{0.01}$ = 0.44 at the end of shelf life)

P$_0$ = Non-packaging, P$_1$ = Packaging

The combined effect of gamma irradiation and postharvest packaging using perforated LDPE bags on shelf life of mango was significant. Data showed that there was significant difference in shelf life of mango (Table 11, Appendix VII).

The highest shelf life (19.00 days) was reported in Ra_3P_1 (0.70KGy irradiated fruit stored in perforated LDPE polybag) and the lowest shelf life (9.00 days) was recorded in Ra_0P_0 (unirradiated fruit without packaging).

Table 11. Combined effect of gamma irradiation and postharvest packaging on shelf life of mango

Treatments	Shelf life (days)
Ra_0P_0	$9.00\ g^z$
Ra_0P_1	12.33 e
Ra_1P_0	13.66 d
Ra_1P_1	14.66 cd
Ra_2P_0	15.00 bc
Ra_2P_1	15.66 bc
Ra_3P_0	16.00 b
Ra_3P_1	19.00 a
Ra_4P_0	11.00 f
Ra_4P_1	12.33 e
LSD (0.01)	1.001
CV (%)	3.07

Ra_0 = 0.00kGy, Ra_1 = 0.30kGy, Ra_2 = 0.50kGy, Ra_3 = 0.70kGy, Ra_4 = 1.00kGy, P_0 = Non-packaging, P_1 = Packaging. ^{z} Means with different letters significantly differ at LSD" s test at P ≤ 0.01; CV: Coefficient of Variation; LSD: Least Significant Difference.

CHAPTER V
SUMMARY AND CONCLUSIONS

The experiment was carried out at the Postharvest Laboratory of Department of Horticulture, Sher-e-Bangla Agricultural University, Dhaka during the period from June to August, 2019. The objectives of the present study were to investigate the effect of gamma irradiation and postharvest packaging on shelf life and quality attributes of mango cv. "Amrapali" after storage. In this two factorial experiment gamma radiation doses were denoted as Factor A and postharvest packaging was denoted as Factor B. Gamma radiation of different doses i.e. Ra_0: 0.00kGy, Ra_1: 0.30kGy, Ra_2: 0.50kGy, Ra_3: 0.70kGy, Ra_4: 1.00KGy from ^{60}Co source and two postharvest packaging i.e. P_1: Perforated LDPE packaging and P_0: Without packaging were used in this experiment. The experiment was laid out in Completely Randomized Design (CRD). In this study observations were made on external and internal fruit attributes, physiochemical properties such as total weight loss, ripening percentage, moisture content, pH, total soluble solid content, Ascorbic acid, β-carotene content, Visual scoring of mango skin on the basis of browning or black spots severity, disease severity and shelf life. In this research work mango of each treatments were collected randomly at three, six, nine, twelve and fifteen days after harvest for physiochemical studies. The data were statistically analyzed and evaluated. The results of the experiment expressed that almost all the parameters studied were significantly influenced by the above factors.

Total four irradiation doses were applied in this experiment along with unirradiated fruit marked as control. Among all those treatments the maximum physiological loss in weight (4.84%, 8.94%, 14.28%, 18.33% and 21.82% at 3rd, 6th, 9th, 12th and 15th day of storage respectively) was found in Ra_0 (unirradiated fruit) and minimum (2.40%, 5.40%, 7.01%, 8.90% and 10.55% at 3rd, 6th, 9th, 12th and 15th day of storage respectively) was found in Ra_3 (0.70 kGy irradiation).The maximum ripening percentage (29.00%, 55.35%, 79.65, and 95.33% at 3rd, 6th, 9th and 12th DAS) value was reported from Ra_0 (0.00

kGy irradiated fruits) and minimum (0.00%, 18.50%, 29.16 % and 45.83% at 3rd, 6th, 9th and 12th DAS) value was obtained from Ra_3 (0.70kGy irradiated fruits). The highest moisture content (84.022%) was noticed in Ra_3 (0.70kGy irradiated treated fruits) while the lowest (77.272%) moisture content was found in Ra_0 (unirradiated fruits). TSS value which was an important quality parameter of mango, the fruits irradiated with 0.50kGy (Ra_2) maintained the lowest TSS value (15.50%) and unirradiated control fruits (Ra_0) maintained the highest TSS value (18.67%). The maximum value (0.36%) of titratable acidity for mango fruits was recorded for 0.70kGy irradiated fruit (Ra_3) and the minimum (0.22%) value was recorded in case of 0.00kGy (Ra_0 or unirradiated fruit).

The pH was found to be the highest (5.56) at the end of shelf life in Ra_0 (0.00 kGy or unirradiated fruits) whereas Ra_4 (1.00kGy irradiated fruits) represented the lowest value (4.74). Ascorbic acid content was found to be the highest (31.05 mg/100g) was recorded in both Ra_2 (0.50kGy irradiated fruit) and Ra_3 (0.70kGy irradiated fruit)) at the end of shelf life, where unirradiated fruit (Ra_0) represented the lowest ascorbic acid content (22.44 mg/100g). However, Ra_3 or 0.70kGy irradiated fruits represented the highest β-carotene content (5.14mg/100 g) and controlled fruits represented lowest (4.26 mg/100g) β-carotene content. Maximum browning or black spots (13.16%, 23.28%, 32.35, and 47.66% at 6th, 9th, 12th and 15th DAS) value was noticed from Ra_0 (0.00kGy irradiated fruits). On the contrary, minimum (2.00%, 6.66%, 11.00 % and 18.16% at 6th, 9th, 12th and 15th DAS) value was obtained from Ra_3 (0.70kGy irradiated fruits). Disease severity was significantly reported (12.16%, 18.66%, 25.83%, and 37.50% at 6th, 9th, 12th and 15th DAS) in Ra_0 (0.00kGy irradiated fruits) and minimum (0.00%, 3.16%, 9.83% and 16.66% at 6th, 9th, 12th and 15th DAS) value was obtained from Ra_3 (0.70kGy irradiated fruits). Above parameter indicated that highest shelf life of mango (17.50) days was obtained from 0.70kGy irradiated fruits and lowest (10.67) shelf life was observed in unirradiated fruits (Ra_0).

In case of postharvest packaging, total weight loss (%) (4.74%, 9.87%, 13.63%, 17.29% and 19.70% at 3rd, 6th, 9th, 12th and 15th DAS), ripening percentage (11.73%, 36.80%, 53.40% and 69.06% at 3rd, 6th, 9th and 12th DAS, pH value (5.41), TSS (18.00%), black or brown spots of mango skin (8.13%, 16.12%, 24.07% and 36.4% at 6th, 9th, 12th and 15th DAS) and disease severity (7.66%, 13.06%, 20.26% and 31.13% at 6th, 9th, 12th and 15th DAS) value was found to be the highest in non-packaging (P_0) mangoes and lowest weight loss (%) (1.87%, 4.10%, 7.01%, 9.80% and 12.17% at 3rd, 6th, 9th, 12th and 15th DAS), ripening (%) (7.53%, 26.66%, 40.80% and 58.04% at 3rd, 6th, 9th and 12th DAS), pH value (5.06), TSS (16.20%), browning or black spots severity (6.00%, 11.40%, 18.00% and 28.00% at 6th, 9th, 12th and 15th DAS) and disease severity (4.13%, 9.00%, 15.33% and 24.66% at 6th, 9th, 12th and 15th DAS) was recorded in P_1 (fruits stored in perforated LDPE polybag). On the other hand, highest value of moisture content (81.69%), TA (0.32%), Ascorbic acid (34.36 mg/100g), shelf life (14.80 days) was found in P_1(fruits stored in perforated LDPE polybag) and lowest TA (0.26%), Ascorbic acid (20.48 mg/100g), shelf life (12.93 days) was found in non-packaging (P_0) mangoes.

The combined effect between the gamma irradiation and postharvest packaging were found that maximum (6.51%, 11.57%, 16.72%, 21.61% and 26.11% at 3rd, 6th, 9th, 12th and 15th DAS) rate of weight loss, ripening percentage (35.00%, 69.00%, 92.66% and 100% at 3rd, 6th, 9th and 12th DAS), pH value (5.84), was observed in Ra_0P_0 (0.00kGy irradiated fruits without packaging) and minimum weight loss (%) (1.00%, 2.78%, 3.76%, 5.03% and 6.16% at 3rd, 6th, 9th, 12th and 15th DAS), ripening (%) (0.00%, 15.66%, 23.33%, and 42.33% at 3rd, 6th, 9th and 12th DAS), was recorded in Ra_3P_1 (0.70kGy irradiated fruit stored in perforated LDPE polybag). In case of moisture and β-carotene content highest (85.767%) moisture and (5.67mg/100g) β-carotene was recorded in Ra_3P_1 and lowest was determined in Ra_0P_0 combination. Again, the significant effect of treatments on TSS gave the maximum value (20.33%) in Ra_0P_0 and minimum

(15.00%) in Ra_2P_1. In case of interaction effect, highest (0.41%) TA value was recorded in Ra_3P_1 and the lowest (0.19%) value was noticed in Ra_0P_0 combination. In the present study, the maximum (34.36 mg/100g) value of Ascorbic acid was observed in Ra_3P_1 and Ra_2P_1, while minimum (20.48 mg/100g) in Ra_0P_0 combination. The highest (16.005%, 29.00%, 40% and 58.33% at 6th, 9th, 12th and 15th DAS) browning or black spot severity, (15.00%, 22.33%, 33.33% and 43.33% at 6th, 9th, 12th and 15th DAS) disease severity was recorded in Ra_0P_0 and lowest black or brown spot severity (1.33%, 4.33%, 9.00%, and 14.64% at 6th, 9th, 12th and 15th DAS), disease severity (0.00%, 2.00%, 8.33%, and 13.33% at 3rd, 6th, 9th and 12th DAS) was found in Ra_3P_1. Combined effect showed that highest shelf life was recorded in Ra_3P_1 treated fruits and lowest shelf life was found in Ra_0P_0 (0.00kGy irradiated fruits without packaging).

So, it can be concluded that fruit of Amrapali mango irradiated with 0.70kGy and stored in perforated LDPE polybag increase the shelf life & maintained better quality.

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APPENDICES

Appendix I: Effect of different dose of gamma irradiation and postharvest packaging on weight loss (%) of mango at different days after storage (DAS)

Mean square	Degrees of freedom	Mean square of weight loss at different days after storage (DAS)				
		3	6	9	12	15
Replication	2	0.03	0.29	0.025	0.581	1.423
Factor A	4	5.32**	13.12**	54.539**	85.978**	125.142**
Factor B	1	61.86**	249.81**	328.286**	421.500**	424.956**
AB	4	0.72**	7.062**	10.981**	13.962**	19.833**
ERROR	18	0.05	4.97	0.215	0.284	0.478

**Significant at 1% level of significance

Appendix II: Effect of different dose of gamma irradiation and postharvest packaging on ripening (%) of mango at different days after storage (DAS)

Mean square	Degrees of freedom	Mean square of ripening (%) at different days after storge (DAS)			
		3	6	9	12
Replication	2	0.433	14.03	31.60	11.10
Factor A	4	858.533**	1194.88**	2360.38**	2267.75**
Factor B	1	132.300**	770.13**	1190.70**	940.80**
AB	4	36.133**	142.88**	88.45**	30.22**
ERROR	18	0.507	2.26	2.19	3.29

**Significant at 1% level of significance

Appendix III: Effect of different dose of gamma irradiation and postharvest packaging on moisture (%), TSS, TA, Ascorbic acid of mango at the end of shelf life

Mean square	Degrees of freedom	Mean square at the end of shelf life			
		Moisture	TSS	TA	Ascorbic Acid
Replication	2	1.2699	0.1000	0.00042	0.784
Factor A	4	32.6517**	8.9667**	0.01655**	92.386**
Factor B	1	68.4634**	24.3000**	0.02296**	201.502**
AB	4	5.6583**	1.9667**	0.00118**	2.844**
ERROR	18	0.2670	0.1370	0.00012	0.539

**Significant at 1% level of significance

Appendix IV: Effect of different dose of gamma irradiation and postharvest packaging on p^H and β-carotene content of mango at the end of shelf life

Mean square	Degrees of freedom	Mean square at the end of shelf life	
		P^H	β-carotene
Replication	2	0.00200	0.00002
Factor A	4	0.655265**	0.69203**
Factor B	1	0.92225**	0.16576**
AB	4	0.02820**	0.00534**
ERROR	18	0.00242	0.00060

**Significant at 1% level of significance

Appendix V: Effect of different dose of gamma irradiation and postharvest packaging on black or brown spots severity (%) of mango at different days after storage (DAS)

Mean square	Degrees of freedom	Mean square of black or brown spot severity (%) at different days after storge (DAS)			
		6	9	12	15
Replication	2	0.233	1.233	1.033	1.60
Factor A	4	100.833**	220.500**	398.783**	1033.78**
Factor B	1	34.1333**	168.033**	264.033**	529.20**
AB	4	6.217**	23.950**	42.950**	80.28**
ERROR	18	0.715	1.159	3.107	5.45

**Significant at 1% level of significance

Appendix VI: Effect of different dose of gamma irradiation and postharvest packaging on disease severity (%) of mango at different days after storage (DAS)

Mean square	Degrees of freedom	Mean square of disease severity (%) at different days after storge (DAS)			
		6	9	12	15
Replication	2	0.700	6.633	1.300	6.300
Factor A	4	121.217**	206.117**	276.783**	388.550**
Factor B	1	93.633**	124.033**	182.533**	313.633**
AB	4	7.217**	5.950**	49.117**	22.383**
ERROR	18	0.552	2.300	5.670	5.930

**Significant at 1% level of significance

Appendix VII: Effect of different dose of gamma irradiation and postharvest packaging on shelf life of mango

Mean square	Degrees of freedom	Mean square of shelf life
Replication	2	0.0333
Factor A	4	45.7833**
Factor B	1	26.1333**
AB	4	8.867**
ERROR	18	3.267

**Significant at 1% level of significance