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Research Paper

Effect of phytosanitary irradiation on the quality of two varieties of pummelos (*Citrus maxima* (Burm.) Merr.)☆

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ABSTRACT

Phytosanitary treatments prevent the introduction of pests such as fruit flies into pest free zones, and are often required for international trade. Irradiation is increasingly being considered as an alternative to cold and chemical phytosanitary treatments, such as methyl bromide. In this study, the effect of low dose gamma irradiation on the post-harvest quality of two varieties of pummelos (*Citrus maxima* (Burm.) Merr.), an emerging crop of interest in the US was evaluated. Two varieties of pummelos grown in California were irradiated at the phytosanitary target dose of 150 Gy and a higher dose of 1000 Gy to exaggerate and hence confirm the effects of treatment. The fruit was stored at 12 °C for 3 weeks and at 20 °C for the 4th week to reflect three weeks of sea shipment at the ideal temperature for storage of pummelos and an additional week of retail under ambient conditions. Neither irradiation nor storage affected juice content, organic acids, sugars, peel or pulp color and consumer sensory preference, although numerous volatiles increased in concentration as a result of irradiation treatment. Irradiation caused an immediate reduction in whole fruit and pulp firmness in 'Chandler' but not 'Sarawak' pummelos at both 150 Gy and 1000 Gy. The quality of irradiated pummelos stored at refrigerated temperature for 3 weeks was similar to untreated pummelos, however, physical handling and exposure to higher temperature resulted in increased peel pitting of irradiated fruit compared to non-treated fruit. The results suggest that irradiation could serve as a potential phytosanitary treatment for Chandler and Sarawak pummelos, provided that the fruit is subjected to minimal handling and not temperature abused.

1. Introduction

Pummelo (*Citrus maxima* (Burm.) Merr.) is one of the largest citrus fruits by size. This fruit is popular throughout Asia and Europe for their desirable taste, flavor and juicy texture and is gaining popularity in the U.S. In August 2014, the United States Animal and Plant Health Inspection Service (APHIS) proposed the importation of five species of citrus fruits, including pummelos, from China into the U.S. (USDA-APHIS, 2014) provided that adequate phytosanitary measures are taken to ensure quarantine pest free fruit shipment. APHIS has identified 22 pests including eight species of Bactrocera fruit flies as quarantine pests that might enter U.S. through importation of citrus fruits from China (USDA-APHIS, 2015). Phytosanitary treatments allowed by APHIS on citrus include chemical fumigation, irradiation, and cold and heat treatments (USDA-APHIS, 2015), although the commercial phytosanitary treatments prevalent in the citrus industry are cold treatment and methyl bromide fumigation (MeBr). Cold treatments (0.56–1.67 °C for 22–18 days) are very effective in eliminating certain insect infestations (USDA-APHIS, 2015), however, the optimum temperature for storage of pummelos is 12 °C, and storage at significantly lower temperature can adversely affect the external appearance and color of pummelos resulting in damage and loss of market quality (International Tree Fruit Network, 2011). Methyl bromide (MeBr) has a depleting effect on the ozone layer and pre-plant use has been mostly phased out as required by the 1987 Montreal Protocol (Kuijpers et al., 2014).

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Due to lack of viable alternatives, MeBr is currently exempted from the ban under the Montreal Protocol for post-harvest phytosanitary purposes (Hallman and Thomas, 2011), although continuous efforts are being made to phase out MeBr completely (USDA-EPA, 2013). The Methyl Bromide Technical Options Committee under the United Nations Environmental Programme has recognized irradiation as a potential phytosanitary alternative to MeBr fumigation (Kuijpers et al., 2014).

Irradiation is a highly efficacious phytosanitary treatment which utilizes ionizing radiation from radioisotopes (gamma rays), electron beam or x-rays to disrupt the genetic material of the pest or microorganism infesting food, causing either sterilization or death of the target organisms. Irradiation is used commercially to treat several fruit including mangos, guavas, litchi, dragon fruit and rambutan in various countries, although it is not currently utilized for citrus products. USDA-APHIS (2015) is considering allowing citrus from China to be treated at 150 Gy, a dose effective against all fruit flies from the family Tephritidae, and in particular the Oriental fruit fly (*Bactrocera dorsalis*).

The effect of irradiation depends upon the variety or cultivar of fruit, irradiation dose, ripening/maturity stage of the fruit, harvest season and post-treatment storage conditions of fruit such as temperature (McDonald et al., 2013; Bustos and Mendieta, 1988; Patil et al., 2004; Miller et al., 2000; Nagai and Moy, 1985). Some fruits such as Valencia and 'Ambersweet' oranges can tolerate irradiation but peel pitting is observed on irradiated navel and 'Hamlin' oranges, and 'Fallglo', 'Sunburst' and 'Temple' hybrid mandarins (McDonald et al., 2013; Miller et al., 2000). Irradiation also causes dose dependent softening of Valencia oranges treated at 300 Gy and higher (Nagai and Moy, 1985), navel oranges treated at 600 Gy and higher (McDonald et al., 2013), and 'Murcott', Minneola and 'Temple' fruit (Miller et al., 2000) whereas other varieties such as 'Hamlin', 'Sunburst' and 'Ambersweet' are more radiotolerant (Miller et al., 2000).

The effect of low-dose gamma irradiation on the post-harvest quality of pummelos has not been documented. Thus, the objective of the research was to observe the effects of low-dose gamma irradiation (150 Gy and 1000 Gy) on the post-harvest quality of two varieties of Pummelos available in California, Chandler (red flesh) and Sarawak (white flesh), after storage at 12 °C for 3 weeks, the time required for sea shipment between the US and Asia, followed by one week at 20 °C to reflect retail conditions. The dose of 150 Gy was selected since it is the specified minimum dose in the PPQ Treatment Manual (USDA-APHIS, 2014). 1000 Gy is the maximum dose allowed by the FDA to treat fresh fruits and vegetables and was selected to exacerbate the negative effects and allow recognition of symptoms of phytotoxicity.

2. Materials and methods

2.1. Fruit procurement

Pummelos were harvested on January 15th, 2015 in Tulare County, CA. The fruits were packed on January 17th, 2015 in Orosi, CA following standard commercial practices. The fruits were first washed using 50–150 mg/L chlorine at the point of dumping, then using a mixture of 100–200 mg/L chlorine and 1–2% sodium bicarbonate in a high pressure washer at 862 kPa (125 psi) followed by a fresh water rinse. After washing, the fruits ware treated with 200–300 mg/L heated imazalil. In addition to treatment with imazalil, the fruits were waxed with carnauba-based wax that had 2000 mg/L imazalil and 3500 mg/L thiabendazole mixed in it. Pummelos were bulk packed in 24 kg cartons, with approximately 12 pummelos in each carton. After packaging, the cartons were stored at 5 °C prior to shipping to Santa Fe Springs, CA (350 km) in a refrigerated truck. The cartons of pummelos were picked up from the distributor and transported in a van to Sterigenics, Inc., Tustin CA (20 km) for gamma irradiation.

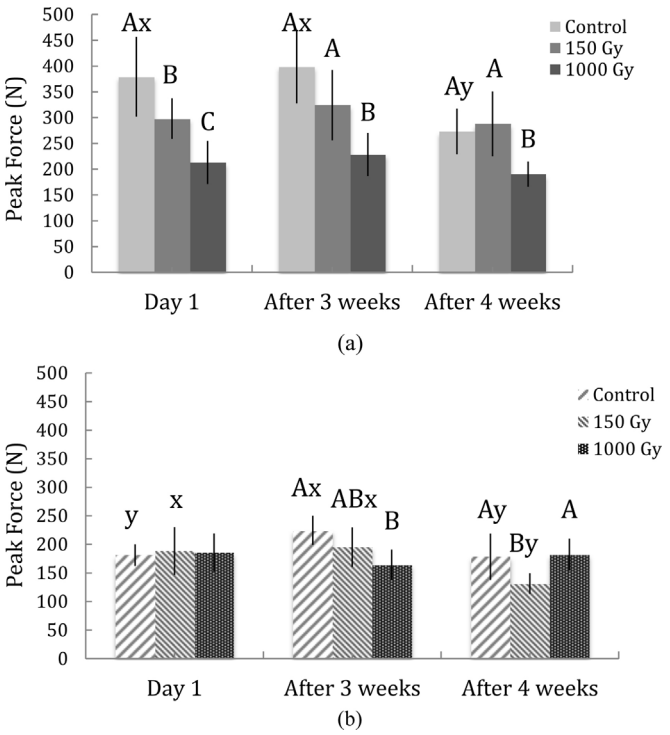

Fig. 1. Pulp firmness of (a) Chandler and (b) Sarawak pummelos stored for three weeks at 12 °C and for an additional week at 20 °C measured using a Kramer shear press. Statistically significant differences ($P < 0.05$) among treatments within the same time point are denoted by letters A-C; and across time points for the same treatment by letters x–z.

2.2. Gamma irradiation

Upon arrival at Sterigenics, the cartons were labeled either control, 150 Gy, or 1000 Gy. Dose mapping was conducted using eight cartons of pummelos in the exact configuration as the sample treatment with 150 Gy and 1000 Gy. Eight boxes were stacked in two rows of four a fixed distance from the Co_{60} source (~278 bq). Dose mapping was conducted by placing 16 alanine pellet dosimeters (FarWest Technology, In, Goleta, CA) at various locations in the cases. The dose rate was determined to be 0.637 Gy s^{-1}. Eight cases of pummelos were placed exactly in the same configuration as the dummy cases to receive treatment at a target dose of 150 and 1000 Gy (4.6–5.5% uncertainity) and Dmax/Dmin ratio of 1.33. The eight cartons used as control fruit did not receive any treatment. After treatment was complete, all the cartons were transported to Chapman University, Orange, CA in a van, covering a distance of approximately 24 miles. Upon arrival, all the cartons were stored at 12 °C for 3 weeks to simulate shipment to and from Asian countries and at 20 °C for the 4th week to simulate one week at retail temperatures. Temperature was verified using LogTags® (Auckland, New Zealand) placed in cartons of pummelos during storage. Analytical and chemical tests were performed on samples taken at day 1 after irradiation, then after 3 and 4 weeks of storage.

2.2.1. Peel pitting and external damage

Ten pummelos per treatment were labeled (control, 150 Gy and 1000 Gy) and used for determining external damage during storage. The fruit was evaluated during storage for surface damage such as peel pitting, scarring bruising and discoloration by three pan-