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Effect of phytosanitary radiation treatments on storage quality and microbiological safety of fresh table apricots (*Prunus armeniaca* L) *cv.* CITH-2

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Abstract

Matured table apricots harvested at commercial maturity were irradiated in the dose range of 0.25-1.0 kGy and stored under refrigerated (3±1 ^{0}C, RH 85 %) conditions. The fruits were evaluated at intervals of 5 days for various physico-chemical parameters. Studies revealed that phytosanitary irradiation treatment maintained the storage quality of table apricots under refrigerated conditions. Positive correlations (r = 0.89) existed between irradiation treatment and firmness retention, whereas an inverse correlation (r = –0.86) existed between radiation and water-soluble pectin. Color scores revealed that L, a and b values increased by 13.1%, 68.9% and 21.5% in un-irradiated apricots compared to 6.1, 44.9 and 14.1% in samples irradiated at 1.0 kGy, after 30 days of storage. During storage, ascorbic acid decreased by 86.8% in control compared to 56.2% in 1.0 kGy treated apricots. Phytosanitary radiation treatment at 1.0 kGy caused a significant ($P \leq 0.05$) increase (7.5%) in total phenolics, besides minimizing subsequent degradation of phenols during storage. Microbial analysis indicated that in samples irradiated at 0.75 kGy and 1.0 kGy, no microbial load was detected up to 10 and 20 days of storage and resulted in about 1.0 log reduction in microbial load after 30 days of storage.

Key words: Table apricots, phytosanitary treatment, gamma irradiation, color score, physicochemical quality, water-soluble pectin, microbial load

Introduction

Apricot (*Prunus armeniaca* L.) is a climacteric fruit and occupies an important place in human nutrition as well as in the socioeconomic life of the people involved in its trade. Fresh apricot is considered as one of the most delicious temperate fruit and is a rich source of vitamin A, vitamin C, iron, potassium, calcium, essential trace minerals and fibre in addition to its highest calorific value. It also contains a good amount of phytochemicals such as carotenoids, flavonoids, lycopene and other antioxidant compounds, which contribute substantially to their antioxidant potential (Wani *et al.*, 2018; Vinha *et al.*, 2013; Sartaj *et al.*, 2011). Besides the nutritional value, apricot fruit has significant pharmacological activities. Several reports indicate that fresh apricots have laxative, antimicrobial, antimutagenic, cardio-protective, hepatoprotective and anti-inflammatory properties (Nazir *et al.*, 2013; Erdogan-Orhan and Kartal, 2011; Parlakpinar *et al.*, 2009; Ozturk *et al.*, 2009). The major apricot-producing countries of the world are Turkey, Iran, Pakistan, Uzbekistan and Italy (Hegedus *et al.*, 2010; Zujko and Witkowska, 2011). In India, apricots are grown commercially in the hills of Himachal Pradesh, Jammu and Kashmir, Utter Pradesh and to a limited extent in the north-eastern hills (Singh *et al.*, 2016). Fresh apricot, owing to its high respiratory rate and ethylene emission, is highly perishable and has a short shelf-life of 4-5 days under ambient conditions and about 2 weeks under low temperature and high relative humidity (85-90%) conditions (Wu *et al.*, 2015). Rapid postharvest softening associated with concomitant fungal growth is one of the major problems of fresh apricot, which constraints their availability and limits their marketing for use as table fruit besides posing potential health risks (Rubio and Infante, 2010). Fresh apricots are treated with chemical fumigants such as methyl bromide to facilitate interstate transport and to mitigate microbial hazards and insect pests to allow export of produce. However; due to adverse health effects, the commercial use of fumigants is being phased out. Further fumigation results in the breaking of the cold chain as it is applied at ambient temperature, which negatively impacts the quality and shelf-life of the produce (Tong *et al.*, 2015).

Irradiation is a novel, non-thermal, physical method of food preservation and has become an effective means of achieving microbial decontamination and insect disinfestation of various food and agriculture-based commodities (Tong *et al.*, 2015; Kim *et al.*, 2014). Irradiation at low doses is a promising phytosanitary treatment and has gained worldwide acceptance for treating various fresh fruits and vegetables (Kume and Todoriki, 2013). The literature available till date reveals that medium dose irradiation (> 1 kGy) was mostly studied for quality retention and enhancing the microbiological safety of dried apricots during storage (Rather *et al.*, 2019; Wei *et al.*, 2014; Hussain *et al.*, 2011). Few studies on fresh apricot irradiation are also reported in the literature and the response of the fresh apricots to irradiation was shown to be cultivar-dependent (Arvanitoyannis *et al.*, 2009).

In order to extend the availability and satisfy the overwhelming consumer demand for fresh table apricots as a health-beneficial food and an active ingredient for use in food and pharmaceutical formulations, it is highly imperative to maintain their quality and extend shelf-life. Further, to meet the strong desire of consumers to obviate and reduce the use of chemical fumigants applied to fresh apricots for extending their storage and controlling microbial

infestation, the use of an effective physical decontamination treatment is a crucial requirement. High-quality decontamination treatment should be effective without reducing the nutritional and sensory quality attributes of treated commodities. To our knowledge, no phytosanitary irradiation study has been conducted to date in the case of fresh table apricots. Therefore, the present study was undertaken with the objective of studying the effect of low-dose irradiation for use as phytosanitary treatment in fresh table apricots for enhancing their storage life and ensuring microbiological safety under refrigerated conditions.

Materials and methods

Raw material preparation: Fresh apricots (cv. CITH-2) of uniform shape and size, firm texture, and proper maturity were procured from the apricot orchards, Central Institute of Temperate Horticulture (CITH), Srinagar, Kashmir (India). The selection of fruit was done from the same orchard. Fruit was pre-cooled by keeping at 2°C for 24 h in a cold storage chamber in order to remove field heat. The pre-cooled fruit was manually graded in order to have uniformity in size and any blemished or diseased fruits present were discarded, followed by packing in cardboard boxes of size 0.5 × 0.3 × 0.3 m^3 each containing 30 fruits. Three boxes were taken for each treatment per sampling period.

Gamma irradiation: The pre-cooled and packaged fruit was subjected to gamma irradiation in the range of 0.25-1.0 kGy using PANBIT irradiator having Co-60 as the gamma-ray source (BARC, Zakura, Jammu and Kashmir). The samples were irradiated at a dose rate of 285 Gy/h as determined by Ceric-Cereous dosimetry. Dosimeters were placed in each box to ensure uniformity of the dose delivered. After irradiation, the apricot samples were kept under refrigeration (3±1 ◦C, RH 85 %) for 30 days. The samples were drawn at 0, 5, 10, 15, 20, 25 and 30 days of storage for physico-chemical and microbial evaluation. Triplicate samples were used for each irradiation treatment at every sampling period. Samples that were not irradiated served as control.

Fruit quality analysis: Objective colour on the surface of un-irradiated (control) and irradiated fresh table apricot was determined using a Hunter Colorimeter (Hunter Assoc, Reston, VA, USA; Mcguire, 1992). Colour measurement was displayed in L (lightness), a (redness/greenness) and b (yellowness/blueness) values (Li-Zhen *et al.*, 2019). Firmness was determined with a hand penetrometer (Model 'FT-327' EFFEGI, Italy) provided with a round plunger (6 mm diameter) on two sides of each whole fruit. To avoid interference of the skin, fruits were peeled at positions where firmness was to be measured. Fruits were brought to room temperature 1h prior to firmness measurement. Total soluble solids (TSS) were determined at 20 ºC using ABEE refractometer model 'RSR-2' (Rajdhani Scientifics, India). Titratable acidity was determined as per the method of Ranganna (1986). The acidity was expressed as % citric acid. Contents of water-soluble pectin were determined by the previously described method (Basanta *et al.*, 2013). Samples of the WSP pectins were assayed for their uronic acid (UA) content by the carbazole-sulfuric acid method using galacturonic acid (GalA) as standard (Liu *et al.*, 2009), and results were expressed as mg GalA/100 g FW (fresh weight). Total ascorbic acid estimation was done as per the method of Pasternak *et al.* (2005) with slight modifications using HPLC (JASCO, Japan). An external standard of L-ascorbic acid and dehydroascorbic acid in 3% metaphosphoric acid was used for the identification and quantification of ascorbic and dehydroascorbic acid. Total ascorbic acid was calculated as the sum of the ascorbic and dehydroascorbic acid. Total phenols were determined according to the Folin-Ciocalteu method as described by Waterhouse (2002) with minor modifications. Total phenols were determined with the use of an external standard curve and expressed as mg gallic acid equivalents (GAE) per 100 g. Total carotenoids as beta carotene equivalents were determined using the method of Kimura and Rodriguez-Amaya (2004). Microbial load as yeast and mold count (YMC) was determined by the serial dilution method using the pour plate technique (Aneja, 1996). A group of five to ten trained panelists was involved in assessing the overall acceptability (OAA) of control and irradiated apricots. OAA based on appearance, texture, taste and odor was evaluated using 4 point scale where 4 = excellent, 3 = good, 2 = fair and 1 = poor. The limit of acceptability was kept as 2.5 and the samples whose acceptability values were below 2.5 corresponding to a particular storage period were rated unacceptable.

Statistical analysis: Statistical analysis of the data was performed using a completely randomized design experiment (Cochran & Cox, 1992). For each measurement, three replicates of samples were tested per treatment per sampling period and mean ± standard deviation values were reported.

Results and discussion

Colour analysis: Color is one of the main attributes that characterizes the freshness of most fruits (Rico *et al.*, 2007). The color scores of fresh table apricots are shown in Table 1. All the color parameters of irradiated and un-irradiated samples were marginally different just after treatment. However, during storage, color parameters of "L", "a" and "b" showed an increasing trend, which was significantly ($P \leq 0.05$) lower in irradiated samples, particularly those irradiated at 1.0 kGy. In unirradiated samples, the increase in "L" and "b" values was non-significant up to 5 days of storage, while the increase in "a" value was significant throughout the storage. In samples irradiated at 1.0 kGy, the increase in "L" value was non-significant up to 15 days of storage, while as "a"and "b" values increased marginally up to 10 days of storage. After the end of 30 days of storage, "L", "a" and "b" values increased by 13.1, 68.9 and 21.5 percent in un-irradiated apricots compared to 6.1, 44.9 and 14.1 percent in samples irradiated at 1.0 kGy. The hue value of the samples decreased during storage, and the decrease was significantly higher in un-irradiated apricots compared to irradiated (1.0 kGy) apricots. The decrease in hue value indicated that colour of the apricots changed faster from yellow-green to orange-red in unirradiated samples. The percentage decrease in hue value in un-irradiated apricots after 30 days of storage was 13.0% compared to 9.4% in 1.0 kGy treated apricots. This decrease in hue value during storage has been attributed to carotenoid accumulation (Ruiz *et al.*, 2005; Kovacs *et al.*, 2008). Chroma, which represents saturation of colour was significantly higher in control samples compared to irradiated samples. Further enhancement in color saturation was non-significant up to 5 days in control and 0.25-0.75 kGy samples compared to 10 days in 1.0 kGy irradiated fruits. The increase in chroma after the end of 30 days of storage was 32.9% in control compared to 21.0% in 1.0 kGy treated apricots. The changes in the colour values of apricot fruits observed in the present study were consistent with the earlier reports (Campbell *et al.*, 2013). Transition in color parameters (increase in redness and loss of greenness) is due to the accumulation of carotenoids during

Table 1. Effect of phytosanitary irradiation doses on colour parameters of table apricots during refrigerated storage

Parameter	Dose	Storage period (days)							
	(kGy)	0	5	10	15	20	25	30	LSD
L	0	54.2±1.4^{a,1}	54.9±1.2^{a,1}	55.7±1.4^{b,2}	57.5±1.5^{b,3}	58.6±1.4^{c,3}	59.7±1.5^{c,4}	61.3±1.5c5	1.1
	0.25	54.4±1.3^{a,1}	54.8±1.2^{a,1}	55.5±1.4b^{,1}	57.3±1.4^{b,2}	58.4±1.4c^{,2}	59.4±1.3^{c,3}	60.8±1.5^{c,4}	1.3
	0.50	54.4±1.2^{a,1}	54.8±1.3^{a,1}	55.2±1.2^{a,1}	56.7±1.5^{b,2}	57.2±1.2^{b,2}	58.1±1.3^{b,3}	59.2±1.2^{b,3}	1.1
	0.75	54.1±1.2^{a,1}	54.5±1.3^{a,}1	54.9±1.1^{a,1}	55.7±1.3^{a,2}	56.6±1.2^{a,2}	57.2±1.1^{a,3}	58.5±1.3^{b,3}	1.3
	1.0	54.1±1.3^{a,1}	54.5±1.4^{a,1}	54.9±1.1^{a,1}	55.5±1.3^{a,1}	56.2±1.1^{a,2}	56.8±1.1^{a,2}	57.4±1.1^{a,2}	1.4
	LSD	0.5	0.6	0.5	0.8	0.7	0.6	0.7	
a	0	20.6±1.1^{a,1}	22.4±1.2b^{,2}	24.7±1.3^{b,}3	26.4±1.3^{c,4}	29.6±1.3^{d,5}	32.4±1.5^{d,6}	34.8±1.4c^{,7}	1.2
	0 25	20.4±1.1^{a,1}	22.2±1.2b^{,2}	24.4±1.3^{b,}3	25.9±1.2^{c,4}	29.1±1.3^{c,5}	31.7±1.3c^{6}	34.5±1.4c^{,7}	1.3
	0.50	20.4±1.2^{a,1}	21.8±1.3^{a,}1	23.2±1.2^{a,2}	24.4±1.3^{b,2}	28.4±1.2^{c,3}	30.5±1.3^{c,4}	33.2±1.3^{c,5}	1.5
	0.75	20.4±1.2^{a,1}	21.6±1.3^{a,1}	22.9±1.1^{a,2}	23.8±1.3^{a,2}	26.6±1.2^{b,3}	28.7±1.2^{b,4}	31.4±1.3^{b,5}	1.6
	1.0	20.5±1.1^{a,1}	21.2±1.3^{a,1}	22.2±1.1^{a,1}	23.2±1.2^{a,2}	25.1±1.1^{a,3}	27.1±1.2^{a,4}	29.7±1.2^{a,5}	1.7
	LSD	0.5	0.8	1.1	1.0	1.1	1.3	1.0	
b	0	40.4±1.3^{a,1}	41.2±1.3^{a,1}	42.1±1.3^{b,2}	44.7±1.4c^{,3}	46.5±1.4^{c,4}	47.8±1.5^{c,4}	49.1±1.5^{c,5}	1.3
	0.25	40.2±1.2^{a,1}	40.9±1.3^{a,1}	41.7±1.3^{a,2}	44.2±1.4^{b,3}	46.1±1.4^{c,4}	47.4±1.3^{c,4}	48.7±1.5^{c,5}	1.3
	0.50	40.6±1.2^{a,1}	41.1±1.2^{a,1}	41.8±1.2^{a,2}	43.4±1.2^{b,3}	44.8±1.3^{b,4}	45.6±1.3^{b,4}	47.2±1.4^{b,5}	1.0
	0.75	39.8±1.3^{a,1}	40.6±1.2^{a,1}	41.1±1.2^{a,1}	42.7±1.3^{a,2}	43.6±1.3^{a,2}	44.8±1.2^{a,3}	46.5±1.3^{b,4}	1.5
	1.0	39.8±1.3^{a,1}	40.6±1.3^{a,1}	41.1±1.2^{a,1}	42.1±1.2^{a,2}	43.1±1.2^{a,2}	44.1±1.2^{a,3}	45.4±1.3^{a,3}	1.7
	LSD	0.9	0.8	0.7	0.8	0.9	0.7	0.7	
h	0	62.9±1.4^{a,4}	61.5±1.3^{a,4}	59.6±1.3^{a,3}	59.5±1.3^{a,3}	57.5±1.2^{a,2}	55.9±1.2^{a,1}	54.7±1.2^{a,1}	1.6
	0.25	63.1±1.3^{a,5}	61.5±1.2^{a,5}	59.7±1.2^{a,4}	59.6±1.2^{a,3}	57.7±1.2^{a,2}	56.2±1.3^{a,1}	54.7±1.2^{a,1}	1.6
	0.50	63.3±1.2^{a,4}	62.0±1.3^{a,4}	60.9±1.2^{b,3}	60.6±1.2^{b,3}	57.6±1.2^{a,2}	56.2±1.3^{a,1}	54.9±1.2^{a,1}	1.3
	0.75	62.9±1.2^{a,5}	62.0±1.2^{a,5}	61.3±1.1^{b,4}	60.9±1.1^{b,4}	58.6±1.3^{b,3}	57.3±1.3^{b,2}	55.9±1.3b^{,1}	1.0
	1.0	62.7±1.3^{a,5}	62.4±1.2^{a,5}	61.6±1.1^{b,4}	61.1±1.2^{b,4}	59.8±1.3^{c,3}	58.4±1.2^{c,2}	56.8±1.3c^{,1}	1.1
	LSD	0.8	0.9	0.75	0.71	0.63	0.6	0.6	
c	0	45.3±1.2^{a,1}	46.9±1.3b^{,1}	48.8±1.4^{b,2}	51.9±1.5c^{3}	55.1±1.5^{c,4}	57.7±1.5^{c,5}	60.2±1.5^{d,6}	1.6
	0.25	45.1±1.3^{a,1}	46.5±1.2^{a,1}	48.3±1.4^{b,2}	51.2±1.4c^{3}	54.5±1.4c^{,4}	57.0±1.4^{c,5}	59.7±1.5^{d,6}	1.7
	0.50	45.5±1.2^{a,1}	46.5±1.2^{a,1}	47.8±1.3^{a,2}	49.8±1.5^{b,3}	53.0±1.4^{b,4}	54.9±1.3^{b,5}	57.7±1.2^{c,6}	1.7
	0.75	44.7±1.3^{a,1}	45.9±1.3^{a,1}	47.1±1.2^{a,2}	48.9±1.3^{a,2}	51.1±1.3^{a,3}	53.2±1.3^{a,4}	56.1±1.3^{b,5}	1.9
	1.0	44.8±1.2^{a,1}	45.8±1.3^{a,1}	46.7±1.2^{a,1}	48.1±1.3^{a,2}	49.9±1.3^{a,2}	51.8±1.3^{a3}	54.2±1.3^{a,4}	1.9
	LSD	0.9	0.9	1.1	1.2	1.3	1.5	1.2	

Values are mean ± SD (n = 3); LSD = least significant difference; L = lightness; a = redness/greenness. b = yellowness/blueness; h = hue; c = chroma. Values within treatments in a column with different superscript lowercase letters (a-d) differ significantly ($P < 0.05$). Values within storage periods in a row with different superscript numerical (1-6) differ significantly ($P < 0.05$).

ripening and storage (Ayour *et al.*, 2016). Changes in "a" and "b" value have been related to chlorophyll degradation (Kasim and Kasim, 2015) where as increased chroma values are attributed to enhanced ripening, indicating that the higher degree of ripeness contributed to the more intense orange-red color. The ability of the radiation treatment (1.0kGy) to maintain the higher hue value and prevent the increase in b value and chroma is attributed to the inhibitory effect of the treatment against carotenoid accumulation and chlorophyll degradation (Jang and Moon, 2011).

Firmness and water soluble pectin (WSP): The effect of gamma irradiation treatment on firmness and WSP of table apricots is shown in Fig. 1 and 2, respectively. Positive correlations (r = 0.89) existed between the irradiation doses and firmness. Further, a non-significant difference existed in firmness between un-irradiated and irradiated samples just after irradiation (0 days of storage). This trend in firmness among treatments was observed up to 5 days of storage. Beyond 5 days, firmness decreased significantly and the decrease was higher in control and 0.25 kGy treated apricots compared to other irradiated samples. After 20 days of storage, the firmness of control and 0.25 kGy apricots was 1.3 and 1.7 kg, respectively, compared to 3.1-6.1 kg in 0.5-1.0 kGy irradiated samples. The firmness of control, 0.25 kGy and 0.5 kGy irradiated samples was below the detection limit after 25 and 30 days of storage, respectively, which is related to excessive softening of the fruit due to enzyme-mediated solubilization of pectic substances as a result of ripening. It is also evident from Fig. 1 that, among treatments, significantly higher retention in firmness was recorded in 1.0 kGy irradiated samples for

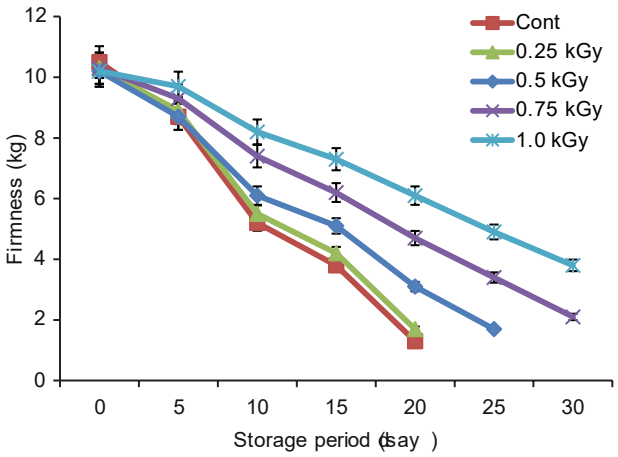

Fig. 1. Effect of phytosanitary radiation treatments on firmness retention of table apricots during refrigerated storage

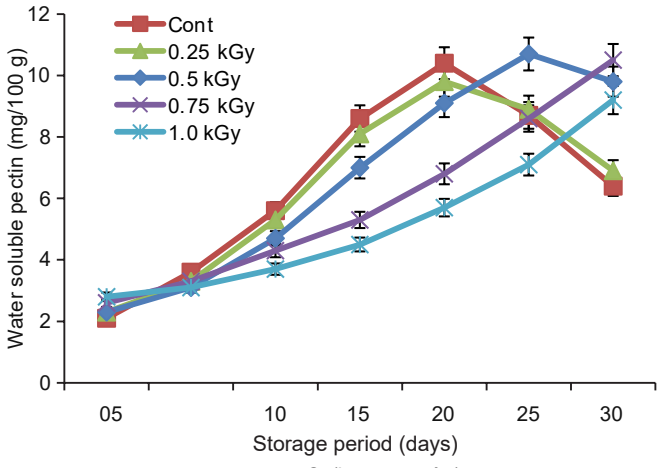

Fig. 2. Effect of phytosanitary radiation treatments on water soluble pectin of table apricots during refrigerated storage

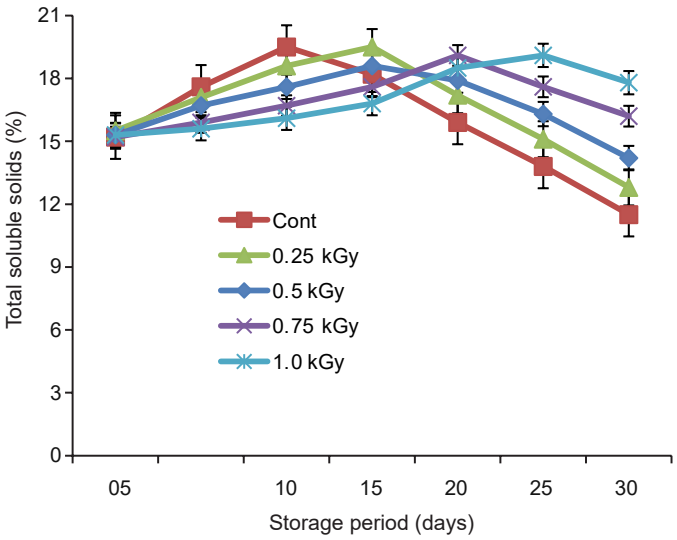

Fig. 3. Effect of phytosanitary radiation treatments on TSS of table apricots during refrigerated storage

all storage periods. The decrease of firmness in un-irradiated apricots after 20 days of storage was 87.6%, whereas in 1.0 kGy samples, the decrease in firmness after 30 days of storage was 62.7%. A decrease in firmness is associated with the conversion of insoluble pectic fractions to soluble forms during ripening. Earlier reports indicated that softening is caused by the degradation and solubilization of cell wall polysaccharides, which consequently decreases cell wall strength and intercellular adhesion (Ella Missang *et al.*, 2012; Fan *et al.,* 2017). Since irradiation delays the ripening and senescence of climacteric fruits (Kader, 1986), the retention of firmness in irradiated samples is attributed to the reduction in the enzymatic activity due to ripening delay as a result of radiation treatment.

The effect of phytosanitary irradiation doses on water-soluble pectin of table apricots is shown in Fig. 2. Data analysis revealed no difference in WSP among treatments, including control just after treatment (0 days of storage). During storage, WSP increased in all the treatments, including control, but the increase was marginal up to 5 days in the case of control and 0.25-0.75 kGy treated samples and 10 days in apricot samples irradiated at 1.0 kGy. After 10 days of storage, the increase in WSP was significant ($P \leq 0.05$) in all the treatments. In control and 0.25 kGy treated samples, WSP reached its maximum value at 20 days of storage, followed by a decrease. In samples irradiated at 0.5 kGy, WSP increased up to 25 days of storage and then decreased.

On the other hand, WSP of apricots irradiated at 0.75 kGy and 1.0 kGy continued to increase throughout the storage. A comparison of the data showed that after 20 days, the increase in WSP was 80.0% in un-irradiated apricots compared to 69.5% after 30 days in 1.0 kGy irradiated apricots. On the basis of the data presented in Fig. 2, it can be inferred that control, 0.25 kGy and 0.5 kGy treated apricots were fully ripe with mealy texture after 20 and 25 days of storage, while as apricots irradiated at 1.0 kGy were still firm even after 30 days of storage. Results of the present study showed an inverse correlation (r = –0.86) between radiation treatment and WSP, thus confirming the higher retention of firmness in apricot samples irradiated at 1.0 kGy.

Total soluble solids (TSS) and titratable acidity: TSS of fresh table apricot fruit is shown in Fig. 3. Data analysis indicated that the TSS of control and irradiated fruits differed marginally at 0 days of storage. During storage, TSS increased in all the treatments, including the control; however, the increase was lower in samples irradiated at 1.0 kGy. Data analysis also revealed that in samples irradiated at 0.75 kGy and 1.0 kGy, the increase in TSS was non-significant up to 5 and 10 days of storage, respectively. In un-irradiated apricot samples, TSS increased up to 10 days, followed by a decrease, whereas in 0.25 kGy and 0.5 kGy apricots, TSS increased up to 15 days. Similarly, in fruits irradiated at 0.75 kGy and 1.0 kGy, TSS increased up to 20 and 25 days and then decreased. A comparison of the data indicated that in un-irradiated apricots, an increase in TSS up to 10 days of storage was 28.3% compared to 24.8% in 1.0 kGy treated apricots up to 25 days. At the end of 30 days of storage, control samples recorded significantly lower TSS (11.5 %) as compared to irradiated samples. Further, after 30 days of storage, in control apricots, a decrease in TSS from its maximum value at 10 days was of the order of 41.0% compared to 6.8 - 34.3 % in irradiated apricots. Among irradiated apricots, a lower decrease (6.8%) in TSS from its maximum value was observed in 1.0 kGy treated samples. The initial increase in TSS during storage is related to the breakdown of polysaccharides into lower sugars and the subsequent decrease is due to the oxidative breakdown of sugars during respiration. Since irradiation delays respiration and senescence, it results in higher retention of TSS during storage (Chetan *et al.*, 2006).

The effect of phytosanitary radiation treatment on the acid content of apricots is shown in Table 2. No significant difference existed in acid content among treatments, including control at 0 days of storage. However, as the storage progressed, the acid content decreased marginally in dose-dependent manner. After 25 days of storage, acid contents were significantly lower in control and 0.25 kGy irradiated apricots compared to other samples. This trend in acidity decrease continued up to 30 days of storage. Among irradiated samples, 1.0 kGy treated apricots retained higher acid values throughout the whole storage period. After 30 days of storage, the percentage decrease in acid content was 40.3% for un-irradiated apricots compared to 22.5% in 1.0 kGy irradiated apricots. Retention of high acid values in samples irradiated at a dose of 1.0 kGy is attributed to radiation-induced delay in ripening and respiration, which are otherwise used as respiratory substrates for the synthesis of other compounds (Wani *et al.*, 2008).

Table 2. Effect of phytosanitary irradiation doses on quality parameters of table apricots during refrigerated storage

Parameter	Dose	Storage period (days)							
	(kGy)	0	5	10	15	20	25	30	LSD
	0	0.87±0.03^{a,4}	0.81±0.02^{a,4}	0.77±0.02^{a,3}	0.72±0.01^{a,3}	0.62±0.01^{a,2}	0.60±0.01^{a,2}	0.52±0.01^{a,1}	0.06
TA	0.25	0.85±0.02^{a,4}	0.82±0.02^{a,4}	0.79±0.02^{a,3}	0.75±0.02^{a,3}	0.68±0.02^{b,2}	0.63±0.02^{a,2}	0.55±0.01^{a,1}	0.05
	0.50	0.85±0.02^{a,3}	0.82±0.02^{a,3}	0.80±0.04^{a,3}	0.77±0.03^{b,2}	0.72±0.03^{b,2}	0.67±0.02^{b,1}	0.61±0.02^{b,1}	0.06
	0.75	0.87±0.04^{a,3}	0.85±0.04^{a,3}	0.83±0.03^{b,3}	0.80±0.03^{b,2}	0.76±0.03^{c,2}	0.71±0.02^{b,1}	0.65±0.02^{b,1}	0.05
	1.0	0.89±0.03^{a,3}	0.89±0.02b3	0.87±0.04^{b,3}	0.84±0.04^{c,3}	0.80±0.02^{c,2}	0.75±0.03^{c,2}	0.69±0.03^{c,1}	0.05
	LSD	0.04	0.04	0.05	0.04	0.04	0.05	0.06	
	0	16.7±0.4^{a,6}	15.2±0.3^{a,6}	12.2i0.5^{a5,}	9.6±0.6^{a,4}	6.3±0.5^{a,3}	4.1±0.6^{a,2}	2.2±0.7^{a,1}	1.6
TAA	0.25	16.5±0.5^{a,6}	15.4±0.2^{a,6}	12.8i0.5^{a,5}	10.4±0.5^{a,4}	7.0±0.4^{a,3}	4.9±0.6^{a,2}	2.8±0.6^{a,1}	
	0.50	16.5±0.3^{a,6}	15.6±0.2^{a,6}	13.4±0.6^{b,5}	11.6±0.5^{b,4}	7.9±0.4^{b,3}	5.7±0.5^{b}2	3.7±0.6b^{,1}	1.5
	0.75	16.4±0.4^{a,5}	15.8±0.4^{a,5}	14.2±0.6^{b,4}	12.6±0.6^{c,4}	9.4±0.5^{c,3}	7.1±0.5^{c,2}	5.2±0.5c^{,1}	1.6
	1.0	16.2±0.3^{a,5}	15.8±0.3^{b,5}	15.0±0.4^{c,5}	13.6±0.5^{d,4}	11.3±0.6^{d,3}	9.1±0.6^{d}2	7.1±0.6d^{,1}	1.3
	LSD	0.6	0.8	0.7	0.8	1.1	1.0	1.0	
TP	0	39.8±1.4^{a,7}	35.4±1.3^{a,6}	31.2±1.5^{a,5}	27.6±1.2^{a,4}	21.4i1.5^{a3}	17.2i1.6^{a,2}	11.2i1.7^{a,1}	3.2
	0.25	40.1±1.5^{a,7}	36.2±1.2^{a,6}	32.8±1.5^{b,5}	29.3±1.3^{b,4}	23.7±1.4^{b,3}	19.7±1.6^{b,2}	13.2±1.5^{b,1}	3.2
	0.50	40.5±1.3^{a,6}	38.5±1.2^{b,6}	35.6±1.2^{c,5}	31.2±1.5^{c,4}	27.2±1.4^{c,3}	23.4±1.5c^{,2}	18.3±1.4c^{,1}	2.8
	0.75	41.2±1.4^{b,6}	40.2±1.4^{c,6}	37.7±1.2^{d,5}	34.2±1.6^{d,4}	30.5±1.5^{d,3}	26.7±1.5d^{,2}	21.4i1.5d^{,1}	2.2
	1.0	42.8±1.3^{c,4}	41.7±1.3^{d,4}	40.3±1.1^{e,4}	37.1±1.5^{e,3}	34.6±1.6^{e,3}	31.3±1.4e2	28.4i1.3e^{,1}	2.5
	LSD	0.7	1.0	1.1	1.3	1.4	1.5	1.5	
TC	0	3.4±0.5^{a,1}	4.7±0.6^{b,2}	5.8±0.7^{b,3}	6.8±0.6^{b,4}	7.6±0.5^{c,4}	8.5±0.7^{c,5}	9.2±0.7^{c,5}	0.8
	0.25	3.4±0.6^{a,1}	4.2±0.5^{b,1}	5.3±0.5^{b,2}	6.2±0.5^{b}2	7.1±0.5^{b,3}	7.9±0.6^{b}3	8.7±0.6^{b,4}	0.9
	0.50	3.2±0.4^{a,1}	3.8±0.5^{a,1}	4.8±0.5^{a,2}	5.7±0.5^{b}2	6.5±0.4^{b,3}	7.3±0.5^{b}3	8.1±0.6^{b,4}	0.9
	0.75	2.9±0.2^{a,1}	3.3±0.4^{a,1}	4.3±0.4^{a,2}	5.1±0.6^{a,2}	5.8±0.5^{a,3}	6.7±0.5^{a,3}	*7.4±0.5*^{a,4}	1.1
	1.0	2.7±0.3^{a,1}	3.0±0.3^{a,1}	3.7±0.4^{a,1}	4.4±0.5^{a,2}	5.1±0.5^{a,2}	5.8±0.6^{a,3}	6.6±0.6^{a,3}	1.1
	LSD	0.8	0.9	1.1	1.2	1.1	1.0	0.8	
YMC	0	3.8±0.5^{a,1}	4.2±0.6^{a,2}	4.4±0.7^{a,2}	4.6±0.6^{b}3	4.8±0.5^{b,3}	5.0±0.7^{c,4}	5.5±0.7^{d,5}	0.3
	0.25	3.7±0.6^{a,1}	4.0±0.5^{a,1}	4.3±0.5^{a,2}	4.5±0.5^{b}2	4.7±0.5^{b,3}	4.9±0.6^{c,3}	5.3±0.6^{c,4}	0.3
	0.50	3.6±0.4^{a,1}	3.9±0.5^{a,1}	4.2±0.5^{a,2}	4.3±0.5^{b}2	4.5±0.4^{b,2}	4.7±0.5^{c,3}	4.9±0.6^{c,3}	0.4
	0.75	ND	ND	ND	3.5±0.4^{a,1}	3.9±0.4^{a,1}	4.2±0.6^{b,2}	4.3±0.5^{b,2}	0.5
	1.0	ND	ND	ND	ND	ND	3.4±0.5^{a,2}	3.7±0.5^{a,1}	0.4
	LSD	0.4	0.3	0.4	0.5	0.4	0.4	0.4	
OAA	0	3.8±0.2^{a,3}	3.5±0.3^{a,3}	3.1±0.3^{a,2}	2.8±0.4^{a,2}	2.4±0.4^{a,2}	1.7±0.5^{a,1}	1.3±0.4^{a,1}	0.7
	0.25	3.7±0.3^{a,3}	3.5±0.4^{a,3}	3.1±0.4^{a,2}	2.8±0.4^{a,2}	2.4±0.3^{a,1}	1.9±0.5^{a,1}	1.3±0.4^{a,1}	0.7
	0.50	3.7±0.3^{a,3}	3.6±0.2^{a,3}	3.3±0.3^{a,}3	3.1±0.3^{b}2	2.7±0.4^{b,2}	2.1±0.4^{b1}	1.6±0.3^{b,1}	0.5
	0.75	3.9±0.1^{a,3}	3.7±0.2^{a,3}	3.4±0.2^{a,3}	3.2±0.2^{b}2	2.8±0.3^{b,2}	2.2±0.3^{b1}	1.8±0.2^{b,1}	0.5
	1.0	3.9±0.1^{a,2}	3.9±0.1^{b,2}	3.7±0.2^{b,2}	3.5±0.3^{c,2}	3.1±0.3^{c,1}	2.9±0.4^{c,1}	2.5±0.3^{c,1}	0.6
	LSD	0.2	0.2	0.3	0.2	0.21	0.3	0.2	

Values are mean ± SD (n = 3); LSD = least significant difference; TA = titratible acidity (%); TAA = total ascorbic acid (mg/100 g); TP = total phenols (mg/100 g); TC = total carotenoids (mg/100 g); YMC = yeast and mold count (log cfu/g sample); OAA = overall acceptability; ND = not detected
Values within treatments in a column with different superscript lowercase letters (a-d) differ significantly ($P < 0.05$).

Total ascorbic acid: The effect of phytosanitary irradiation treatment on the ascorbic acid content of fresh table apricots (Table 2) revealed that the ascorbic acid content of fruits treated with irradiation was marginally lower compared to the control on the first day of storage. During storage, a decrease in ascorbic acid was observed in all the treatments, including control. Further, the decrease in ascorbic acid was statistically non-significant up to 5 days of storage in control and 0.25-0.75 kGy irradiated samples and up to 10 days in the case of 1.0 kGy irradiated apricots. After 15 days of storage, ascorbic acid was significantly lower in control and 0.25 kGy treated samples compared to other irradiated samples. This trend in ascorbic acid continued up to 30 days of storage. Among irradiated samples, a significantly lower decrease in ascorbic acid was observed in samples irradiated at 1.0 kGy. After 30 days of storage, a decrease in ascorbic acid was of the order of 86.8% in control; 68.3% in 0.75 kGy samples and 56.2% in 1.0 kGy samples, respectively. The ascorbic acid loss during storage is because of its antioxidant activity, especially under postharvest storage conditions. Many authors have also reported similar changes in ascorbic acid content during irradiation of whole and minimally processed foods (Lee *et al.*, 2003).

Total phenols: The total phenols of table apricots are presented in Table 2. The data revealed that irradiation at 0.75 kGy and 1.0 kGy caused a significant increase in the total phenols of table apricots just after the treatment. Just after treatment, an increase of 3.5% and 7.5% in total phenols was observed in samples treated with doses of 0.75 kGy and 1.0 kGy. During storage, total phenols decreased in all the samples, including control and the decrease was non-significant up to 5 and 10 days in samples irradiated at 0.75 kGy and 1.0 kGy, respectively. After 10 days of storage, total phenols were lower in un-irradiated apricots compared to irradiated apricots. This trend in total phenols continued till the end of storage. Among irradiated samples, significantly higher total phenols were retained in samples irradiated at 1.0 kGy throughout the entire storage. After 30 days of storage, control samples recorded a decrease of 71.8% in total phenols compared to 48.0% and 33.6% in 0.75 kGy and 1.0 kGy irradiated samples, respectively. The present study revealed the existence of positive correlations (r = 0.91) between total phenols and irradiation treatment, thus confirming the increase in total phenols with an increase in dose.

The decline in total phenolics observed during storage is due to the oxidation of phenolic compounds. However, irradiation hampers the physiological processes responsible for this oxidative breakdown, resulting in higher levels of total phenols in table apricots during storage. (Krishna *et al.*, 2018).

Total carotenoids: The total carotenoid content of control and irradiated apricot in shown in Table 2. No significant difference existed in carotenoid content among control and irradiated fruits just after treatment. During storage, carotenoids recorded an increasing trend and the increase was higher in control compared to irradiated samples. In apricot samples irradiated in the range of 0.25 -0.75 kGy and at 1.0 kGy, the increase in carotenoid content was marginal up to 5 and 10 days of storage, respectively. After 15 days of storage, carotenoid content was significantly higher in control, 0.25 kGy and 0.50 kGy irradiated apricots compared to those irradiated at 0.75 kGy and 1.0 kGy. After 20 days of storage, carotenoid content was significantly higher in control only compared to the irradiated samples and this trend continued till 30 days of storage. Among the irradiated samples, 1.0 kGy treated fruits had significantly lower carotenoid accumulation throughout the storage. After 30 days of storage, the highest carotenoid content (9.2 ± 0.7 mg/100g) was recorded in control fruits, whereas the lowest level was recorded in 1.0 kGy irradiated samples (6.6 ± 0.6 mg/100g). The present study revealed that a moderate inverse correlation (r =-0.77) existed between irradiation treatment and carotenoid accumulation, thereby indicating an inhibitory effect of radiation treatment, particularly at doses above 0.5 kGy on the carotenoid accumulation. This reduction in carotenoid accumulation in irradiated fruits is attributed to the ripening delay due to irradiation. Our results are consistent with a recent study conducted by Silva-Sena *et al.* (2014) who reported a 30.0% decrease in the carotene content accumulation of irradiated papaya fruit *cv.* Golden.

Microbial load: Data analysis revealed that phytosanitary irradiation treatment significantly decreased the yeast and mold count of table apricots in dose dose-dependent manner (Table 2). In samples irradiated at 0.75 kGy and 1.0 kGy, no microbial load was detected up to 10 and 20 days of refrigerated storage, thereby resulting in around 4.4 and 4.8 log reductions in yeast and mold count after 10 and 20 days of storage. This beneficial effect of radiations at doses above 0.5 kGy in keeping the yeast and mold count below detection level up to 10 and 20 days of storage is attributed to the radio-static effect of radiations, wherein cells become dormant upon exposure to radiations for an extended period by virtue of radiation-induced reparable mutations. Once the damage is repaired, the cells then operate normally (Zhang *et al.*, 2006). With further advancement in storage, the yeast and mold counts increased irrespective of treatment; however, the counts were lower in irradiated samples compared to the control. After 30 days of storage, among treatments, the dose of 1.0 kGy was significantly effective in keeping the microbial load of fresh table apricots at very low levels and resulted in about 1.0 log reduction in microbial load. Further, based on the daily visual observation, it was found that un-irradiated and 0.25 kGy irradiated apricot samples showed incidences of fungal growth and onset of decay after 15 days of storage as in 1.0 kGy irradiated samples, no decay and onset of visual fungal growth was observed up to 25 days of refrigerated storage.

Overall acceptability (OAA): Overall acceptability based on appearance, texture, taste and odor of fresh table apricots treated with phytosanitary irradiation doses is shown in Table 2. Data analysis indicated no significant difference in the overall acceptability of apricots among treatments after 0 day of storage. After 5 days of storage, the overall acceptability of control and 0.25–0.75 kGy treated apricots differed marginally with respect to each other and was significantly lower compared to the overall acceptability of 1.0 kGy treated apricots. With further increase in storage, OAA decreased in all the samples, including control in a dose-dependent manner. A comparison of the data indicated that in the case of 0.75 kGy and 1.0 kGy treated apricots, a decrease in firmness during storage was marginal up to 10 and 15 days, respectively, compared to 5 days in control and 0.25 kGy treated apricots. After 20 days, the overall acceptability of 1.0 kGy treated apricots was significantly higher compared to all other treatments, including control and this trend continued till 30 days. Further based on the limit of acceptability, control and 0.25 kGy treated apricots were unacceptable after 20 days, while 0.5 kGy and 0.75 kGy treated apricots were unacceptable after 25 days of storage. The table apricots irradiated at 1.0 kGy were acceptable up to 30 days of storage. Towards the end of the storage, a 65.8 % decrease in overall acceptability was recorded in un-irradiated control apricots compared to 35.9 % in 1.0 kGy irradiated apricots. Therefore, it is inferred that irradiation of fresh table apricots at phytosanitary doses resulted in around two-fold retention of overall acceptability.

The results of this study show that phytosanitary radiation treatment at 1.0 kGy maintained the texture, higher levels of total phenols and ascorbic acid, and inhibited mold growth in fresh table apricots stored for 25 days in the fridge. After 25 days of storage, apricots treated with above irradiation dose had higher overall acceptability (2.9) in appearance, texture, taste, and odor. After 30 days of storage, table apricots processed with 1.0 kGy had reduced yeast and mold counts by 1.0 log, improving microbial safety. This study found that phytosanitary radiation treatment of fresh table apricots can preserve storage quality for 25 days, compared to 15 days in unirradiated apricots under refrigeration.

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