

# Organic Quarantine Treatments for Tree Fruits

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*Additional index words.* Malus, Prunus, apple, cherry, peach, nectarine, codling moth, oriental fruit moth, Western cherry fruit fly

**Abstract.** Organic production of pome and stone fruits in the United States has greatly increased during the past few years. To compete and enter lucrative export markets, these fruit must meet stringent quarantine requirements. For some countries, these requirements dictate that the fruit crops must be treated with a synthetic chemical fumigant, which is not compliant with organic standards. Therefore, nonchemical quarantine treatments for organically produced pome and stone fruits have been developed using the Controlled Atmosphere/Temperature Treatment System (or CATTs) technology. This technology applies a short-term heat treatment under a low-O<sub>2</sub>/high-CO<sub>2</sub> environment, and is effective in controlling the most prominent quarantine insect pests while maintaining commodity quality. The technology has progressed beyond laboratory-scale research units to 1- to 2-ton commercial units. The development of these treatments and their effect on both insect mortality and commodity quality are discussed.

The presence or potential presence of internal feeding insects in tree fruits grown in the United States has caused the development and implementation of specific quarantine procedures to prevent the accidental introduction of these pests to areas where they do not occur. Some countries require the issuance of a phytosanitary certificate under a systems approach (Northwest Horticultural Council, 2006). Although organic apples can meet the stringent provisions of the “systems” approach (incorporation of production, harvesting, and packing practices) to meet quarantine requirements, the requirement for methyl bromide fumigation for entry into other countries does not coincide with current United States and international

organic standards (McEvoy, 2003; National Organic Program, 2006).

Most nonchemical quarantine treatments involve the application of high or low temperatures (Neven, 2000, 2003; Wang et al., 2006). Combinations of low-temperature and controlled atmospheres (CAs) (low O<sub>2</sub>/elevated CO<sub>2</sub>) have also been widely used (Hallman, 1994). High-temperature treatments have been traditionally developed for tropical and subtropical fruits and vegetables (Armstrong, 1994). Low-temperature CA treatments were seen as the only viable method of disinfestation for temperate crops, such as apples and pears. However, research from Israel in the 1990s indicated that apples could tolerate high-temperature treatments and that these treatments could also effectively alleviate some postharvest disorders such as superficial storage scald (Klein, 1994; Klein and Lurie, 1992; Klein et al., 1990; Lurie et al., 1990, 1991). Although the temperatures and heating rates used in these studies did not effectively control internal feeding pests such as codling moth (CM) (Neven and Rehfield, 1995), they suggested that heat treatments for apples to control these pests could be developed (Neven, 1998a,b; Neven and Rehfield-Ray, 2006b; Neven et al., 1996).

Deciduous tree fruits were not thought to be able to tolerate high-temperature quarantine treatments. In addition, the way the fruit are harvested, with a wide range of fruit sizes represented in any given load, posed a potential thermodynamic and logistical problem. However, the treatment of a wide range of fruit sizes using slow heating allows for equilibrium heating of the fruit, which was based on fruit thermal capacity. Other heat treatments performed on tropical and subtropical fruits do not use this approach. Those treatments ramp up the chamber temperature as quickly as possible and hold at the chamber target temperature as the fruit heats up, often with great differentials between chamber and fruit surface temperatures and fruit surface and core temperatures. We found in our work with apples (Neven et al., 1996) that large differences in chamber-to-fruit surface temperatures caused significant phytotoxicity. However, if we took the rate at which the fruit naturally heated and used that linear rate

to treat the fruit, phytotoxicity was no longer a problem (Neven et al., 2001; Obenland et al., 2005).

It is known that plants have a relatively high capacity for anaerobic metabolism, whereas insects have a very limited capacity for anaerobic metabolism. The presence of oxygen is critical for insect acclimation to thermal stress (Yocum and Denlinger, 1994; Neven, 2003). In addition, terrestrial insect respiration is chiefly regulated by the presence of carbon dioxide. These differences in plant and insect physiological responses to thermal and respiratory stress were capitalized on by the invention of the Controlled Atmosphere Temperature Treatment System (CATTs) technology (Neven and Mitcham, 1996). This system combined the application of a moist-forced hot air (MFA) or vapor-forced hot air (VFA) under a CA. Moist-forced hot air refers to hot forced air treatments conducted under a noncondensing humidity environment, whereas VFA refers to hot forced air treatments under a condensing humidity environment. This technology is similar to existing VFA and MFA treatment systems currently approved and are in use for a number of commodities destined for numerous countries throughout the world. The only difference in CATTs is the application of a CA. However, this addition is critical for the success of this treatment in providing appropriate pest control and preserving commodity quality. Research using CATTs or CATTs-type technology has been increasing for the past 11 years (Neven 2004, 2005; Neven and Drake, 2000a,b; Neven and Mitcham, 1996; Neven and Rehfield-Ray, 2006b; Neven et al., 2001, 2006; Obenland et al., 2005; Shellie et al., 2001; Whiting and Hoy, 1997; Whiting et al., 1999; Yahia, 2000a,b,c).

This review describes a body of work on the development of a CATTs treatment for disinfestation of deciduous tree fruits from internal feeding pests. How these treatments were developed in regard to fruit tolerance and insect intolerance is described. Large-scale efficacy and confirmatory tests were performed on the major quarantine insects in both laboratory- and commercial-scale CATTs treatment chambers. The effects of these treatments on both fruit quality and

This research was funded by grants from the Washington State Tree Fruit Research Commission, California Tree Fruit Agreement, U.S. Pear Board, Oregon Cherry Growers Association, U.S. Department of Agriculture–Foreign Agricultural Service, and U.S. Department of Agriculture–Animal and Plant Health Inspection Service.

Mention of a 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. I would like to thank all my co-authors who have worked with me on developing the Controlled Atmosphere/Temperature Treatment System (CATTs) technology, especially Drs. E.J. Mitcham, K. Shellie, D. Obenland, S. Drake, and G. Hallman. I would also like to thank all those from the staff at the Yakima Agricultural Research Laboratory (YARL) who provided technical assistance, including L. Rehfield-Ray, A. Kenny-Chapman, R. Barnhart, D. Hallauer, T. Wurtz, M. Morford, J. Schlaman, J. Jewett, M. Heidt, and M. Watkins. I would also like to thank my co-workers at YARL for their support of my research and cooperation in lending technical assistance. I would like to thank my cooperators who donated time and resources to the development of CATTs treatments, especially H. Ostenson (PacOrganic), K. Mathison (Stemilt), R. Valicoff (Valicoff Fruit), Snokist Fruit, Inland-Joseph Fruit, and Valley Fruit. I would also like to thank Dan Black and all the employees of Techni-Systems (Chelan, WA) for developing the CATTs chambers and the control system, and for their continued technical support.

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insect mortality are discussed in the following sections.

## SWEET CHERRIES

Perhaps the most challenging project was to develop a high-temperature treatment for sweet cherries. Every cherry grower in the world knows that cherries have to be kept cold after harvest to maintain quality. However, sweet cherries on the tree experience rather dramatic changes in temperature (G. Brown, pers. comm.). The ability of cherries to tolerate high preharvest temperatures indicated that postharvest tolerance to CATTs would be likely.

The two major pests of quarantine concern in sweet cherries grown in the Pacific Northwest are codling moth (CM) (*Cydia pomonella*) and Western cherry fruit fly (WCFF) (*Rhagoletis indifferens*). Codling moth is a lesser concern on sweet cherries, because sweet cherries are known to be a poor host for CM (Hansen and Rehmke, 2003). Western cherry fruit fly is a risk, but there is a zero tolerance for this pest in the orchard and at the packing shed. However, because both insects pose a risk to foreign markets like Australia and Japan (in the case of WCFF and CM respectively) and domestic markets like California (for WCFF), suitable treatments must be developed to protect against the accidental introduction of these pests.

*Most tolerant stage of codling moth.* The first step in developing a treatment is the determination of the developmental stage of the target pest that is most tolerant to that particular treatment. That stage will be the subject of larger scale tests to determine efficacy of the treatment. We compared the CATTs tolerance of the three embryonic stages of eggs and the five instars of CM using probit analysis (Neven, 2005). We determined that all egg stages were less tolerant to CATTs treatments than all larval stages. The third and fourth instars were the most tolerant to CATTs ( $df = 1, P < 0.0001$ ), but were about equal to each other in tolerance. Analysis of covariance revealed that the egg stages are about equal to each other in tolerance.

*Efficacy tests on codling moth.* Third instars were used in the efficacy tests because current methyl bromide fumigation treatments against CM in sweet cherries destined to Japan are designed to control the third instar (Moffitt et al., 1992; Wearing et al., 2001), and this stage is relatively as tolerant to CATTs as the fourth instar. Also, it is generally recognized by both the United States and Ministries of Agriculture, Forestries, Fisheries (Japan) that the third instar is the stage most likely to be in the fruit at time of harvest (Moffitt et al., 1992). Treatments at 45 °C for 45 min at a 1 kPa O<sub>2</sub>, 15 kPa CO<sub>2</sub> atmosphere with humidity maintained at 2 °C below dew point and 2 m/s air speed were used to treat 5067 third instars, resulting in zero survivors (Table 1) (Neven, 2005). Treatments at 47 °C for 25 min at a 1 kPa

Table 1. Summary of Controlled Atmosphere/Temperature Treatment System treatments for sweet cherries for control of codling moth (CM) and Western cherry fruit fly (WCFF).

Chamber temperature (°C)	Time to core 42 °C <sup>z</sup> (min)	Total treatment time <sup>y</sup> (min)	Final core temperature <sup>x</sup> (°C)	CM killed <sup>w</sup> (n)	WCFF killed <sup>v</sup> (n)
45	7-9	45	44.5	5067	6315
47	7-9	25	45.5	5759	5800

<sup>z</sup>Critical time for core average temperature to reach 42 °C.

<sup>y</sup>Total treatment time from initial placement of fruit into chamber until its removal.

<sup>x</sup>Final core average temperature of cherries.

<sup>w</sup>Number of third instar codling moths (CM) killed with zero survivors in efficacy tests.

<sup>v</sup>Estimated number of Western cherry fruit fly (WCFF) killed with zero survivors in efficacy tests.

All Controlled Atmosphere/Temperature Treatment System treatments conducted at 1 kPa O<sub>2</sub>, 15 kPa CO<sub>2</sub>, with a dew point set at 2 °C below the lowest fruit surface temperature.

O<sub>2</sub>, 15 kPa CO<sub>2</sub> atmosphere with humidity maintained at 2 °C below dew point and 2 m/s air speed were used to treat 5759 third instars, with zero survivors (Table 1) (Neven, 2005). Average control mortality was less than 10% in all treatments. The number killed was adjusted from the control mortality and larval recovery (insects outside of fruit) during transfer from infesting bins to treatment lugs. These tests indicate that these treatments are efficacious for control of CM larvae in sweet cherries.

*Most tolerant stage of Western cherry fruit fly.* Western cherry fruit fly is a very difficult insect with which to work because it has a univoltine life cycle (one generation per year) and an obligatory pupal diapause, which is extremely difficult to break. After 4 years of research, determinations regarding the most tolerant WCFF stage were inconclusive (Neven and Rehfield-Ray, 2006a). When mortality of each stage in the two treatments was plotted out, all stages followed a similar curve, and no stage emerged as being most tolerant when we compared mortalities with SEMs.

*Efficacy tests of Western cherry fruit fly.* Both CATTs treatments (chamber temperatures of 45 °C or 47 °C at 1 kPa O<sub>2</sub>, 15 kPa CO<sub>2</sub>, with humidity maintained at 2 °C below dew point) effectively controlled all stages of WCFF from naturally infested fruits (Neven and Rehfield-Ray, 2006a). We estimate that all egg and larval stages were represented in the infested fruit because we observed pupation from the control fruit for 3 weeks after treatment. We estimated that we treated and killed 6315 WCFFs in the 45 °C treatment and 5800 WCFFs in the 47 °C treatment (Table 1). Efficacy trials generally require killing 5000 of the most tolerant stage with zero survivorship. These studies indicate that CATTs can be effective in achieving control of WCFF in sweet cherries.

*Sweet cherry quality.* The two CATTs treatments developed to control both CM and WCFF were used to test commodity quality of sweet cherries (Neven and Drake, 1998, 2000a; Neven et al., 2001; Shellie et al., 2001). Neven and Drake (1998) found that heat-treated 'Bing' sweet cherries were slightly redder than untreated control fruit. Fruit and stem subjective visual values were slightly lower for the heat-treated fruit after 14 d of storage, but more pronounced for 21 d of storage. Firmness was unaffected. Soluble

solid content (SSC) was unaffected, except for fruit stored under modified atmosphere packaging (MAP) for 14 d, where values were higher in heat-treated fruit. Changes in titratable acidity (TA) were minimal. Pitting and bruising were more evident in heat-treated fruit, but there was not any visible decay in CATTs treated cherries over all storage periods.

Neven and Drake (1998) found that there were no significant changes in fruit color of CATTs-treated 'Rainier' cherries. Stem color was slightly browner in CATTs-treated fruit stored for 21 d in MAP. Fruit and stem subjective visual values were slightly lower for CATTs-treated fruit. Firmness was slightly lower (but within 0.5 N) for CATTs-treated fruit. The effects of CATTs treatment on SSC and TA were not significant (SSC differences were usually higher for heat-treated fruit). Both pitting and bruising were significantly higher in CATTs-treated fruit. No visible decay was found in any CATTs treatment.

Further research (Neven and Drake, 2000a) compared various potential quarantine treatments against conventional methyl bromide fumigation, and found that fruit quality of CATTs-treated cherries was superior to methyl bromide fumigated fruits, with the exception of pitting. Pitting was attributed to the low temperature of the hydro-cooling water (0-2 °C). Further studies using forced air cooling at 2 °C reduced this problem (Shellie et al., 2001). These treatments show great promise as both an alternative to methyl bromide fumigation for conventionally grown sweet cherries and a new treatment for organically grown sweet cherries.

## 'BARTLETT' PEARS

*Codling moth and oriental fruit moth mortality.* Two treatments were developed to control both CM and oriental fruit moth (OFM; *Grapholitha molesta*) in 'Bartlett' pears. The first treatment incorporated a heating rate of 12 °C/h whereas the other used a heating rate of 100 °C/h from a starting chamber temperature of 23 °C to a final chamber temperature of 46 °C (Neven, 2004). We found that 'Bartlett' pears could tolerate a very rapid rate of heating while maintaining market quality (Mitcham et al., 1999). We found that we could obtain 100%

mortality of CM and OFM in 2.5 h using the 100 °C/h heating rate CATTs treatment, whereas it took 3 h to obtain the same level of mortality using the 12 °C/h heating rate CATTs treatment (Neven, 2004).

**Market quality.** ‘Bartlett’ pears are one of the few fruits that cannot tolerate most traditional postharvest quarantine treatments designed to control insect pests like CM or OFM. Therefore, these fruit are not commonly exported to markets restricting these pests. Also, ‘Bartlett’ pears are not known to store for extended periods of time like apples and winter pears. Considerable time and effort is required when processing ‘Bartlett’ pears, which often requires canning operations to pay overtime to workers to ensure that the harvest is processed before commodity quality is lost as a result of overripening during storage. It is possible that heat treatments before cold storage could delay ripening, and therein give canners extra time to process the harvest. Previous research with apples and winter pears showed that CATTs treatments delayed ripening by 3 to 5 d, which might also be the case for ‘Bartlett’ pears.

The quality of fruit directly after CATTs treatments was not significantly different from nonheated controls. We found that the longer the duration of the heat treatment, the firmer the pears after the ripening period. The levels of SSC were not significantly different between treatments, whereas there was a slight decrease in TA, less than 1%, in the 3-h CATTs-treated cold-stored fruit after the 4-d ripening period. However, this decrease was not observed in the 7-d ripened fruit; for the CATTs-treated fruit, the TA values were slightly higher. There was an increase in external injury evident in the 2- and 3-h CATTs-treated cold-stored fruits, which may result from handling hot fruit after treatment. The L (Hunter L, measure of lightness) values of CATTs-treated cold-stored fruits were slightly lower than controls, whereas the H (hue) values tended to be slightly increased at the 4-d but not the 7-d ripening periods (Mitcham et al., 1999).

These data indicate that CM and OFM can be effectively controlled in ‘Bartlett’ pears with CATTs while maintaining commodity market quality.

## WINTER PEARS

Winter pears, like summer pears, do not respond well to methyl bromide fumigations designed to control the two major internal feeding pests: CM and OFM. In addition, winter pears have not been widely exported because of issues with fire blight (*Erwinia amylovora*). However, in preliminary studies to determine the potential of CATTs for pest control in winter pears, we found that they respond quite well to heating rates of 4 to 12 °C/h to core temperatures between 43 and 45 °C (Neven and Drake, 2000b; Neven et al., 2001). This is not surprising because these fruits, as well as apples, grown in Washington state commonly reach 42 °C at a rate of

nearly 4 °C/h during a typical summer day (Howell and Schmidt 2002). There was little difference in fruit quality when heat treatments were performed under air (Neven and Drake, 2000b) or under a 1 kPa O<sub>2</sub>, 15 kPa CO<sub>2</sub> environment (Neven et al., 2001). The addition of CA to the heat treatment did have a dramatic effect on CM mortality, which resulted in complete control of CM in less time compared with heat-only treatments (Neven and Rehfield-Ray, 2006b; Neven et al., 2001).

**Winter pear quality.** Controlled Atmosphere/Temperature Treatment System-treated ‘Anjou’ fruit were greener than controls, with hue values 12 to 15 U higher than untreated controls (Neven and Drake 2000b, Neven et al., 2001). Firmness was higher in heat-treated fruit by more than 26 N. Soluble solids concentration values were not appreciably changed by heat treatments compared with controls. Titratable acidity decreased slightly in treatments and was significantly lower than controls. The SSC-to-TA ratio was greatly increased in treatments, with values 16 to 25 U higher than controls (Neven and Drake, 2000b; Neven et al., 2001).

Controlled Atmosphere/Temperature Treatment System-treated ‘Bosc’ fruit firmness was higher by as much as 26 to 40 N (Neven and Drake, 2000b; Neven et al., 2001). There were no appreciable changes in hue, SSC, and TA. The SSC-to-TA ratio was higher in treatments by nearly twofold (Neven and Drake, 2000b; Neven et al., 2001).

It is interesting to note that superficial scald was not noticed in any of the CATTs-treated fruit, but was observed in some of the controls (Neven et al., 2001). These findings are in agreement with preliminary research performed in Israel (Klein, 1994; Klein and Lurie, 1992; Klein et al., 1990; Lurie et al., 1990, 1991). This is significant for the organic industry because there is no reliable means to prevent the development of superficial scald in pears that meet current organic standards.

## PEACHES AND NECTARINES

Codling moth and OFM are the major pests of quarantine concern in peaches and nectarines grown in California and exported to Japan (CM), Mexico (OFM), and British Columbia, Canada (OFM). Although “systems” approaches have been approved by

both Mexico and British Columbia, Canada, it is oftentimes difficult to achieve complete control of OFM without a subsequent methyl bromide fumigation. Japan has never accepted any commodities that could be potentially infested with CM without requisite methyl bromide fumigation.

**Codling moth and oriental fruit moth mortality.** Controlled Atmosphere/Temperature Treatment System treatments using a heating rate of either 12 or 24 °C/h to a final chamber temperature of 46 °C at a 1 kPa O<sub>2</sub>, 15 kPa CO<sub>2</sub> atmosphere were sufficient to control the most tolerant stages of CM and OFM (Table 2). Although there was a difference in thermotolerance of the egg and larval stages of each species to heat treatments under regular atmospheres (Yokoyama and Miller, 1987; Yokoyama et al., 1991), the application of CA masked this response. Stage-specific thermotolerance was reported to diminish in six tortricid pests when heat treatments were accompanied with a low-O<sub>2</sub> environment (Whiting et al., 1995). Although the heating rate and atmosphere concentrations differed from those used in this study, the pattern of diminishing differential stage thermotolerance was similar to our results. The influence of anoxia on insect physiological response to temperature was documented in flesh fly (*Sarcophaga crassipalpis*) cold hardiness response (Yocum and Denlinger, 1994), in which anoxic conditions blocked the ability of flesh flies to cold harden rapidly. There is also an indication that anoxia can inhibit the formation of heat shock proteins in CM (Neven, unpublished data). Heat shock proteins were shown to participate in CM thermotolerance (Yin et al., 2006), where it was shown that heat-stressed CM larvae produced elevated levels of heat shock proteins, which were related to increased thermotolerance. Thus, the inhibition of the production of heat shock proteins could mask the differences in thermotolerance in different insect life stages.

The commercial viability of these treatments is still a concern to the industry without a demonstration of treatment efficacy in a commercial unit. We have tested CATTs treatments on packed boxes in a 2-ton (8800-kg) commercial CATTs chamber in George, WA, during the summers of 2004 and 2005. We were able to force heat through domestic commercial boxes in the 2004 runs. However, when export boxes were used in

Table 2. Summary of Controlled Atmosphere/Temperature Treatment System treatments for peaches and nectarines for control of codling moth (CM) and oriental fruit moth (OFM).

Heating rate <sup>z</sup> (°C/h)	Final chamber temp (°C)	Total treatment time <sup>y</sup> (min)	Final low core temperature <sup>x</sup> (°C)	CM killed <sup>w</sup> (n.)	OFM killed <sup>v</sup> (n.)
12	46	180	44.0	31,154	5674
24	46	150	45.2	30,884	5453

<sup>z</sup>Rate of temperature increase in the chamber.

<sup>y</sup>Total treatment time from initial increase in temperature in the chamber until the fruit is removed from the chamber.

<sup>x</sup>Final core low temperature of peaches and nectarines.

<sup>w</sup>Number of fourth instar codling moths (CM) killed with zero survivors in confirmation tests.

<sup>v</sup>Estimated number of fourth instar oriental fruit moths (OFM) killed with zero survivors in efficacy tests. All Controlled Atmosphere/Temperature Treatment System treatments conducted at 1 kPa O<sub>2</sub>, 15 kPa CO<sub>2</sub>, with a dew point set at 2 °C below the lowest fruit surface temperature.

2005, heat transfer was more problematic because of the location of the ventilation holes on the ends rather than along the sides of the boxes. We are currently working with the industry to construct a special commercial CATTs unit that could treat a pallet of boxed fruit, because this is their desired format for fruit treatment by the industry. We expect this chamber to be completed some time in 2007.

*Peach and nectarine quality.* Fruit quality was very similar for both heating rates. Compared with the untreated controls, CATTs-treated fruit displayed slightly higher amounts of surface injury, although the increase in surface injury was only an important factor to marketability in cultivars that had high amounts of surface injury before treatment (Obenland et al., 2005). The percentage of free juice in the flesh, a measure of juiciness, was slightly less in CATTs-treated 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-treated fruit. Soluble solids, acidity, weight loss, and color all were either unaffected or changed to a very small degree as a result of CATTs treatment. Members of a trained sensory panel preferred the taste of untreated fruit over fruit that had been CATTs-treated, but the ratings of treated and nontreated fruit were generally close together and it is unclear whether an average consumer could detect the difference (Obenland et al., 2005). The fact that we did not find significant differences in treatment efficacy between peaches and nectarines indicates that this treatment is equally effective for both types of fruit (Obenland et al., 2005). The reason for this may be related to the slow rate of heating used in this system. Although further work needs to be done regarding the influence of CATTs on taste, it otherwise appears that CATTs treatment does not adversely affect the marketability of good-quality fruit and therefore shows promise as a nonchemical quarantine treatment for peaches and nectarines. These treatments are an improvement over traditional methyl bromide fumigation in that they extend shelf life (Obenland et al., 2005).

These CATTs treatments were demonstrated to provide complete control of the two major quarantine pests infesting peaches and nectarines. These treatments are efficacious

regardless of fruit type (peach or nectarine) and, in a flow-through system, regardless of fruit size. These treatments hold great promise as either a replacement for methyl bromide for conventional fruit or as a new direct treatment for organically grown fruit.

## APPLES

Codling moth and OFM are the two major internal feeding pests of quarantine concern in apples produced in the Pacific Northwest. The other two pests of quarantine concern, not prevalent in the Pacific Northwest, are apple maggot (*Rhagoletis pomonella*) and plum curculio (*Conotrachelus nenuphar*). Preliminary research indicated that OFM and CM were more CATTs tolerant than apple maggot and plum curculio (G. Hallman, unpublished).

*Codling moth and oriental fruit moth mortality.* We found very little differences in tolerance to CATTs treatments between CM and OFM instars. It appears that the addition of a CA to a heat treatment either masks or blocks the acclimation process in CM and OFM. Previous published research (Yokoyama and Miller, 1987, Yokoyama et al., 1991) demonstrated that CM fourth and fifth instars are the most thermal-tolerant immature stages in this species and they are also more thermal tolerant than the most tolerant stage of OFM fourth instar. Further research (Neven and Mitcham, 1996) indicated that the addition of a CA to a heat treatment would reduce the duration needed to achieve 100% mortality by nearly 50%. We later showed that it is necessary to have both elevated CO<sub>2</sub> and low O<sub>2</sub> to achieve optimal insect mortality of CM in sweet cherries (Neven, 2005). The fourth instar of both species was determined to be the most tolerant stage after consideration in variation of response (Neven and Rehfield-Ray, 2006b). Both CM and OFM fourth instars were controlled by a CATTs treatment using a heating rate of 12 °C/h to a final chamber temperature of 46 °C under a 1 kPa O<sub>2</sub>, 15 kPa CO<sub>2</sub> environment (Table 3).

*Fruit quality of apples.* It was determined that fruit treated with heat alone (12 °C/h heating rate to chamber temperatures of 44 or 46 °C, with humidity maintained at 2 °C below dew point, 2 m/s air speed, in air) were not as firm as fruit treated with the combination heat plus CA (heating rate of 12 °C/h to

chamber temperatures of 44 or 46 °C, with humidity maintained at 2 °C below dew point, 2 ms<sup>-1</sup> air speed, at 1 kPa O<sub>2</sub> and 15 kPa CO<sub>2</sub>) (Neven et al., 2001). All heat-treated fruit were firmer than untreated control fruit. Heat-treated fruit stored as long as the untreated control fruit. In 'Golden Delicious' apples, sunburn was more prevalent in control fruit but not as common in heat-treated fruit. 'Gala' apples were more susceptible to internal breakdown after heat plus CA treatments. 'Red Delicious' apples withstood the treatments very well. 'Fuji' apples at harvest had severe water core and did not withstand more than 90 d of storage. 'Granny Smith' apples stored for 150 d showed a dramatic suppression of storage scald in the heat-treated fruit. Control fruit had 100% scald whereas heat-treated fruit were showed less than 1% storage scald. In all heat-treated fruit, the SSC-to-TA ratio was increased, which is generally reflected in a sweeter tasting fruit.

## SUMMARY

The CATTs treatment effectively controlled all stages of CM, OFM, and WCFF that infest fresh fruit. We have demonstrated that CATTs treatments can be effective in both laboratory and commercial CATTs units for apples. We have also demonstrated from previous research that CATTs treatment can result in acceptable apple (Neven et al., 2001), peach and nectarine (Obenland et al., 2005), sweet cherry (Neven and Drake, 2000a; Neven et al., 2001; Shellie et al., 2001), and pear (Mitcham et al., 1999; Neven et al., 2001) quality. We believe that this treatment can provide quarantine security for export of organic tree fruits attempting to gain market access to countries currently requiring direct postharvest quarantine treatments while maintaining organic certification.

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Table 3. Summary of Controlled Atmosphere/Temperature Treatment System treatments for apples for control of codling moth (CM) and oriental fruit moth (OFM).

Heating rate <sup>a</sup> (°C/h)	Final chamber temp (°C)	Total treatment time <sup>b</sup> (min)	Final core		
			low temperature <sup>c</sup> (°C)	CM killed <sup>w</sup> (n.)	OFM killed <sup>v</sup> (n.)
12	46	180	43.5	30861	5497

<sup>a</sup>Rate of temperature increase in the chamber.

<sup>b</sup>Total treatment time from initial increase in temperature in the chamber until the fruit is removed from the chamber.

<sup>c</sup>Final core low temperature of peaches and nectarines.

<sup>w</sup>Number of fourth instar codling moths (CM) killed with zero survivors in confirmation tests.

<sup>v</sup>Estimated number of fourth instar oriental fruit moths (OFM) killed with zero survivors in efficacy tests. All Controlled Atmosphere/Temperature Treatment System treatments conducted at 1 kPa O<sub>2</sub>, 15 kPa CO<sub>2</sub>, with a dew point set at 2 °C below the lowest fruit surface temperature.

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