

Conditioning 'Kensington' Mango with Hot Air Alleviates Hot Water Disinfestation Injuries

Keryl Jacobi

Horticulture Postharvest Group, Queensland Department of Primary Industries, 19 Hercules Street, Hamilton 4007, Queensland, Australia

Janet Giles

Biometry Section, Queensland Department of Primary Industries, 665 Fairfield Road, Yeerongpilly 4105, Queensland, Australia

Elsbeth MacRae and Teresa Wegrzyn

Postharvest Science Group, Horticulture and Food Research Institute of New Zealand, Mt. Albert Research Centre, Private Bag 92 169, Auckland, New Zealand

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Abstract. In an effort to develop an inexpensive alternative to vapor-heat insect disinfestation of 'Kensington' mango (*Mangifera indica* Linn.), the effect of postharvest hot water treatments (HWT) on fruit quality was determined. Fruit were given 46C HWT for 30 minutes at a fruit core temperature of 45C either 24 hours after harvest or after various conditioning treatments of 4 to 24 hours at 39 ± 1C in air. Fruit were compared to nontreated fruit after a subsequent 7 days at 22C. The HWT increased fruit softening and reduced chlorophyll fluorescence and disease incidence. The longer conditioning times produced softer fruit. Conditioning reduced damage to the fruit caused by HWT. Preconditioning for ≥8 hours resulted in <1% of fruit being damaged as shown by cavities, skin scald, and starch layer formation. The quantitatively measured higher mesocarp starch content paralleled the visible starch layer injury. Skin yellowing increased in response to HWTs that were not damaging to the fruit. Fruit ripening changes were unequally affected by HWT and by conditioning before HWT; thus, the sequence and extent of these changes must be determined to establish a reliable and useful hot water disinfestation treatment.

Heat disinfestation treatments have been tested on Australian-grown 'Kensington' mango as a possible substitute for fumigation treatments for fruit fly disinfestation (Heather et al., 1991; Jacobi and Wong, 1992, 1993). Vapor heat successfully disinfested 'Kensington' mango from Queensland fruit fly (*Bactrocera tryoni* Frogatt) and Mediterranean fruit fly (*Ceratitis capitata* Wiedemann) without causing damage to the fruit (Jacobi and Wong, 1992, 1993). However, facilities for such treatments are costly to establish. Hot water disinfestation is less expensive and has been developed and tested for various tropical horticultural crops, including mango (Jacobi and Wong, 1991, 1992; Nascimento et al.,

1992; Sharp et al., 1989a, 1989b, 1989c). The treatment window between successful insect kill and loss of fruit quality is normally narrow. 'Kensington' mango damage symptoms due to excessively long exposure to hot water include skin scalding, external cavities, starch layer and starch spot development in the mesocarp, internal cavities, and uneven ripening (Jacobi and Wong, 1991; Joyce et al., 1993; Smith and Chin, 1989). The fruit core temperature that must be reached and maintained for a specific exposure time is crucial to kill larvae found in situ. Hence, fruit surface temperatures are maintained at water temperature for a longer period than the core. A conditioning treatment of 7 h at 37C (at the fruit core) in hot air with a subsequent water heat treatment of 25 min at 47C (at the fruit core) resulted in less fruit damage than when fruit were immediately subjected to 47C (Joyce et al., 1993). Preliminary experiments on conditioning of fruit after harvest before hot water treatment indicated that exposure to between 38C and 40C for ≤24 h alleviated fruit damage due to hot water treatment (HWT) (K.J., unpublished data). Therefore, we evaluated the effects of varying exposures to conditioning temperatures before a fixed-length HWT on the quality of fruit after ripening.

Commercially harvested 'Kensington' mangoes (Holmes et al., 1990) were selected randomly from two orchards at Ayr (lat. 19°S); four at Mareeba (lat. 16°S); and four at Childers (lat. 25°S), Australia. Fruit were transported within 24 h by air or road to Brisbane, Australia, at ambient temperatures (25 to 35C). Uniform, unblemished fruit (380 to 440 g) were selected, and a tray (an experimental unit) of either 16 or 20 fruit were assigned to a range of treatments. Fruit were kept at either 22C continuously or exposed to 0, 4, 8, 16, or 24 h at 39 ± 1C, followed by a 46C HWT until the fruit core was at 45C, where it remained for 30 min. Then, fruit were air-dried, placed into cartons, and stored for 7 days at 22C (at 90% to 95% relative humidity). Conditioning was performed in a forced-air, computer-controlled chamber (chamber volume 0.29 m³; airflow 2 m·s⁻¹, air 39 ± 1C; relative humidity 80%) that allowed the fruit to reach a uniform core temperature (39 ± 1C) within 2 h, followed by holding for the required time in a constant-temperature cabinet. HWT was performed as described by Jacobi and Wong (1992). Fruit were assessed after 7 days at 22C.

Color was assessed subjectively on a scale from 1 to 6 (where 1 = fruit fully green; 2 = tinge yellow; 3 = 25% of surface area showing yellow; 4 = 50% yellow; 5 = 75% yellow; and 6 = fruit fully yellow) and objectively using a spectroradiometer (labscan 6000; Hunter Associates Lab, Reston, Va.) fitted with a 25-mm orifice, D65 illuminant, and 10 degree observer. Hunter L, a, and b values were recorded on both sides of each fruit, and hue angle and chroma were calculated (McGuire, 1992). Fruit firmness was measured to a 2-mm penetration depth using an Instron universal testing machine (model 1122; Instron, Buckinghamshire, England) with an 8-mm spherical probe. Total solids (TS) were determined according to the Association of Official Analytical Chemists' methods (1984). The presence of skin scalding, internal cavities, starchy areas, and disease were noted. Overall fruit marketability was assessed subjectively on a scale from 1 to 9 (where 1 = highly unacceptable; 3 = moderately unacceptable; 5 = marginally acceptable; 7 = moderately acceptable; and 9 = highly acceptable). Fruit chlorophyll fluorescence was measured on both sides of the fruit using a plant productivity fluorometer (model SF30; Brancker, Ottawa, Canada) after 1 h of pre-equilibration in darkness and expressed as $F^v/F^m \times 100\%$.

For starch analysis, a group of five fruit was considered an experimental unit. From all Mareeba and Childers sites, five fruit at harvest and per treatment were subsampled (except the 16-h conditioning treatment), frozen in liquid N, and stored at -20C until analyzed. Starch analysis was performed using the amyloglucosidase assay (Boehringer Mannheim, 1979) as modified by Bowen et al. (1988) using corn amylopectin as the standard. Starch content was expressed as milligrams per gram of fresh weight.

Data were tested by analysis of variance

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for a split-plot design. For comparing production regions, the grower was the experimental unit, and the production region effect was tested against variability among growers within regions. For comparing treatments and the interaction between production region and treatment, a tray of 16 or 20 fruit (or a group of five fruit in the case of starch analyses) was the experimental unit. These effects were tested using the interaction between treatments and growers within regions as the error term. All statistical testing was carried out at $P = 0.01$. For the variables disease incidence, skin scalding, cavities, and starch layer, the angular transformation was applied before analysis.

The treatment effect was partitioned into orthogonal comparisons. Nontreated fruit were compared with the average of the hot-water-treated fruit. The effect of conditioning time for the HWTs was split into linear, quadratic, and lack-of-fit components. Before fitting the polynomials, conditioning time was square-root transformed. The quadratic component was not significant for firmness, so only linear and lack-of-fit components were fitted. Neither quadratic nor linear components were significant for disease incidence, so polynomials are not presented for this variable. For all other variables, the quadratic fit was significant. The treatment \times region interaction was similarly partitioned. For the polynomials fitted, only two of the regions \times polynomial components interactions were significant. In both these cases, the interaction was of minor importance, so interactions are not presented. Dunnett's procedure was used to compare nontreated with each of the heat treatments.

Results and Discussion

HWT alone significantly reduced the marketability score of the fruit, but this effect was overcome by conditioning for ≥ 4 h (Fig. 1). Fruit from Ayr and Mareeba (rated 6.9 and 6.3, respectively) were more marketable than fruit from Childers (rated 5.4). The marketability score was influenced by color (ripeness), fruit firmness, degree of damage resulting from HWT, and presence of disease. There was no difference in TS (overall mean 15.7%) among fruit of different origins or treatment. All HWT fruit were significantly softer than nontreated fruit (Fig. 1), with fruit becoming softer with longer conditioning periods. HWT did not affect the fruit color rating, but conditioning did. Maximum color rating, minimum hue angle, maximum chroma values, and maximum reflectance were achieved after conditioning for 7 to 8 h. The intermediate conditioning treatments may have increased the enzyme activity associated with chlorophyll breakdown (e.g., chlorophyllase) in the mango skin, similar to the rapid chlorophyll breakdown in heat-treated cucumbers (*Cucumis sativus* L.) associated with the activation of the degreening system involving the enzyme chlorophyllase (Chan and Linse, 1989). Extending the conditioning period to 24 h may have partially inactivated this enzyme system. The production region had an effect on fruit color, with fruit from Childers (color rating

4.2) being greener than fruit from Ayr or Mareeba (5.2 and 5.3, respectively).

HWT (with or without conditioning) reduced fruit chlorophyll fluorescence (Fig. 2). This result parallels the findings of Smillie et al. (1987), where heat stress applied to fruit decreased induced fluorescence. Minimum fluorescence was produced after 5 h of conditioning. These differences paralleled those of the skin color rating (Fig. 1) and may result from less chlorophyll in the fruit peel, therefore lowering chlorophyll fluorescence. The less yellow fruit from Childers also had a higher chlorophyll fluorescence value (25.1)

than fruit from either Ayr (14.3) or Mareeba (14.9). The chlorophyll fluorescence measurements did not provide a measure of skin scalding but did indicate that the fruit had experienced heat treatment. Potential applications of this technique may include detection of changes in fruit skin due to applied temperature treatments or ripening. Without conditioning, 73% of the HWT fruit developed scalding. Conditioning reduced scalding severity, and after ≥ 8 h, $<1\%$ of the fruit had scalded (Fig. 2). There was no difference in the extent of scalding among fruit from different regions (data not shown).

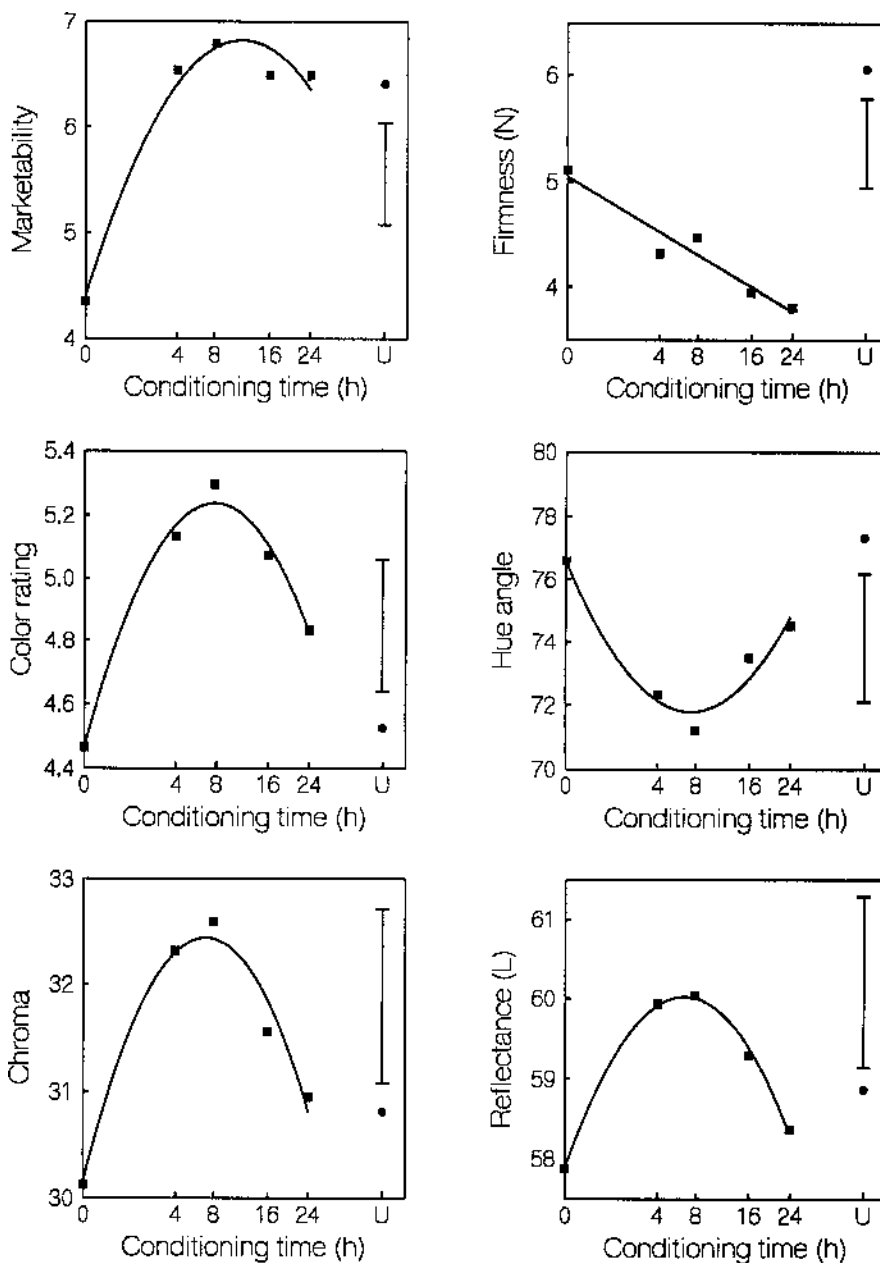


Fig. 1. Effect of conditioning in $39 \pm 1\text{C}$ air for 0 to 24 h, followed by hot water treatment (HWT) (fruit core of 45C held for 30 min in 46C water) on 'Kensington' mango marketability, firmness, color rating, hue angle, chroma, and reflectance. Fruit were assessed after an additional 7 days at 22C . Marketability is rated using a 1 to 9 scale, where 1 = highly acceptable, 5 marginally acceptable, and 9 = highly acceptable. Color is rated using a 1 to 6 scale, where 1 = fully green, 4 = 50% of surface area showing yellow, and 6 = fruit fully yellow. U = untreated. The height of the bars is the size of difference required for individual HWTs to be significantly different from the untreated (Dunnett's procedure).

Conditioning reduced the severity of HWT damage expressed as either cavity formation or the presence of starchy areas in the fruit (Fig. 2). Conditioning for 8 h was sufficient to reduce the incidence of both forms of damage to acceptable (<1% of fruit) levels. Measurements of starch content confirmed this trend. Fruit contained high starch levels at harvest (35.9 mg·g⁻¹ fresh weight), and these levels degraded following harvest. Fruit subjected to HWT without preconditioning retained the most starch at the time of fruit assessment and had the most severe starch layer disorder. Starch content declined with conditioning time, and after conditioning but before HWT, it had reached levels similar to that of nontreated

fruit. There was no difference among regions in starch content and HWT damages (data not shown).

HWT reduced the incidence of the two main diseases—anthracnose [*Colletotrichum gloeosporioides* (Penz.) Penz. & Sacc.] and stem-end rot [*Dothiorella dominicana* Petrak et Cif. and *Lasiodiplodia theobromae* (Pat.) Griff. & Maubl.]—with all HWTs averaging 1% disease incidence compared to 7% for nontreated fruit. Conditioning had no effect on disease incidence. Disease incidence in these experiments was low and did not differ among regions (data not shown).

Conditioning mangoes with hot air alleviates heat and cold injuries. Joyce et al. (1993)

found that conditioning 'Kensington' mango at 37C for 7 h before a HWT that held the core at 47C for 25 min did not impair fruit softening or skin color change, but largely ameliorated the heat injuries of starchy areas and internal cavities. During fruit ripening, there was some repair of mesocarp injury. Our heat treatments differed from those used by Joyce et al. (1993), and these differences may explain the differences in fruit response obtained with the same mango cultivar. For example, Joyce et al. (1993) wrapped fruit in plastic before conditioning fruit over 7 h to a fruit core temperature of 37C using 37C air. We, however, rapidly increased the fruit core temperature to 38C to 40C using 40C air over 2 h and maintained that temperature for certain periods. Conditioning 'Keitt' mango at 38C for 0, 24, or 48 h has been tested to alleviate chilling injury associated with storage at 5C for 11 days (McCollum et al., 1993). The heating reduced rind pitting and discoloration and caused fruit to soften slightly faster, thus correlating with our findings.

The success of our conditioning treatments in alleviating mango heat injuries may be due partly to the mechanism of fruit ripening. Partial ripening of fruit before heat disinfection treatments or cool storage ameliorates damage. Smith and Chin (1989) found that surface scalding of several mango cultivars after HWT of 42 to 48C for 30 to 90 min was greatly reduced if fruit were treated 24 or 48 h after harvest rather than immediately after harvest. This period between harvest and treatment would have allowed partial ripening to occur and may have contributed to injury reduction. Whitaker (1994) suggested that under certain conditions heat treatment (38C for 3 days) of tomato (*Lycopersicon esculentum* Mill.) fruit may not reduce chilling injury as effectively as partial ripening (20C for 3 days).

Conditioning of 'Kensington' mango shows potential to reduce the heat injuries incurred by the fruit as a result of hot water disinfection treatments. Partial or accelerated ripening of the mango fruit may be the mechanism through which the conditioning treatments are being effective. The effects of heat conditioning (40C for a number of hours) or simply holding fruit at ambient temperature (to allow partial ripening), both followed by HWT, on fruit ripening and injury need to be compared. Confirmation that these treatments satisfy quarantine restrictions also is required before an effective treatment can be established commercially.

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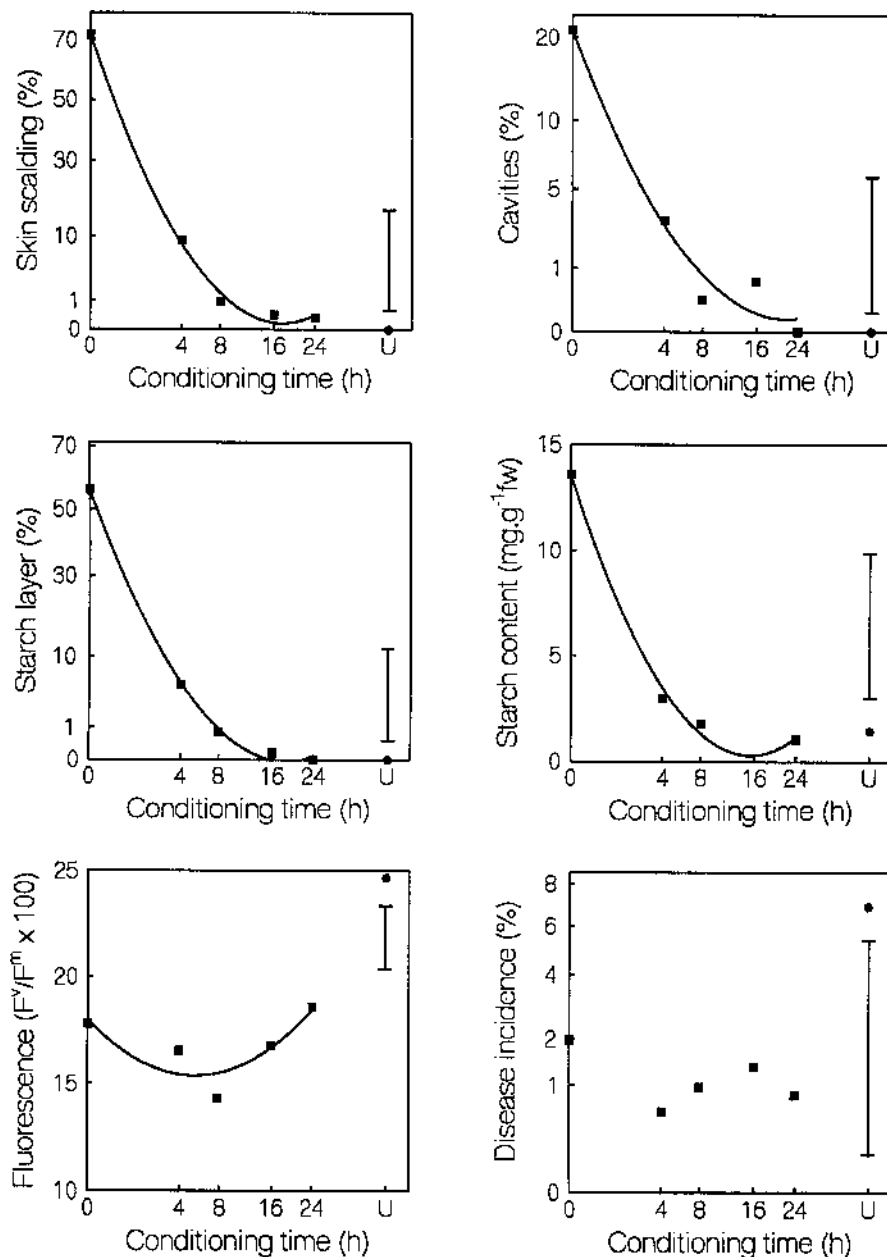


Fig. 2. Effect of conditioning in 39 ± 1C air for 0 to 24 h, followed by hot water treatment (HWT) (fruit core of 45C for 30 min in 46C water) on 'Kensington' mango skin scalding, cavities, starch layer, starch content, chlorophyll fluorescence, and disease incidence. Fruit were assessed after an additional 7 days at 22C. U = untreated. The height of the bars is the size of difference required for individual HWTs to be significantly different from the untreated (Dunnett's procedure).

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