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Low-dose gamma irradiation following hot water immersion of papaya (*Carica papaya* linn.) fruits provides additional control of postharvest fungal infection to extend shelf life

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HIGHLIGHTS

- Storage of papaya extended to 28 days whilst retaining commercial quality.
- Additive effect of low gamma irradiation (0.08 kGy over 10 min) and hot-water treatment.
- Significant reduction in surface fungal lesions.
- No significant impact on colour change or flesh quality during storage.

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ABSTRACT

Low-dose gamma irradiation (0.08 kGy over 10 min), a level significantly below that required to satisfy the majority of international quarantine regulations, has been employed to provide a significant reduction in visible fungal infection on papaya fruit surfaces. This is appropriate for local and national markets in producer countries where levels of commercial acceptability can be retained despite surface lesions due to fungal infection. Irradiation alone and in combination with hot-water immersion (50 °C for 10 min) has been applied to papaya (*Carica papaya L.*) fruits at both the mature green and 1/3 yellow stages of maturity. The incidence and severity of surface fungal infections, including anthracnose, were significantly reduced by the combined treatment compared to irradiation or hot water treatment alone, extending storage at 11 °C by 13 days and retaining commercial acceptability. The combined treatment had no significant, negative impact on ripening, with quality characteristics such as surface and internal colour change, firmness, soluble solids, acidity and vitamin C maintained at acceptable levels.

1. Introduction

This study investigates the combination of low-dose gamma irradiation and hot water treatment to look for an improved extension of papaya fruit shelf life, with the possibility of minimal, associated loss of fruit quality. Outcomes of the study will be measured in terms of an extension to overall shelf life that brings commercial benefit. Higher gamma radiation doses required to eliminate entirely insect infestation for international trade have not been considered.

Papaya (*Carica papaya* Linn.) is an economically significant fruit crop in many tropical and subtropical countries, with a global production of 12.4 M tonnes. There is a vibrant export market but, overall, most papaya enters local and national supply chains (FAOStat, 2014). Appearance, flavour and nutritional value of papaya fruits can be compromised by factors such as harvesting at an inappropriate stage of development (Greenwel et al., 1997), extreme or fluctuating storage and transport temperatures (Paull et al., 1994; Pimentel and Walder, 2004; Nunes et al., 2006) and mechanical damage resulting from poor handling practices (Chen et al., 2007; Proulx et al., 2005). Reduction of papaya shelf life owes much to fungal rot, particularly infection by anthracnose (*Colletotrichum gleosporioides*) and other pathogens that vary with

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location (Palhano et al., 2004). In this Malaysian investigation, stem end rot (*Lasiodiplodia theobromae*) and Rhizopus fruit rot (*Rhizopus stolonifer*) were locally significant.

The shelf life of papaya fruits has been prolonged in a limited way (up to 10 days) with respect to fungal disease levels by hot-water dipping, typically at 50 °C for up to 20 min (Chavez–Sanchez et al., 2013; Couey 1989; Li et al., 2013; Martins et al., 2010; Nishijima, 1993; Sivakumar and Wall, 2013) and, with a double-dip variant, to lower insect infestation (Couey and Hayes, 1986).

Gamma radiation, at doses typically between 0.25 and 1.00 kGy can increase the shelf life of papaya and other climacteric, fresh fruits by delaying ripening, (Camargo et al., 2007; Cia et al., 2007; Lacroix and Ouattara, 2000; Paull, 1996; Pimentel and Walder, 2004; Purwanto and Maha, 1998; Sivakumar and Wall, 2013; Wall, 2008; Zhao et al., 1996). At levels at 1.0–1.5 kGy, fungal infections can also be eliminated (Lacroix and Ouattara, 2000). Irradiation is most commonly used to eradicate insect infestation (Hallman, 2011; Sivakumar and Wall, 2013) and a dose of 0.15 Gy has been approved for papaya import to the USA, for control of tephritid fruit flies (USDA-APHIS, 2006). In practise, however, a dose of 0.40 kGy is used to ensure that zero tolerance requirements for surface pests are met (Sivakumar and Wall, 2013). These relatively high doses of gamma irradiation provide relatively little benefit in terms of an extension of shelf life and continue to limit market growth in some countries due to consumer concerns over irradiated foods (Deliza et al., 2010; Hallman, 2011).

The combination of hot water treatment with irradiation at 0.25 kGy or greater has, to date, provided a relatively limited extension of the shelf life of papaya fruit (up to 8 days), by reducing the level of fungal rots (Purwanto and Maha,1998; Pimentel et al., 2007). The aim of this study is to find a combined treatment, using a lower radiation dose, that can significantly reduce, but perhaps not eliminate, visible fungal infection on papaya fruit surfaces, to extend the window of acceptability of fruits in the local and national markets of producer countries.

2. Materials and methods

2.1. Plant material

Papaya fruits (*C. papaya* var. Frangi) were supplied by the Malaysian Agrifood Corporation Berhad (MAFC) No. 3, and selected for shape and size (mean length c.20 cm, mean weight c.500 g) without visible imperfections or quality defects. Fruits were sorted into populations at maturation index 2 (MI2) with yellow colouring on $<10\%$ of the fruit surface and MI4 with yellow colouring between 10–30% cover (Pimentel and Walder, 2004). On arrival at the laboratory, the fruits were water washed, allowed to dry in air and then individually wrapped in non-absorbent paper. Fruits at each maturity stage were packed in groups of 9 in cardboard cartons ($34\times41\times17$ cm^3) and maintained at 11 ± 1 °C overnight before treatment. Four cartons at each maturity index were randomly selected for each treatment.

2.2. Postharvest treatments

Fruits from both maturity groups were allocated randomly to one of the treatments outlined below (I–IV).

I. Control-no further treatment.
II. Incubation in a water bath at 50 °C for 10 min, allowed to air dry, repacked.
III. Irradiated in the carton for 10 min.
IV. Incubation in a water bath at 50 °C for 10 min, air dried, repacked and irradiated (within 1 h) as in III.

Irradiation was delivered via a Cobalt-60 source (Gamma Beam 650-Nuclear Agency of Malaysia) and dosimetry carried out using Harwell Gammachrome YR PMMA dosimeters sealed in aluminium foil/polyethylene laminate sachets. The dose range was 0.47–0.50 kGy h^{-1} for both treatments III and IV, giving a dose uniformity of 1.06. Radiation exposure was 10 min giving a dose range for the fruits of 0.078–0.083 kGy. The mean value of 0.08 kGy has been used throughout the text. Following treatment the cartons were held at 11 ± 1 °C and 80–90% RH for up to 28 days to simulate storage/transport. Subsequently they were exposed to ambient temperature (24 ± 2 °C) for 7 days to simulate retail conditions, during which time typical ripening processes resumed.

2.3. Disease incidence and severity

The combined incidence of anthracnose (*Colletotrichum gleosporioides*), stem end rot (*Botryodiplodia theobromae*) and Rhizopus fruit rot (*Rhizopus stolonifer*) was recorded in each carton and used to calculate the percentage of visibly infected fruits in the entire population. All lesions were included regardless of size. Disease severity was described in terms of the proportion of the fruit surface occupied by lesions with $<5\%$ being acceptable for trading, 5–25% being viewed as tolerable for trade, 25–50% seen as having little possibility of commercial use and $>50\%$ as unusable (Azevedo, 1998).

2.4. Shelf life

Calculated from daily estimates of disease severity on the same 5 fruits from each replicate and considered as ended when the fruits had little or no commercial viability (disease severity $>25\%$)

2.5. Fruit characteristics

All destructive measurements were made on the same 5 randomly-selected fruits from each treatment at each sampling date.

2.5.1. Surface and pulp colour

Surface colour measurements were made after 28 days storage using a CR-300 Minolta ChromaMeter (Minolta Corp., Japan) calibrated against a standard white tile. Measurements were made at the stem and blossom ends and the equator of opposing faces of each fruit and a mean value calculated from measurement of 5 fruits. Measurements were taken avoiding fungal lesions. For the internal colour measurements the same fruits were sliced along the median longitudinal axis and comparable positioning employed on opposing, sliced faces.

To provide data directly linked to consumer perception the *L*, *a*. *b* values generated by the Minolta system were used to calculate the colour difference (ΔE) between treated and untreated fruits using DELTA E for Adobe AIR (Adobe Systems Incorporated, San Jose CA, USA), based on the CIEDE 2000 colour-difference formula of the Central Bureau of the International Committee on Illumination (CIE, 2001; Fraser et al., 2004; Luo et al., 2001). Untreated fruit were used as the colour reference. A ΔE value of 4 indicates a colour difference just evident to most observers when direct and immediate comparison with the colour reference can be made. Values decreasing below 4 indicate differences that are increasingly more difficult to discern, particularly without direct comparison to the colour reference. Values of 5 and above indicate differences evident with recall of, but not direct comparison with, the colour reference.

2.5.2. Firmness

Flesh firmness (in Newtons, N) was measured with a penetrometer (Instron 5543, Instron Corp, USA) using a 6 mm diameter