Ripening Behavior and Quality of ‘Brazilian’ Bananas following Hot Water Immersion to Disinfest Surface Insects

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Abstract. The fruit quality and ripening response of ‘Brazilian’ bananas (*Musa* sp., group AAB) were determined following hot water immersion treatments for surface disinfestation. Summer-harvested fruit were exposed to 47, 49, or 51 °C water for 10, 15 and 20 minutes and ripened at 20 °C. The summer experiment established the exposure time and temperature limits for fruit injury. Winter-harvested fruit were immersed in 48, 49, or 50 °C water for 5, 10 and 15 minutes, stored for 12 d at 14 °C, and ripened at 22 °C. The hot water exposure time had a greater effect than the water temperature on banana fruit ripening. Nontreated bananas ripened after 13 to 15 d, and ripening was delayed by 2 to 7 d when fruit were exposed for 15 or 20 minutes to hot water. Hot water treatments did not inhibit pulp softening, but peels tended to be firmer for bananas immersed in 49 to 51 °C water than control fruit. Heat-treated bananas were not different from control fruit in soluble solids content or titratable acidity, however the conversion of starch to sugars was reduced at higher temperatures and exposure times. Bananas exposed for 20 minutes to hot water had delayed respiratory peaks and ethylene production, especially at 51 °C. Mild peel injury was observed on fruit exposed to higher temperatures (49 to 51 °C) for longer durations (15 or 20 minutes).

Fifteen to twenty percent of global banana production is traded internationally, and most bananas are of the Cavendish subgroup (*Musa* sp., AAA). Producing countries grow and consume a variety of domestic types that are genetically diverse (diploid, triploid, and tetraploid) (Turner, 1997). In Hawaii, the ‘Brazilian’ banana (*Musa* sp., group AAB), locally called the apple banana, is grown widely and marketed within the state (Simmonds, 1954). ‘Brazilian’ bananas had a farm gate value of \$4.3 million in 2001 (Hawaii Agricultural Statistics Service, 2002). The fruit can be exported at the mature green stage under a nonhost quarantine status for Mediterranean [*Ceratitis capitata* Wiedemann], melon [*Bactrocera cucurbitae* (Coquillett)], and oriental fruit flies [*Bactrocera dorsalis* (Hendel)] (Armstrong, 1983; 2001). However, quarantine inspections for the presence of “hitchhiker” surface insects can delay or impede the shipment of bananas, and lead to postharvest losses. The possible rejection of a shipment due to the presence of one or more surface insects poses a high financial risk for growers. Hot water immersion treatments are being investigated for disinfesting bananas from surface insects, especially the coconut scale [*Aspidiotus destructor* (Signoret)], a quarantine pest for bananas exported to Cali-

fornia from Hawaii. In preliminary studies, a 48.2 °C hot water treatment for 12.5 min killed coconut scales on the surface of bananas (unpublished data).

Hot water has been used more widely for postharvest disease control than for insect control (Couey, 1989). However, hot water immersion treatments have been developed to disinfest bananas, papayas (*Carica papaya* L.), longans (*Dimocarpus longan* Lour.), lychees (*Litchie chinensis* Sonn.), guavas (*Psidium guajava* L.), and mangoes (*Mangifera indica* L.) from tephritid fruit flies (Armstrong, 1982; Couey and Hayes, 1986; Follett and Sanxter, 2002; Follett and Sanxter, 2003; Gould and Sharp, 1992; Sharp and Spalding, 1984). Armstrong (1982) found that a 50 °C hot water immersion for 15 min was an effective quarantine treatment against Mediterranean, oriental and melon fruit flies without detriment to either banana appearance or shelf life if the fruit were at the unripe stage 1 or stage 2 (Del Monte, 1992). Riper fruit (stages 3 to 7) showed peel scalding. Reyes et al. (1998) found that exposing banana fruit to 50 °C hot water for 20 min reduced crown rot (*Chalara paradoxa*) incidence to <3%. Exposure to hot water at 55 °C for 10 min or longer caused severe skin scald and a failure to soften. Scald generally occurred on fruit treated at 50 °C when exposure time was 30 min or longer, and there were seasonal differences in the severity of fruit injury. Except for scald, no physiological and quality responses to hot water immersion were determined in these studies.

The objectives of this study were to determine the quality and fruit ripening patterns of ‘Brazilian’ bananas following hot water immersion treatments for surface disinfestation.

Experiment 1. Bananas (*Musa* sp., ‘Brazilian’, ‘apple’, AAB group) were harvested on 1 May, 10 July, and 21 Aug. 2002 from an orchard near Keaau, Hawaii. Only mature green (stage 1) fruit were selected. Two bunches were selected at each harvest date, for a total of six bunches. A bunch represented a block for statistical analyses. Three hands were removed from the middle of each bunch and labeled. The hands were transported immediately to the laboratory and cut into clusters with four fruit per cluster.

The clusters from a bunch were randomly assigned to 10 treatments (described below). One finger was removed from each cluster and placed into 2-L glass jars with lids fitted with septa. After 2 h, gas samples were removed for initial respiration and ethylene measurements. Carbon dioxide evolution was determined with an infrared gas analyzer (model 6600; Illinois Instruments, Johnsonburg, Ill.), and ethylene was measured using a gas chromatograph (model 5830A; Hewlett Packard) fitted with an alumina column and a flame ionization detector.

Degree of ripeness was assessed on peel color using an industry scale of 1 (dark green), 2 (green, trace of yellow), 3 (half green-half yellow), 4 (three quarters yellow with green), 5 (yellow with green tip), 6 (full yellow), and 7 (yellow with black spots) (Del Monte, 1992). In addition, surface color measurements were taken at three positions per fruit for all fingers in a cluster with a chromameter (model CR-300; Minolta Corp., Ramsey, N.J.) and recorded as lightness (L^*), chroma (C^*), and hue angle (H°) under standard illuminant C.

Hot water immersion treatments were applied to the fruit clusters on the morning after harvest. Fruit clusters were placed in plastic mesh bins (16.5 × 26 × 6.3 cm) with lids. The bins had openings over at least 60% of the surface area for water circulation through the bins. The water bath was heated with immersion circulators (model 73; Polyscience, Niles, Ill.). The water temperature was monitored continuously with thermistors and a datalogger (OmniData International, Inc., Logan, Utah). There were 10 treatments: 9 hot water treatments (3 temperatures × 3 times) plus a control. The treatments were selected to establish the upper limits that caused fruit injury, while remaining within a range of temperatures that may kill surface insects. Fruit were immersed in 47, 49, or 51 °C hot water for 10, 15, and 20 min. All fruit were immediately cooled in 24 °C water for 20 min following hot water treatment. Control fruit were not immersed in hot water. After treatment, fruit were air dried and placed at 20 °C to ripen.

Respiration, ethylene, and surface color measurements were repeated on the fingers 1 d following hot water treatment and every 2 d, thereafter, until the fruit had reached stage 6 of the ripeness scale. At that time, final nondestructive measurements were made, and destructive measurements for firmness, percent soluble solids, starch content, and sugar concentrations were conducted. Firmness was measured using a force gauge (Ametek, Largo, Fla.) having an 8-mm-diameter probe,

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Table 1. Composition of summer-harvested 'Brazilian' bananas following hot water immersion treatments and ripening at 20 °C.

Treatment	Days to ripening ^z	Concn (mg·g ⁻¹ fresh wt)				
		Starch ^y	Sucrose	Glucose	Fructose	Total
Control	13.1 a ^x	51.3 a	99.4 a	25.8 ab	18.7 a	143.9 a
47 °C, 10 min	14.4 abc	72.6 abc	96.3 a	21.7 abc	15.7 abc	133.7 a
15 min	14.3 abc	53.7 ab	97.2 a	26.8 a	19.4 a	143.4 a
20 min	16.1 bcd	80.0 bc	89.8 a	21.6 abc	15.2 abc	126.6 a
49 °C, 10 min	14.2 ab	75.6 abc	86.2 a	22.3 abc	16.1 abc	124.6 a
15 min	16.5 cd	58.8 ab	85.0 a	23.7 ab	17.3 ab	126.0 a
20 min	17.2 d	91.1 c	89.1 a	19.0 bc	13.9 bc	122.0 a
51 °C, 10 min	14.6 abc	75.3 abc	90.4 a	22.1 abc	15.8 abc	128.3 a
15 min	16.9 d	88.9 c	85.2 a	23.1 abc	16.7 ab	125.0 a
20 min	19.9 e	97.2 c	82.1 a	16.6 c	12.1 c	110.8 a

^zAverage number of days to reach stage six maturity (full yellow). Values are means for 24 observations.

^yStarch and sugar values are means of six replications, with a composite sample of four bananas per replication.

^xMeans within columns followed by the same letter are not significantly different ($P > 0.05$) according to the Waller Duncan k ratio t test.

and mounted on a motorized test stand. The peak force (kg) was measured at a penetration depth of 7 mm, and the data were converted to Newtons (N). A 10-g sample of pulp was homogenized with 10 g water for 1 min, and the soluble solids of the liquid was measured with a refractometer (Atago, Kirkland, Wash.).

For starch and sugar determinations, pulp (10 g) from four fruits was combined in a test tube and homogenized in 80% ethanol for 1 min at high speed. The slurry was immediately boiled for 15 min, cooled, and filtered through Whatman #4 paper. The filter cake was rinsed with additional ethanol, and dried for 48 h at 70 °C to obtain the alcohol insoluble solids (AIS) for starch analysis. The sugar extract was brought to a final volume of 100 mL with 80% ethanol. A 5-mL aliquot was filtered through a 0.22 µm membrane filter into vials for high pressure liquid chromatography (HPLC).

HPLC was used to separate and quantify glucose, fructose, and sucrose in the banana samples. Carbohydrates were analyzed by injecting 20 µL of sample into an Agilent 1100 series liquid chromatograph (Agilent Technologies, Wilmington, Del.) with premixed HPLC-grade water (25%) and acetonitrile (75%) as the mobile phase, and an aminopropylsilane column as the stationary phase (Agilent ZORBAX carbohydrate analysis column, 4.6 mm ID × 150 mm, 5 µm), followed by an Agilent refractive index detector. A flow rate of 1.4 mL·min⁻¹ was used, and the column and detector temperatures were set at 30 °C. The mobile phase was vacuum filtered through a 0.45-µm membrane filter before use.

Sucrose, glucose, and fructose standards were prepared at five concentrations ranging from 250 to 2000 µg·mL⁻¹ to calibrate the HPLC. Carbohydrate peaks of the samples were identified according to HPLC retention times in comparison with authentic standards. For recovery tests, samples were spiked with standard solutions before extraction. The detection limit for each sugar was 1 µg, and the recovery was 95%.

Starch was determined by combining 30 mg of AIS with 10 mL distilled water, and heating at 100 °C in a water bath for 90 min (Hagenimana et al., 1994). A soluble starch standard was included also. After cooling, 5 mL of 0.01 M sodium acetate (pH 4.5) containing

10 units/mL of amyloglucosidase was added to each sample and the standard. The test tubes were incubated at 55 °C for 30 min. Following enzymatic hydrolysis, the total reducing sugars were measured using the method of Blakeney and Mutton (1980).

Experiment 2. Fruit for Expt. 2 were harvested in the winter (7 Jan. and 11 Feb. 2003) from an orchard in Pepeekeo, Hawaii. Mature green (stage 1) fruit were destined for the mainland market and were harvested 1 week earlier than fruit for local market. Fruit were sampled and prepared for hot water immersion treatments in the same manner as for Expt. 1. However, based on the results of Expt. 1 and preliminary studies with coconut scales, the ranges of temperatures and exposure times were narrowed. The hot water immersion treatments were 48, 49, or 50 °C for 5, 10, and 15 min. Fruit were immediately cooled in 24 °C water for 15 min. Control fruit were immersed in 24 °C water for 15 min.

Following treatment, the fruit were stored for 12 d at 14 °C and 89% relative humidity (RH) to simulate shipping and distribution on the mainland. Fruit were stored in plastic bags with perforations, designed for bananas, and placed into cardboard boxes. After storage, the fruit were ripened at 22 °C.

All quality evaluations and analytical methods were the same as in Expt. 1, however destructive analyses were performed when the fruit reached stage 7. In addition, a peel

injury rating was assigned to each finger after treatment and during ripening. The percentage of the surface area showing a brownish discoloration was estimated visually, and a rating scale of 0 = 0%, 1 = 1% to 20%, 2 = 21% to 40%, 3 = 41% to 60%, 4 = 61% to 80%, and 5 = 81% to 100% was used. Fruit weight loss and titratable acidity also were measured in Expt. 2. Titratable acidity was determined by titration with 0.01 N NaOH and calculated as malic acid equivalents.

Statistics. Data for destructive measurements were subjected to analysis of variance using the general linear models (GLM) procedure (SAS Institute, 1999) for a randomized complete block design, with six blocks for Expt. 1 and four blocks for Expt. 2. A block consisted of one bunch of fruit. Data for non-destructive measurements were analyzed for repeated measures over time using the GLM procedure. The Waller-Duncan k ratio t test was used for means separations.

Results and Discussion

Experiment 1. Postharvest heat treatments can delay or disrupt fruit ripening, and the degree of impact depends on exposure temperature and duration (Paull and Chen, 2000). In Expt. 1, the hot water exposure time had a greater effect than the treatment temperature on banana fruit ripening. Bananas exposed for 10 min to 47, 49, or 51 °C hot water ripened

Table 2. Firmness and color of summer-harvested 'Brazilian' bananas following hot water immersion treatments and ripening at 20 °C.

Treatment	Stage of ripeness ^z	Firmness (N) ^y		Peel color ^x	
		Peel	Pulp	L*	Hue (°)
Control	6.0 a ^w	22.19 a	4.97 a	70.1 ab	89.6 a
47 °C, 10 min.	6.1 a	28.06 ab	5.28 a	70.1 ab	89.4 ab
15 min.	6.2 ab	25.77 ab	4.81 a	70.5 a	89.6 a
20 min.	6.4 b	28.15 ab	5.24 a	69.4 abc	89.0 abc
49 °C, 10 min.	6.2 ab	26.57 ab	5.28 a	69.4 abc	89.6 a
15 min.	6.4 b	28.50 ab	4.96 a	69.0 bc	88.6 bcd
20 min.	6.2 ab	37.31 cd	6.61 a	68.2 c	88.0 cd
51 °C, 10 min.	6.0 a	31.09 bc	5.24 a	70.0 ab	89.4 ab
15 min.	6.3 b	30.99 bc	6.54 a	68.2 c	87.8 d
20 min.	6.7 c	43.70 d	8.25 a	63.9 d	85.1 e

^zMean stage of ripeness when destructive analyses were performed. Stage of ripeness was assessed on peel color using a scale of 1 = dark green, 2 = green with a trace of yellow, 3 = more green than yellow, 4 = more yellow than green, 5 = green tip, 6 = fully yellow, and 7 = yellow with black spots. Values are means of 24 observations.

^yValues are means of 24 observations.

^xLightness (L*) is on a scale of 0 to 100. A hue angle of 90° = yellow. Values are means of 24 observations.

^wMeans within columns followed by the same letter are not significantly different ($P > 0.05$).

Fig. 1. Carbon dioxide (A and C) and ethylene (B and D) production of summer-harvested 'Brazilian' bananas immersed in 47, 49, and 51 °C hot water for 10 (A and B) or 20 (C and D) min.

at a similar rate as control fruit (Table 1). Ripening was delayed by 3 to 7 d when fruit were exposed for 20 min to 47, 49, or 51 °C hot water treatments. Ripening was incomplete for some individual fingers treated for 20 min at 51 °C. Nontreated 'Brazilian' bananas ripened after 13 d (Table 1). This is similar to 'Dwarf Brazilian' bananas that ripened in 14 d at 20 °C (Paull, 1996).

Treatments differed in their effects on banana peel firmness ($P = 0.0001$), but not pulp firmness ($P = 0.22$) (Table 2). Fruit exposed to 49 °C water for 20 min or 51 °C for 10 to 20 min had firmer peels than control fruit (Table 2). Also, peel scalding and darkening were observed only on fruit treated with 51 °C water for 15 or 20 min (data not shown).

Hot water treatments did not affect the total sugar ($P = 0.29$) or sucrose concentrations ($P = 0.55$) of ripening bananas (Table 1). However, the starch concentrations remained higher than control fruit for bananas treated for 15 min at 51 °C, and for 20 min at 47, 49, or 51 °C hot water. Glucose and fructose concentrations were reduced in bananas immersed in 49 or 51 °C hot water for 20 min compared with control fruit.

The respiration rates of bananas exposed for 10 min to 47, 49, or 51 °C water were similar to the rates for nontreated bananas (Figure 1a). Fruit exposed for 20 min to hot water had delayed respiratory peaks and ripening, especially at 51 °C (Fig. 1c). Fruit in treatments exhibiting decreased CO₂ production also tended to have the highest starch and lowest sugar concentrations. The conversion of starch to sugars during banana ripening involves several enzymes and pathways, and requires energy (Seymour, 1993). Exposure to hot water (49 and 51 °C) for 20 min may have inhibited starch hydrolytic enzymes, therefore less carbon was available to enter the glycolytic and gluconeogenic pathways. Also, ripening is dependent on the maintenance of glycolysis to provide energy for sugar synthesis (gluconeogenesis) (Beaudry et al., 1989).

Ethylene production of control fruit peaked after 12 d of ripening (Fig. 1b). Paull (1996) reported that ethylene peaked 10 d after harvest for 'Dwarf Brazilian' bananas ripened at 22.5 °C. Ethylene production was reduced and delayed for bananas immersed in hot water for 20 min, especially at 51 °C (Fig. 1d). High temperature exposure can inhibit ethylene

production in fruits through inactivation of 1-aminocyclopropane-1-carboxylic acid (ACC) synthase and ACC oxidase (Chan, 1986; Ketsa et al., 1999).

Experiment 2. Fruit ripening was delayed by 2 to 6 d in bananas immersed for 15 min in 48, 49, or 50 °C water (Table 3). Control fruit placed at 22 °C ripened 15 d after removal from 14 °C storage, for a total postharvest life of 27 d. 'Dwarf Brazilian' bananas stored 14 d at 15 °C, and ripened at 20 °C, had a similar postharvest life of 28 d (Paull, 1996).

Heat-treated bananas were not different from control fruit in soluble solids content ($P = 0.78$), titratable acidity ($P = 0.64$), and glucose, fructose and sucrose concentrations ($P = 0.19$, 0.21, 0.24, respectively). However, differences among treatments were detected for starch ($P = 0.03$) and total sugar concentrations ($P = 0.02$), indicating that the conversion of starch to sugars was reduced at higher temperatures and exposure times.

The fruit were evaluated at stage 7 ripeness in Expt. 2, because 'Brazilian' bananas are commonly consumed at this stage. Therefore, starch concentrations were lower and sugar concentrations higher in Expt. 2 when compared with Expt. 1. In both experiments, sugar concentrations were high when compared with values reported for 'Cavendish' bananas (*Musa* sp., AAA group). The total sugar concentration of ripe 'Cavendish' bananas was 113.8 mg·g⁻¹ (Li et al., 2002), whereas the sugar concentrations of 'Brazilian' bananas were 143.9 and 177.6 mg·g⁻¹ for summer and winter harvested fruit, respectively (Tables 1 and 3).

In Expt. 2, the respiration rates of control fruit were similar to fruit in Expt. 1, reaching a peak at 138 mg·kg⁻¹·h⁻¹ (Fig. 2a). Carbon dioxide production remained elevated after the climacteric, as described by Beaudry et al. (1989). The respiratory response of fruit exposed for 10 min to hot water also was similar to Expt. 1 (Figs. 1a and 2a). However, there was some delay in the respiratory rise in fruit immersed for 15 min, especially at 50 °C (Fig. 2c). This was not as pronounced as the 20 min exposure to 51 °C water in Expt. 1 (Fig. 1c).

Ethylene production reached peak levels (9.7 to 12.9 µg·kg⁻¹·h⁻¹) 18 d after storage for fruit exposed to hot water for 0 or 10 min (Fig. 2b). Ethylene production was suppressed for bananas exposed to 50 °C water for 15 min

Table 3. Composition of winter-harvested 'Brazilian' bananas following hot water immersion treatments, storage at 14 °C for 12 d, and ripening at 22 °C.

Treatment	Days to ripening ^a	Soluble solids (%) ^b	Titratable acidity (%)	Concn (mg·g ⁻¹ fresh wt)				
				Starch	Sucrose	Glucose	Fructose	Total
Control	15.3 a ^x	25.7 a	0.65 a	4.6 a	114.2 a	31.6 a	31.8 a	177.6 a
48 °C, 5 min	17.5 d	25.4 a	0.60 a	7.6 ab	103.5 a	31.6 a	31.7 a	166.8 ab
10 min	16.0 abc	25.3 a	0.65 a	13.7 bc	101.3 a	26.9 a	26.9 a	155.0 abc
15 min	17.0 bcd	24.9 a	0.66 a	10.9 abc	107.7 a	25.7 a	25.6 a	159.0 abc
49 °C, 5 min	17.3 cd	25.6 a	0.60 a	9.6 abc	95.8 a	29.5 a	29.4 a	154.7 abc
10 min	17.0 bcd	24.8 a	0.65 a	14.3 bc	87.5 a	22.5 a	22.5 a	132.4 c
15 min	17.5 d	24.8 a	0.68 a	15.5 c	92.1 a	21.5 a	21.4 a	135.0 c
50 °C, 5 min	15.8 ab	24.6 a	0.68 a	14.0 bc	86.7 a	23.9 a	23.9 a	134.5 c
10 min	15.8 ab	24.6 a	0.72 a	13.2 bc	97.3 a	22.4 a	22.4 a	142.1 bc
15 min	21.0 e	25.0 a	0.64 a	13.7 bc	99.0 a	28.0 a	28.1 a	155.1 abc

^aAverage number of days to reach stage 6 to 7 maturity following 12 d storage at 14 °C. Values are means for 12 observations.

^bSoluble solids, titratable acidity, starch, and sugar values are means of four replications, with a composite sample of three bananas per replication.

^xMeans within columns followed by the same letter are not significantly different ($P > 0.05$) according to the Waller Duncan k ratio *t* test.

Fig. 2. Carbon dioxide (A and C) and ethylene (B and D) production of winter-harvested 'Brazilian' bananas immersed in 48, 49, and 50 °C hot water for 10 (A and B) or 15 (C and D) min.

(Fig. 2d). Heat treatments more severe than 49 °C for 15 min may compromise the fruit's ability to rapidly recover the protein synthesis necessary for ethylene production.

Bananas lost weight during storage and ripening, and treatment effects were significant ($P = 0.0001$) (Table 4). However, only bananas immersed in 50 °C water for 15 min had greater weight loss (14.9%) than nontreated fruit (11%). Most of the weight loss occurred during ripening when the relative humidity (RH) averaged 70%. Therefore, the vapor pressure deficit was likely too high, and the evaporation rate was excessive during ripening (Turner, 1997). The percent weight loss averaged only 2% to 4% during the storage period when the RH was maintained at 89% (data not shown).

Hot water immersion treatments affected the banana peel firmness ($P = 0.004$) more so than pulp firmness ($P = 0.05$). The 49 and 50 °C treatments for 10 or 15 min durations tended to have firmer peels than the control fruit (Table 4). Control fruit had similar pulp firmness as bananas exposed to any of the hot water treatments. 'Dwarf Brazilian' bananas failed to soften after exposure to 55 °C hot water for 10 min or longer (Reyes et al., 1998). In other fruit, abnormal softening is a symptom of thermal injury during quarantine treatment for fruit fly control (Díaz-Pérez et al., 2001; Paull and Chen, 1990).

Visual ratings for peel injury were different among treatments ($P = 0.001$), but only fruit exposed to 49 or 50 °C for 15 min had more visible discoloration than control fruit (Table

4). The discoloration appeared mostly on the shoulders and ridges of individual fingers and was similar to mild chilling injury symptoms (dull brown or gray, under-peel discoloration). High vapor pressure deficits during ripening can produce peel symptoms similar to chilling injury (Turner, 1997), and this may explain the peel discoloration of the control fruit and some hot water treated fruit. In all cases the visible peel discoloration was mild, such that surface color measurements of ripened fruit were not affected by hot water immersion ($P = 0.11$ for lightness and $P = 0.74$ for hue angle) (Table 4).

Armstrong (1982) reported that banana appearance was not impacted by a 15 min exposure to 50 °C hot water. In another report, scald generally occurred only on bananas immersed in 50 °C water for 30 min or longer, but mild scald was observed on some fruit after a 20 min exposure (Reyes et al., 1998). Bananas exposed to 50 °C hot air for 15 or 30 min had scald on about 10% and 30% of the peel surface area, respectively (Jiang et al., 2002). Higher temperatures (55 °C) caused fruit damage even at short exposure times (Armstrong, 1982; Reyes et al., 1998).

Conclusions

Hot water immersion treatments below 50 °C for <15 min generally did not reduce the quality of 'Brazilian' bananas. Immersion at 48 to 49 °C for 15 min may be an effective quarantine treatment for surface insects, because a 48.2 °C treatment for 12.5 min killed coconut scales on the surface of bananas (unpublished data). In both experiments, bananas exposed to 49 °C water for 15 min ripened 2 to 3 d later than control fruit. Delayed ripening can be an advantage during postharvest handling, especially when fruit are shipped long distance from Hawaii. Exact temperature control would be necessary if a 49 °C treatment for 15 min is used for quarantine purposes, because a 1 °C temperature increase could injure the fruit.

Table 4. Percent weight loss, firmness, and peel characteristics of winter-harvested 'Brazilian' bananas following hot water immersion treatments, storage at 14 °C for 12 d, and ripening at 22 °C.

Treatment	Stage of maturity ²	Wt loss (%) ³	Firmness (N) ⁴		Peel color ⁵		Peel injury rating ⁶
			Peel	Pulp	L*	Hue (°)	
Control	6.5 abc ^u	11.1 a	14.32 a	4.61 ab	71.8 a	89.9 a	1.4 bc
48 °C, 5 min	6.5 abc	12.7 ab	14.39 a	4.76 ab	72.1 a	88.8 a	1.0 a
10 min	6.7 c	12.3 a	16.91 abc	4.98 b	70.3 a	88.3 a	1.1 ab
15 min	6.6 bc	12.4 ab	17.49 abc	4.57 ab	70.6 a	88.1 a	1.6 c
49 °C, 5 min	6.5 abc	12.0 a	15.98 ab	4.49 a	70.6 a	88.3 a	1.4 bc
10 min	6.5 abc	12.1 a	20.73 c	4.83 ab	71.5 a	88.3 a	1.6 c
15 min	6.4 ab	12.6 ab	19.51 bc	4.76 ab	70.4 a	88.1 a	2.1 d
50 °C, 5 min	6.3 a	11.5 a	17.25 abc	4.72 ab	71.0 a	88.6 a	1.4 bc
10 min	6.2 a	11.4 a	19.01 bc	4.74 ab	70.6 a	88.0 a	1.5 c
15 min	6.3 a	14.9 b	18.04 abc	4.45 a	69.6 a	87.8 a	2.1 d

²Mean stage of ripeness when destructive analyses were performed. Stage of ripeness was assessed on peel color using a scale of 1 = dark green, 2 = green with a trace of yellow, 3 = more green than yellow, 4 = more yellow than green, 5 = green tip, 6 = fully yellow, and 7 = yellow with black spots. Values are means of 16 observations.

³Weight loss values are means of four replications, with a composite sample of three bananas per replication.

⁴Firmness values are means of 12 observations.

⁵Lightness (L*) is on a scale of 0 to 100. A hue angle of 90° = yellow. Values are means of 16 observations.

⁶Percentage of the surface area showing discoloration, where a rating of 0 = 0%, 1 = 1% to 20%, 2 = 21% to 40%, 3 = 41% to 60%, 4 = 61% to 80%, and 5 = 81% to 100%. Values are means of 16 observations.

^uMeans within columns followed by the same letter are not significantly different ($P > 0.05$).

More research is needed to determine whether a 10 min exposure to 49 °C water would kill surface insects. This treatment also would insure good fruit quality.

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