Heating Rate and Tolerance of Naturally Degreened 'Dancy' Tangerine to High-temperature Forced Air for Fruit Fly Disinfestation

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Summary. **'Dancy' tangerines (*Citrus reticulata* Blanco) were harvested after color break and exposed to high-temperature forced air (HTFA) at 45C for 3.5 or 4 h to kill Mexican fruit fly [*Anastrepha ludens* (Loew)] larvae. Heat-treated and control fruit were stored subsequently for 2 weeks at 4C. Tangerines harvested after color break (naturally degreened) tolerated exposure to HTFA in a similar fashion as tangerines harvested before color break and degreened by postharvest exposure to ethylene. Titratable acidity (TA) was significantly lower after heat treatments. Flavor, soluble solids concentration, external appearance, incidence of decay, percent juice yield, percent weight change, and flavedo color of heat-treated fruit were not different from nonheat-treated, control fruit. Exposure to HTFA is a viable alternative to methyl bromide for disinfestation of 'Dancy' tangerine.**

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Much of the United States fresh-market supply of 'Dancy' tangerine is grown in or marketed through regions infested with Mexican fruit fly. Because 'Dancy' tangerine is a host for Mexican fruit fly (Leyva et al., 1991), a quarantined insect pest in the United States, tangerines grown or marketed in a region infested with Mexican fruit fly must. be treated according to a U.S. Dept. of Agriculture Animal and Plant Health Inspection Service (USDA-APHIS) approved protocol. Tangerines are fumigated commonly with methyl bromide to ensure quarantine security (USDA, 1990). The Clean Air Act mandates removal of methyl bromide from commercial use in the year 2000 (USDA, 1993). An alternative treatment to methyl bromide fumigation is needed to ensure the availability of tangerines.

The market quality of 'Dancy' tangerines harvested green and gassed postharvest with ethylene was maintained after exposure to 45C forced air for 4 h (Shellie et al., 1993). Postharvest exposure to ethylene gas at 21 C may condition the fruit to tolerate the heat treatment. Houck (1967) reported that citrus tolerated exposure to high temperatures better after curing at 16C. Paull and Chen (1990) reported thermotolerance in papaya subsequent to a conditioning heat shock and associated it with the appearance of stress proteins. If tangerines tolerate insecticidal heat treatments only after previous exposure to a conditioning temperature such as postharvest degreening , then this conditioning treatment must be part of the disinfestation protocol. The purpose of this study was to ascertain whether 'Dancy' tangerine harvested after color break (not exposed to ethylene gas) tolerate a 4-h exposure to 45C forced air.

'Dancy' tangerines were harvested from a commercial orchard near Veracruz, Mexico, three times in 1991 and 1992. Fruit were harvested after color break, at or beyond minimum commercial maturity [soluble solids concentration (SSC) between 8.9% and 10.5% , with a 1% maximum titratable acidity (TA)]. Tangerines were transported in an enclosed van to the USDA/ARS Crop Quality and Fruit Insects Research Unit, Weslaco,Texas. Elapsed time from harvest until exposure to the heat treatments was between 24 and 48 h.

Tangerines were heated in a high-temperature forced-air (HTFA) chamber similar to that described by Sharp et al. (1991). Fruit center and surface temperatures, and chamber temperature, relative humidity (RH), and airflow rate were recorded every 60 s as described by Shellie et al. (1993). Air speed inside the chamber was maintained at 2 $m \cdot s^{-1}$ during the heat treatment. Dewpoint temperature inside the chamber was maintained 2C cooler than the coolest fruit surface temperature to prevent condensation on the fruit surface. Humidity inside the chamber was maintained by steam injections.

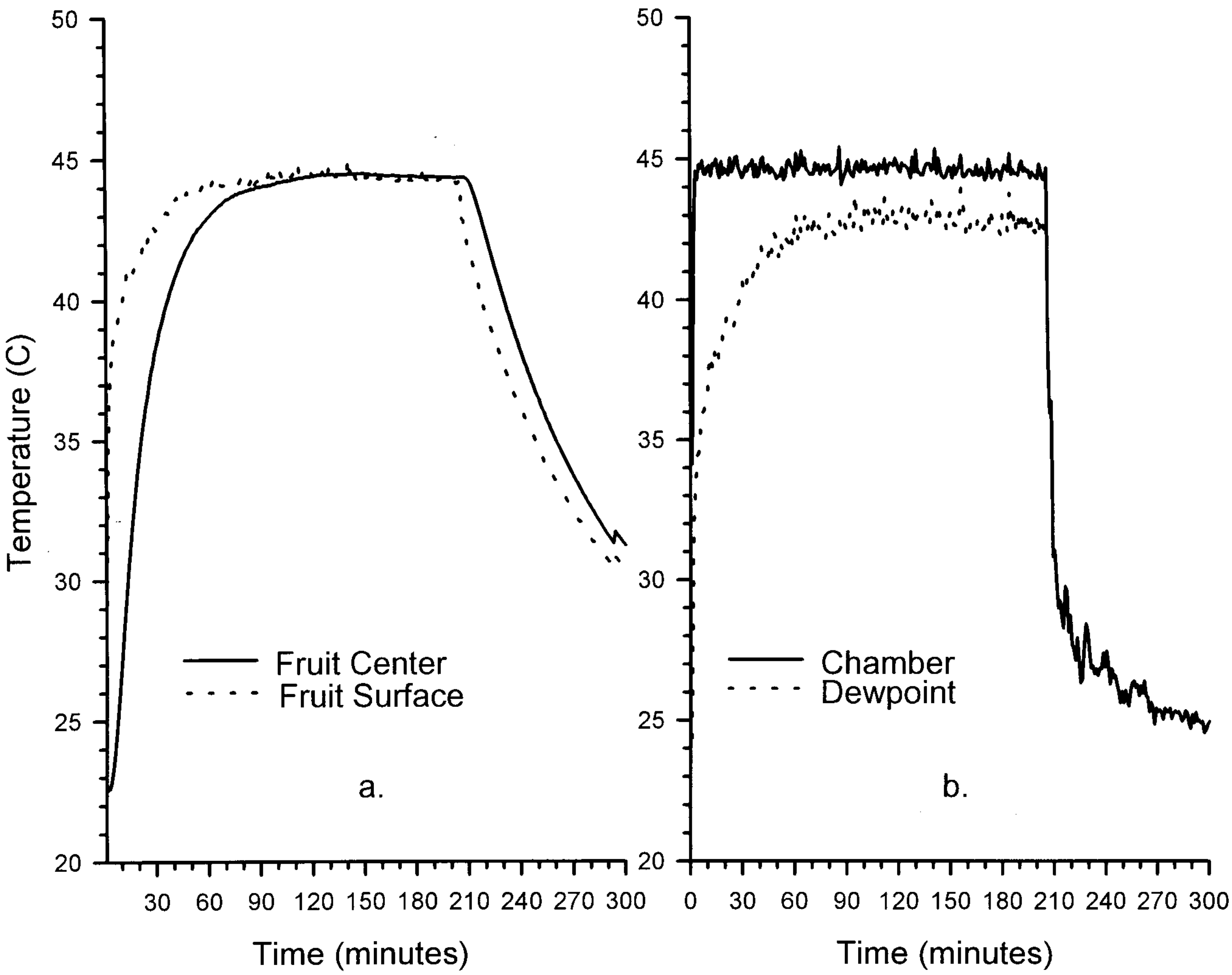

Fig. 1. Average temperatures during three replications of a 3.5-h, 45C forced-air treatment. Thefruit were cooled in ambient temperature air. (a) Center and surface temperature of 30 and 23fruit, respectively. (b) Chamber and dewpoint temperature during three treatment replications.

Table 1. Mean squares (MS) and mean values for quality characteristics of 'Dancy' tangerines exposed to moist (dewpoint 2C below surface temperature of coolest fruit), forced (2 m·s⁻¹) air at 45C, and nonheat-treated control fruit.

						Ratings[z]			
		Titratable acidity (%)		Soluble solids (%)		Flavor		External appearance	
Source	df	1991	1992	1991	1992	1991	1992	1991	1992
Treatment (TMT)	1	0.11	0.69*	5.92	0.28	37.07	12.04	0.53	6.07
Fruit size (SZ)	1	0.24	0.06	1.41	0.15	399.37*	2.21	115.05	6.88
TMT × SZ	1	0.01	0.02	0.02	1.60	27.84	1.69	0.70	14.56
Error	8	0.17	0.13	4.91	9.61	49.65	4.70	70.22	11.81
				Means					
TMT (h at 45C)									
Control		0.76 a	0.73 a	10.04 a	12.39 a	8.28 a	5.9 a	9.72 a	5.8 a
Treated		0.69 a	0.57 b	10.54 a	12.50 a	7.75 a	6.3 a	9.65 a	5.5 a

[z]Means based on ratings from 20 judges for each evaluation, with dislike extremely = 1, like extremely = 14 (1991) or 9.5 (1992).
*Significant at P 0.05.

Tangerines were exposed to HTFA at 45C for 4 h in 1991. In 1992, fruit were heated for 3.5 h because data collected in 1991 predicted 100% mortality of *Anastrepha ludens* larvae after 3,5 h. Thirty small (94 ± 17 g) and large (130 ± 13 g) fruit from each harvest were selected at random for the heat treatment or as a control in 1991, and 35 small (84 ± 11 g) and large (112 ± 13 g) fruit were selected at random for heat treatment or control in 1992. Weight and flavedo color were evaluated before and immediately after the HTFA treatment. After the treatment, the fruit were stored for 2 weeks at 4 ± 0.7C and 80% RH. In 1992, the fruit were stored for an additional week at 23C. Percent incidence of decay was recorded after storage at 23C. After cold storage, six or 10 fruit for 1991 and 1992, respectively, were juiced and evaluated for juice yield, SSC, and TA. Fruit were judged for flavor and external appearance by untrained panelists after cold storage in 1991 and after cold and ambient storage in 1992.

Percent weight change was determined by dividing the difference between the posttreatment weight and the pretreatment weight, by the pretreatment weight, and multiplying by 100. Flavedo color was measured with a chromameter (model CR-200; Minolta Corp., Ramsey, N.J.) at three marked sites on the surface of each fruit. The chromameter was calibrated to a standard white plate under illuminant condition C. Color was measured in the L*CH° color mode [L* = white to black, C = chroma or ($a^{*2} + b^{*2}$), Ho = hue angle or the arctangent of b*/a*] (Little, 1975). Percent change in L*, C, and H° due to the heat treatment was determined by calculating the ratio of the posttreatment color to the pretreatment color and multiplying by 100. SSC was measured with a benchtop refractometer and TA was determined by titration with 0.325 N sodium hydroxide as described by Shellie et al. (1993). Percent juice yield was determined by dividing the weight of extracted juice by pretreatment fruit weight and multiplying by 100.

Flavor and external appearance of heat-treated and control fruit were evaluated by a 20-member, untrained panel (American Society for Testing and Materials, 1968). Judges evaluated flavor by tasting peeled fruit sections at independently randomized stations. External appearance was evaluated by rating whole fruit displayed at independently randomized stations. Attributes were evaluated on a sensory score sheet containing a line scale anchored with the terms "dislike extremely" at the left end and "like extremely" at the right end. Judges indicated their preference for each attribute by placing a vertical line on the line scale. Preferences were quantified by measuring the distance from the left end of the line scale to the judges' vertical line.

Quality data were subjected to a factorial analysis of variance. The factorial design partitioned the effects of the heat treatment and fruit size. Separation of significant main effects was accomplished with Duncan's multiple range test. A completely randomized design was used with the interaction of harvests, treatments, and size as the error term.

Fruit heatinq rate. Ten minutes were required for the treatment chamber to reach set-point temperature (Fig. 1). The fruit surface temperature equilibrated with the chamber temperature after about 40 min. Heat was transferred to the center of the fruit rapidly during the first 60 min of treatment (Fig. 1). The fruit center temperature reached 45C after about 120 min and was maintained at 45C for about 90 min during the 3.5-h treatment (1992) and 120 min during the 4-h treatment (199 1). Results from this research are only applicable for tangerines treated under conditions resulting in a heating profile similar to that presented in Fig. 1.

Quality. Heat-treated fruit had lower TA than nonheat-treated control fruit, although the difference was only significant at *P* 0.05 in 1992 (Table 1). Judges rated the flavor of heat-treated fruit similar to control fruit (Table 1), even though a reduction in TA enhanced the ratio of SSC : TA. The external appearance of heat-treated fruit was rated similar to control fruit (Table 1) and the peel color of heat-treated fruit was similar to control fruit (data not shown). Percent juice yield of heat-treated fruit was not significantly different from control fruit, and heat-treated fruit weighed 0.6% less than control fruit (data not shown). Heat-treated fruit did not lose much weight, most likely because the chamber dewpoint temperature was maintained precisely throughout the entire treatment period (Fig. 1). The heat treatment did not significantly affect the incidence of decay during storage. Decay was observed in 16 out of 150 control fruit (10.6%) and 17 out of 150 (11.3%) heat-treated fruit.

Tangerines harvested after color break tolerated exposure to HTFA in a fashion similar to tangerines harvested before color break and degreened with ethylene gas before the heat treatment (Shellie et al., 1993). Flavedo color, percent juice yield, SSC, and flavor ratings of early season, degreened tangerines exposed to 45C HTFA for 4 h were not statistically different from control fruit (Shellie et al., 1993). 'Dancy' tangerine tolerated exposure to 45C HTFA for up to 4 h regardless of whether the fruit were harvested before or after color break or whether the fruit were gassed with ethylene before the heat treatment. 'Dancy' tangerines tolerated exposure to 45C for up to 4 h under the treatment conditions used in this study (air speed of 2 $m \cdot s^{-1}$, and dewpoint maintained 2C below the coolest fruit surface temperature). Under these conditions, a 3.5-h exposure time will most likely kill all Mexican fruit fly larvae. High-temperature, moist, forced air is a viable nonchemical alternative to methyl bromide fumigation for meeting the phytosanitary requirements of 'Dancy' tangerine.

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