HortScience 40(5):1425–1430. 2005.

Peach and Nectarine Quality Following Treatment with High-temperature Forced Air Combined with Controlled Atmosphere

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Additional index words. quarantine, sensory evaluation, mealiness, codling moth, oriental fruit moth

***Abstract*. Yellow- and white-fleshed peach [*Prunus persica* (L.) Batsch] and nectarine [*Prunus persica* (L.) Batsch var. *nectarina* (Ait) Maxim.] cultivars of mid- and late-season maturity classes were subjected to combined controlled atmosphere–temperature treatment system (CATTS) using heating rates of either 12 °C/hour (slow rate) or 24 °C/hour (fast rate) with a final chamber temperature of 46 °C, while maintaining a controlled atmosphere (CA) of 1 kPa oxygen and 15 kPa carbon dioxide. Fruit seed surface temperatures generally reached 45 °C within 160 minutes and 135 minutes for the slow and fast heating rate, respectively. The total duration of the slow heating rate treatment was 3 hours, while 2.5 h was required for the fast heating rate treatment. Following treatment the fruit were stored at 1 °C for either 1, 2, or 3 weeks followed by a ripening period of 2 to 4 d at 23 °C and subsequent evaluation of fruit quality. Fruit quality was similar for both heating rate treatments. Compared with the untreated controls, CATTS fruit displayed higher amounts of surface injury, although increased injury was only an important factor to marketability in cultivars that had high amounts of surface injury before treatment. The percentage of free juice in the flesh was slightly less in CATTS fruit early in storage but was often greater in treated fruit toward the end of the storage period. Slower rates of softening during fruit ripening were apparent in CATTS fruit. Soluble solids, acidity, weight loss and color all were either not affected or changed to a very small degree as a result of CATTS. Members of a trained sensory panel preferred the taste of untreated fruit over fruit that had been CATTS but the ratings of treated and nontreated fruit were generally similar and it is unclear whether an average consumer could detect the difference. Although further work needs to be done regarding the influence of CATTS on taste, it otherwise appears that CATTS does not adversely affect the marketability of good quality fruit and therefore shows promise as a nonchemical quarantine treatment for peaches and nectarines.**

A substantial portion of the income generated from the production of peaches [*Prunus persica* (L.) Batsch] and nectarines [*Prunus persica* (L.) Batsch var. *nectarina* (Ait) Maxim.] in California is derived from export sales. Since these commodities are also host to several insect pests that are quarantined by importing nations, postharvest treatments often must be applied before shipment to gain entry into those markets. A systems approach to eliminate the possibility of infestation in the field also is sometimes utilized but is not possible in many instances. Currently, methyl bromide is the quarantine treatment of choice but use of this fumigant is becoming problematic due to legislated restrictions on its use (U.S. Environmental Protection Agency, 2001). Although postharvest export uses of methyl bromide are exempt from current phase-out plans, the rising cost of methyl bromide may make its use cost prohibitive. This along with the problems encountered with methyl bromide-induced injury to peaches and nectarines as well as increasing consumer preference for chemical-free fruit give impetus to the development of nonchemical quarantine treatments for these commodities.

Subjecting fruit to temperature extremes is a well-known means of quarantine insect disinfestation. Cold treatment, while effective for commodities that can tolerate long periods of cold storage, is not an option for peaches and nectarines due to a rapid quality loss that occurs under such conditions. Heat treatment, being a much more rapid process, may be a viable option. Obenland and Aung (1997) found that for nectarines a 25-min dip in 50 °C water, a treatment effective against fruit flies, caused severe damage to the peel surface and rendered the fruit unmarketable. Inclusion of 200 mM sucrose in the dip solution to minimize entry of water into the fruit reduced the injury but not to a degree that the treatment would be useable. Some success in using hot water dips for peaches was reported by Kerbel et al. (1985) using a 40-min dip at 40 °C, but damage occurred at 43 °C. Lay-Yee and Rose (1994) reported that nectarines can tolerate forced hot air treatment at 41 °C for 24 h and suggested that this treatment might be useful in the control of thrips (*Thrips obscuratus* (Crawford)). Obenland et al. (1999) treated nectarines using a forced hot air treatment protocol originally developed to disinfest papayas of Mediterranean fruit flies (Armstrong et al., 1989) that involved raising the fruit seed surface temperature to 47.2 °C during 4 h. Although no adverse quality changes were found in any of the cultivars as a result of treatment, a subsequent study indicated that the treatment could enhance the development of mealiness in some susceptible cultivars (Obenland and Carroll, 2000) .

Addition of a controlled atmoshphere (CA) to heat treatments has been shown to be effective in enhancing insect mortality (Whiting and Hoy, 1997; Whiting et al., 1995; Yahia and Ortega-Zaleta, 2000), thus allowing heat treatments of shorter duration (Neven and Mitcham, 1996). Researchers have tested hot forced air CA treatments on a number of different commodities including apples, pears and cherries (Lay-Yee et al., 1997; Neven, 2004; Neven and Drake, 2000) and in general have achieved promising results. Similar combination treatments using citrus, however, have to date shown mixed effectiveness (Shellie et al., 1997). Given that heat treatment alone was fairly successful for nectarines in that all evaluated quality factors besides mealiness were not adversely affected (Obenland et al., 1999), it was thought that addition of a CA with the corresponding ability to then reduce both temperature and treatment duration could enhance the usefulness of the treatment. The following study documents an evaluation of a combined controlled atmosphere–temperature treatment system (CATTS) on the quality of California mid- and late-season peaches and nectarines.

Materials and Methods

Fruit source. Peaches and nectarines of commercial maturity and classified as either size 56 (average weight = 172 g/fruit) or 64 (average weight = 142 g/fruit) were obtained

Received for publication 9 Dec. 2004. Accepted for publication 15 Jan. 2005. Mention of trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture and does not imply its approval to the exclusion of other products or vendors that also may be suitable. We Thank Tom Eisele and Melinda Semon, TreeTop, Inc., for cooperation on the sensory evaluation portion of the study. This work was supported by the California Tree Fruit Agreement.
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Table 1. List of peach and nectarine cultivars subjected to controlled atmosphere–temperature treatment system (CATTS)

Cultivar	Harvest season	Flesh color
Peaches		
Elegant Lady	Mid	Yellow
Diamond Princess	Mid	Yellow
Klondike	Mid	White
Summer Sweet[x]	Mid	White
Ryan Sun	Late	Yellow
Nectarines		
Fire Sweet	Mid	Yellow
Summer Bright[x]	Mid	Yellow
Summer Fire	Mid	Yellow
Fire Pearl	Mid	White
Arctic Snow	Late	White
Arctic Mist	Late	White

[x]Cultivars used only in the sensory panel evaluation experiment.

from local packing houses and transported to the laboratory in air conditioned vans. Fruit that were not to be treated on the following day (different replications) were placed into storage at 1 °C. Before treatment, fruit were removed from cold storage and stored overnight at 23 °C for equilibration to the treatment starting temperature. Since hundreds of varieties exist that are commercially grown in California and that could have different treatment tolerances, representative commonly grown peach and nectarine varieties were chosen for this test that included both yellow and white flesh types (Table 1). All of the varieties were harvested during early July through September (mid- or late-season) as fruit from this period of the growing season are the most likely to be exported and require quarantine treatment.

CATTS. CATTS were conducted using a chamber designed by Techni-Systems (Chelan, Wash.) that was capable of regulating temperature, dew point, air speed and atmospheric composition. This unit is the same as has been previously described (Neven and Mitcham, 1996) with the exception of the addition of a cooling system that was used to regulate temperature overruns and provide post-treatment cool down. A total of 24 temperature probes were used to monitor fruit surface and core temperatures during each run. Gas standards of carbon dioxide and oxygen were used to calibrate the respective sensors before the runs. Two heating protocols were chosen for evaluation based upon efficacy studies for the disinfestation of codling moth (*Cydia pomonella* L.) and Oriental fruit moth (Grapholita molesta Busck) that had been previously conducted (L. Neven, unpublished results). 1) Chamber temperature ramp from 23 to 46 °C at 12 °C/h and holding at 46 °C for a total treatment time of 3 h (slow CATTS). 2) Chamber temperature ramp from 23 °C to 46 °C at 24 °C/h and holding at 46 °C for a total treatment time of 2.5 h (fast CATTS).

In the case of the slow CATTS, a portion of the fruit were removed from the treatment chamber after 2 h to provide an estimate of the effect of treatment duration on fruit quality. The atmospheric composition during both protocols was 1 kPa oxygen and 15 kPa carbon dioxide. Treatment time was initiated when the correct atmosphere was established. Dewpoint was maintained 2 °C below the temperature of the coolest probed fruit and airspeed set at 2 $m \cdot s^{-1}$. Each individual treatment run was considered a separate replication with thirty fruit treated per replication and four replications. After the completion of CATTS the fruit were removed from the treatment chamber and placed into cold storage at 1 °C.

Quality evaluation. Following 1, 2, and 3 weeks of cold temperature storage treated and control fruit were taken from cold storage and ripened until firmness readings were 13.4 N or less as determined by a penetrometer (U.C. Firmness Tester) with a 7.9-mm tip. Generally, ripening required 2 to 3 d for untreated fruit but CATTS fruit required an additional 1 to 2 d. Five fruit from each treatment lot that had been randomly selected, weighed and marked before treatment were again individually weighed. Weight loss was calculated by subtracting the weights from the pretreatment values and a mean weight loss for the five fruit determined. Using a chromameter (Minolta, Ramsey, N.J.) coloration of the external surface of the same five fruit was measured and expressed as L* C* h color coordinates. Measurement was performed inside of a single circled region on the fruit in an area of representative ground color. The same circled area had also been measured before treatment enabling determination of color change due to treatment and storage. Fruit were then subjectively rated for the amount of surface injury present and placed into classes where 0 = none, 1 = very slight, 2 = slight, 3 = moderate and 4 = severe. An average rating index was calculated by multiplying the number of fruit in each class by the class number (0 to 4), summing, and dividing by the total number of fruit in each class. Average values exceeding 2.0 were questionable in their marketability and 2.5 and above were definitely nonmarketable. Almost all of the injury observed was in the form of brown lesions on the skin surface. Free water present in the flesh was quantified using a method similar to that of Crisosto and Labavich (2002). Five fruit were randomly selected from each of the treatments lots and a 10 g longitudinal slice removed from each fruit. The slices were wrapped with 4 layers of cheesecloth and squeezed in a press at a constant 667 N of force for 1 min. The sample was pressed in this manner three additional times, the sample being turned between each pressing. Juice that was released from the fruit was collected, centrifuged at 6,000 g_n for 10 min to remove solid material, and weighed. Division of this value by the original tissue weight gave the percentage of free water present. Soluble solids concentration (SSC) was determined from the juice using a temperature corrected digital refractometer (Atago, Kirkland, Wash.). From the same juice titratable acidity (TA) was measured by diluting 10 mL of juice to a total volume of 25 mL with distilled water and then titrating the diluted juice to pH 8.1 with 0.1 N NaOH. The volume of NaOH required was recorded and a calculation made to convert to a percent malic acid basis.

Sensory panel evaluation. In an experiment separate from that described for the quality evaluation, fruit from five peach and nectarine cultivars was obtained from a local packing house and transported to the Parlier, CA laboratory. Preparation of the fruit for treatment as well as the actual CATTS of the fruit were as previously described using both the fast and slow CATTS. After treatment the fruit were placed into storage at 1 °C for 10 d after which the fruit were transported to a laboratory in Wapato, Wash., and held for ripening at 23 °C for 3 to 5 d before evaluation. After the fruit had ripened to a firmness of 13.4 N or less they were taken to TreeTop, Inc. (Selah, Wash.) and evaluated by a taste panel. The panel consisted of 24 to 30 TreeTop employees that had been previously trained to recognize and evaluate various attributes of peach and nectarine taste and texture. Each sample presented to the panelists consisted of three to four wedges of fruit without the skin, each wedge being from a separate fruit. Samples were served in private tasting booths divided by partitions and illuminated by red lighting. One cultivar was evaluated per day with the initial testing being a forced choice triangle test (Stahl and Einstein, 1973) to determine if the panelists could differentiate between control fruit and CATTS fruit using either a slow or fast heating rate. In this test a panelist was presented with three samples and had to choose the one that was different. Samples were presented in random order and each combination of presentation order was randomly assigned among the total number of tests. If a difference was found for a given comparison by a statistically significant number ($P \geq 0.05$) of the panelists then the panelists were presented with additional samples from that comparison to perform attribute and preference testing. For the attribute testing panelists were asked to evaluate the treated sample relative to the control for overall flavor, peach flavor, sweetness, acidity, juiciness, mealiness and firmness and place a mark on a numbered scale for each of the taste attributes. The line scales ranged from 1 (much less) to 9 (much more) with the control value (no difference) being anchored at 5. Due to a lack of fruit, attribute testing was not conducted for the fast CATTS for 'Diamond Princess' and 'Summer Bright'. For the preference testing the panelists were presented with samples of either treated or untreated fruit and asked to place a checkmark next to the descriptor that best matched how well they liked or disliked the sample. Descriptors ranged from 1 (dislike extremely) to 5 (neither like nor dislike) to 9 (like extremely). Preference testing for the 'Diamond Princess' fast CATTS was not possible due to a shortage of fruit.

Statistical analysis. The analysis model used for the fruit quality work was a split-split-plot in time with cultivar, storage and CATTS time as the fixed effects. Cultivar (1 to 9) was considered a whole-plot treatment, time (0, 2, or 3 and 0 or 2.5) the subplot treatment and week (1, 2, or 3) the sub-subplot treatment. Transformations were applied to the data to stabilize variances when appropriate.

Tables were consulted to determine if a statistically significant ($P \leq 0.05$) number of panelists were able to determine a difference between treatments during the triangle testing portion of sensory evaluation (Stahl and Einstein, 1973). Attribute testing was analyzed in the form of a t test of whether each attribute score was different ($P \leq 0.05$) from a score of 5.0 (no difference). A one-way analysis of variance procedure and Tukey's HSD were used to determine treatment differences for the preference testing.

Results

Typical heating profiles initiated after the establishment of 1 kPa oxygen and 15 kPa carbon dioxide atmospheres are presented in Fig. 1 for both the 12 ºC (slow) and 24 ºC (fast) heating rates. Fruit heated using the fast rate required 120 min to reach 45 °C while 160 min was needed for the slow rate to reach the same temperature. These heating regimes in combination with 1 kPa oxygen and 15 kPa carbon dioxide have been shown to be effective in achieving complete control of both codling moth and oriental fruit moth (L. Neven, personal communication).

Fruit quality evaluation results and corresponding analyses are presented in Table 2 for the slow CATTS heating rate and in Tables 3 and 4 for the fast CATTS heating rate. Treatment effects are reported by cultivar and time (treatment duration) when this interaction is significant (Tables 2 and 4) but are given only by time when the interaction is not significant (Table 3). The effect of storage on treatment effect is described in the text when the interaction between storage and treatment time for the quality attribute is significant.

Surface injury, mainly in the form of small brownish lesions, was greater in the CATTS fruit from both heating rates (Tables 2 and 3) and tended to increase when the heating duration was extended from 2 to 3 h using the slow heating rate (Table 2). The difference, averaged across storage times, however, was slight and was only significant in four of the nine varieties using the slow heating rate. The overall injury rating across cultivars and storage times averaged 1.58 for the slow treatment and 1.61 for the fast treatment, indicating that the effect of both heating rates on injury was similar. These ratings correspond to a category that is less than slight, indicating that the fruit would be marketable. Only 'Diamond Princess' had injury significantly different from the control that exceeded the category of slight (Table 2). Surface injury tended to increase slowly during the 3-week storage period for both heating rates, although the amount of increase was small (data not shown).

Free juice percentage, which is a measure of the juiciness of the flesh (Crisosto and Labavich, 2002), was less in the treated fruit when averaged across storage times for five of the nine cultivars for both heating rates (Tables 2 and 4). 'Fire Sweet' on the other hand was juicier following slow CATTS than was the untreated fruit. The juiciness of a number of the cultivars was unchanged by CATTS. Those cultivars that exhibited a decrease averaged a loss of 4.3% for slow CATTS and 5.4% for fast CATTS. Although the relationship of free juice percentage to expression of the symptoms of mealiness and flesh drying can differ between different cultivars (Obenland et al., 2003), most of the cultivars were at a percent juice level that indicated that the fruit could be classified as juicy regardless of the small differences in free juice between treated and untreated fruit. In addition, the effect of CATTS on free juice was dependent on how long the fruit were held in cold storage (storage × treatment time $P \leq 0.01$). If values are averaged across cultivars and compared, the slow CATTS had 6.7% less free juice than the control after 1 week of storage, 2.8% less after 2 weeks and showed a 6.8% greater amount after the 3 weeks (data not shown). The pattern exhibited by the fast CATTS was similar to this.

SSC was increased in the majority of cultivars following slow CATTS (Table 2). The increase, however, was slight and when averaged across cultivars was only 0.1% for the 2 h treatment and 0.3% for the 3 h treatment. Similarly, SSC was higher in fruit treated using fast CATTS than in the controls, the difference being 0.7% (Table 3). Although both increases were statistically significant and potentially beneficial to overall quality, it is doubtful that such small differences would be noticed by a consumer. Storage duration had no effect on SSC.

TA was unaffected by either CATTS or by storage duration for either of the heating rates (Tables 2 and 3). Although a few of the cultivars treated with slow CATTS had TA values that were different from the controls these differences were too small to be noticeable to a consumer.

Fruit weight loss of most cultivars was increased ($P \leq 0.01$) by both heating rate treatments (Table 2). With slow CATTS, seven of the nine cultivars lost an average of 1.3% more weight than did control fruit stored at the same temperature and for the same amount of time. The average total weight loss increased from 5.7% to 6.1% and then to 6.6% for 0, 2 and 3 h of slow CATTS, respectively. Five cultivars treated using fast CATTS lost a greater amount of weight than the controls, the loss averaging 2.0% (Table 4). In the case of the fast treatment the overall weight loss averages were 5.7% for the control and 7.0% for the treated fruit. Differences in weight loss between treated and untreated fruit were greater during the initial week of storage than during subsequent weeks for the fast CATTS (data not shown). During surface evaluation of the fruit a difference in visual symptoms of water loss, such as wrinkling, was not noted between treated and untreated fruit so at least visually there did not appear to be a negative effect of the difference in water loss due to CATTS.

Skin color became slightly redder in both control and slow CATTS fruit during the storage and ripening period as evidenced by the decrease in hue angle (Table 2). The shift toward more redness, however, was greater in the 3 h CATTS fruit for seven of the nine cultivars. This change in coloration became less pronounced as the fruit were stored longer (data not shown). Generally, a difference in hue angle of 2.5 or greater is believed to be necessary for the difference to be visually detectable (Sacks and Francis, 2001). While the difference exceeded the theoretical detection limit for a number of the cultivars, we were unable to see a color difference in side by side comparisons of treated and untreated fruit. In contrast to slow CATTS fruit, hue angle was not altered by fast CATTS (data not shown).

Triangle testing during the sensory evaluation experimentation indicted that a significant ($P \leq 0.05$) number of panelists were able to determine a difference in flavor between both the slow and fast CATTS and the untreated controls for all of the five cultivars tested (data not shown). Preference testing was then conducted for each of the cultivars to determine which of the sensory attributes being evalu-

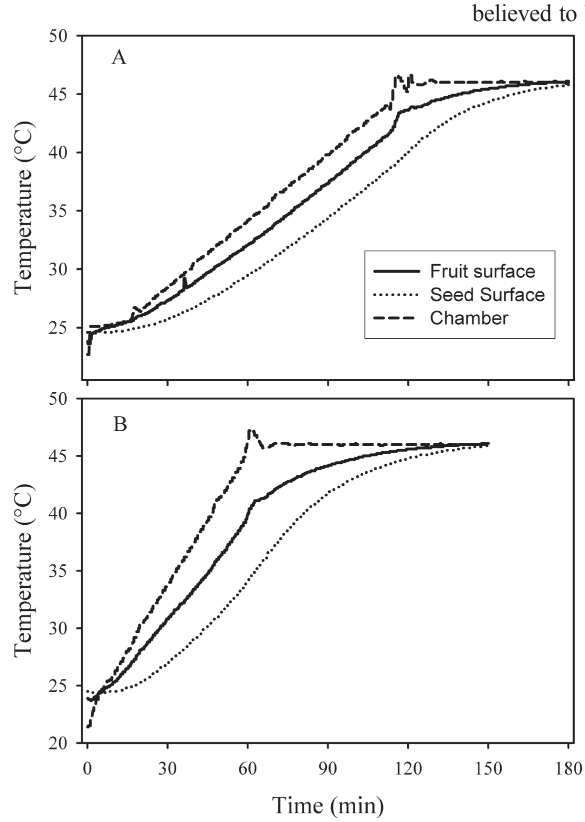

Fig. 1. Fruit surface, seed surface and chamber temperatures during controlled atmosphere–temperature treatment system (CATTS) using either a heating rate of 12 °C/h (**A**) or 24 °C/h (**B**).

Table 2. Quality attributes following 0, 2, or 3 h of slow controlled atmosphere–temperature treatment system (CATTS), storage at 1 °C, and ripening at 23 °C. Values are means across storage times of 1, 2 and 3 weeks.

Cultivar	Time (h)[z]	Surface injury (rating)[y]	Free juice (%)	SSC (%)	TA (%)	Wt loss (%)[x]	Skin color change (h°)[w]
Klondike	0	1.96 a[v]	50.6 a	11.2	0.31 a	7.5 a	–2.32 a
	2	2.79 b	47.0 b	11.3	0.31 a	8.1 a	–5.88 b
	3	2.13 a	45.3 b	11.7	0.28 b	8.7 b	–7.38 b
Elegant Lady	0	1.50 a	38.8 a	11.8	0.56 a	6.1 a	–6.09 a
	2	1.76 b	33.1 b	12.5	0.55 a	7.9 b	–8.67 ab
	3	1.85 b	40.5 a	12.7	0.55 a	8.3 b	–9.60 b
Diam. Princess	0	2.00 a	52.8 a	10.5	0.44 a	5.2 a	–1.85 a
	2	2.14 ab	49.7 b	10.4	0.48 b	6.4 b	–6.98 b
	3	2.30 b	49.3 b	10.8	0.48 b	6.4 b	–9.02 b
Ryan Sun	0	1.29 a	42.0 a	12.6	0.36 a	4.4 a	–5.07 a
	2	1.33 a	41.7 a	12.4	0.37 a	4.7 a	–5.13 ab
	3	1.48 a	45.2 a	12.4	0.36 a	5.7 b	–6.20 b
Fire Sweet	0	1.61 a	36.6 a	12.4	0.34 a	5.7 ab	–1.97 ab
	2	1.92 b	36.1 a	12.9	0.34 a	5.4 a	–3.02 a
	3	1.97 b	42.6 b	13.4	0.33 a	6.4 b	–0.88 b
Fire Pearl	0	0.80 a	43.9 ab	12.1	0.58 ab	3.2 a	–1.11 a
	2	0.98 a	42.7 a	11.8	0.55 a	3.5 a	–2.32 b
	3	1.41 b	46.5 b	12.4	0.60 b	5.0 b	–3.01 b
Summer Fire	0	1.30 a	52.0 a	10.8	0.40 a	4.2 a	–2.66 a
	2	1.49 a	47.3 b	10.6	0.40 a	4.9 b	–2.60 a
	3	1.40 a	47.3 b	10.9	0.38 a	5.0 b	–5.29 b
Arctic Snow	0	1.08 a	35.4 a	17.1	0.33 a	10.2 a	–9.75 ab
	2	1.10 a	22.9 b	18.3	---	9.1 ab	–11.76 a
	3	1.09 a	32.6 c	16.9	0.32 a	8.7 b	–8.66 b
Arctic Mist	0	0.66 a	37.4 a	15.3	0.36 a	5.2 a	–11.74 a
	2	0.57 a	25.4 b	15.6	---	4.9 a	–12.10 a
	3	0.60 a	32.2 b	15.4	0.34 a	5.0 a	–7.99 b
Cultivar (C)		**	**	**	**	**	**
Storage (S)		**	**	NS	**	**	**
C × S		**	**	NS	NS	NS	**
Time (T)		**	**	*	NS	**	*
C × T		**	**	NS	*	**	**
S × T		NS	**	NS	NS	NS	**
C × S × T		NS	NS	NS	NS	NS	NS

[z]Time is the duration of CATTS.
[y]Visual rating: 0 = no injury, 1 = very slight, 2 = slight, 3 = moderate, 4 = severe.
[x]Loss from immediately before treatment to end of storage and ripening period.
[w]Skin color change values, as measured using a Minolta chromameter, are changes in hue (h°) calculated by subtracting hue at the time of evaluation from pretreatment hue.
[v]Values in columns followed by different letters within a cultivar are statistically significant ($P \leq 0.05$).
NS,*,**Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively.

Table 3. Surface injury, SSC and TA following fast controlled atmosphere–temperature treatment system (CATTS), storage at 1 °C, and ripening at 23 °C. Values are overall means across cultivars and storage times.

Time (h)[z]	Surface injury (rating)[y,x]	SSC (%)[x]	TA (%)[x]
0	1.36 a	12.3 a	0.41 a
2.5	1.61 b	13.0 b	0.40 a
Cultivar (C)	**	**	**
Storage (S)	**	NS	**
C × S	**	NS	NS
Time (T)	**	**	NS
C × T	NS	NS	NS
S × T	NS	NS	NS
C × S × T	NS	NS	NS

[z]Time is the duration of CATTS.
[y]Values followed by different letters within a storage time are statistically significant ($P \leq 0.05$).
[x]Visual rating: 0 = no injury, 1 = very slight, 2 = slight, 3 = moderate, 4 = severe.
NS,*,**Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively.

ated had been altered by treatment. The results of this testing differed depending on cultivar and on treatment (Table 5). Slow CATTS 'Diamond Princess' peaches were thought by panelists to be less flavorful and slightly less acidic than the untreated control fruit. Similarly, 'Elegant Lady' peaches that were treated were believed to have less flavor than untreated fruit. In this case of this cultivar, however, a very slight increase in the mealiness of the flesh was also noted. For 'Summer Sweet' peaches a decrease in firmness and a slight loss of juiciness (fast CATTS) were noted by the panelists to be the major changes caused by treatment. In the case of 'Fire Pearl' nectarines less flavor, including a decrease in sweetness, were the primary attributes found to differ between slow CATTS and untreated fruit. Fast CATTS fruit for this cultivar, on the other hand, differed not by flavor but due to textural issues. Acidity was the only sensory attribute different from the control fruit for slow CATTS 'Summer Bright' nectarines. Attribute testing was useful in detailing sensory differences between untreated and treated fruit but in order to determine the effect of treatment on likeability of the fruit a separate preference test was conducted (Table 6). With the exception of 'Summer Sweet', for which likeability was not altered by treatment, CATTS fruit were rated slightly lower in likeability than untreated fruit. Fast CATTS fruit generally received a lower rating than fruit that had been treated using slow CATTS and for two of the four cultivars tested were rated in the "dislike" side of the rating scale.

Discussion

Prior experimentation had cast doubt on the suitability of heat as a quarantine treatment for stone fruit given that heat treatment was shown to enhance the development of mealiness in some cultivars of peaches and nectarines (Obenland and Carroll, 2000). The application in this study of a combination of heat and CA using CATTS enabled the use of lower

Table 4. Percentages of free juice and weight loss following fast controlled atmosphere–temperature treatment system (CATTS), storage at 1 °C for 1, 2, or 3 weeks and ripening at 23 °C. Values presented are means across storage times.

Cultivar	Time[z] (h)	Free juice[y] (%)	Wt loss[y,x] (%)
Klondike	0	50.6 a	7.5 a
	2.5	45.5 b	9.6 b
Elegant Lady	0	38.7 a	6.1 a
	2.5	39.6 a	8.9 b
Diam. Princess	0	52.7 a	5.2 a
	2.5	48.0 b	7.3 b
Ryan Sun	0	42.0 a	4.4 a
	2.5	44.0 a	5.0 a
Fire Sweet	0	36.6 a	5.7 a
	2.5	40.2 a	6.4 a
Fire Pearl	0	43.9 a	3.2 a
	2.5	44.1 a	4.6 b
Summer Fire	0	52.0 a	4.2 a
	2.5	46.6 b	5.7 b
Arctic Snow	0	35.4 a	10.2 a
	2.5	28.8 b	9.8 a
Arctic Mist	0	37.4 a	5.2 a
	2.5	32.3 b	6.0 a
Cultivar (C)		**	**
Storage (S)		**	**
C × S		**	NS
Time (T)		**	**
C × T		**	*
S × T		**	**
C × S × T		NS	NS

[z]Time is the duration of CATTS.

[y]Values followed by a different letter within cultivar are significantly different ($P \leq 0.05$).

[x]Loss from immediately before treatment to end of storage and ripening period.

[NS,*,**]Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively.

temperatures and shorter treatment times than had been previously used to achieve quarantine security and was an attempt to overcome this difficulty. Peaches and nectarines lose free juice as a normal consequence of cold storage and, if stored long enough, can become mealy in texture (Lill et al., 1989). Although CATTS appeared in some cultivars to reduce the free juice in the initial portion of storage the reduction did not enhance the incidence of mealiness in the treated fruit. During longer storage, CATTS tended to be inhibitory to the free juice decline that is characteristic of many cultivars during more extended storage and slowed the development of mealiness. It is unclear by what physiological mechanism CATTS is affecting free juice. Polygalacturonase activity, the loss of which is believed to be centrally involved in the development of cold storage-induced mealiness (Ben-Arie and Sonego, 1980), is not altered by CATTS in a manner that is consistent with it being the causal factor (D. Obenland unpublished data). Weight (mostly water) loss as a result of treatment was not a factor determining differences in free juice between treated and untreated fruit as there was no relationship evident between amount of weight loss and loss of free juice. Loss of free juice and the development of mealiness during cold storage of stone fruit is generally considered to be a form of chilling injury. The ability of a heat treatment to inhibit chilling injury has been documented (Lurie and Sabehat, 1997; Porat et al., 2000) and therefore the inhibitory effect of CATTS on loss of free juice during extended storage may not be unexpected. In the case of peaches and nectarines, though, it appears that the amount of heat that the fruit receives is important in determining whether or not the treatment promotes or inhibits the development of mealiness.

Although CATTS did not initiate a large amount of surface injury in this study it tended to enhance surface injury that was present before treatment. A good example for this was treatment of ‘Diamond Princess’, a midseason peach that had a relatively high injury rating of 2.30 (between slight and moderate) following 3 h of slow CATTS but also had a fairly high injury rating of 2.00 (slight) for the untreated fruit (Table 2). For CATTS to be successful it is very important that good quality fruit with minimal surface blemish be used or it is possible that the treatment could render the fruit unmarketable. Forced air cooling was tried as a means of reducing the enhancement of surface injury by CATTS but was found to have no beneficial effect (data not shown).

As has been often noted in the literature with other heat treatments (Biggs et al., 1988; Eaks, 1978; Maxie et al., 1974), CATTS caused a delay in softening as the fruit ripened subsequent to storage. This inhibitory effect on ripening may be due to an inhibition of ethylene synthesis (Biggs et al., 1988; Lay-Yee and Rose, 1994) and be at least partially mediated by inhibitory effects on the synthesis of cell wall enzymes (Yoshida et al., 1984). Generally, 1 to 2 additional days were required to ripen CATTS fruit to a similar degree of softness as the untreated fruit. This could be seen as a beneficial side effect of treatment in that it may serve to help maintain the quality of the fruit when fruit softening becomes a problem due to extended storage or improper temperature control. A potential negative to the inhibition in ripening is that a longer required ripening time could lead to greater opportunity for decay.

Members of a trained sensory panel were able to differentiate CATTS fruit from untreated fruit for each of the five cultivars tested on the basis of taste and textural differences that varied depending upon on the cultivar tested. Although differences between the treatments were detected, many were fairly subtle as indicated by the small separations in ratings for the attribute testing that were generally less than one unit out of a one to nine unit scale (Table 5). Also, with the exception of the ‘Summer Bright’ fast CATTS, the panelists judged the likeability of the treated and untreated fruit to be fairly similar even when the difference was statistically significant (Table 6). Differences of this magnitude, although noticeable to someone trained and skilled in detecting differences, may be not noticeable to the average consumer. This conclusion is also suggested by results from a previous experiment using nectarines where

Table 5. Average flavor and texture ratings from a trained sensory panel comparison of peach and nectarine cultivars subjected to either slow or fast controlled atmosphere–temperature treatment system (CATTS) to fruit that were untreated. Fruit were stored for 10 d at 1 ºC and ripened for 3 to 5 d at 23 ºC before evaluation.

	Comparison rating[z]							
Sensory	Diamond Princess	Elegant Lady		Summer Sweet		Fire Pearl		Summer Bright
attribute	Slow	Slow	Fast	Slow	Fast	Slow	Fast	Slow
Overall Flavor	3.81*	4.33*	4.34	5.25	4.81	3.88*	4.52	4.61
Peach/Nect. Flavor	4.01*	4.21*	4.29*	5.47	4.71	3.55*	4.45	4.71
Sweetness	4.51	4.71	5.02	5.12	5.07	3.46*	4.60	4.47
Acidity	4.23*	4.62	4.72	5.05	4.98	4.87	4.77	5.69*
Juiciness	4.78	4.52	4.56	5.09	4.45*	4.42	4.75	4.72
Mealiness	5.22	5.52*	5.80*	5.28	5.30	5.48	5.73*	5.03
Firmness	4.96	4.84	4.59	4.30*	4.40*	4.85	4.25*	5.11

[z]Scale of ratings was from 1 to 9 with the control (no difference between untreated and CATTS) set at 5.0.

*Comparison ratings followed by an asterisk indicate that the treated fruit is significantly different ($P \leq 0.05$) than the untreated fruit for that sensory attribute within a cultivar.

Table 6. Hedonic preference ratings obtained from a trained sensory panel for untreated peaches and nectarines or fruit subjected to either slow or fast controlled atmosphere–temperature treatment system (CATTS). Before evaluation the fruit had been stored for 10 d at 1 °C followed by ripening for 3 to 5 d at 23 °C.

	Rating[z]		
Cultivar	Untreated	Slow CATTS	Fast CATTS
Diamond Princess	6.87 a[y]	6.03b	
Elegant Lady	6.59 a	5.17b	4.86 b
Summer Sweet	6.04 a	5.86 a	5.39 a
Fire Pearl	6.85 a	5.20 b	5.70 ab
Summer Bright	7.52 a	5.91 b	3.52 c

[z]Ratings: 9 = like extremely, 8 = like strongly, 7 = like moderately, 6 = like slightly, 5 = neither like nor dislike, 4 = dislike slightly, 3 = dislike moderately, 2 = dislike strongly, 1 = dislike extremely.
[y]Sample ratings followed by different letter superscripts within a row are significantly different ($P \leq 0.05$).

untrained panelists were unable to differentiate in taste between fruit that were untreated and fruit treated using a heat treatment more severe than the one used in this experiment (Obenland et al., 1999).

In summary, a variety of mid- and late-season peach and nectarine cultivars have been evaluated for tolerance to two CATTS protocols suitable for quarantine disinfestations of codling moth and oriental fruit moth. Fruit quality attributes were not adversely affected by either treatment to a degree that would influence marketability in almost all of the cultivars, the only exceptions being fruit that had a high amount of surface injury before the imposition of treatment. In these cases, CATTS should not be performed as it can act to enhance the preexisting injury and render the fruit unmarketable. Preference testing by a trained sensory panel indicated that the panelists preferred eating untreated fruit over fruit that had been CATTS but the relatively small differences between the ratings make it unclear whether or not an average consumer would be able to recognize the difference. Although further testing is needed to determine the impact of CATTS on taste and texture, this treatment appears to hold promise as a replacement for methyl bromide.

Literature Cited

Armstrong, J.W., J.D. Hansen, B.K.S. Hu, and S.A. Brown. 1989. High-temperature, forced-air quarantine treatment for papayas infested with tephritid fruit flies (Diptera: Tephritidae). J. Econ. Entomol. 82:1667–1674.

Ben-Arie, R. and L. Sonego. 1980. Pectolytic enzyme activity involved in woolly breakdown of stored peaches. Phytochemistry 19:2553–2555.

Biggs, M.S., W.R. Woodson, and A.K. Handa. 1988. Biochemical basis of high temperature inhibition of ethylene biosynthesis in ripening tomato fruit. Physiol. Plant. 72:572–578.

Crisosto, C.H. and J.M. Labavich. 2002. Developing a quantitative method to evaluate peach (*Prunus persica*) flesh mealiness. Postharvest Biol. Technol. 25:151–158.

Eaks, I. 1978. Ripening, respiration, and ethylene production of 'Haas' avacado fruits at 20 to 40 °C. J. Amer. Soc. Hort. Sci. 103:576–578.

Kerbel, E.L., F.G. Mitchell, and G. Mayer. 1985. Effect of postharvest heat treatments for insect control on the quality and market life of peaches. HortScience 20:725–727.

Lay-Yee, M. and K.J. Rose. 1994. Quality of 'Fantasia' nectarines following forced-air heat treatments for insect disinfestation. HortScience 29:663–666.

Lay-Yee, M., D.C. Whiting, and K.J. Rose. 1997. Response of 'Royal Gala' and 'Granny Smith' apples to high temperature controlled atmosphere treatments for control of *Epiphyas postvittana* and *Nysius huttoni*. Postharvest Biol. Technol. 12:127–136.

Lill, R.E., E.M. O'Donoghue, and G.A. King. 1989. Postharvest physiology of peaches and nectarines. Hort. Rev. 11:413–453.

Lurie, S. and A. Sabehat. 1997. Prestorage temperature manipulations to reduce chilling injury in tomatoes. Postharvest Biol. Technol. 11:57–62.

Maxie, E.C., F.G. Mitchell, N.F. Somner, R.G. Snyder, and H.L. Rae. 1974. Effects of elevated temperatures on ripening of 'Bartlett' pears *Pyrus communis*. L. J. Amer. Soc. Hort. Sci. 99:344–349.

Neven, L.G. 2004. Hot forced air with controlled atmospheres for disinfestation of fresh commodities, p. 325. In: R. Dris and S.M. Jain (eds.). Production practices and quality assessment of food crops. Postharvest treatments. Kluwer Academic Publ.

Neven, L.G. and S.R. Drake. 2000. Comparison of alternative postharvest quarantine treatments for sweet cherries. Postharvest Biol. Technol. 20:107–114.

Neven, L.G. and E.J. Mitcham. 1996. CATTS (controlled atmosphere/temperature treatment system): A novel tool for the development of quarantine treatments. Amer. Entomol. (Spring):56–59.

Obenland, D.M., M.L. Arpaia, and L.H. Aung. 1999. Quality of nectarines subjected to forced-air heat treatment for Mediterranean fruit fly disinfestation. J. Hort. Sci. Biotechnol. 74:553–555.

Obenland, D.M. and L.H. Aung. 1997. Sodium chloride reduces damage to nectarines caused by hot water treatments. Postharvest Biol. Technol. 12:15–19.

Obenland, D.M. and T.R. Carroll. 2000. Mealiness and pectolytic activity in peaches and nectarines in response to heat treatment and cold storage. J. Amer. Soc. Hort. Sci. 125:723–728.

Obenland, D.M., C.H. Crisosto, and J.K.C. Rose. 2003. Expansin protein levels decline with the development of mealiness in peaches. Postharvest Biol. Technol. 29:11–18.

Porat, R., D. Pavoncello, J. Peretz, S. Ben-Yehoshua, and S. Lurie. 2000. Effects of various heat treatments on the induction of cold tolerance and on the postharvest qualities of 'Star Ruby' grapefruit. Postharvest Biol. Technol. 18:159–165.

Sacks, E.J. and D.M. Francis. 2001. Genetic and environmental variation for tomato flesh color in a population of modern breeding lines. J. Amer. Soc. Hort. Sci. 126:221–226.

Shellie, K.C., R.L. Mangan, and S.J. Ingle. 1997. Tolerance of grapefruit and Mexican fruit fly larvae to heated controlled atmospheres. Postharvest Biol. Technol. 10:179–186.

Stahl, W. and M. Einstein. 1973. Sensory testing methods, p. 609–644. In: F. Snell, L. Ettre, and C. Hilton (eds.). Encyclopedia of industrial chemical analysis. John Wiley and Sons, New York.

U.S. Environmental Protection Agency. 2001. Protection of stratospheric ozone: Process for exempting quarantine and preshipment applications of methyl bromide. Rules and regulations. Fed. Reg. 66:37752–37769.

Whiting, D.C. and L.E. Hoy. 1997. High-temperature controlled atmosphere and air treatments to control obscure mealybug (Hemiptera: Pseudococcidae) on apples. J. Econ. Entomol. 90:546–550.

Whiting, D.C., G.M. O'Conner, J. Van Den Heuvel, and J.H. Maindonald. 1995. Comparitive mortalities of six tortricid (Lepidoptera) species to two high-temperature controlled atmospheres and air. J. Econ. Entomol. 88:1365–1370.

Yahia, E.M. and D. Ortega-Zaleta. 2000. Mortality of eggs and third instar larvae of *Anastrepha ludens* and *A. obliqua* with insecticidal controlled atmospheres at high temperatures. Postharvest Biol. Technol. 20:295–302.

Yoshida, O., H. Nakagawa, N. Ogura, and T. Sato. 1984. Effect of heat treatment on the development of polygalacturonase activity in tomato fruit during ripening. Plant Cell Physiol. 25:505–509.