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Postharvest Quality of 'Valencia' Orange after Exposure to Hot, Moist, Forced Air for Fruit Fly Disinfestation

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Abstract. **'Valencia' oranges [*Citrus sinensis* (L.) Osbeck] were exposed to moist, forced air (MFA) at 46, 47, or 50C for 1, 2, 3, or 4 hours to identify the maximum temperature and duration of exposure for which there was no detectable reduction in fruit quality. The flavor of oranges exposed to MFA at 47 or 50C was rated significantly inferior to that of oranges exposed to 46C. The degree minutes that accumulated in the center of the fruit between 2 and 4 hours and the maximum fruit center temperature during the heat treatment were associated with inferior fruit flavor. Oranges exposed to MFA at 46C for up to 4 hours could not be distinguished from the nonheated fruit. MFA at 46C is a promising quarantine treatment for 'Valencia' oranges.**

States with the greatest production of 'Valencia' oranges (California, Florida, Texas, and Arizona) have climates conducive for establishing various fruit fly species. Mexican [*Anastrepha ludens* (Loew)], Mediterranean [*Ceratitis capitata* (Wied.)], or Caribbean [*Anastrepha suspensa* (Loew)] fruit flies could establish themselves in selected U.S. citrus production regions and infest 'Valencia' oranges (Norrbom and Kim, 1988). Oranges can become infested by fruit flies before harvest when an adult fly lays her eggs just below the surface of the fruit (Christenson and Foote, 1960). The larvae feed on fruit tissue until they eventually tunnel out of the fruit to pupate in the soil. Harvested fruit may contain either eggs or larvae depending on the elapsed time between fly ovipositing and fruit harvest.

When a live, fertile fruit fly is encountered in an orchard during mandatory routine trapping surveillance, the entire production region may be placed under quarantine. Fruit harvested from a quarantined area must be exposed to a commodity treatment that has been approved by the U.S. Dept. of Agriculture, Animal and Plant Health Inspection Service (APHIS), before they can be marketed.

The treatments approved by APHIS for fruit fly disinfestation of oranges include exposure to vapor heat with pulp temperatures reaching 43.3C or storage at 0 to 2C for 10 to 22 days (U.S. Dept. of Agriculture, 1993). The vapor heat treatment approved by APHIS in the 1930s fell out of favor in the 1950s when chemical fumigants, such as ethylene dibromide, became available. The vapor treatment required expensive equipment and 10 h per treatment (Balock and Starr, 1945). Disinfestation by cold storage can induce chilling injury in the fruit (Hardenburg et al., 1986) and use up to 40% of the marketable shelf life. Concern for the environment and chemical residues in the food supply renewed an interest in nonchemical disinfestation methods. Technological advances since the 1950s have led to the development of high-temperature, forced-air treatments that heat fruit much faster than the APHIS-approved vapor heat treatment (Gaffney and Armstrong, 1990; Gaffney et al., 1990; Sharp et al., 1991). APHIS has approved high-temperature, forced-air treatments for grapefruit (*Citrus paradisi* M.), papaya (*Carica papaya* L.), and mango (*Mangifera indica* L.) (U.S. Dept. of Agriculture, 1993).

The probability of a fruit fly outbreak increases throughout the citrus harvest season. Since 'Valencia' is a late-season cultivar, it has a high risk of being infested by fruit flies. A commercially acceptable disinfestation treatment for 'Valencia' oranges is needed to ensure against market losses in the event of a fruit fly outbreak. The purpose of this research is to identify the air temperature and length of time 'Valencia' oranges can be exposed to forced air without a significant reduction in fruit quality. Once a fruit's tolerance threshold has been identified, then the duration of exposure required to obtain Probit 9 quarantine security against the Mexican fruit fly can be determined.

Materials and Methods

'Valencia' oranges were obtained from a commercial grower in Montemorrelos, Mexico, during the 1992 and 1993 growing seasons. The fruit were harvested at commercial maturity [minimum soluble solids concentration (SSC) of 8.5% with a minimum SSC : titratable acidity (TA) ratio of 10] and transported in an enclosed van to the U.S. Dept. of Agriculture, Agricultural Research Service (USDA–ARS) Crop Quality and Fruit Insects Research Unit, Weslaco, Texas. The average fruit weight was 254 ± 50 g in 1992 and 240 ± 43 g in 1993. The fruit were not degreened, waxed, or treated with postharvest fungicides. All heat treatments were evaluated once in each of two harvests in 1992 and once in each of four harvests in 1993. Fruit were harvested 1 month apart to control for field temperatures that potentially could condition the fruit for subsequent heat exposure.

In 1992, fruit were exposed to moist, forced air (MFA) at 46 or 47C for 1, 2, 3, or 4 h, or at 50C for 1 h followed by a reduction to 45C for 1, 2, or 3 h. The objective of the 50 to 45C step-down heating approach was to allow the fruit to heat faster initially than is possible at 46 or 47C, yet prevent the fruit centers from reaching potentially damaging high temperatures. Control fruit were not heated. Results from 1992 indicated that exposure to MFA at 46C was the maximum temperature the fruit could tolerate, so fruit harvested in 1993 were exposed to MFA at 46C. We anticipated Probit 9 quarantine security against Mexican fruit fly after the fruit were exposed to MFA at 46C for 230 min. Fruit harvested in 1993 were, therefore, exposed to MFA at 46C for 230 min. The quality of heated fruit was compared to that of nonheated controls.

The oranges were stored at 23C for 12 h before the heat treatments to ensure homogeneity of initial pulp temperatures, and then heated in a chamber similar to that described by Sharp et al. (1991). In 1992, four plastic, mesh-bottomed trays containing the fruit to be treated were stacked in columns over the outlet vent inside the chamber. A tray was removed hourly from the top of the column during the MFA treatment to give treatment durations of 1, 2, 3, or 4 h. In 1993, a single plastic bin was placed for 230 min over the outlet vent inside the forced-air chamber. The dry bulb temperature, dewpoint, relative humidity, and air flow inside the chamber, and fruit surface and center temperatures were recorded every 60 sec during the heat treatment. Dewpoint was maintained at 2C below the coolest fruit surface temperature, ensuring that moisture did not condense on the surface of the fruit. Air speed was maintained at 2 $m \cdot s^{-1}$ during the treatment. Temperatures were monitored with 36-gauge (0.13-mm) Type T copper constantan thermocouples. Heated fruit were cooled in air at 23C until center temperatures reached 25C. Nonheated control fruit were stored at 23C throughout the heat treatment and cool-down period.

Thirty oranges were exposed to each heat treatment in 1992 (46, 47, or 50C for 1, 2, 3, or

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4 h). Thirty oranges also were selected as nonheated control fruit. The weight and flavedo color of 10 of the 30 heated and control oranges were measured before and immediately after the MFA treatment. These 10 oranges were then juiced with an electric rotary juicer, and the juice was used to evaluate juice yield, SSC, and TA. The remaining 20 heated and control fruit were stored at 5C in individual plastic bags for 18 days. The plastic bags were left open on one end and used to prevent cross contamination of storage molds. The weight and flavedo color of the cold-stored fruit also were evaluated after cold storage. Ten of the 20 cold-stored, heated, or control fruit were juiced and evaluated for juice yield, SSC, and TA. The remaining 10 heated and control fruit were judged for flavor and external appearance, juiciness, flavor, and overall preference by 25 untrained panelists.

Similar methods were used in 1993, except that 20 instead of 30 fruit were exposed to MFA at 46C for 230 min. Twenty fruit also were randomly selected as nonheated control fruit. Heated and control fruit were stored for 18 days at 5C in individual plastic bags left open on one end. As in 1992, 10 fruit were juiced and used to evaluate juice yield, SSC, and TA. The remaining 10 fruit were evaluated by 25 untrained panelists for external appearance and flavor.

Percent weight change after MFA treatment and after storage was determined by dividing the difference between posttreatment weight (or poststorage weight) and 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* C* h° color mode [L* = darkness, C* = color intensity or $(a^{*2} + b^{*2})^{1/2}$, h° = hue or the arctangent of b*/a*] (Little, 1975; McGuire, 1992). The percent change in L*, C*, and h° was determined by calculating the ratio of the posttreatment or poststorage color to the pretreatment color and multiplying by 100. SSC and TA were evaluated 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. Quantitative preference analysis (American Society for Testing and Materials, 1968) was used to evaluate ratings for flavor, external appearance, juiciness, and overall preference for heat-treated and control fruit by the untrained panelists. The oranges were evaluated as either whole fruit or peeled fruit sections at independently randomized stations. Sensory attributes were evaluated on a score sheet containing a 9.5-cm line scale anchored with the terms "dislike extremely" at the left end and "like extremely" at the right end. The 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 lines.

The data were subjected to a factorial analysis of variance using SAS (GLM procedure; SAS Inst., 1988). In 1992, heat-treated fruit were analyzed separately from control fruit to determine the time and temperature at which a reduction in quality became apparent. A factorial design was used to partition the main effects of air chamber temperature (temperature), duration of exposure to MFA (time), cold storage (storage), and their interaction terms. The quality attributes of fruit exposed to MFA at 46C and corresponding control fruit were subjected to an independent factorial analysis with duration of exposure to MFA (time) and cold storage (storage) as main effects. The 1993 data were subjected to an analysis of variance with treatment (0 or 230 min) as the main effect. Analyses were based on means of fruit or judges. Harvests were considered replications. Mean separation of significant main effects was accomplished with Duncan's multiple range test.

Results and Discussion

MFA at 46, 47, or 50C for 1, 2, 3, or 4 h. The chamber temperature averaged between 23.0 and 24.5C at the initiation of the heat treatments (Fig. 1). The chamber set point temperature was reached usually within 10 min after initiation of a heat treatment. The maximum standard deviation among fruit center temperatures during the 46C exposures in 1993 was ≈0.8C and occurred during the first 60 min of treatment (Fig. 1). Variability in fruit heating rates most likely was due to variable chamber heating rates among replications rather than temperature differences within the chamber during a run (Fig. 1). The variability in temperature among fruit centers and among replications decreased as fruit center temperatures equilibrated with the chamber temperature after ≈60 min of heating (Fig. 1). The fruit cooled nonuniformly after the heat treatments (data not shown). Hydrocooling or forced-air cooling could reduce variable fruit cooling rates.

Oranges exposed to MFA at 46C had significantly superior flavor ratings than those exposed to MFA at 47 or 50C (Table 1B). The overall preference of the judges corresponded with their flavor ratings (data not shown). Judges could not distinguish between the external appearance (Table 1A) and juiciness (data not shown) of oranges exposed to MFA at 46, 47, or 50C. Fruit exposed to MFA at either 46, 47, or 50C did not significantly differ in percent weight loss; percent juice yield; TA; SSC; SSC : TA; or flavedo L*, C*, or h° values (data not shown).

The flavor of oranges that were heated for 4 h was significantly inferior to that of oranges heated for only 1 or 2 h (Table 1B). Heating for 3 or 4 h resulted in significantly inferior external appearance ratings. Juiciness; percent juice yield; TA; SSC; SSC : TA; and flavedo L*, C*, and h° values were not significantly influenced by the duration of heating (data not shown).

Storage at 5C improved the flavor (Table 1B) and overall preference (data not shown) of oranges. The storage mean square for flavor was twice the size as the time mean square for flavor and 3 times the size of the temperature mean square for flavor (Table 1A), which indicates that cold storage affected flavor more strongly than did either the temperature of the MFA or the duration of exposure to the MFA. Cold-stored 'Dancy' tangerines also were rated superior in flavor compared to tangerines that

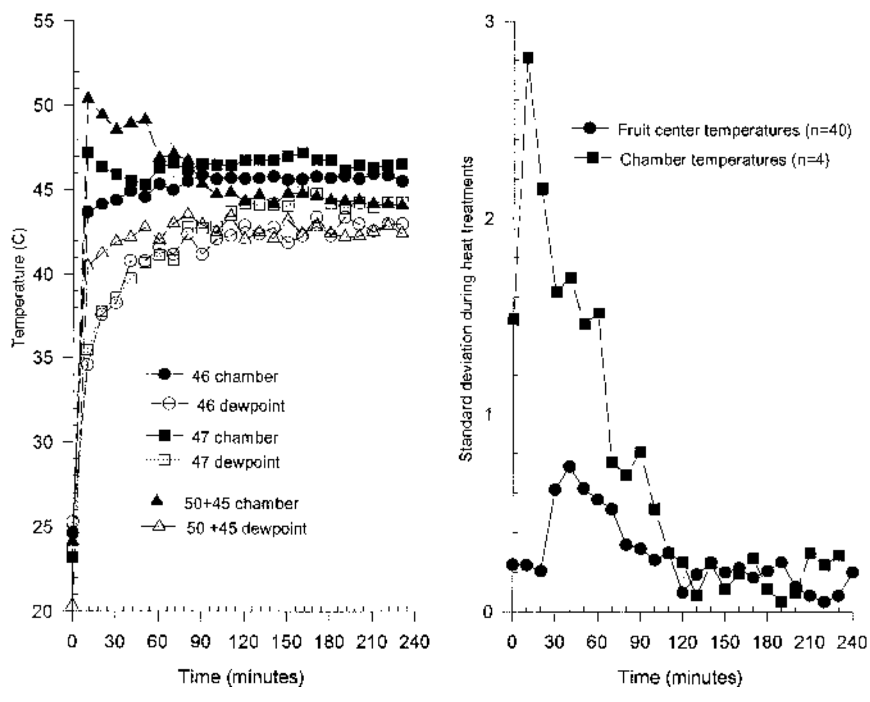

Fig. 1. (**left**) Average chamber and dewpoint temperatures during moist, forced-air (MFA) treatments at 46 or 47C for 4 h, or 50C for 1 h followed by 45C for 3 h. Mean of two replications. (**right**) Standard deviation of center temperatures among 40 fruit and of chamber temperatures among four replications during MFA treatments at 46C for 230 min.

Table 1. Mean squares and mean values for judges' ratings[z] of 'Valencia' oranges in 1992 and 1993.

		1992: 46, 47, and 50C[y] 0, 1, 2, 3, 4 h		1992: 46C 0, 1, 2, 3, 4 h		1993: 46C 0, 230 min	
Source	df	Flavor	Appearance	Flavor	Appearance	Flavor	Appearance
A. Mean squares							
Temperature (TMP)	2[x](NE[w])[v, u]	0.76*	0.08	NE	NE	NE	NE
Time (T)	3[x](4)[v](1)[u]	1.12**	0.38*	0.39	0.02	0.15	0.69*
Storage (STO)	1[xv](NE)[u]	2.52**	0.01	0.04*	0.06	NE	NE
TMP × T	6[x](NE)[v, u]	0.11	0.21	NE	NE	NE	NE
T × STO	3[x](4)[v](NE)[u]	0.06	0.08	0.91	0.05	NE	NE
TMP × STO	2[x](NE)[v, u]	0.4	0.34*	NE	NE	NE	NE
TMP × T × STO	6[x](NE)[v, u]	0.24	0.17	NE	NE	NE	NE
Error	24[x](10)[v](6)[u]	0.21	0.1	0.23	0.07	0.05	0.04
B. Means							
TMP (°C)							
46		7.21 a[t]	NS	NE	NE	NE	NE
47		6.83 b					
50		6.85 b					
T (h)							
1		7.22 a	7.68 a	NS	NS	NS	
2		7.21 ab	7.87 a				
3		6.85 bc	7.53 b				
4		6.58 c	7.47 b				
T (min)							
0							6.8 a
230							6.2 b
STO (weeks)							
0		6.74 a	NS	6.9 a	NS	NE	NE
4		7.19 b		7.4 b			

[z]Means based on ratings from 20 judges for each evaluation, with 1 = dislike extremely and 9.5 = like extremely.
[y]50C for 1 h, followed by 45C for 1, 2, or 3 h.
[x]Degrees of freedom and error [Rep(TMP × T × STO)] for 1992 data: 46, 47, 50C for 1, 2, 3, or 4 h.
[w]NE = not evaluated.
[v]Degrees of freedom and error [Rep(T × STO)] for 1992 data: 46C for 0, 1, 2, 3, or 4 h.
[u]Degrees of freedom and error (Rep × T) for 1993 data: 46C for 0 or 230 min.
[t]Mean separation in columns by Duncan's multiple range test, $P \leq 0.05$ (lowercase letters).
NS, *, ** Nonsignificant or significant at $P \leq 0.05$ and 0.01, respectively.

had not been cold-stored (Shellie et al., 1993). Palatability of citrus increases directly with the SSC : TA ratio, and the slightly enhanced SSC : TA ratio (18.1 vs. 18.6) may be partially responsible for the superior flavor ratings of stored oranges.

The factors responsible for a reduction in quality after exposure to heated MFA have not been identified. The dose of heat or the rate of heating at the center of the fruit may influence fruit tolerance to a heat treatment. Oranges exposed to the 50C step-down treatment (50C for 1 h followed by 45C for 1, 2, or 3 h) heated faster for the first 2 h than oranges exposed to 46 or 47C MFA (Fig. 2). The center of oranges exposed to MFA at 46 or 47C heated similarly for the first 2 h. Since no significant time × temperature interaction was observed for flavor, it is unlikely that the different rates of heating observed in this experiment had any affect on fruit flavor.

The degree minutes >30C that accumulated at the center of the fruit was higher for oranges exposed to 47 or 50C MFA for 4 h (15,664 and 17,612, respectively) than for oranges exposed to MFA at 46C (15,557) for 4 h. The heat dose as opposed to the heating rate may have contributed to off-flavor development.

MFA at 46C for various durations. The flavor, external appearance, and juiciness of 'Valencia' oranges exposed to MFA at 46C in 1992 for 0, 1, 2, 3, or 4 h was not significantly different from that of oranges that had not been heated (data not shown). Judges had no preference between heated and nonheated fruit. The duration of time the fruit were exposed to MFA at 46C (1, 2, 3, or 4 h) did not significantly affect percent weight loss; percent juice yield; TA; SSC; SSC : TA; or flavedo L*, C*, or h° values (data not shown). Cold-stored oranges had significantly superior flavor (Table 1B) and were significantly preferred over (data not shown) oranges that had not been stored. Stored fruit had significantly lower flavedo L* (98.2% vs. 99.4%) and higher C* (107.9% vs. 102.6%) values than fruit that had not been stored. Lower L* values indicate a darker

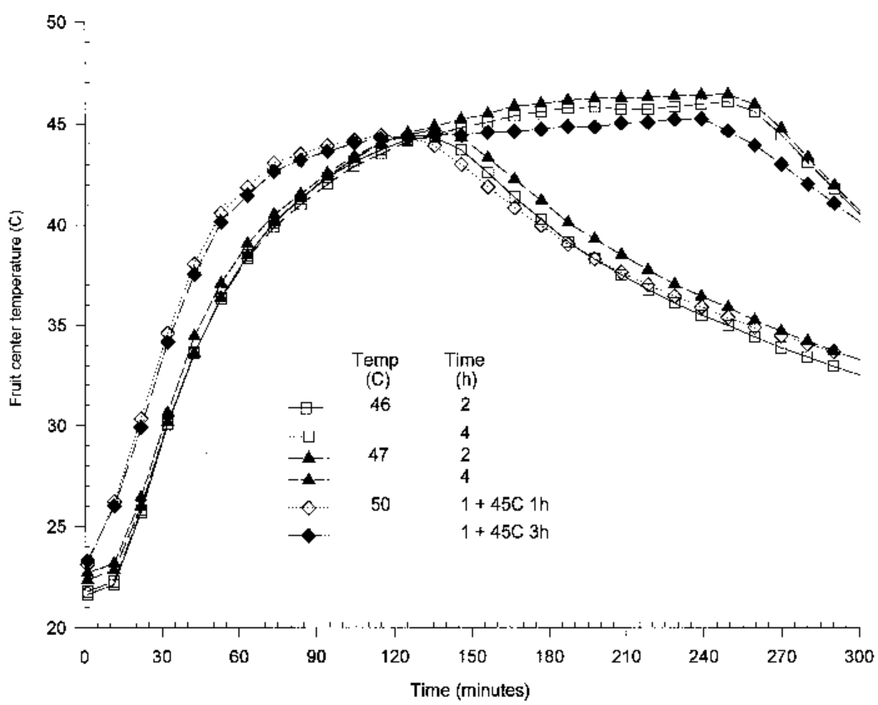

Fig. 2. Center temperature of 'Valencia' oranges during exposure to moist, forced air at 46 or 47C for 2 or 4 h, or 50C for 1 h followed by 45C for 1 or 3 h. Mean of two replications (12 fruit).

flavedo, and higher C* values indicate a greater intensity or saturation of color.

The external appearance of oranges exposed to MFA at 46C for 230 min in 1993 was rated significantly inferior to that of nontreated fruit (Table 1B). However, both heated and nonheated oranges still were rated as above average (5.25) in external appearance. Exposure to MFA at 46C did not significantly affect fruit flavor (Table 1A), percent weight loss, percent juice yield, TA, SSC, or SSC : TA (data not shown).

'Valencia' oranges tolerate exposure to MFA at 46C for up to 230 min without compromising market quality. A 230-min exposure to 46C MFA most likely will ensure quarantine security for the Mexican fruit fly. This heat treatment also may be adequate for quarantine security of Mediterranean and Caribbean fruit flies. Heated MFA is a promising quarantine treatment for 'Valencia' oranges because a) it eliminates the need for potentially toxic chemicals that may leave a residue on the fruit, b) it requires less than one-half the amount of time as the APHIS-approved vapor heat treatment, and c) it does not damage the fruit or decrease marketable shelf life.

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