J. Agric. Sci. Technol. (2024) Vol. 26 (5): 1127-1142

Synergistic Effect of Gamma Irradiation and Methyl Jasmonate on the Postharvest Quality of Fresh Apricots (*Prunus armeniaca* cv. 'CITH-1') Stored under Refrigeration

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ABSTRACT

Apricots being highly perishable and often results in significant postharvest losses that affect their marketability and commercial viability. A study was conducted to investigate the synergistic effect of postharvest application of gamma irradiation and Methyl Jasmonate (MeJ) on the quality, enzyme-specific activities, and shelf life of the apricot *(Prunus armeniaca* cv. 'CITH-1'). Apricots were gamma irradiated at a dosage of 0.5 kGy and submerged in different concentrations of MeJ before being refrigerated (1±1°C, RH 80-85%) for 35 days. Apricots treated with a 0.5 kGy dose and 0.1 mmol L^{-1} MeJ followed by refrigeration significantly (P< 0.05) retained higher levels of antioxidant activity. The quality of apricots was effectively preserved, and their shelf life was extended through treatments of 0.5 kGy irradiation dosage and 0.2 mmol L^{-1} MeJ, which significantly (P< 0.05) reduced decay percentage, weight loss, and enzyme activity while maintaining fruit firmness. The study's results suggest that applying a postharvest treatment of MeJ at a concentration of 0.1 and 0.2 mmol L^{-1} in combination with an irradiation dosage of 0.5 kGy is a viable method for preserving the quality and bioactive compounds of fresh apricots during refrigerated storage for up to 35 days.

Keywords: Antioxidant activity, Decay percentage, Enzyme-specific activities, Firmness, Postharvest shelf life.

INTRODUCTION

Apricots are widely recognized for their juicy and pleasant flavor. Apricots belong to the genus 'P*runus*' in the family 'Rosaceae' and are characterized by a fleshy exocarp covering the hard endocarp pit with the seed inside. The family Rosaceae includes more than 3000 species (Hummer and Janick, 2009). Apricots are a good source of vitamins, minerals (Ali *et al.*, 2015), and phytochemicals including flavonoids, carotenoids, etc. (Wani *et al.*, 2017). They are also rich in phenolic compounds such as α-resorcyclic acid, ferulic acid, vanillic acid, quercetin, etc. contributing significantly to their antioxidant activity (Vinha *et al.*, 2012).

Apricots, being climacteric, have a shelf life of 3-5 days at ambient conditions (Morsy and Rayan, 2019). Apricots deteriorate faster at room temperature due to rapid respiration. One of the main causes of postharvest loss in apricots is mechanical injury (bruises, cuts, etc.), which can occur during harvesting, packing, and transportation and result in browning (Ioannou and Ghoul, 2013). Browning affects the colour, taste, flavour, and nutritional properties of the apricots. Apricots are highly perishable and require proper storage to prevent spoilage. Another cause of postharvest loss or deterioration in stone fruits is improper storage conditions, which may result in Chilling Injury (CI) when stored at low temperatures (< 5°C) (Liu *et al.*, 2019; Choi *et al.*, 2021). Due to the fact that not all cultivars are suitable for storage and transit, firmness as a post-harvest quality factor is

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[DOI: 10.22034/JAST.26.5.1127]

important in determining how apricots are treated following harvest (Manganaris and Crisosto, 2020). Firm-pulp apricots are ideal for transportation and storage, but soft-pulp apricots are often processed into other products right after they have been brought from the field.

To minimize postharvest losses and extend the shelf life of apricots, it is important to implement proper handling, storage, and transportation practices. Many national organizations have recognized irradiation as a promising food processing technology. Gamma (γ) irradiation has been shown to delay ripening in climacteric fruits when used alone or in combination with other treatments like refrigeration (Mathur and Chugh, 2020). Foods irradiated up to 10 kGy are toxicologically safe, according to the Joint Expert Committee (FAO/IAEA/WHO) on the Wholesomeness of Irradiated Foods (Joint FAO and WHO Organization, 1981). Irradiation at low doses can be used to extend the shelf life of fresh apricots (Raja *et al.*, 2023b).

Methyl Jasmonate (MeJ), a methyl ester of jasmonic acid, is a natural growth regulator widely found in plants and synthesized via the lipoxygenase pathway (González-Aguilar *et al.*, 2006). MeJ improves the postharvest quality of blackberries, strawberries, raspberries, etc., (Ruiz-García and Gómez-Plaza, 2013) and inhibits microbial growth in fruits and vegetables (Wang and Buta, 2003). In a new study, the role of MeJ as a postharvest treatment for fresh apricots was investigated. It was found that treating apricots with MeJ considerably improved their shelf life and enhanced their marketability when kept under refrigeration (Raja and Masoodi, 2023a). However, studies on the synergistic effect of MeJ and gamma irradiation on enzyme activity, texture, decay percentage, and shelf life of fresh apricots are limited.

The present investigation assesses the synergetic effects of gamma irradiation and MeJ on the quality and shelf life of fresh apricots.

MATERIALS AND METHODS

Procurement of Fresh Apricots

Fresh apricot (*Prunus armeniaca* cv. 'CITH-1') at the pre-climacteric stage (Skin colour: yellowish-orange with reddish tinge; TSS: 12.3° Bx; Firmness: 4.8N) were collected from Central Institute of Temperate Horticulture (CITH), Rangreth, union territory of Jammu and Kashmir (Lat-33.988, Long-74.796) in the last week of May. *Prunus armeniaca* cv. 'CITH-1', produced by clonal selection at CITH, Rangreth, J&K, is a self-fertile, mid-season fruit that first appeared in 2009. Fruits of this cultivar are spherical and symmetrical, with a smooth distal end, early ripening, non-susceptible to most apricot diseases, and ideal for cultivation throughout the North Western Himalayas. They were harvested early in the morning at 10-15°C and transported in perforated cardboard boxes in an air-conditioned vehicle to the Department of Food Science and Technology, University of Kashmir, Srinagar (Lat-34.128, Long-74.836). Before the harvest characteristics analysis, the fruits were allowed to cool in a storage chamber (4 ± 1°C, RH 80-85%) for 24 hours to remove the field heat.

Chemicals and Reagents

Chemicals and reagents used for the analysis of raw apricots were purchased from HIMEDIA (Einhausen, Germany).

Standard Phenolic Acids

Standard phenolic acids, including β-resorcyclic acid, p-coumaric acid, gallic acid, caffeic acid, p-hydroxybenzoic acid, m-hydroxybenzoic acid, 3,5-dihydroxybenzoic acid, ferulic acid, syringic acid, gentisic acid, vanillic acid, trans chlorogenic acid, quercetin, and shikimic

[DOI: 10.22034/JAST.26.5.1127]

acid were obtained from Sigma Chemical Co. (Steinheim, Germany).

Application of MeJ and Gamma Irradiation

In a study on apricot cv. 'CITH-1', a total of 1,000 fruits were sorted into ten groups of 100 fruits each. Four concentrations of 0.1, 0.2, 0.3, and 0.4 mmol L^{-1} were used as MeJ dip in some groups, and others were irradiated with a standard dosage of 0.5 kGy. To aid in the application of the MeJ, 0.5 mL of Tween-20 surfactant was added. Fruits that had previously been treated with different concentrations of methyl jasmonates were irradiated at a standardised dose of 0.5 kGy (Raja *et al*., 2023b) using a PANBIT irradiator (make: Isotope Division, BARC, India) with Cobalt-60 as the source of gamma rays at the Bhabha Atomic Research Centre, Srinagar, J&K, India (Lat-34.154, Long-74.832). During irradiation, the fruits were exposed to an average rate of 190 Gy h^{-1}. During the process, the fruits were periodically rotated 180 degrees. Dosimetry, using ferrous sulfate, was employed to determine the dose rate. Before irradiation, the fruits were labelled according to whether irradiation had been done or not: 'GS0' represents fruits without irradiation, and 'GS' represents the fruits given a 0.5 kGy dose. The groups that were chosen for investigation are all refrigerated (R) after treatment and labelled accordingly as shown in Table 1.

Fruit Analysis

Moisture Content (MC)

Moisture content was determined using the official method 925.09 of AOAC (González-Herrera *et al.,* 2016)**.**

Total Soluble Solids (TSS)

The TSS content of the fruit was measured using a handheld digital refractometer (Atago Co., Tokyo, Japan) and expressed as ^{o}Brix as recommended in official method of AOAC, 2000.

Titratable Acidity (TA)

The official method of AOAC, 2000 was used to calculate the titratable acidity, and the results were reported in terms of malic acid.

pH

After calibration with standard buffers of 4 and 7, the pH of the apricot samples was measured using a microprocessor pH meter (Labtronics).

Total and Reducing Sugars

The method of Lane and Eynon (AOAC,

Table 1. Labelling of refrigerated, gamma irradiated and methyl jasmonate treated samples.

MeJ concentration	Irradiation	Label
Control	Unirradiated	GS0/M0/R
	Irradiated	GS/R
0.1 mmolL^{-1}	Unirradiated	M1/R
	Irradiated	M1/GS/R
0.2 mmolL^{-1}	Unirradiated	M2/R
	Irradiated	M2/GS/R
0.3 mmolL^{-1}	Unirradiated	M3/R
	Irradiated	M3/GS/R
0.4 mmolL^{-1}	Unirradiated	M4/R
	Irradiated	M4/GS/R

[DOI: 10.22034/JAST.26.5.1127]

1980) was employed to estimate the total sugar, while the DNSA (3,5-dinitro salicylic acid) reagent was used to determine the reducing sugars, following the method of Miller (1959).

Total Phenolic Compounds (TPC)

The concentration of phenolic compounds was measured by the Folin-Ciocalteu assay, as described by Raja *et al.,* (2023b), and the results were expressed as milligrams of Gallic Acid Equivalents (GAE) per gram of fresh fruit weight.

Ascorbic Acid (A_A)

To determine the concentration of ascorbic acid, the accepted titrimetric technique (AOAC, 2000) was employed. In brief, a titration was performed using ten mL of 3% HPO_3 and the dye solution (50 mg DCIP and 42 mg $NaHCO_3$ dissolved in hot distilled water). The concentration of ascorbic acid was calculated using the following formulae (Dharwal *et al*., 2020):

$$AA = \frac{Titre\ value\ X\ Dye\ factor\ X\ volume\ made\ X\ 100}{aliquot\ of\ sample\ X\ volume\ of\ sample}$$

Where, (AA) is Ascorbic acid (mg/100mg)

$$\text{Dye factor} = \frac{0.5}{\text{Titre value}}$$

Antioxidant Activity (AA) by DPPH Assay

Using the procedure outlined by Wani *et al.,* (2017), the radical scavenging activity of apricot samples was evaluated through the DPPH (1, 1-Diphenyl-2-Picrylhydrazyl) assay. To perform the assay, a 50-gram homogenized sample underwent three methanol extractions. The combined extracts were then filtered using Whatman filter paper no. 42 and centrifuged at 14,000 rpm for 20 minutes at 4 ± 1°C. The resulting supernatant was stored at 2±1°C. A working solution with a concentration of 0.01 mg mL^{-1} was prepared. For the assay, 80 µL of the sample was mixed with 200 µL of 0.05% DPPH in a total volume of 4 mL of methanol. The mixture was vigorously shaken and kept in the dark at room temperature for 30 minutes to allow for reaction. Afterward, the absorbance at 517 nm was measured. The results were expressed as the percentage of DPPH inhibition.

$$\%\ \text{inhibition} = \frac{\text{Absorbance of control} - \text{Absorbance of sample}}{\text{Absorbance of control}} X\ 100$$

Flesh Firmness

The TA-XT2 Plus texture analyzer (Stable Micro Systems, Surrey, UK) was used to evaluate the instrumental textural properties of fresh apricots. The fruits were individually placed on a Heavy-Duty Platform (HDP) and the following parameters were set before evaluation: Load cell= 5 kg, Probe= P/5 cylindrical, Penetration distance= 50 mm, Pre-test speed= 1.0 mm s^{-1}, Post-test speed= 1.0 mm s^{-1}, Test-speed= 1.5 mm s^{-1}. The results obtained were reported as firmness, with each value representing an average of 10 assessments.

Enzymes Specific Activities: Polyphenol Oxidase (PPO) and Peroxidase (POX))

Polyphenol Oxidase (PPO) was assessed following the protocol outlined by Fernandes *et al.* (2011) with slight modifications. A 10 g sample was homogenised using a homogenizer (HG-15D, 27000 rpm, Germany) with 30 mL of 0.2M phosphate buffer (pH 6.5) and 0.6 g of PVPP (polyvinylpolypirrolidone) for three minutes, with a one-minute interval after each minute. Two drops of Triton X-100 solution were added to the mixture during the last minute of homogenization. After homogenization, the mixture underwent centrifugation (5810R, Eppendorf Hamburg, Germany) at 10,000 rpm for 30 minutes. The resulting mixture was then filtered through

[DOI: 10.22034/JAST.26.5.1127]

four layers of cheesecloth, and the supernatant was collected and measured. For the assay, 0.1 mL of the aliquot was combined with 2.80 mL of catechol (0.16M). The rate of absorbance increase at 420 nm over a duration of 60 seconds was measured using a spectrophotometer (UV-1900i, Shimadzu Corp., Tokyo, Japan). Catechol was used as a reference blank. The enzyme activity (U g^{-1} FW min^{-1}) was determined based on the linear section of the activity curve as a function of time.

The POX activity was measured with the method outlined by the Ezzat *et al.* (2020). To prepare the enzyme extract, the flesh from 10 fruits (totalling 10 grams) was homogenized in 25 mL of a 50 mmol L^{-1} sodium borate buffer (pH 8.8) containing 5 mmol β-mercaptoethanol and 0.5 g of polyvinyl pyrrolidone (PVPP). In brief, a 0.5 mL enzyme extract was combined with 2 mL of a buffer containing 100 mmol L^{-1} sodium phosphate (pH 6.4) and 8 mmol L^{-1} guaiacol. The resulting solution was placed in an incubator at 30 ˚C for 5 minutes. Afterward, 1 mL of H_2O_2 (24 mmol L^{-1}) was added to the sample, and the absorbance increase was measured at 460 nm five times at 30, 60, 90, 120, and 150 seconds. The activity of Peroxidase (POD) was then expressed as units per gram fresh weight per minute (U mg^{-1} FW min^{-1}).

Quantification of Phenolics

Polyphenol analysis was carried out using the method outlined by (Wani *et al.,* 2017). The analysis of phenolic acids was carried out using an Agilent HPLC 1260 infinity series instrument at the Department of Food and Drug Laboratory, Dalgate, Srinagar. The instrument was equipped with the following: C18-A11608 column; DAD detector (G1315D); quaternary solvent pumps; and a manual injection port. The instrument was operated at 25°C. Water filtered and purified on a Milli-Q system (Millipore, Bedford, MA, USA) was used in the preparation of standard polyphenol solutions. Gradient elution with varying flow rates was used (see Table 2).

Decay Percentage (D_P)

To determine the Percentage of Decayed fruits (D_P), the initial number of fruits was divided by the number of fruits showing signs of decay, and the result was multiplied by 100, as described by El-Anany *et al.* (2009). However, visibly damaged fruits were discarded from each assessment of the coated and uncoated fruits.

Weight Loss (W_L)

The percentage of weight loss was calculated every seven days (using three replicates of ten fruits) during storage using the following equation:

$$\text{weight loss } \% = \frac{WS}{WI} X100$$

Where, WS is the Weight of an apricot at

Table 2. Gradient program applied during polyphenol analysis of apricots by HPLC.[a]

Analysis time (Min)	Eluent A (%)	Eluent B (%)	Eluent C (%)	Flow rate (mL min^{-1})	Temperature (˚C)
1-5	0	1.0	99.0	1.0	25
5-45[b]	38.0	2.0	60.0	1.0	25
45-50	38.0	1.0	60.0	1.0	25
50-55	75.0	1.0	24.0	1.2	25
55-65	75.0	1.0	24.0	1.2	25
65-75	0.0	1.0	99.0	1.2	25

[a] Eluent A: Methanol; Eluent B: Acetic acid; Eluent C: Acetonitrile; Eluent A: Eluent B: Eluent C= 33:33:34 (v/v). [b] For 5-45 minutes: the amount of solvent C was successively increased by 10% after each 5 minutes.

[DOI: 10.22034/JAST.26.5.1127]

the time of Sampling, and WI is the Initial Weight of an apricot.

Statistical Evaluations

The data were analyzed statistically using a two-way Analysis Of Variance (ANOVA) with commercial statistical software (IBM SPSS Statistics 28.0.1.1). Mean differences were determined using Duncan's multiple range test ($P< 0.05$).

RESULTS AND DISCUSSION

Physicochemical and Phytochemical Composition

The results of the harvest characteristics of the apricot cultivar 'CITH-1' are summarised in Table 3. At the time of harvest, the average moisture content and TSS were calculated to be 88.23% and 12.32 ^{o}Bx, respectively, which is comparable with the findings of Kumar *et al.* (2016) in their research on apricot varieties in India's northwestern Himalayan region. Titratable acidity (%) and pH were confirmed to be 1.02 and 3.46, respectively. Organic acids in apricots, such as citric, maleic, fumaric, ascorbic, and acetic acids, contribute to titratable acidity (Gao *et al.,* 2012). The titratable acidity values obtained in this study were higher than those reported by Kumar *et al.* (2016) in their study of different apricot varieties. The variation may be due to the difference in TSS and cultivar used. The results also agree with those of Valentini *et al.* (2006), who studied the physicochemical parameters of Italian apricot varieties. The total sugar and reducing sugar content were 8.16 and 5.60%, respectively. These findings are consistent with the results reported by Ali *et al.* (2011) while evaluating the physicochemical properties of Pakistani apricots. The Total Phenol Content (TPC) was 37.40 mg GAE g^{-1}. This value is comparable to the research done by Wani *et*

Table 3. Physicochemical and phytochemical composition (harvest characteristics) of apricot cultivar CITH-1 grown in CITH, J&K (UT), India.[a]

Cultivar	Moisture (%)	TSS (^{o}Brix)	TA (%)	pH	Reducing sugar (%)	Total sugars (%)	TPC (mg GAE g^{-1})	A_A (mg 100 g^{-1} FW)
CITH-1	88.23±2.54	12.32±1.28	1.02±0.11	3.46±0.35	5.60±0.76	8.16±1.34	37.40±1.35	14.80±1.29

[a] **TSS**: Total Soluble Solids; **TA**: Titratable Acidity; **TPC**: Total Phenolic Content; $\mathbf{A_A}$: Ascorbic Acid. Each value is the mean±standard deviation (n= 3).

al. (2015). The average percentage of ascorbic acid was 14.80, which is comparable to the ascorbic acid levels reported by Raja *et al.* (2023b) in their research of three different cultivars developed at CITH, Rangreth, India, and by Thompson and Trenerry (1995) in their study of Turkish apricot varieties. These findings provide valuable information for further research on apricot cultivars and their potential health benefits.

HPLC Quantification of Phenolic Acids

Figure 1(A-B) shows the HPLC chromatograms of fourteen polyphenol standard solutions and apricot samples. The study found that *Prunus armeniaca* cv. 'CITH-1' had a total phenolic acid concentration of 5.14 mg kg^{-1} FW, with the presence of twelve phenolic acids. Six Hydroxybenzoic Acids (HBA) and six Hydroxycinnamic Acids (HCA) were found with a total concentration of 3.21 and 1.93 mg kg^{-1}, respectively. The primary phenolic acid, α-resorcyclic acid, was detected at a total concentration of 1.54 mg kg^{-1}. Table 4 summarizes the phenolic acid content of 'CITH-1'apricots. These findings are consistent with the results reported by Wani *et al*. (2017), who studied the antioxidant properties of apricot varieties from North India. These findings provide important information on the potential health benefits of consuming *Prunus armeniaca* cv. 'CITH-1' and suggest that it could be a good source of phenolic acids.

Effect of MeJ and Gamma Irradiation

Antioxidant Activity (% Inhibition of DPPH)

The undesirable changes in the environment disrupt the metabolic pathways in plants, resulting in the production of reactive oxygen species (ROS). This disruption can result in irreversible damage and oxidation of cellular components and, therefore, decline in fruit storage life (Madani *et al.,* 2019). Different treatments have been utilised by the researchers to overcome the effects of production of ROS to the plants. The antioxidant activity (% inhibition of DPPH) of apricot fruits during refrigerated storage was influenced by various treatments, as illustrated in Figure 2. The control fruits (GS0/M0/R) indicated significantly lower ($P< 0.05$) antioxidant activity than the treated ones, with significant variations ($P< 0.05$) in antioxidant activity among various MeJ dosages. The antioxidant activity of the control and treated apricot fruits did not show any significant ($P< 0.05$) difference up to 7 days of storage. However, there was a sharp decline in the antioxidant activity of the control fruits after the 7^{th} day. Among the treatments, fruits treated with a 0.2 mmol L^{-1} MeJ and a 0.5 kGy dosage had the highest inhibition (%) of 52.34 after 35 days of storage, while the control had the lowest inhibition (%) of 42.24. No significant difference ($P< 0.05$) was observed in M3/GS/R, M1/R and M4/R and M3/GS/R after 35 days of storage. MeJ has been established as a signalling molecule in plants (Fariduddin *et al.,* 2019), and several studies have reported that MeJ and gamma irradiation treatments can effectively prolong shelf life by enhancing the oxidation resistance of various fruits (Raja and Masoodi, 2023a; Raja *et al.,* 2023b).

POX and PPO Enzyme Activities

Enzyme-specific activities also play a crucial role during the fruit ripening process (Verma *et al.,* 2015). During storage (see Figure 3-a), the POX enzyme activity of different treated and non-treated apricots gradually increased. However, the data revealed that MeJ concentrations had a significant ($P< 0.05$) effect on regulating POX activity during refrigerated storage. Compared to the control and other treatments, apricots treated with 0.2 mmol L^{-1} and 0.5

[DOI: 10.22034/JAST.26.5.1127]

Table 4. Phenolic acid content (mg kg^{-1} fw) of apricot cultivars CITH-1 grown in J&K (UT).

Phenolic acids	Concentration (mg g^{-1} FW)
Hydroxybenzoic Acids (HBA)	
Gallic acid	0.13
β-resorcyclic acid	0.07
p-hydroxybenzoic acid	0.59
m-hydroxybenzoic acid	-
α-resorcyclic acid	1.54
Syringic acid	-
Gentisic acid	0.63
Vanilic acid	0.25
Total HBA	3.21
Hydroxycinnamic Acids (HCA)	
Caffeic acid	0.14
p-coumaric acid	0.57
Ferulic acid	0.17
Trans chlorogenic acid	0.75
Quercetin	0.21
Shikimic acid	0.09
Total HCA	1.93
Total phenolic acids	5.14

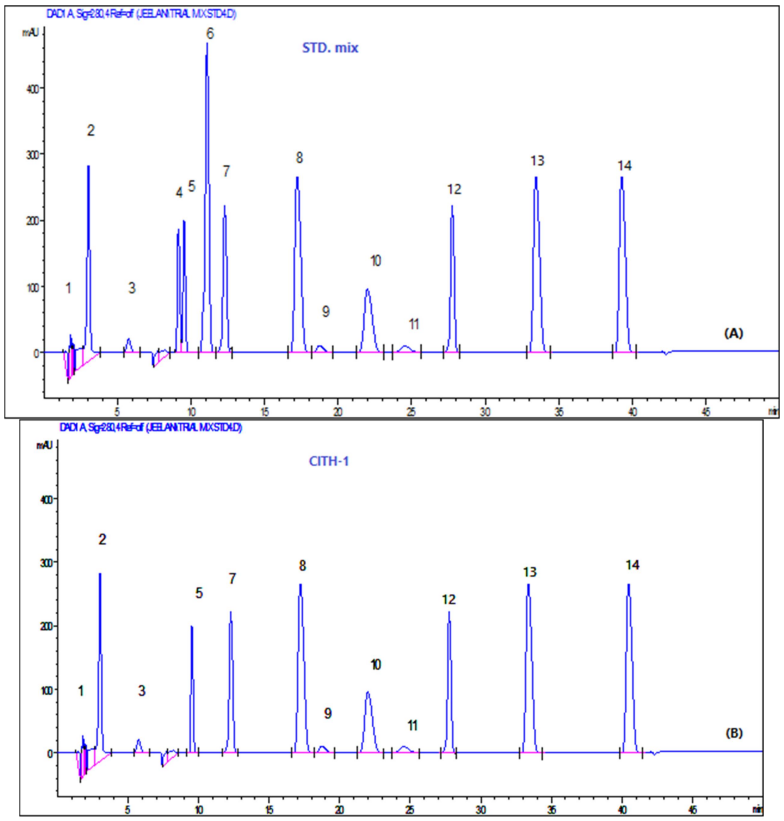

Figure 1. Representative HPLC chromatogram of polyphenol standards and apricot samples-14 polyphenol standards (A); CITH-1 (B); Peak identification as 1= Gallic acid; 2= Caffeic acid; 3= β-resocyclic acid; 4= p-Coumaric acid; 5= p-Hydroxybenzoic acid; 6= m-Hydroxybenzoic acid; 7= 3, 5-Dihydroxybenzoic acid; 8= Syringic acid; 9= Gentisic acid; 10= Ferulic acid; 11= Vanillic acid; 12= Trans-chlorogenic acid; 13= Quercetin; 14= Shikimic acid.

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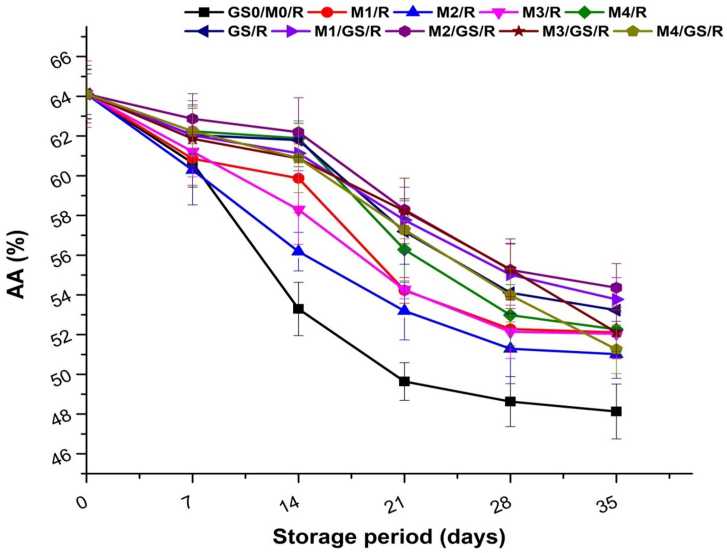

Figure 2. Effect of gamma irradiation and MeJ on antioxidant activity (% inhibition of DPPH) of the apricot cultivar (CITH-1) under refrigeration.

kGy significantly (P< 0.05) suppressed the activity of the POX enzyme. Furthermore, a combination of 0.3 mmol L^{-1} MeJ and 0.5 kGy was an effective treatment for reducing POX enzyme activity during refrigerated storage. During storage, the PPO activity also significantly (P< 0.05) increased in all treatments. However, when apricots treated with MeJ were gamma-irradiated, their PPO activity decreased, as shown in Figure 3b. Apricots treated with 0.5 kGy and 0.1 mmol L^{-1} MeJ had the lowest PPO activity among the other treatments from day 7 onward in refrigerated storage. The data in the present study showed that the synergistic effect of gamma irradiation and MeJ significantly decreased the activities of POX and PPO, which may effectively protect them against microbial damage during storage at low temperatures. These results suggested that the suppressed activities of POX and PPO may be one part of the mechanism of MeJ and gamma irradiation in maintaining the quality of apricot fruit. This may be due to the interaction between MeJ and gamma irradiation with the induced defensive pathways of the plant, which could build up the antioxidant enzymes and chemicals. A similar finding was reported in pomegranate fruit, where methyl jasmonate and gamma irradiation improve its quality between harvest and consumption (Pareek *et al.,* 2015).

Flesh Firmness

Loss of water and enzyme-induced hydrolysis result in a degradation of texture in fruits (Phanumong *et al.,* 2019). Table 5 shows the texture of apricots as a measure of firmness. With storage, it was shown that the control fruits lost firmness significantly (P< 0.05) more than the treated ones. However, no significant difference (P< 0.05) was observed among the treatments M4/R and GS/R after 35 days of storage, which reveals that application of MeJ alone at 0.4 mmol L^{-1} concentration under refrigeration has the same effect on firmness as that of irradiated fruits (0.5 kGy) under refrigeration. Furthermore, after 5 weeks of storage, the treatments M2/R and M2/GS/R were shown to be the best among the treatments. Apricot

[DOI: 10.22034/JAST.26.5.1127]

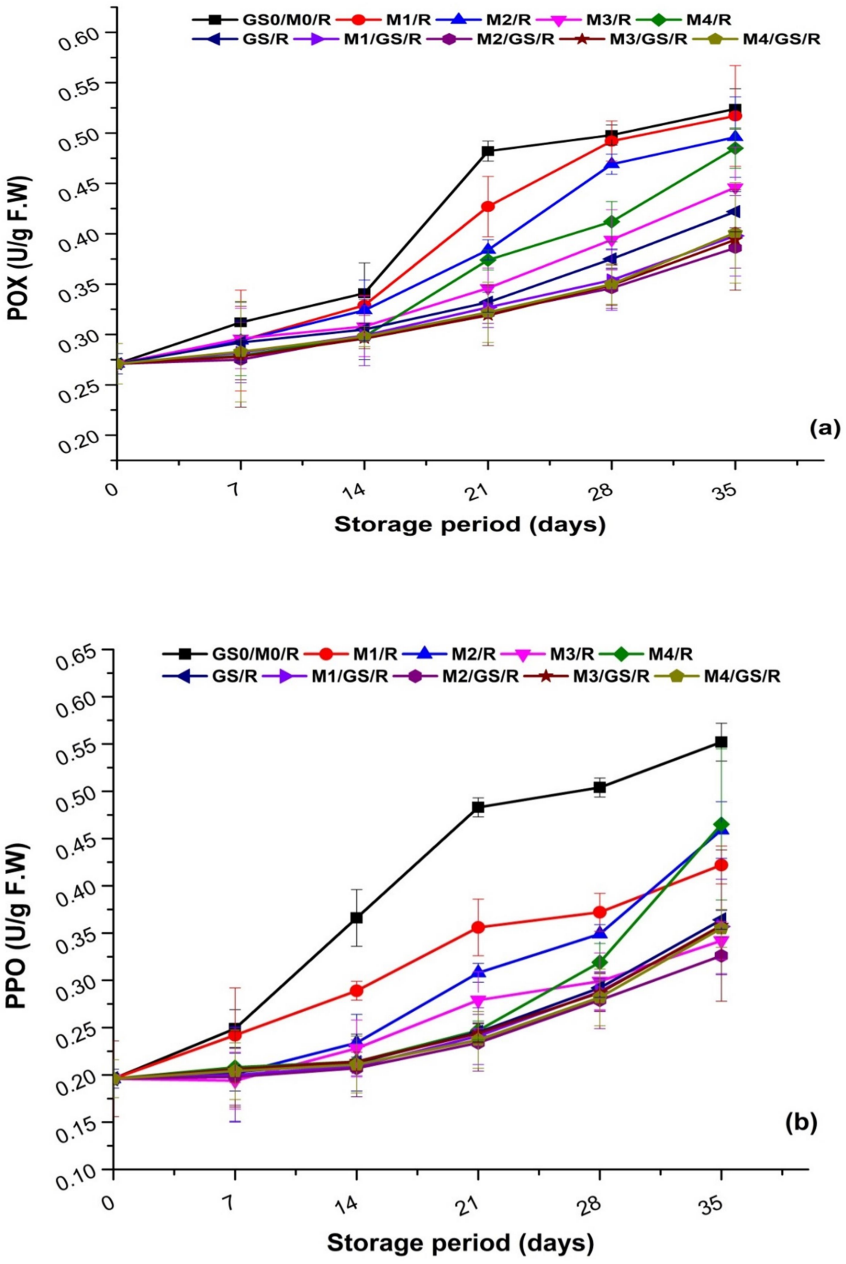

Figure 3. Effect of gamma irradiation and MeJ on enzyme-specific activities POX (a) and PPO (b) of the apricot cultivar (CITH-1) under refrigeration.

[DOI: 10.22034/JAST.26.5.1127]

Table 5. Effect of gamma irradiation and MeJ on flesh firmness (N) of the apricot cultivar (CITH-1) under refrigeration.[a]

	Storage period (Days)					
Treatments[b]	0	7	14	21	28	35
(GS0/M0/R)	4.88 ± 0.02^{eA}	4.23 ± 0.02^{dA}	4.00 ± 0.02^{cA}	3.85 ± 0.02^{bA}	3.65 ± 0.02^{bA}	3.32 ± 0.02^{aA}
(M1/R)	4.88 ± 0.02^{dA}	4.43 ± 0.02^{cC}	4.17 ± 0.02^{bB}	4.03 ± 0.02^{bB}	3.86 ± 0.02^{aB}	3.69 ± 0.02^{aB}
(M2/R)	4.88 ± 0.02^{dA}	4.49 ± 0.02^{cC}	4.26 ± 0.02^{bC}	4.19 ± 0.02^{bC}	4.08 ± 0.02^{aC}	4.00 ± 0.02^{aE}
(M3/R)	4.87 ± 0.02^{eA}	4.33 ± 0.02^{dB}	4.19 ± 0.02^{cB}	4.08 ± 0.02^{cB}	3.93 ± 0.02^{bB}	3.77 ± 0.02^{aB}
(M4/R)	4.88 ± 0.02^{eA}	4.42 ± 0.02^{dC}	4.29 ± 0.02^{cC}	4.15 ± 0.02^{bC}	4.07 ± 0.02^{bC}	3.81 ± 0.02^{aC}
(GS/R)	4.87 ± 0.02^{eA}	4.50 ± 0.02^{dD}	4.28 ± 0.02^{cC}	4.12 ± 0.02^{bC}	4.02 ± 0.02^{bC}	3.85 ± 0.02^{aC}
(M1/GS/R)	4.88 ± 0.02^{eA}	4.66 ± 0.02^{dE}	4.41 ± 0.02^{cD}	4.29 ± 0.02^{bE}	4.16 ± 0.02^{bD}	3.97 ± 0.02^{aD}
(M2/GS/R)	4.88 ± 0.02^{eA}	4.69 ± 0.02^{dE}	4.54 ± 0.02^{dE}	4.35 ± 0.02^{cE}	4.20 ± 0.02^{bE}	4.07 ± 0.02^{aE}
(M3/GS/R)	4.87 ± 0.02^{eA}	4.53 ± 0.02^{dD}	4.37 ± 0.02^{cD}	4.25 ± 0.02^{bD}	4.15 ± 0.02^{bD}	3.94 ± 0.02^{aD}
(M4/GS/R)	4.88 ± 0.02^{eA}	4.57 ± 0.02^{dD}	4.31 ± 0.02^{cD}	4.17 ± 0.02^{bD}	4.11 ± 0.02^{bD}	3.99 ± 0.02^{aD}

[a] (A-E and a-e): Means with different letters in the columns (A-E) and rows (a-e) and are significantly different ($P< 0.05$). [b] **GS0**: 0 kGy dose, **GS**: 0.5 kGy, **M** without MeJ, **M1**: 0.1 mmol L^{-1} treated, **M2**: 0.2 mmol L^{-1} treated; **M3**: 0.3 mmol L^{-1} treated; **M4**: 0.4 mmol L^{-1} treated; **R**: Refrigerated.

fruits that were only gamma irradiated were also effective in preserving the firmness of the fruits. When MeJ and gamma irradiation were used together, the fruit remained firmer than when either treatment was used alone. The results were in line with the study of gamma irradiation on fresh apricots carried out by Raja *et al.* (2023b). The present study demonstrated that dipping apricots in MeJ (0.2 mmol L^{-1}) and gamma irradiation dosage (0.5 kGy) followed by refrigerated storage can be used to improve their quality and extend their shelf life up to 35 days.

Decay Percentage

The synergistic effect of gamma irradiation and methyl jasmonate application also has an impact on the decay percentage of fresh apricots. The decay percentage of untreated refrigerated apricots was significantly higher ($P< 0.05$) than that of treated apricots, as seen in Figure 4. The highest decay percentage was shown in GS0/M0/R after 35 days of storage. Treatment M2/GS/R was more effective than the other concentrations in reducing decay. This could be due to the thin film that MeJ at 0.2 mmol L^{-1} concentration forms on the apricot surface, acting as a protective barrier against mold infection and reducing decay incidence during storage. The free radicals produced during the process of gamma irradiation directly damage the DNA of the microbe and indirectly cause the oxidation of proteins and lipids, which eventually results in the leakage of electrolytes from the cell and thereby damages their membranes (Reddy *et al.,* 2018). Furthermore, gamma-irradiated fruits dipped in MeJ (0.2 mmol L^{-1}) had a lower decay percentage. Similar results in terms of decay percentage were reported in Citrus unshiu (Jeong *et al.,* 2016) and strawberries (Maraei and Elsawy, 2017; Geransayeh *et al.,* 2015) when exposed to gamma irradiation.

Weight Loss (%)

All apricot fruits, whether treated or untreated, experienced weight loss during storage, as shown in Figure 5. Gamma-irradiated and MeJ-dipped apricots had significantly ($P< 0.05$) lower weight loss

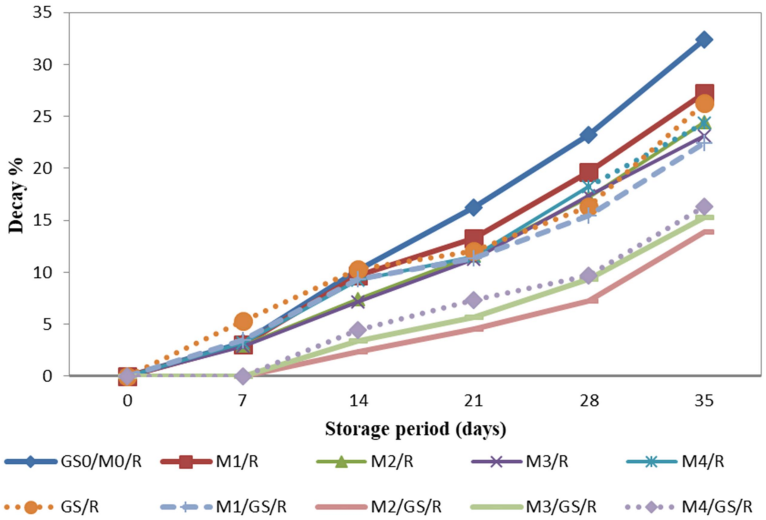

Figure 4. Effect of gamma irradiation and MeJ on decay percentage of the apricot cultivar (CITH-1) under refrigeration.

[DOI: 10.22034/JAST.26.5.1127]

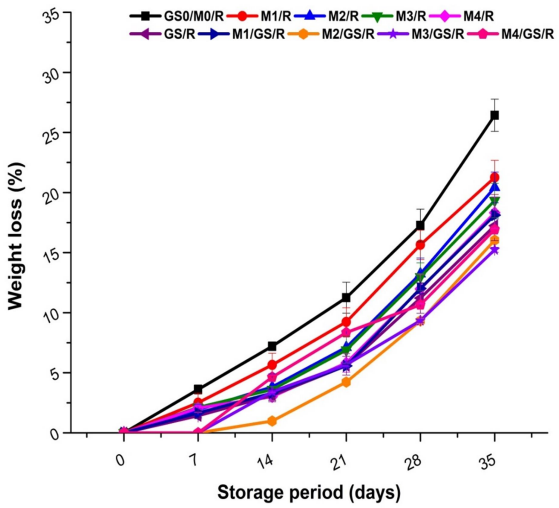

Figure 5. Effect of gamma irradiation and MeJ on weight loss of apricot cultivar (CITH-1) under refrigeration.

than MeJ-treated alone apricots. There were also significant variations in weight loss among different concentrations of MeJ. Apricots with 0.2 mmol L^{-1} MeJ treatment, previously gamma irradiated, showed the lowest weight loss (%) after 35 days of storage. This might be due to the anti-senescent activity and retention of cellular integrity by Methyl Jasmonate and gamma irradiation. Furthermore, the highest weight loss was observed in GS0/M0/R, followed by M1/R, M2/R. The results are comparable to the research done by Raja *et al.* (2023b) while evaluating the effect of gamma irradiation on different cultivars of apricot developed at CITH, Rangreth, India.

CONCLUSIONS

This study provides strong confirmation for the remarkable synergistic effect of methyl jasmonate (MeJ) treatment in combination with gamma irradiation under refrigeration storage, illustrating its profound benefits in improving texture, reducing weight loss and, subsequently, extending the shelf life of fresh apricots. The research results provided shed light on an innovative and new approach to fruit preservation, providing practical options to reduce post-harvest losses and enhance overall apricot fruit quality. By subjecting the apricots to the combined treatment of MeJ (0.2 mmol L^{-1}) and gamma irradiation (0.5 kGy), a remarkable improvement in texture was observed. The synergistic action of these treatments also exhibited a pronounced effect on reducing weight loss during storage, minimizing the detrimental impact of moisture loss, and maintaining the fruit's visual appeal. Furthermore, the results of this study demonstrated that the synergistic effect of MeJ and gamma irradiation exerted a significant influence on the extension of apricot shelf life. This intervention effectively delayed the onset of fruit softening and prevented the occurrence of post-harvest diseases, ensuring the prolonged market availability of fresh apricots and reducing economic losses for growers and suppliers.

Overall, this research highlights the immense potential of combining MeJ treatment with gamma irradiation under refrigeration storage as a highly effective

[DOI: 10.22034/JAST.26.5.1127]

strategy for enhancing the texture, reducing weight loss, and increasing the shelf life of fresh apricots. By harnessing the synergistic benefits of these treatments, the fruit industry can embrace sustainable post-harvest practices, improve fruit quality, and meet the growing consumer demand for high-quality, longer-lasting apricot products. These findings pave the way for further exploration and adoption of innovative preservation techniques to revolutionize fruit storage and contribute to a more sustainable food supply chain.

ACKNOWLEDGEMENTS

The authors are thankful to the Bhaba Atomic Research Centre, Zakura, GOI for its technical support.

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اثرهم‌افزایی پرتودهی گاما و متیل جاسمونات بر کیفیت پس از برداشت زردآلو تازه (*Prunus armeniaca* cv. 'CITH-1') نگهداری شده در یخچال

ق. جیلانی راجا، و ف. ا. مسعودی

چکیده

زردآلو میوه‌ای بسیار فاسد شدنی است و اغلب منجر به تلفات قابل توجه پس از برداشت می شود که بر بازارپسندی و دوام تجاری آن تأثیر می گذارد. این پژوهش برای بررسی اثر هم‌افزایی کاربرد پرتودهی گاما و متیل جاسمونات (MeJ) بر کیفیت، فعالیت‌های خاص آنزیمی، و ماندگاری پس از برداشت زردآلو (*Prunus armeniaca* cv. 'CITH-1') انجام شد. (به این منظور) زردآلوها با دوز ۰.۵ kGy پرتودهی شدند و در غلظت‌های مختلف MeJ غوطه‌ور شد و سپس به مدت ۳۵ روز در یخچال (۱ ± ۱ درجه سانتی‌گراد، ونم‌نسبی ۸۵-۸۰ درصد) قرار گرفت. زردآلوهای تیمار شده با دوز ۰.۵ kGy و ۰.۱ میلی مول در لیتر متیل جاسمونات و به دنبال آن سرد کردن، به گونه‌ای معنادار ($p<0.05$) فعالیت آنتی اکسیدانی را در سطوح بالاتری حفظ کرد. کیفیت زردآلو به طور موثر حفظ شد و عمر ماندگاری آنها از طریق تیمارهای ۰.۵ kGy دوز تابش و ۰.۲ میلی مول در لیتر متیل جاسمونات افزایش یافت که به طور قابل توجهی ($P< 0.05$) مقدار پوسیدگی، کاهش وزن، و فعالیت آنزیمی را کاهش داد و در همان‌حال سفتی میوه را حفظ کرد. نتایج این پژوهش نشان می‌دهد که استفاده از تیمار متیل جاسمونات پس از برداشت در غلظت‌های ۰.۱ و ۰.۲ میلی مول درلیتر در ترکیب با دوز تابش ۰.۵ kGy روشی مناسب برای حفظ کیفیت و ترکیبات زیست فعال زردآلو تازه در طول نگهداری در یخچال طی مدت زمان طولانی ۳۵ روز است.

[DOI: 10.22034/JAST.26.5.1127]