Quality and Disease Incidence of 'Waimanalo Solo' Papaya following Forced-air Heat Treatments

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Abstract. Papaya fruit (*Carica papaya* L. cv. Waimanalo Solo), at color break ripeness, were either not heated (controls) or forced-air heated to center temperatures of 47.5, 48.5, or 49.5 °C, and held at these temperatures for 20, 60, 120, or 180 minutes. Following heat treatment, fruit were hydrocooled until reaching a center temperature of 30 °C, treated or not treated with prochloraz, allowed to ripen at 26 °C and then assessed for quality. Treatment at 48.5 °C or 49.5 °C for ≥60 minutes was associated with skin scalding. No significant scald was observed in other treatments or in the controls. Both control and heat-treated fruit had relatively high levels of decay. Heat treatment increased the incidence of body rots but did not affect the incidence of stem-end rots. Prochloraz treatment significantly reduced the incidence of decay. With the inclusion of a prochloraz treatment to control postharvest decay, fruit tolerated treatments of 47.5 °C for up to 120 minutes, and 48.5 °C and 49.5 °C for 20 minutes with no significant damage. Chemical name used: 1-*N*-propyl-*N*-(2-(2,4,6-(trichlorophenoxy)ethyl)-1*H*-imidazole-1-carboxamide (prochloraz).

Papaya grown in the Cook Islands must be subjected to a quarantine treatment to control the fruit fly species *Bactrocera melanotus* (Coquillett) and *B. xanthodes* (Broun) before shipment to New Zealand. Prior to 1994, ethylene dibromide (EDB) fumigation was used for this purpose. However, the setting of a maximum residue level for EDB of 0.1 ppm by the New Zealand Health Dept. in 1994 (Knox, 1992) effectively prevented the use of this fumigant as a postharvest treatment for papaya, thus necessitating the development of an alternative quarantine treatment.

Heat treatments have potential for controlling a number of pests and diseases on various horticultural crops (Couey, 1989; Paull, 1990). A forced hot air disinfestation protocol has been established for controlling *Ceratitis capitata* (Wiedermann), *Bactrocera cucurbitae* (Coquillett), and *Bactrocera dorsalis* (Hendel) in papaya 'Kapoho Solo' exported from Hawaii to the U.S. mainland (Armstrong et al., 1995). The effectiveness of this treatment indicated that hot air could also have potential

for disinfesting Cook Island papaya. However, in the Cook Islands, the fruit fly species differ from those found in Hawaii, and the papaya cultivar ('Waimanalo Solo') is larger than the Hawaiian export cultivar Kapoho Solo, thus necessitating the development of a new heat treatment schedule. Waddell et al. (1997) investigated the efficacy of a range of hot air treatments in controlling *B. melanotus* and *B. xanthodes*. One treatment found to be effective involved ramping fruit center temperature from ambient to 47.0 °C over a minimum period of 3 h, and maintaining this temperature for a period of 20 min. Fruit were subsequently cooled under a shower of water (≈22 °C) until fruit center temperature was reduced to 30 °C or less. For commercial quarantine treatment, target temperature specifications are applied to the largest fruit in a load, positioned at the coldest locations in the heat treatment chamber (National Agricultural Security Service, 1993). We have found that during treatment in a commercial heat treatment chamber, smaller fruit and those positioned at warmer locations in the chamber can reach temperatures higher than that specified by the quarantine treatment (Waddell et al., 1997). This overheating could reduce fruit quality.

The objective of the present study was to evaluate the effect of forced hot air disinfestation treatments, over a range of temperatures and durations likely to be experienced under commercial heat treatment conditions, on the quality of 'Waimanalo Solo' papaya fruit. In addition, the effect of treating fruit with the fungicide prochloraz after heat treatment was investigated.

Fruit. 'Waimanalo Solo' papaya fruit were harvested at color break ripeness from a commercial orchard in Rarotonga, Cook Islands, and held at 25 °C overnight. Fruit weighing 1.0 ± 0.05 kg, were heated in a computer-controlled, experimental high-temperature forced-air (HTFA) heat chamber to a fruit center temperature of 47.5, 48.5 or 49.5 °C, and held at these temperatures for 20, 60, 120, or 180 min. Fruit typically reached target temperature in 6 to 7 h. Fruit center temperatures were monitored during heat treatment using thermistor temperature probes inserted into the seed cavity of selected fruit (one fruit per treatment combination per replicate). Probed fruit were discarded after treatment. Relative humidity was maintained at ≈60% by injection of steam. To avoid condensation on the fruit, steam was not injected during the first h of treatment. Air speed was maintained at 4 m·s⁻¹ for all the HTFA runs and air-flow direction was reversed every 15 min.

Immediately following heat treatment, fruit were weighed to determine mass loss and, within 5 min, hydrocooled with water (≈22 °C) until fruit center temperature was reduced to 30 °C (≈70 min). Following hydrocooling, fruit were either immersed in a solution of prochloraz (0.025%) (Sportak 45 EC) for 30 s or not treated, allowed to dry overnight at 25 °C in air, packed in cardboard export cartons and allowed to ripen at 26 ± 1 °C. For each temperature treatment, a set of control fruit was held at 25 °C during treatment, placed under the hydrocooling shower for 70 min, either treated with prochloraz or not treated, and allowed to ripen as indicated for heat-treated fruit.

Fruit were assessed when ripe by external color (90% to 100% yellow) and fruit firmness (as judged by resistance to slight finger pressure on the fruit). Time to ripen, incidence and severity of external and internal disorders and decay, flesh firmness (fruit pressure tester, 11-mm head; Effegi, Alfonsine, Italy) and soluble solids concentration (SSC) (electronic refractometer; Atago Co., Tokyo) were determined. Severity of disorders and decay were rated on a subjective scale of 0 to 3 (0 = disorder absent, 1 = slight, 2 = medium, and 3 = disorder severe). The incidence of a factor was defined as the percentage of fruit exhibiting a severity rating >0. An informal taste test involving six people was also carried out at the time of assessment. Fruit were subjectively rated on a scale of 0 to 10 where 0 = very unacceptable and 10 = very acceptable.

Experimental design and statistical analysis. The experimental design was a 3 × 5 × 2 factorial with three fruit center temperatures (47.5, 48.5, or 49.5 °C), five durations of heat treatment [0 (no heat treatment), 20, 60, 120, 180 min] and two prochloraz treatments (0% and 0.025%). Each treatment combination (temperature/duration/prochloraz) consisted of three replicates of seven fruit, each replicate being a separate heat unit run. Results were analyzed using multifactorial analysis of variance. For analysis, percentage data (*p*) were

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transformed using an angular [$\arcsin \sqrt{p}$] transformation. For clarity, only percentage data are presented.

Results

Fruit mass loss measured immediately after hot air treatment increased with increasing length of heat treatment, and ranged from 0.8% for a 20-min treatment at center temperature of 47.5 °C, to 1.9% for a 180-min treatment at 49.5 °C (Table 1). Nonheated controls had 0% mass loss. The average time for fruit to ripen ranged from 6.2 to 9.7 d depending on treatment. In general, as treatment temperature increased, days to ripen increased, al-

though, at 49.5 °C for 120 and 180 min without prochloraz, mean number of days to ripen was less than for the equivalent treatments at 47.5 and 48.5 °C. Fruit firmness at time of assessment decreased as treatment temperature increased. At 49.5 °C, fruit firmness decreased with increasing treatment time. Informal taste tests suggested that the 47.5, 48.5, and the shorter 49.5 °C (up to 60 min) treatments had no significant effect on fruit taste (Table 1). However, fruit treated for 120 and 180 min at 49.5 °C developed off-flavors, particularly in the absence of prochloraz. No significant difference was observed in color development or SSC (overall mean = 11.7% $\pm$ 0.1%) between treated and control fruit (data not shown).

No scald (external browning) was observed in the nontreated control fruit (Table 1). The incidence of scald increased with increasing temperature and duration, with 49.5 °C treatments at 120 and 180 min having the highest levels of scald. A low incidence of scald was observed in the 60-min 47.5 °C treatment with no prochloraz; however, there was no scald in the other 47.5 °C treatments up to 120 min, or in the 48.5 and 49.5 °C treatments for 20 min. The severity of scald also increased with increasing treatment temperature and duration (data not shown). Hard lumps, unripened flesh in ripe fruit (Armstrong et al., 1989), were observed in 4.8% of fruit treated at 49.5 °C for 60 min without prochloraz and in 14.3% of

Table 1. Mass loss, flesh firmness, days to "ripen," taste, and incidence of disorders for 'Waimanalo Solo' papaya fruit as affected by heat treatment, with (+) or without (-) subsequent prochloraz treatment.

	Temp (°C)	Treatment duration ² (min)	Mass loss ³ (%)	Days to “ripen”	Flesh firmness (N)	Taste ^x	Scald (%)	Body rots (%)	Stem-end rots (%)	Undamaged (%)
Prochloraz	47.5	0 ^w	0.0	7.5	30.6	6.0	0.0	0.0	47.6	48.8
–		20	0.8	7.7	36.3	6.5	0.0	19.0	47.6	30.5
		60	0.9	8.3	42.5	6.3	4.8	23.8	52.4	33.3
		120	1.1	8.2	45.6	6.5	0.0	23.8	47.6	41.3
		180	1.3	8.3	48.9	6.3	9.5	9.5	42.9	51.6
		Mean	0.8	8.0	40.8	6.3	2.9	15.2	47.6	41.1
	48.5	0	0.0	8.3	29.0	5.9	0.0	19.0	47.6	42.9
		20	0.8	8.4	18.8	6.2	0.0	30.2	71.4	19.0
		60	1.1	9.5	31.3	6.2	11.1	33.3	55.6	34.9
		120	1.8	9.2	32.4	5.9	48.4	52.4	73.8	16.7
		180	1.4	8.2	21.1	6.3	73.8	76.2	64.3	23.3
		Mean	1.0	8.7	26.5	6.1	26.7	42.2	62.5	27.4
	49.5	0	0.0	9.5	34.2	5.7	0.0	14.3	52.4	38.1
		20	1.1	8.8	19.3	6.4	0.0	33.3	81.0	10.3
		60	1.2	9.2	14.6	6.0	52.4	71.4	61.9	4.8
		120	1.6	6.9	ND	5.1	100.0	100.0	61.9	0.0
		180	1.9	6.2	ND	5.4	100.0	100.0	33.3	0.0
		Mean	1.2	8.1	22.7	5.7	50.5	63.8	58.1	10.6
	Mean (–)		1.0	8.3	30.0	6.1	26.7	40.4	56.1	26.4
+	47.5	0	0.0	8.9	31.5	5.8	0.0	0.0	9.5	90.5
		20	0.9	8.4	37.2	6.1	0.0	9.5	9.5	81.0
		60	0.9	9.4	50.3	6.3	0.0	4.8	4.8	90.5
		120	1.2	9.2	62.9	6.3	0.0	0.0	4.8	95.2
		180	1.4	8.7	55.6	6.2	14.3	0.0	0.0	85.7
		Mean	0.9	8.9	47.5	6.1	2.9	2.9	5.7	88.6
	48.5	0	0.0	8.9	38.9	6.1	0.0	0.0	0.0	100.0
		20	0.9	9.5	42.5	6.5	0.0	4.8	4.8	90.5
		60	1.5	9.3	48.8	6.1	0.0	15.1	0.0	84.8
		120	1.2	9.5	44.8	6.3	19.0	4.8	4.8	71.4
		180	1.6	9.4	31.8	6.1	85.7	23.8	4.8	14.3
		Mean	1.0	9.3	41.4	6.2	21.0	9.7	2.9	72.2
	49.5	0	0.0	9.0	47.0	6.2	0.0	4.8	0.0	95.2
		20	1.1	9.5	35.8	6.6	0.0	4.8	0.0	95.2
		60	1.2	9.3	43.3	6.0	47.6	33.3	6.7	47.6
		120	1.6	9.7	17.8	6.2	90.5	66.7	15.1	9.5
		180	1.9	8.3	6.9	5.6	100.0	95.2	5.6	0.0
		Mean	1.2	9.2	30.2	6.1	47.6	41.0	5.5	49.5
	Mean (+)		1.0	9.1	39.7	6.2	23.8	17.8	4.7	70.1
LSD _{0.05}			0.5	1.3	25.2	0.7	28.4	27.7	35.3	34.9
Significance										
Prochloraz			NS	NS	NS	NS	NS	*	*	*
Temperature			NS	*	*	NS	*	*	NS	*
Time (duration)			***	NS	NS	*	***	***	NS	***
Prochloraz × temp			NS	NS	NS	*	NS	NS	NS	*
Temp. × time			NS	***	***	*	***	***	NS	*
Prochloraz × temp × time			NS	NS	NS	NS	NS	NS	NS	*

²Time at fruit center target temperature.

³Determined immediately following treatment.

^xTaste subjectively rated on a scale of 0 to 10 (0 = very unacceptable, 10 = very acceptable).

^w0 = Control fruit held at 25 °C during treatment.

ND = not determined (fruit were too decayed).

NS, *, ***Nonsignificant or significant at $P \leq 0.05$ or 0.001, respectively.

fruit treated at 49.5 °C for 180 min with prochloraz (data not shown). White rice-like spots in the fruit flesh, termed 'ricy spot' (Jacobi and Wong, 1992), were only observed in 7.1% of the fruit treated at 49.5 °C for 180 min with prochloraz (data not shown). These two disorders were not found in the other treatments or in the controls.

A high incidence of body and stem-end rots occurred in both controls and heat-treated fruit in the absence of prochloraz treatment (Table 1). The incidence of body rots, due mainly to *Colletotrichum gloeosporioides* (Penzig) Penzig and Saccardo, increased with increasing temperature and duration of treatment. There was no effect of heat treatment on the incidence of stem-end rots due to *Phoma exigua* (Desm.). A post-heat treatment immersion in prochloraz reduced the incidence of rots, particularly stem-end rots, in both control and heat-treated fruit. Decay was significantly reduced with prochloraz treatment in the controls, the 47.5 °C treatments, and the 20-min treatments at 48.5 and 49.5 °C. The incidence of decay in the longer 48.5 and 49.5 °C treatments was higher but, with the exception of the 49.5 °C, 180-min treatment, was still significantly lower with prochloraz treatment than without.

In the absence of prochloraz, the mean percent undamaged fruit at 47.5 °C remained relatively constant over treatment time, ranging from 30.5% to 51.6%, and was not significantly different from that of the controls. At 49.5 °C, and to a lesser extent at 48.5 °C, the percentage of undamaged fruit decreased initially with increasing length of treatment time and then leveled off. With the inclusion of prochloraz, the percentage of undamaged fruit at 47.5 °C ranged from 81.0% to 95.2%, and again was not significantly different from controls. For the 48.5 and 49.5 °C treatments, the percentage of undamaged fruit decreased with increasing treatment duration.

Discussion

Fruit from the 47.5 °C and the shorter 48.5 °C treatments tended to soften more slowly and were firmer at the time of assessment than nonheated controls (Table 1). A delay in softening by heat treatment has previously been observed in papaya fruit (Chan et al., 1981). These workers subjected papaya fruit to hot water treatment at 46 °C and reported a heat-associated delay in softening, which was correlated with a decrease in polygalacturonase (PG) activity. Polygalacturonase is an enzyme which catalyzes the hydrolysis of pectins, a component of plant cell walls. Heat treatment has also been reported to maintain firmness in apples, possibly because of heat inhibition of cell-wall degrading enzymes (Klein and Lurie, 1990). In the present study at the highest temperature (49.5 °C), papaya fruit tended to

have a lower fruit flesh firmness than control fruit at the 90% to 100% yellow stage. The high levels of damage and decay in fruit treated at 49.5 °C may have contributed to their accelerated softening.

Heat treatment of papaya was associated with skin scalding (Table 1). This has also been observed following hot air treatment of other crops, including nectarines (Lay-Yee and Rose, 1994) and persimmons (Woolf et al., 1997). No significant scald developed on fruit heated to a center temperature of 47.5 °C and held at that temperature for up to 120 min (Table 1). The incidence of scald increased as treatment temperature increased, especially at durations longer than 60 min.

In general, heat treatment did not affect the incidence of stem-end rots but was associated with an increased incidence of body rots (Table 1). Although heat treatments are effective in controlling postharvest diseases in various crops (Couey, 1989), enhanced susceptibility to decay has been observed in mango (McGuire, 1991) and nectarines (Lay-Yee and Rose, 1994). This phenomenon may reflect reduced resistance of fruit tissue to attack by certain decay organisms following specific heat treatments. Nishijima et al. (1992) reported that a hot-air treatment of 48.5 °C for 3 to 4 h, in which the fruit center temperature reached 47.2 °C, did not significantly affect the incidence of postharvest diseases in 'Kapoho Solo' papaya. These workers reported that treatment with thiabendazole following the hot air treatment significantly reduced the level of decay, but resulted in increased fruit damage in the form of 'lumpy fruit' (hard lumps). In the present work, immersion in prochloraz following heat treatment markedly reduced the incidence of both body and stem-end rots, without detrimental effects on fruit quality. Hard lumps were only observed in a small percentage of fruit from two of the higher temperature treatments (49.5 °C, 60 min without prochloraz; 49.5 °C, 180 min with prochloraz). The reason for the differential effect in terms of fruit damage is not known, although fruit treated by Nishijima et al. (1992) were stored at 10 °C prior to ripening whereas fruit in the present study were not.

The response of papaya fruit to heat treatment may vary depending on season, with fruit being the most susceptible to injury during cooler periods (Paull, 1995). The results reported here represent work carried out in spring, although our preliminary studies carried out in late winter indicated a similar response (data not shown).

In conclusion, our results indicate that, with the inclusion of a prochloraz treatment to control postharvest decay, 'Waimanalo Solo' papaya fruit tolerated treatments with a center temperature of 47.5 °C for up to 120 min, and 48.5 and 49.5 °C for 20 min with no significant damage. These treatments are effective in con-

trolling the quarantine fruit fly species *B. melanotus* and *B. xanthodes* (Waddell et al., 1997).

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