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Postharvest irradiation as a quarantine treatment and its effects on the physicochemical and sensory qualities of Korean citrus fruits

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ABSTRACT

Two Korean citrus fruits, *Jinjihyang* and *Chunggyun,* were exposed to gamma irradiation at 0, 0.4 and 1 kGy as an ionizing quarantine treatment and were then subjected to evaluations of physicochemical and sensory quality attributes during storage at 4 ± 1 °C for 0, 10 and 20 days. Upon irradiation at 1 kGy, the narinrutin content of *Jinjihyang* significantly decreased (109.64–94.80 mg/100 g), while hesperidin content remained stable. However, both flavonoids decreased significantly during storage in both fruit varieties. Vitamin C was stable after irradiation but a significant decrease (42.97–27.21 mg/100 mL) was observed in 1 kGy-irradiated sample at the 20th day of storage. Brix, organic acids, and sensory properties of both fruits were not affected by irradiation or storage. The 1 kGy-treated fruits showed the highest titratable acidity (%) but this was not reflected in the sensory scores, even though *Jinjihyang* was more susceptible to irradiation than *Chunggyun*. Overall, irradiation at less than 1 kGy shows a potential to be used as a postharvest quarantine treatment for Korean citrus fruits.

1. Introduction

Citrus fruits, known for their health benefits and sensory attributes, are cultivated worldwide with a 100 million ton annual yield. Most Korean citrus fruits are used as fresh fruits or for juice production. The citrus fruits harbor health-promoting substances, including dietary fiber, vitamin C, flavonoids, and carotenoids (Park et al., 2016; Yu et al., 2014). The diverse biological activities of citrus fruits against free radicals, inflammation, and pathogens may be due to the presence of abundant phytochemical compounds such as flavonoids, coumarins, carotenoids, limonoids, and alkaloids as secondary metabolites and bioactive compounds. Unlike phenolic acids, all flavonoids share the two aromatic carbon rings and a heterocyclic ring with one oxygen atom (Ghasemzadeh and Ghasemzadeh, 2011). Among these, the most predominant subclasses of bioactive compounds are the flavanones, flavanonols, and methoxylated flavones (Gattuso et al., 2007). Among citrus-derived flavonoids, flavanones comprise approximately 95% of the total flavonoids (Peterson et al., 2006). Naringin (neohesperidoside), neohesperidin (neohesperidoside), narirutin (rutinoside), and hesperidin (rutinoside) are commonly present in major quantities. Monosubstituted phenolic acids (*p*-coumaric acid, o-coumaric acid, and 4-OH-phenylacetic acid) are reported to have very low activity in citrus according to Jabri Karoui and Marzouk (2013).

Agricultural commodities are usually treated with effective phytosanitary treatment to disinfest quarantine pests and to comply with the shipment requirements out of quarantined areas. No adverse effects are exerted by the irradiation as cold pasteurization technique as far as the physicochemical and quality attributes of agricultural produce are concerned during extended storage period. Therefore, use of irradiation is increasing worldwide as a promising phytosanitary treatment to increase trade of irradiated foodstuffs. Soon after the discovery of the irradiation phenomenon during late 19th century, it was revealed that irradiation effectively sterilized the biological organisms on exposure to low-dose treatments without any pertinent effects (Hunter, 1912). In 1972, first petition was files by Hawaii to the U.S. Food and Drug Administration (FDA) for approval of phytosanitary application of irradiation on papayas (Moy and Wong, 2002) and 14 years later the use of irradiation was approved by the FDA (1986) up to applied dose of 1 kGy for insect-pest disinfection of foods from arthropods. Similarly, approval of generic dose was of 400 Gy was granted for all insects by The United States Department of Agriculture-Animal and Plant Health Inspection Services (USDA-APHIS) excluding pupae and adults of Lepidoptera (APHIS, 2006). USDA-APHIS in coordination with other international regulatory bodies, such as the International Atomic Energy Agency (IAEA) and the International Plant Protection Convention (IPPC), have published compliance guidelines for irradiation treatments

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to meet existing export and quarantine restrictions (Molins et al., 2001).

Hence, the objective of this research was to demonstrate the effects of variable dose levels (0.4 and 1 kGy) of gamma irradiation as per the regulation of phytosanitary treatments on the physicochemical properties of two Korean citrus fruits, *Jinjihyang* and *Chunggyun*, during 20 days of storage. The results of the physicochemical measurements were also compared with sensory ratings to evaluate for any prominent changes during storage. Finally, this study was intended to evaluate the effects of gamma irradiation as feasible phytosanitary method on physicochemical and sensorial changes of Korean citrus fruits during storage.

2. Materials and methods

2.1. Procurement of Korean citrus fruits and irradiation

Korean citrus fruits, *Jinjihyang* (hybrid of *Citrus unshiu Marc*, *C. sinensis Osbeck*, and *C. unshiu*) and *Chunggyun* (hybrid of *C. unshiu Marc* and *C. sinensis Osbeck*), were procured from a local market in Daegu, Korea. *Jinjihyang* (114 ± 7 g/fruit, 42 ± 2 fruits/5 kg/box) and *Chunggyun* (138 ± 9 g/fruit, 70 ± 2 fruits/10 kg/box) were divided into three groups in the same-sized cardboard box (36 × 26 × 12 cm) and stored overnight at 4 °C. The fruits were then subjected to gamma irradiation at doses of 0, 0.4, or 1 kGy at 20 ± 2 °C with a dose rate of 0.6 kGy h^{-1} using a Cobalt-60 irradiator with a source strength of 100 kCi at the Korea Atomic Energy Research Institute (KAERI), Jeongeup. Dosimeter for absorbed dose was performed by using alanine dosimeter with 5 mm dia. (Bruker Instruments, Rheinstetten, Germany) placed on the top and bottom of the boxes within the error range of ± 5.6%. Post-irradiation, the citrus fruits were stored at 4 ± 2 °C for 20 days.

2.2. Determination of weight loss and firmness

The weight of 10 designated fruits was measured using an analytical balance (MS105; Mettler Toledo, Greifensee, Switzerland) on every 10 days, and weight loss was calculated by comparing with the initial weight before irradiation. The firmness was determined using a rheometer (Compac-100II; Sun Scientific, Tokyo, Japan) with adaptor No. 5 (2 mm diameter). The peel around the equator was removed to avoid interference. The force required to compress a fruit by 10% of its diameter was recorded at a strain rate of 60 mm/min. Thirty fruits were selected randomly and evaluated for firmness, and the mean values were expressed in g/cm^2.

2.3. Preparation of juice sample

Ten fruits were peeled and then the pulp were juiced using a commercial juicer (HR-2870; Philips, Amsterdam, Netherlands). After centrifugation at 2500 x g at 4 °C for 20 min, the filtered juice samples (Whatman No. 4) were kept at a temperature of −18 °C until chemical quality analysis.

2.4. Total soluble solids (TSS), titratable acidity (TA), and TSS/TA ratio

The TSS content of juice samples was determined using a digital refractometer (Master-M; Atago, Tokyo, Japan). One mL juice samples was added into 9 mL distilled water, and TA was measured by titration with 0.1 N NaOH to an endpoint of pH 8.2. TA concentration was calculated as percent citric acid.

2.5. Determination of vitamin C content

The juice samples were filtered (0.45 μm) and injected into high-performance liquid chromatography (HPLC) equipment (Agilent 1260 Infinity; Agilent Technologies, CA, USA) with a μBondapak C18 column (3.9 × 300 mm; Waters Co., Milford, MA, USA). The mobile phase was H_2SO_4 (5 mM, pH 2.4), and the flow rate was 1 mL min^{-1} at 30 °C. Detection was performed with an Agilent 1260 Infinity multiple wavelength detector at 254 nm. Concentrations were expressed as mg per 100 g fresh weight (FW).

2.6. Determination of organic acid content

The fruit juice was passed through a 0.45 μm pore size membrane filter before injection. Organic acids were analyzed in the Agilent 1260 Infinity HPLC system with an Aminex HPX-87H column (300 × 7.5 mm; Bio-Rad, USA) and a multiple wavelength UV detector (1260 MWD VL, Agilent) set at 210 nm. The mobile phase was H_2SO_4 (5 mM) at a flow rate of 0.6 mL min^{-1}. Each organic acid was identified by comparison of the retention time with the standards. Concentrations were expressed as mg per 100 g (FW).

2.7. Determination of free sugar content

Analysis of sugar content was performed using an Agilent 1260 Infinity HPLC using a carbohydrate column (300 × 3.9 mm; Waters, USA) and a refractive index detector (1260 RID; Agilent, USA). The mobile phase was 80% acetonitrile at a flow rate of 1 mL min^{-1}. Concentrations were expressed as mg per 100 g FW.

2.8. Determination of flavonoid content

Five grams of fruit peel was added to methanol (100 mL) and extracted using sonication treatment (1 h). The separation of flavonoids was carried out on Agilent 1260 Infinity HPLC with a C18 column (ZORBAX Eclipse Plus, 4.6 × 150 mm; Agilent, USA) at 35 °C with a gradient solvent system (aqueous acetic acid solution: methanol) as the mobile phase. Initially, the gradient was 90:10 for 20 min and increased linearly to 60:40 at 40 min, 40:60 at 50 min, and 80:20 at 60 min. The flow rate was 0.4 mL min^{-1}. Peaks were detected under UV at 285 nm.

2.9. Sensory evaluation

The sensory assessment was done to study the influence of irradiation on consumer acceptance. Sliced fruit numbered with 3-numeral codes was given to twenty students. The preferences regarding color, aroma, taste, and overall acceptability were recorded using a 7-point hedonic scale (1-extreme dislike, 3-dislike, 4-fair, 5-like, 7-extreme like).

2.10. Statistical analysis

All the experiments were performed for more than thrice and results were reported as mean ± standard deviation. The data analysis was carried out by using Statistical Analysis Software (SAS version 8.1, SAS Institute, Cary, NC, USA). Mean values were compared by applying Duncan's multiple range test ($p < .05$) one-way analysis of variances (ANOVA).

3. Results and discussion

3.1. Effects of irradiation and storage on weight loss and firmness

Weight loss during storage is important to the stability of food. Higher weight loss drastically modifies the textures of the foods (Dhall, 2013; Paul and Pandey, 2014). In our study, the weight loss (%) increased at the end of storage of *Jinjihyang* and *Chunggyun* fruits; however, irradiation had no significant effect on weight loss ($p > .05$). Hence, gamma ray doses up to 1 kGy do not alter weight loss, but storage increases it within a short timeframe. Significant weight loss was observed after 10 days of storage in both the non-irradiated and irradiated Korean citrus fruits. The highest weight loss was observed