High-temperature Conditioning Reduces Hot Water Treatment Injury of ‘Kensington Pride’ Mango Fruit

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Abstract. Mango (*Mangifera indica* L.) fruit can be injured by heat disinfestation protocols imposed to kill insects. We determined if mango fruit have the capacity to acclimate, thereby becoming more tolerant of heat disinfestation treatments. Conditioned ‘Kensington Pride’ mango fruit (7-hour heating-up period to a 37C core temperature maintained for ≤12 hours) showed less pulp injury on ripening following hot water treatment (1.5 hours for previously conditioned fruit to 2 hours for fruit not previously conditioned) than fruit not conditioned before hot water treatment. During treatment, the core reached 47C and was maintained for 25 minutes. Extending the conditioning period by ≤12 hours beyond the 7-hour heating-up period (total of 19 hours) gave no additional benefit. Conditioning did not consistently reduce peel injury that was hot water treatment-induced as indicated by irreversible loss of chlorophyll variable fluorescence.

Mango is an important fruit crop in the Australian tropics and subtropics, and there is potential for export of Australia’s main cultivar Kensington Pride to Japan. However, Queensland fruit fly (*Bactrocera tryoni* Froggatt) and other fruit flies are endemic in Australian mango production areas (Heather et al., 1991), which makes postharvest quarantine control necessary. Fumigants, such as ethylene dibromide, are effective, but their use has been curtailed because of consumer health risks associated with residues.

Heat treatment is an alternative to chemical disinfestation of mangoes (Heard et al., 1990; Heather et al., 1991). Submerging mangoes in 46C water for 75 or 90 min, depending on mango size, effectively disinfests them of a variety of internal fruit fly pests (Sharp et al., 1989a, 1989b). However, such hot water treatments can lead to fruit injury (Jacobi and Wong, 1992). Conditioning at elevated temperature (≈37C) for hours to days can acclimate plant tissues to become more tolerant of high-temperature stress (Anderson et al., 1990; Lafuente et al., 1991; Lester, 1986; Lin et al., 1984). Papaya fruit have been acclimated successfully against heat stress (Paull and Chen, 1990).

Commercial adoption of conditioning for mangoes depends on showing that the response is effective and reproducible. Accordingly, our objectives were to determine 1) how long ‘Kensington Pride’ mangoes need to be conditioned in 37C forced air to acclimate so that a 47C hot water dip did not injure fruit and 2) if the acclimation response was consistent in ‘Kensington Pride’ mangoes from diverse

growing regions and various harvest times during the season in one region.

Materials and Methods

Fruit. ‘Kensington Pride’ mangoes were harvested from three successively cooler growing regions where fruit mature at progressively later dates: Darwin (Northern Territory), Ayr (northern Queensland), and Nambour (Yandina and Palmwoods sites in southern Queensland). Fruit from the two former regions were air-freighted to the Brisbane laboratory. Fruit from Nambour were selected at harvest for size and maturity uniformity and transported by car. For both forms of transport, fruit were harvested in the morning and arrived at the laboratory on the same day. Treatments commenced the same evening that they arrived. Darwin fruit were used in two successive seasons (1990–91 and 1991–92). Fruit from the other regions were used only in the second season. Two farms provided Nambour fruit; at one, fruit was once-over harvested from blocks of trees (Yandina), and at the other, there were multiple harvests from individual trees (Palmwoods).

Fruit were first “desapped” (peduncle removed and fruit held upside down to allow the sap to drain) to minimize sappy injury and associated fungal decay. Then, they were placed in the evaluation and ripening room at 22C.

Treatments. Two experimental designs were adopted. First, various conditioning times, each followed by hot water treatment, were compared with controls (no treatment and hot water only) to determine the effective conditioning period. Second, using a single conditioning treatment, the responses of fruit from different regions and of varying harvest time within regions were evaluated in factorial experiments where the treatments were no con-

ditioning or conditioning (–/+c) and no hot water or a hot water treatment (–/+h). We conducted three conditioning time experiments (one with 1991–92 Darwin fruit and two with Yandina fruit) and seven factorial experiments (one with 1990–91 Darwin fruit, one with Ayr, three with Yandina, and two with Palmwoods fruit). For the 1991–92 season, harvest times were assigned relative to day 0 for the initial Darwin fruit harvest.

Conditioning was performed by wrapping fruit in plastic cling wrap (11-μm-thick, low-density polyethylene) (Gladwrap; Glad Products of Australia, Rhodes) and holding them in a nonhumidified, fan-forced, 37C incubator (HLS Scientific, Sydney) for the 7-h heating-up period (the time for the core temperature of the fruit to rise from 22 to 37C) plus the following periods: 0, 3, 6, or 12 h at 37C. The 1991–92 Darwin harvest was an exception; 2 and 7 h were used in place of 3 and 6 h, respectively. Film wrapping was adopted to avoid peel desiccation, and to minimize possible variation in fruit temperature associated with uneven air flow (velocity not measured) and varying disruption of the unstirred boundary layer around fruit in different parts of the incubator. Film wraps may have resulted in atmosphere modification within fruit, especially at elevated temperatures; therefore, we chose a thin film to minimize this effect (Ben-Yehoshua and Cameron, 1989).

The hot water treatment was applied by submerging naked fruit in stirred 47C water baths. Fruit were held in the hot water bath for 25 min after the pulp temperature next to the seed reached 47C. The heating-up period was 2 h for fruit heated from 22 to 47C. The heating-up period for conditioned fruit at 37C to reach 47C on transfer to hot water was 1.5 h. Thus, fruit that were conditioned before hot water treatment were in the hot water for 30 min less than those subjected to the hot water treatment only. Temperature was monitored with thermocouples (Digi-Temper 3527 with type K thermocouples; Tsuruga Electric Works, Osaka, Japan).

Measurements. Fruit firmness was recorded daily and final fruit condition was evaluated on the day after all fruit in one treatment of an experiment were judged to be edibly ripe (i.e., had a hand firmness score ≥7 for 2 days). Except where hot water treatments disrupted normal ripening, fruit ripening within treatment lots (e.g., nontreated control fruit) was uniform. Hand firmness, peel color, peel disorders, pulp color, and pulp disorders were evaluated subjectively using the following scales: hand firmness, 1 = hard, 3 = firm, 5 = slightly soft, 7 = soft (edible), and 9 = very soft (overripe); peel color, 1 = green, 2 = breaker, 3 = 1/4 color change, 4 = 1/2 color change, 5 = 3/4 color change, and 6 = full color change (Jobin-Decor, 1988); peel disorders, 1 = none, 3 = slight, 5 = moderate, 7 = severe, and 9 = extreme; pulp color, 0 = white, 1 = pale yellow, 2 = clear yellow, and 3 = bright orange; and pulp disorders—the same as peel. Skin wrinkle and dark discoloration were typical peel disorders. In the pulp, inhibited starch breakdown was confirmed by starch-iodine staining.

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Fruit were weighed, and weight loss was expressed as a percentage of initial fresh weight (after desapping). Change in peel chlorophyll fluorescence is a useful, nondestructive index of heat-induced peel damage (Schreiber and Bilger, 1985) and was measured in the second season (1991–92) with a PAM 101, 103 fluorometer (Walz, Effeltrich, Germany) for F_0 [all photosystem II reaction centers open (oxidized)] and F_m [all photosystem II reaction centers closed (reduced)]. Fruit were held in darkness for 30 min before measurement, and variable fluorescence ($F_v = F_m - F_0$, where F_m is maximum fluorescence and F_0 background fluorescence) and the $F_v : F_m$ ratio were calculated (Smillie et al., 1987).

The respiration of the fruit from Palmwoods was measured before and after treatment. Individual fruit were sealed in 600-ml glass preserving jars held at 22°C. Carbon dioxide accumulation was measured using a gas chromatograph with a thermal conductivity detector (model 111; Carle Instruments, Anaheim, Calif.) and a 2.5-m-long, 3-mm-outside-diameter stainless steel column packed with Porapak Q.

Completely randomized experiment designs were used with 10 fruit per treatment. Data were tested by analysis of variance (ANOVA) (one-way or 2×2 factorial ANOVA models, as appropriate), using MSTAT-C software (MSTAT Development Team, 1989).

Results and Discussion

Visible symptoms of peel injury induced by the hot water treatment included translucence, shriveling, dimples, brown discoloration, and decay. Visible symptoms of pulp injury were starchy bands of variable thickness (often occupying the whole mesocarp), small starch islands near the seed, and air-filled voids at the stem end and near the seed. Inhibition of starch degradation was confirmed by iodine staining for starch of fruit exposed to the various treatments. The symptoms reported resemble the spongy tissue and rice disorders that Lizada et al. (1984) described for 'Carabao' mango and stem-end cavity that Bagshaw and Brown (1989) described for 'Kensington Pride' mango.

Conditioning times. Darwin 1991–92 fruit (day 0) were exposed to no treatment (control; -c, -h), hot water treatment (-c, +h), and conditioning for 0 [7-h heating-up time only (heating up + 0 h), +h], 2 (heating up + 2 h, +h), 7 (heating up + 7 h, +h), and 12 h (heating up + 12 h, +h) followed by hot water treatment. No significant ($P \leq 0.05$) differences between any of the six treatment regimes were recorded for firmness (softening), peel color, final weight loss, peel disorders, pulp disorders, or pulp color (data not shown). Hot water treatment in the absence and presence of prior conditioning caused a significant ($P \leq 0.05$) decrease (from 0.75 to ≈ 0.67) in the $F_v : F_m$ ratio. This decrease was related to a transient increase in F_0 and a decrease in F_v . An increase in F_0 , mostly reversible on cooling, is characteristic of transient heat-induced injury of thylakoid membranes (Schreiber and Bilger, 1985).

Fig. 1. Effect of conditioning in 37°C forced air for heating-up (+c, core temperature increased from 22 to 37°C over 7 h) and holding periods of 3 (+3c), 6 (+6c), and 12 h (+12c), followed by hot water treatment (+h, 47°C pulp temperature maintained for 25 min), on (A) mango fruit firmness, (B) chlorophyll fluorescence F_0 , and (C) the $F_v : F_m$ ratio values [fruit from Yandina (day 49 harvest)]. Vertical bars show SE.

Fruit harvested on day 49 at the Yandina site, which were subjected to a 47°C hot water treatment without prior conditioning (-c, +h), failed to soften normally (Fig. 1A). These fruit had a rubbery texture 1 day after the hot water treatment. Conditioned, hot-water-treated fruit (e.g., +c, +h) softened slightly faster than the nontreated control fruit (-c, -h). There was a tendency for final weight loss to be highest for hot-water-treated fruit, whether conditioned or not (Table 1, A). External (peel) and inter-

nal (pulp) color development was retarded in hot-water-treated fruit (-c, +h) that exhibited extensive peel and pulp disorders (Table 1, A). Conditioning before the hot water treatment largely prevented peel and pulp disorders associated with the hot water treatment. Hot water treatment caused a significant ($P \leq 0.05$) increase in F_0 , which tended to decline with time after treatment (Fig. 1B). The $F_v : F_m$ ratio was decreased by the hot water treatment (Fig. 1C), reflecting a sustained reduction in F_v . Hot

water treatment effects on chlorophyll fluorescence were not ameliorated to a significant ($P \leq 0.05$) extent by prior conditioning.

Fruit harvested on day 70 at the Yandina site were also used to assess the influence of conditioning time (Table 1, B). However, in contrast with fruit harvested on day 49 at that farm (Fig. 1A) and regardless of prior conditioning treatments, hot water treatment of fruit harvested later and from different trees had no significant ($P \leq 0.05$) effect on the mango softening rate compared to nontreated control fruit (data not shown). For the later Yandina harvest, weight loss was higher for all fruit exposed to the hot water treatment than for nontreated controls (Table 1, B). Unlike fruit harvested on day 49 from Yandina (Table 1, A), the peel and pulp of hot-water-treated fruit colored normally with or without prior conditioning, but peel disorders induced by hot water treatment were not ameliorated by conditioning (Table 1, B). Pulp disorders, however, were less in fruit conditioned before hot water treatment (Table 1, B). F_0 and the $F_v : F_m$ ratio (data not shown) were increased and decreased, respectively, due to hot water treatment with and without prior conditioning, similar to data recorded for fruit harvested on day 49 from Yandina (Fig. 1).

Our experiments indicate that, where hot water treatment caused pulp injury, a 7-h heating-up period to 37°C in forced air before a 47°C hot water treatment effectively reduced pulp, but not peel, injury (Table 1). Conditioning for the heating-up period alone was as effective as exposure to 37°C for the heating-up period plus 3-, 6-, or 12-h periods (Table 1).

Factorial experiments. The results of the six factorial experiments (–/+c, –/+h) conducted in the 1991–92 season are combined in Figs. 2 and 3. Results of a 7th factorial experiment conducted in the preceding season (1990–91) with Darwin fruit are not presented in these figures but are discussed. Comparable data from the day 49 and day 70 conditioning time experiments (1991–92 season) with Yandina fruit are included for completeness (Figs. 2 and 3). The additional treatment of +c,–h was imposed only for the 1991–92 Darwin harvest (day 0), the first of the three conditioning time experiments.

Results of the factorial (–/+c, –/+h) experiments on mangoes from Darwin (1990–91, data not shown), Ayr (day 27), Yandina (days 51, 58, and 65), and Palmwoods (days 72 and 79) were generally similar and supported observations for the two Yandina conditioning time experiments (days 49 and 70). The exception was the Darwin fruit harvested from 1991 to 1992 (day 0), for which hot water treatment with or without prior conditioning had no differential effect on any of the measured attributes of fruit condition, compared to nontreated control fruit (Fig. 2).

In the 1990–91 and all six (harvest days 27, 51, 58, 65, 72, and 79) of the 1991–92 factorial experiments and two (harvest days 49 and 70) of the three conditioning time experiments (Fig. 2A), hot water treatment resulted in greater weight loss than no treatment or conditioning alone. Weight loss was generally not reduced

Table 1. Effect of prior conditioning in 37°C air on weight loss and peel and pulp appearance of hot-water- (47°C) treated mango fruit produced at Yandina.

Treatment ^y	Wt loss (%)	Peel rating ^z		Pulp rating ^z	
		Disorders	Color	Disorders	Color
A. Fruit harvested 7 Jan. 1992 (day 49)					
–c, –h	9.5 b ^a	1.6 b ^a	3.8 ab ^x	1.0 c ^x	2.1 b ^x
–c, +h	12.0 a	7.2 a	2.9 b	7.4 a	0.8 c
+c, +h	10.6 ab	2.0 b	3.9 a	2.8 b	2.7 ab
+3c, +h	11.1 ab	2.4 b	4.3 a	1.8 bc	2.9 a
+6c, +h	12.1 a	2.2 b	4.3 a	2.2 bc	2.9 a
+12c, +h	11.6 a	1.8 b	4.0 a	1.4 bc	2.9 a
B. Fruit harvested 28 Jan. 1992 (day 70)					
–c, –h	8.8 d	1.0 b	4.6 a	1.0 b	2.3 a
–c, +h	12.5 c	4.6 a	4.1 a	5.0 a	1.7 a
+c, +h	15.4 a	5.8 a	4.9 a	1.8 b	1.8 a
+3c, +h	14.8 ab	5.6 a	4.8 a	1.0 b	1.6 a
+6c, +h	15.1 a	6.2 a	4.6 a	2.2 b	2.1 a
+12c, +h	12.9 bc	5.4 a	4.6 a	1.8 b	2.0 a

^zRatings were based on the following scales: peel disorders, 1 = none, 3 = slight, 5 = moderate, 7 = severe, and 9 = extreme; peel color, 1 = green, 2 = breaker, 3 = 1/4 color change, 4 = 1/2 color change, 5 = 3/4 color change, and 6 = full color change; pulp disorders—the same as peel disorders; pulp color, 0 = white, 1 = pale yellow, 2 = clear yellow, and 3 = bright orange.

^y–c = not conditioned, –h = not hot water treated; +c = 7 h heating up in core temperature from 22 to the 37°C conditioning temperature; +3c, +6c, and +12c = 3, 6, and 12 h at 37°C following the 7-h heating-up period; +h = submersion in 47°C water until a core temperature of 47°C was reached and maintained for 25 min.

^xMean separation within columns and harvest dates by Tukey's HSD test at $P \leq 0.05$ (MSTAT Development Team, 1989).

Fig. 2. Effect, measured on ripening for nine consecutive harvests [days 0 (fruit from Darwin), 27 (Ayr), 49 (Yandina), 51 (Yandina), 58 (Yandina), 65 (Yandina), 70 (Yandina), 72 (Palmwoods), and 79 (Palmwoods)] over the 1991–92 season, of conditioning in 37°C forced air for a heating-up period of 7 h (+c, core temperature increased from 22 to 37°C) followed by hot water treatment (+h, 47°C pulp temperature maintained for 25 min) on (A) mango fruit weight loss (percent), and ratings for (B) peel color, (C) peel disorders, (D) pulp disorders, (E) pulp color and (F) firmness. Vertical bars show SE. In D, data for +c,–h are identical to (i.e., symbols are hidden) data for –c,–h.

by prior conditioning for hot-water-treated fruit.

Similarly, in six (1990–91 harvest; harvest days 27, 51, 58, 72, and 79) of the seven factorial experiments and two (harvest days 49 and 70) of the three conditioning time experiments, hot water treatment alone resulted in fruit with poorer peel color. The exception was fruit harvested on day 65, when control fruit (–c,–h) also colored poorly (Fig. 2B). Conditioning tended to counter the adverse effects of hot water treatment on peel color, but not consistently. Heat-induced peel disorders were not ameliorated by conditioning in five (harvest days 51, 58, 65, 72, and 79) of the seven factorial experiments (Fig. 2C). The exceptions were Darwin fruit harvested in the 1990–91 season and fruit harvested on days 27 and 49 (a conditioning time experiment), where conditioning before hot water treatment markedly reduced peel damage but did not prevent it.

Where pulp disorders were caused by hot water treatment, the disorders were markedly reduced by conditioning—viz in the 1990–91 harvest and factorial experiments conducted on harvest days 27, 51, 58, 65, 72, and 79 and in two (harvest days 49 and 70) of the three conditioning time experiments (Fig. 2D). The hot water treatment resulted in poorer pulp color in five (days 27, 51, 58, 72, and 79) of the six 1991–92 factorial experiments and in one (harvest day 49) of the three conditioning time experiments (Fig. 2E), possibly due to impaired carotenoid synthesis. Pulp color scores for conditioned hot-water-treated fruit were generally higher (better color) and fruit were softer than hot-water-treated mangoes that were not conditioned.

Hot water treatment alone resulted in failure of fruit to soften normally in five (1990–91 harvest; harvest days 27, 51, 72, and 79) of the seven factorial experiments and in two (harvest days 49 and 70) of the three conditioning time experiments. The exceptions were fruit from day 58 and 65 harvests, where there was no difference between control (–c,–h) and hot-water-treated (–c,+h) fruit (Fig. 2F). Hot water treatment alone caused a sudden slight firmness loss (cf. Fig. 1A), followed by slow softening that later became more rapid in two of the six 1991–92 factorial experiments (data not shown). There was a general tendency (six of the seven factorial experiments) for fruit that were conditioned and then hot water treated to soften the fastest. When the results for hot-water-treated fruit (–c,+h) (i.e., damaged fruit) were disregarded, nontreated fruit softened the slowest in four of the seven factorial experiments.

In all six 1991–92 factorial and the three conditioning time experiments, hot water treatment caused an immediate increase in F_0 (Fig. 3A). In the cases of two factorial experiments (days 72 and 79), F_0 remained elevated throughout the shelf-life period (data not shown). Otherwise, there was a general trend for F_0 to decline with a second increase for hot-water-treated mangoes (cf. Fig. 1B) toward the end of the experiments (Fig. 3B). The $F_v:F_m$ ratio was reduced by hot water treatment in all experi-

ments (Fig. 3C) and did not recover during shelf life in five (harvest days 51, 58, 65, 72, and 79) of the six factorial and two (harvest days 49 and 70) of the three conditioning time experiments conducted in the 1991–92 season (Fig. 3D).

Respiration was lowest in nonconditioned, hot-water-treated fruit (Fig. 4). Conditioned fruit and those conditioned before hot water treatment had respiration patterns similar to control fruit—both had a marked respiratory rise during ripening.

One possible mechanism of fruit acclimation to heat is that heat shock proteins appear during conditioning to protect fruit from subsequent heat treatment (Paull and Chen, 1990).

In our experiments, fruit from Darwin were less sensitive to hot water treatment than fruit from more southern areas. The hotter growing conditions at Darwin may have resulted in fruit being already acclimated, as Paull and Chen (1990) reported for papaya.

We have shown that 'Kensington Pride' mango fruit can acclimate at elevated temperature (37°C), resulting in reduced pulp injury (Fig. 2) following a subsequent hot water disinfestation treatment (47°C). The conditioning, however, was not sufficiently ameliorative to completely eliminate pulp disorders (Fig. 2) or to consistently prevent peel injury (Figs. 2 and 3) caused by the hot water treatment.

Fig. 3. Effect of conditioning in 37°C forced air for a 7-h heating-up period (+c, core temperature increased from 22 to 37°C), followed by hot water treatment (+h, 47°C pulp temperature maintained for 25 min), on mango fruit peel chlorophyll fluorescence measured immediately after heat treatment [(A) F_0 , (C) $F_v:F_m$ ratio] and on fruit ripening [(B) F_0 , (D) $F_v:F_m$], measured for nine consecutive harvests [days 0 (fruit from Darwin), 27 (Ayr), 49 (Yandina), 51 (Yandina), 58 (Yandina), 65 (Yandina), 70 (Yandina), 72 (Palmwoods), and 79 (Palmwoods)] over the 1991–92 season. Vertical bars show SE.

Fig. 4. Respiratory drift for nontreated control (–c,–h), conditioned (+c,–h), hot-water-treated (–c,+h), and conditioned and hot-water-treated (+c,+h) mango fruit harvested from Palmwoods on day 79 (cf. Figs. 2 and 3). Vertical bars show SE (n = 3).

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