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Impact of radiation processing on quality during storage and post-refrigeration decay of plum (*Prunus domestica* L.) cv. Santaroza

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HIGHLIGHTS

- Irradiation at 1.2–1.5 kGy delayed decay of plum up to 18 days of ambient storage.
- Irradiation extended the shelf-life by 8 days at 25 ± 2 °C following 35 days of refrigeration.
- The treatment can help marketing of plum during glut season and enabling good returns.

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ABSTRACT

Gamma irradiation treatment was tested for maintaining storage quality and extending the shelf life of plum fruit. Matured green plums were irradiated in the dose range of 0.2–1.5 kGy and stored under ambient (temperature 25 ± 2 °C, RH 70%) and refrigerated (temperature 3 ± 1 °C, RH 80%) conditions. Studies revealed that irradiation treatment significantly ($p \leq 0.05$) maintained the storage quality of plum fruit under ambient as well as refrigerated conditions. Positive correlations ($r=0.88$) existed between the irradiation doses and firmness retention under both the storage conditions. In samples irradiated at 1.0 kGy, 1.2 kGy and 1.5 kGy, no microbial load was detected up to 8 and 12 days of ambient storage. Dose range of 1.2–1.5 kGy significantly inhibited the decaying of plums up to 16 days of ambient storage. Irradiation in combination with refrigeration prevented the decaying of plums up to 35 days as against the 12.5% decay in un-irradiated control samples. Irradiation dose of 1.2–1.5 kGy also gave an extension of 8 days during additional ambient storage of the plums at 25 ± 2 °C, RH 70% following 35 days of refrigeration.

1. Introduction

Plum is a perishable climacteric stone fruit which undergoes rapid ripening. This is responsible for its short shelf-life and represents a serious constraint for its handling and transportation. Quick softening after harvest and subsequent microbial infestation lead to losses in the marketing chain. For this reason the fruits are picked at a pre-climacteric stage in order to withstand the handling process. Low temperature storage of plums is recommended to extend fruit postharvest life and maintain quality Wang (1993). However, extended storage of plums at low non-freezing temperature is limited and leads to physiological disorders such as gel formation, abnormal fruit ripening and development of chilling injuries such as internal and external browning, flesh breakdown, reddish discoloration, increased incidence of decay and loss in consumer acceptance (Guerra and Casquero, 2008; Manganaris et al., 2008). The use of conventional chemicals as anti-ripening, anti-senescence and microbial fumigants has been phased out and restricted throughout the world. These chemicals pose serious health hazards and environmental effects (Cetinkaya et al., 2006). The adverse effects of these chemicals lower or limit the export capabilities of fresh as well as dried fruits. To overcome these adverse effects, quarantine barriers and at the same time extend the shelf-life and maintain storage quality of fresh fruits, alternate processes are needed.

Gamma irradiation has become an effective means of processing and preserving food products (Molins, 2001; Fan et al., 2003). The process is gaining much importance as it can be performed at room temperature, and due to its cold nature and high efficiency, for inactivation of food borne pathogens and parasites (Bidawid et al., 2000). Irradiation has been recognized as an alternative to chemicals for treating fresh and dried agricultural products to overcome quarantine barriers in international trade, as a mode of decontamination, disinfestations, delaying the ripening and senescence of fruits and vegetables and for improving nutritional attributes and shelf-life (McDonald et al., 2012; Hong et al., 2008;

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Lacroix and Ouattara, 2000; Hallman, 2000). Gamma irradiation can extend shelf-life of treated foods without including the formation of any radionuclide in food products. Food can be treated with radiations in a pre-packed form thereby limiting the chances of cross contamination. A joint FAO/IAEA/WHO Expert Committee on the wholesomeness of irradiated foods has ruled that foods subjected to low and medium dose of irradiation are safe and do not require toxicological testing (WHO, 1981).

The effectiveness of gamma-irradiation treatment for stone fruits with respect to delay in ripening and senescence, control of fungal diseases during storage and insect infestation has been reviewed (Thomas, 1986c), but very little information is available in the literature on radiation processing of plums. Moy et al. (1982) reported that in Casselman plums irradiated at disinfestations dose levels (0.3–1 kGy), no significant differences in color, aroma and texture were observed up to 0.3 kGy when compared with control, but at 0.5 kGy, there were detectable significant differences in color and texture between the irradiated and the control. However, at 1.0 kGy differences were noted only in texture. In another variety Stanley, treatment with doses of 0.5–1.0 kGy was shown to extend the storage life which increased with increasing doses up to 1.0 kGy. There hardly seems any information available in the literature regarding the radiation processing of plums of Santaroza variety. Therefore, the present study was conducted to determine the effect of gamma irradiation treatments on maintaining storage quality and shelf-life extension of Santaroza plums grown in the valley of Kashmir.

Table 1
Dose delivered and absorbed dose at various box position during plum irradiation.

Box position	Dose delivered (kGy)	Absorbed dose (kGy)	Box position	Dose delivered (kGy)	Absorbed dose (kGy)
FM	0.2	0.23	FM	1.0	1.3
FMC1	0.2	0.21	FMC1	1.0	1.1
FMC2	0.2	0.22	FMC2	1.0	1.2
CM	0.2	0.20	CM	1.0	1.0
CMC1	0.2	0.197	CMC1	1.0	0.99
CMC2	0.2	0.199	CMC2	1.0	0.97
BM	0.2	0.24	BM	1.0	1.2
BMC1	0.2	0.23	BMC1	1.0	1.3
BMC2	0.2	0.22	BMC2	1.0	1.3
FM	0.6	0.63	FM	1.5	1.7
FMC1	0.6	0.62	FMC1	1.5	1.7
FMC2	0.6	0.63	FMC2	1.5	1.6
CM	0.6	0.61	CM	1.5	1.5
CMC1	0.6	0.598	CMC1	1.5	1.497
CMC2	0.6	0.598	CMC2	1.5	1.497
BM	0.6	0.64	BM	1.5	1.7
BMC1	0.6	0.64	BMC1	1.5	1.6
BMC2	0.6	0.62	BMC2	1.5	1.6

Values are mean, $n=3$.
Box position: (i) Maximum dose position: FM, front middle; BM, back middle; FMC1, front middle corner 1; BMC1, back middle corner 1; FMC2, front middle corner 2; BMC2, back middle corner 2. (ii) Minimum dose position: CM, center middle; CMC1, center middle corner 1; CMC2, center middle corner 2.

2. Materials and methods

2.1. Raw material preparation

Mature green fruit of uniform shape, size and firm texture was procured from the local plum orchards of Shalimar, Kashmir. After harvesting, the fruit was cooled at 2 °C for 24 h in a cold storage chamber. The pre-cooled fruit was manually graded in order to have uniformity and packed in cardboard boxes each containing 25 fruits.

2.2. Gamma-irradiation

The pre-cooled and packaged fruit was subjected to gamma-irradiation in the range of 0.2–1.5 kGy using PANBIT irradiator having Co-60 as the gamma-ray source. Before starting fruit irradiation, complete dose mapping was done at various box positions namely front middle (FM), front middle corner-1 (FMC1), front middle corner-2 (FMC2), center middle (CM), center middle corner-1 (CMC1), center middle corner-2 (CMC2), back middle (BM), back middle corner-1 (BMC1) and back middle corner-2 (BMC2) so as to determine the dose rates around the conveyor of PANBIT using Ceric-Cereous dosimetry. As the procedure was two side irradiation and to ensure uniformity of dose, boxes were turned by 180° half-way through the irradiation time. The over dose ratios (Dmax/Dmin) calculated at middle, corner-1 and corner-2 box position were found to be 1.3, 1.1 and 1.2 respectively. Fruit was irradiated at a minimum dose rate of 128 Gy/h using two side irradiation procedure. To ensure that fruit receives the exact dose, the dosimeters were placed in each fruit box for each treatment at high as well as low dose spots. The dose delivered and absorbed dose at various box positions during fruit irradiation is presented in Table 1. After irradiation, the fruit was kept separately under ambient (temperature 25 ± 2 °C, RH 70%) and refrigerated (temperature 3 ± 1 °C, RH 80%) storage conditions and periodically evaluated for physico-chemical parameters like firmness, total soluble solids (TSS), water soluble pectin, chlorophyll content, total anthocyanins, CO_2 evolution, weight loss, decay percentage and overall acceptability. Three boxes each containing 25 fruits were evaluated for each parameter after every 4 days in case of ambient storage and every 7 days in case of refrigerated storage.

2.3. Fruit analysis

2.3.1. Firmness

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. Triplicate samples of 15 fruits were selected randomly and evaluated for firmness and mean value was expressed in kg.

2.3.2. Total soluble solids

The fruits initially used for firmness measurement were subjected to juice extraction using laboratory juicer (HL-1631, Philips, India). The juice so obtained was further filtered through two layer muslin cloth. Total soluble solids (TSS) were determined at 20 °C using ABEE refractometer model "RSR-2" (Rajdhani Scientifics, India).

2.3.3. Total anthocyanins

Total anthocyanins were determined according to the pH-differential method (Guisti and Wrolstad, 2001). Homogenized fruit samples (3 g) were extracted using ethanol 1 N HCl (85:15, v/v). Clear extract (1 ml) was placed into 25 ml volumetric flask, made up to a final volume with pH1.0 buffer (1.49 g of KCl/100 ml water and 0.2 N HCl, with a ratio of 25:67) and mixed thoroughly. Another 1 ml of extract was also placed into a 25 ml volumetric flask, made up to a final volume with pH4.5 buffer (1.64 g of sodium acetate/100 ml of water, adjusted to pH4.5 with 0.2 N HCl) and mixed. Absorbance was calculated as $\Delta A=(A_{510nm}-A_{700nm})$ pH1.0 $-(A_{510nm}-A_{700nm})$ pH4.5 with a molar extinction coefficient of 26,900 for cyanidin 3-glucoside. Results were calculated using the following equation and expressed as mg of