USE OF HARVISTA™ (1-MCP) IN THE FIELD OR AS A POSTHARVEST DIP TO EXTEND THE HARVEST WINDOW, INCREASE FRUIT SIZE AND IMPROVE POST-STORAGE FRUIT QUALITY

A report for the California Pear Advisory Board
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Summary

Pre-harvest 1-methylcyclopropane (Harvista™, 1-MCP) application has been shown to provide partial delay of firmness loss on the tree, delayed ripening-associated changes after harvest, and reduced physiological disorders after cold storage in California 'Bartlett' pears. This report summarizes maturity and ripening effects obtained in our field trial performed in summer 2007. During this season, 50 and 100 mg/L 1-MCP were applied at 21lbf or 18lbf maturity, or double application at both stages. The best 1-MCP treatments maintained approximately 1 to 1.5lbf higher firmness on the tree and delayed ripening immediately after harvest, even when fruit were treated with ethylene and held at 68F to ripen. The best firmness maintenance on the tree occurred when fruit were treated at 18 rather than 20.5lbf maturity and harvest occurred 1 to 2.5 weeks after application. Immediately after harvest, ripening-associated changes, including softening, respiration rate, ethylene production and skin color development were delayed by 1-MCP treatment when the fruit were harvested 1 week after treatment at 18 lbf. However, when fruit were harvested 2½ weeks after 1-MCP treatment, there was no delay in ripening at harvest. Fruit ripened at normal rates after 4½ months or 4 months in cold storage, regardless of harvest time. Shorter storage times were not evaluated. After 4½ and 4 months of cold storage and ripening, 1-MCP treated fruit and adjuvant treated fruit had lower internal breakdown and scald incidence and severity. Parallel to this experiment, 1-MCP and 1-naphthaleneacetic acid (NAA) were tested for fruit drop control. Both NAA and 1-MCP controlled fruit drop during the period of study (5 weeks after application), but the NAA treatment was more effective.

Introduction

1-MCP is a gas that inhibits ethylene action that has been used, especially after harvest to reduce ethylene-associated changes, including ripening and senescence processes. During the last three years, AgroFresh has made available for research a formulation that can be applied preharvest and that has been shown to partially control fruit drop, delay maturity and ripening, and decrease the incidence of internal breakdown and scald in California Bartlett pears

In our trial in 2006, we found 0.5 to1lbf higher firmness in treated fruit compared with the control fruit when 1-MCP (28 and 56 mg/L) was applied at 18 lbf and harvested 1 to 2 weeks later. In this same season and after 3.5 months in storage at 30°F, 1-MCP treated fruit presented a delay in ripening at 68°F of approximately 1 to 2 days and a reduction of scald incidence after ripening, varying from 38% in the control

fruit to 9% in fruit treated with 56 mg/L 1-MCP. Although our preliminary data indicates that maturity at application, time between application and harvest and 1-MCP concentration could have an impact in the final 1-MCP effect on maturity, ripening and control of physiological disorders, more research is required to determine with accuracy the interaction between these factors.

This report describes the results obtained in 2007. During this year, we identified the following objectives as priority for our experiment:

1) to evaluate higher 1-MCP concentrations compared with previous years (50 and 100 mg/L)
2) to determine the effect of application time and periods between application and harvest on fruit drop, maturity, ripening, and physiological disorders after harvest and after 4 m storage.

Methods

Objective 1.: Determine the optimum application method, timing and concentration for 1-MCP spray applications in the field

Pear trees in a commercial orchard in Finley, California were treated (see Figure 1 and 2) at different maturities (see Table 1) with 0, 50 and 100 g A.I. of 1-MCP (AFxRD-038, AgroFresh) mixed with HI Supreme Spray Oil, Silwet L-77, and foam buster (Doc Farwell's, silicone antifoam) (1%, 0.1% v/v, and ≈ 3 drops respectively), application volume of 2.6 to 2.8 gallons per tree using nozzle OC-12 and application pressure of ≈48-50psi. Treatments were applied in the early morning between 6 to 9:30 am using a large droplet size to encourage slow drying, and care was taken to reduce agitation of the solution prior to spraying.

Figure 1. Spray and orchard used for the experiment. The spray is pressurized by CO_2 (small aluminum tank) through a connection to the 1-MCP solution tank. August 13, 2007, Finley, CA.

The tank mixing procedure was the following: 1) spray tank was filled with approximately two-thirds of the total volume of water required, 2) HI Supreme Spray Oil, Silwet L-77, and foam buster were added to the spray tank and mixed (swirl) for a few seconds, 3) AFxRD-038 powder (1-MCP) was added into the spray tank and mixed with a drill at low speed for ≈ 15 seconds, 4) remaining water was added, 5) spraying of the plots was performed within 30 minutes after mixture preparation.

Figure 2. Fruit covered by the solution. Each tree was applied with approximately 2.6 to 2.8 gallons of solution. August 13, 2007, Finley, CA.

The experimental design was a randomized complete block design (four blocks, one tree per block per treatment). Treatments were applied on July 27, 2007 at 20.5 lbf firmness and August 13, 2007 at 18 to 19 lbf (there was some firmness variability between treatments at this application because some treatments were applied twice; see Table 1 for more detail). Fruit from all treatments were harvested on August 20 and 30, 2007. After both harvests, fruit were transported to the postharvest lab in Davis, CA in a cargo van with air conditioning, stored overnight at room temperature, and sorted the following day to remove damaged or blemished fruit. A subset of fruit were treated the same day of sorting with 100 µL L^{-1} of ethylene for 24 h at 68ºF to stimulate ethylene production for immediate ripening, and then transferred to 68ºF in regular air (RA) conditions. The remaining fruit were placed into pear boxes with plastic liners (with holes in them to allow gas exchange) for storage during 4-4.5 months in RA. Fruit condition was evaluated upon removal from storage and again after ripening.

Fruit toxicity evaluation

Fruit phytotoxicity was evaluated after harvest using eight fruit per treatment per block. Fruit phytotoxicity was rated with the following scale: 0=none; 1=slight; 2=moderate; 3=severe.

Fruit Evaluation

Ripening time varied depending on the harvest time and was determined based on the ripeness level of the untreated fruit. Thirty two fruit (8 per block) for each treatment were assessed for fruit weight, color and firmness each evaluation time. In addition, 24 fruit (6 per block) were used to determine daily or every two days (depending on storage time) ethylene and carbon dioxide production (respiration rate) for each treatment during the ripening period at 68ºF.

Firmness was measured objectively using a Gűss Penetrometer fitted with an 8 mm probe. Carbon dioxide and ethylene production at 68 ºF was measured by placing six fruit from each treatment and block into a one gallon jar and sealing it for 10 to 60 minutes. The headspace gas was evaluated for CO_2 and ethylene using rapid gas analysis (VIA510, Horiba, Japan) and gas chromatography (Model AGC Series 400, Hach-Carle Co., USA), respectively. Color was measured subjectively using the California Department of Agriculture color chart (1=green; 2=light green; 3=light yellow; 4=yellow). Internal browning and scald severity were measured subjectively using the following scale: 0=none; 1=slight; 2=moderate; 3=severe.

Table 1. Treatments and maturity conditions during the 2007 harvest season.

Treatment	Fruit firmness at application (lbf)	Days until Harvest 1 (Aug. 20)	Days until Harvest 2 (Aug. 30)
1. Control	18	7	17
2. Adjuvant [1/]	18	7	17
3. 1-MCP (50 mg/L) [2/]	18	7	17
4. 1-MCP (100 mg/L/) [2/]	18	7	17
5. Adjuvant	21	24	34
6. 1-MCP (100 mg/L/) [2/]	21	24	34
7. Adjuvant	18.4 & 21	7 + 24	17 + 34
8. 1-MCP (50 mg/L) [2/]	19 & 21	7 + 24	17 + 34

[1/] HI Supreme Spray Oil, Silwet L-77, and foam buster (Doc Farwell's, silicone antifoam) (1%, 0.1% v/v, and ≈ 3 drops respectively),
[2/] 1-MCP (AFxRD-038, AgroFresh) with adjuvant as **[1/]**.

Fruit Drop Experiment

A separate experiment was performed to evaluate the effect of 1-MCP on fruit drop. This experiment was conducted in the same orchard as that used for the experiment discussed previously. Four treatments were established;

1) Control- no application of 1- naphthaleneacetic acid (NAA) or 1-MCP,
2) Adjuvants only (as described in table 1),
3) 1-MCP 50 mg/L + adjuvants (as described in table 1),
4) 1-NAA 0.04 L g A.I. / acre.

NAA was applied commercially on July 24, 2007 while all the remaining treatments were applied on July 27, 2007 when fruit presented 20.5 lbf maturity. Fruit drop was evaluated weekly during 5 weeks counting the number of fruit on the ground. The experimental design was a randomized complete block design with four blocks total (one tree per block per treatment). Trees in this experiment were not sampled or harvested at any time after the application of the treatments to decrease fruit drop caused by artificial intervention.

Fruit from this orchard were affected by codling moth. The larval stage of this insect enters the fruit at the blossom end (calyx), consuming or eating most of the endocarp and in extreme cases parts of the mesocarp. This damage inside the fruit is difficult to detect in some cases without cutting the fruit. Even though in this experiment harvesting fruit with damage was avoided or when harvested not included during most of the firmness evaluations, the group of fruits used for the initial firmness evaluation at harvest 1 had approximately 10% moderate to severe damage. For respiration and ethylene production, sampled fruit were also carefully selected, but most of the treatments ended up having some fruit with insect damage. These fruits ripened and softened normally according with the tendency of the unaffected fruit in each treatment, but damage was detected when sampled at the end of the experiment. The effect of this damage in some of the fruit sampled during the experiment is not known.

Objective 2: Determine the effect of 1-MCP spray applications on post-storage quality and ripening of Bartlett pears

Fruit from harvest 1 and 2 was evaluated after 4.5 and 4 m cold storage at -30F. The quality evaluation was performed as described previously in the section Fruit Evaluation, except that respiration and ethylene production was measured daily. In addition, each fruit was rated for storage scald and internal breakdown incidence and severity at 0 and 4 days after removal from cold storage. The following hedonic scale was used: 0=none; 1=slight damage; 2=moderate damage; 3=severe damage.

Results

Maturity Effects

As shown in Figure 3, fruit treated with 1-MCP at 18lbf or twice at 19 and 21lbf presented delays in fruit softening on the tree of approximately 1 to 1.5lbf compared with control fruit during both harvests. The delay in fruit softening was more evident in fruit treated at 18lbf with 50mg/L rather than 100mg/L, suggesting that using higher rates than 50mg/L do not necessarily guarantee stronger effect, at least in delaying on tree maturity.

Furthermore, when 1-MCP was applied at 21lbf the effect was less as compared with fruit treated at 18lbf, suggesting that maturity at application is an important variable to consider. Fruit treated with 1-MCP twice (19 and 21 lbf) in this experiment did not show stronger maturity delays than fruit only treated at 18lbf which agrees with the fact that 1-MCP applied at 21lbf did not provide any or had very limited benefits under the conditions of this experiment (Figure 3).

Even though the time difference between harvest 1 and harvest 2 was 10 days, the differences in fruit firmness afforded by 1-MCP when compared with the control fruit was obtained in both harvests (Figure 3), suggesting that the 1-MCP effect remains for at least 1 to 2.5 weeks after the last application. In our 2006 trial, we found that 1-MCP treated fruit did not present maturity differences with the control fruit after approximately 3 weeks of application. It remains to be determined whether this efficacy period can vary season to season.

Interestingly, in 2007 and also in our previous trials in 2005 and 2006, the adjuvants used during the application provided slight effects on softening control on the tree (Figure 3). This might be associated with alteration in the internal atmosphere of the fruit since the adjuvant could potentially interfere with gas exchange between the inside and the outside. Changes in carbon dioxide and oxygen concentration inside the fruit could produce some effects on maturity.

Ripening Effects at Harvest*: Firmness, Respiration Rate, Ethylene Production, and External Color*

As shown in Figures 4, 5, 6, and 7, 1-MCP partially delayed fruit softening and reduced respiration rate, ethylene production and skin color development compared with the control fruit when fruit were ripened immediately after harvest at 68°F.

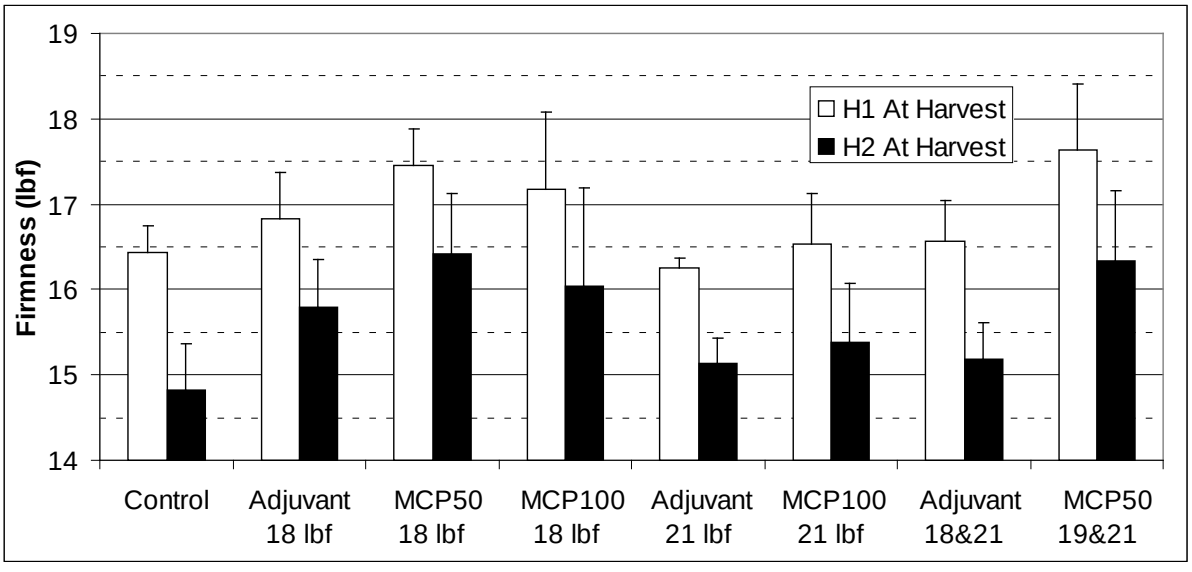

Figure 3. Maturity effects of 1-MCP applied at different rates and maturities and harvested on July 20 (H1) and July 30, 2007 (H2). 1-MCP rates are indicated with 50 or 100 (mg/L). Maturity at harvest is also indicated (18,19 or 21lbf).

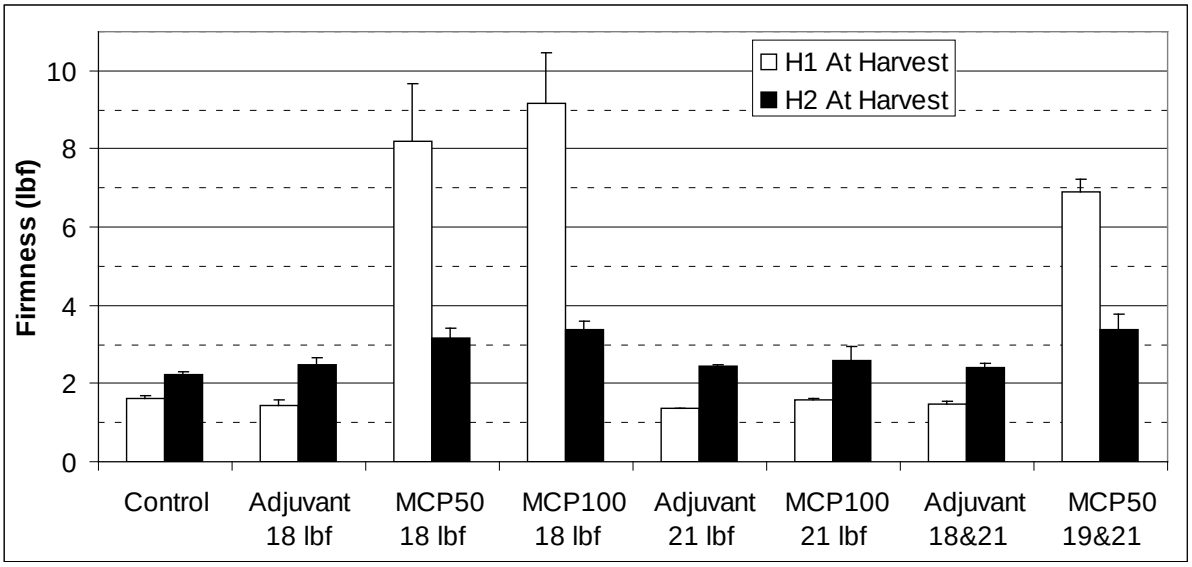

Figure 4. Firmness after harvests plus 8 (H1) or 6 (H2) days ripening at 68F. All fruit were treated with 100 ppm ethylene during 24 hr after harvest and subsequently held at 68F to ripen.

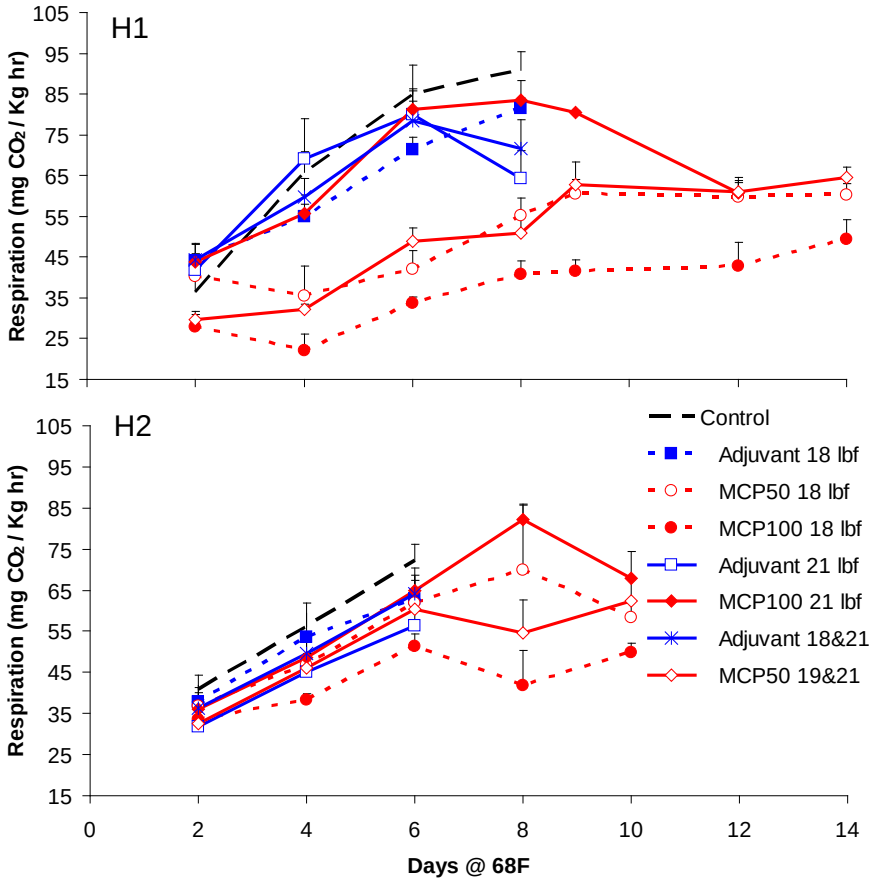

Figure 5. Respiration values by treatment after harvest and during ripening at 68F of California 'Bartlett' pears harvested on August 20 (H1) and August 30, 2007 (H2).

The 1-MCP effect was much more evident after H1 when the difference between the last application and harvest was only 1 week. These results suggest that the time between application and harvest could play a key role for 1-MCP effects during ripening, as also shown for maturity in Figure 3.

Furthermore, 1-MCP reduced fruit softening, respiration rate, ethylene production and color development (figures 4-7) to a greater extent in those treatments applied at 18lbf than those applied at 21lbf, as was also shown for maturity (figure 3). Fruit treated with 1-MCP twice had higher firmness (19lbf) than the previously untreated fruit (18lbf) treated on the same day, indicating that treatment at 21lbf maintained higher fruit firmness, at least for some time. Fruit treated twice presented similar ripening rates after harvest as those treatments applied only at 18lbf, indicating that the benefits of the first application (21lbf) had worn off prior to harvest. In contrast to what was shown for reduction of softening on the tree (maturity control), the highest 1-MCP concentration (100mg/L, applied at 18lbf) had stronger effects compared with 50mg/L in controlling ripening-associated changes after both harvest times (figures 4-7).

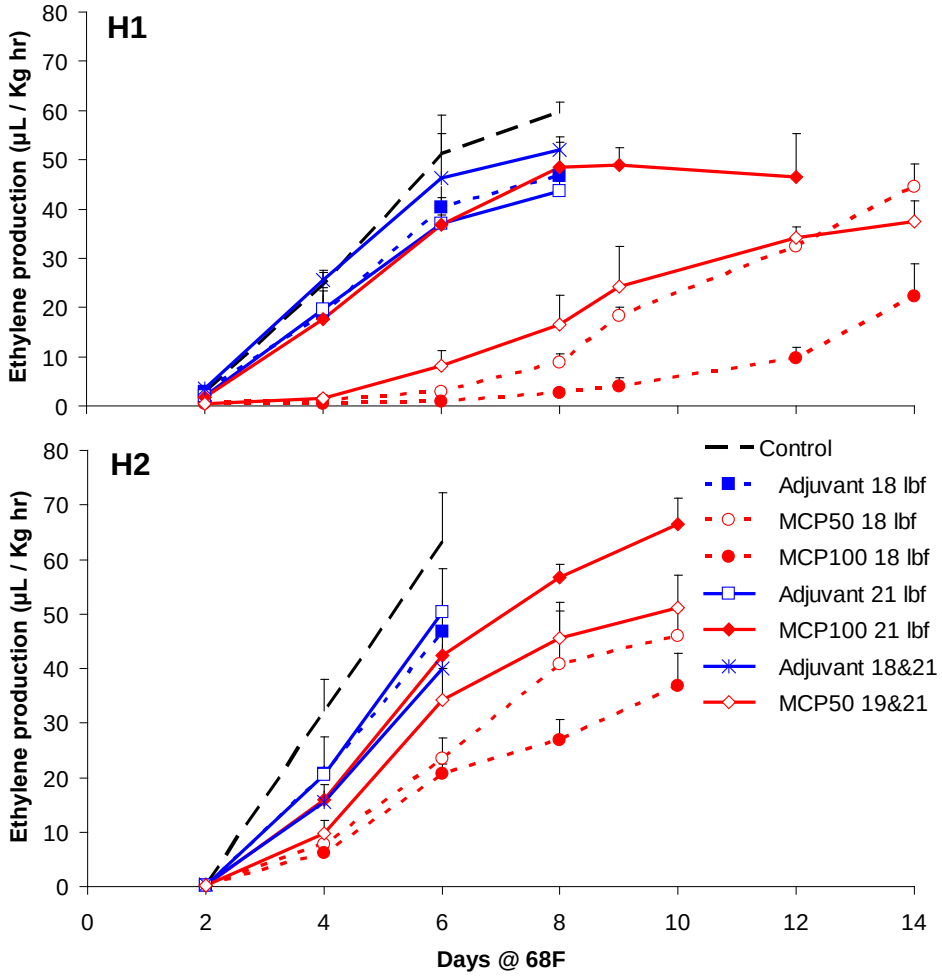

Figure 6. Ethylene production by treatment after harvest and during ripening at 68F of California 'Bartlett' pears harvested on August 20 (H1) and August 30, 2007 (H2).

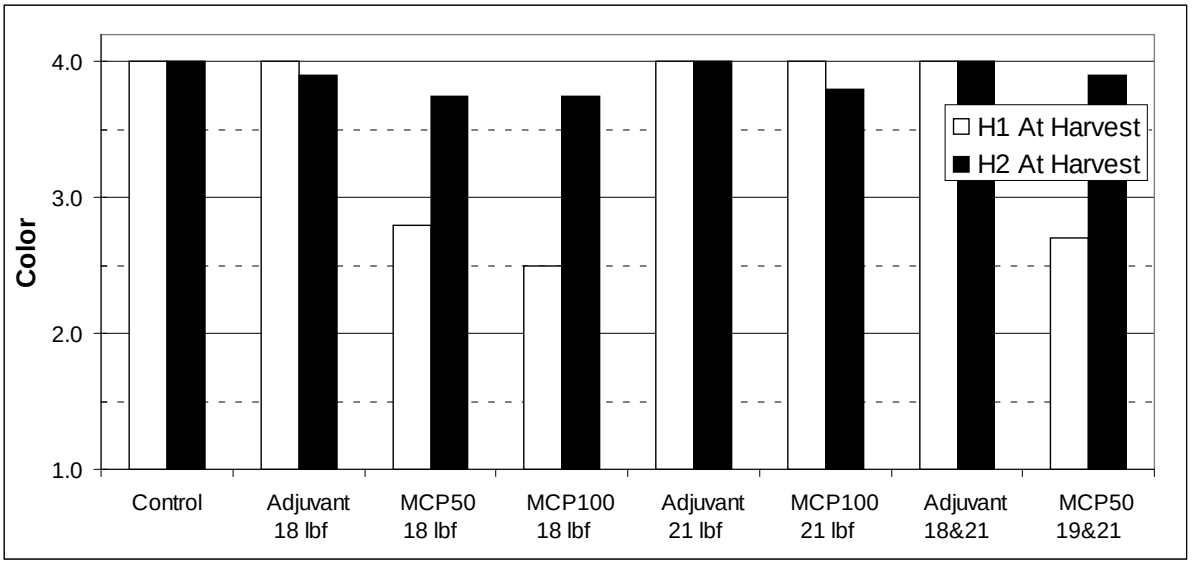

Figure 7. Color after harvest plus 8 (H1) or 6 (H2) days ripening at 68F. All treatments were treated with 100 ppm ethylene during 24 hr after harvest and subsequently held at 68F to ripen. Color was graded according to the CA Dept. Ag. Color chart (1= green, 2= light yellow, 3= light yellow, 4= yellow).

Fruit Weight

Figure 8 presents fruit weight at both harvests and shows that, for unknown reasons, the most effective 1-MCP treatment for maturity control (50 mg/L, applied at 18lbf) had lower average fruit weight than control fruit at both harvests. We did not observe this effect in the previous year's work, but this observation warrants further investigation to assure that 1-MCP treatment does not inhibit fruit growth.

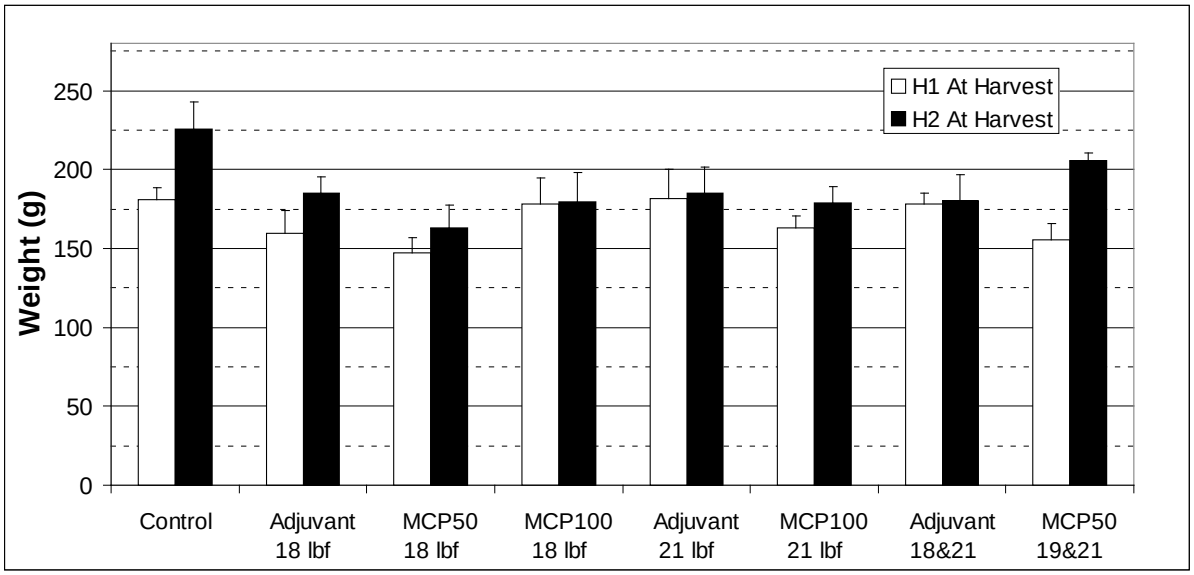

Figure 8. Average fruit weight by treatment of 'Bartlett' pears harvested on August 20 (H1) and August 30, 2007 (H2)

Fruit Drop

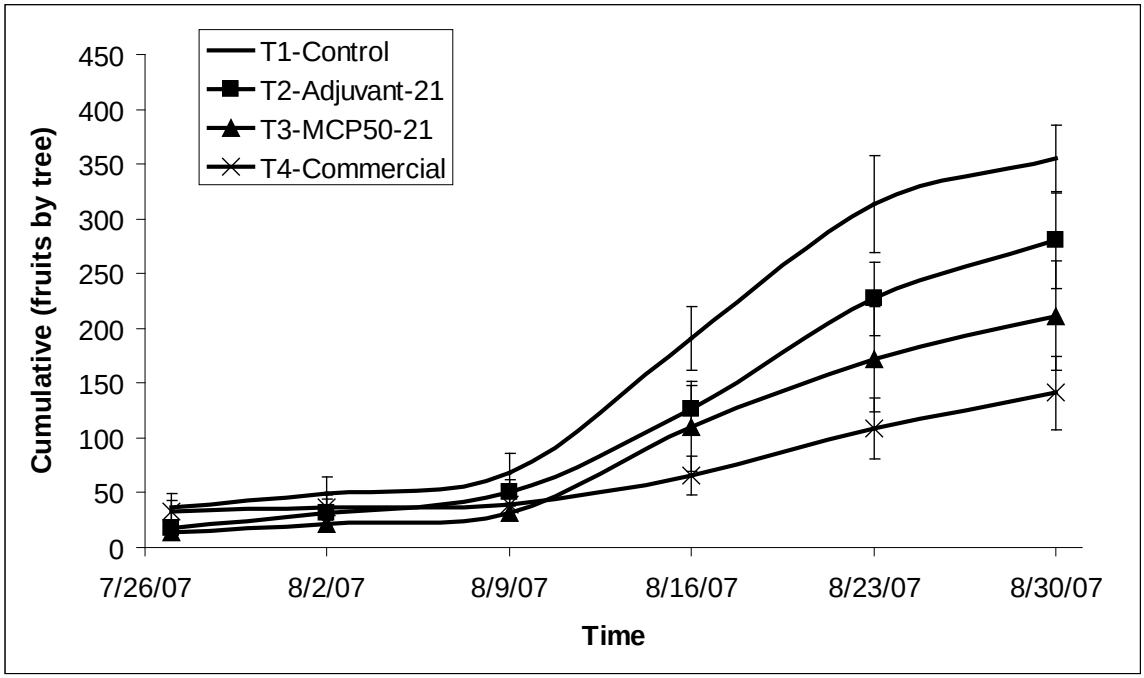

Figure 9. Fruit drop in fruit treated with 1-MCP (50 mg/L + Adjuvants) and NAA (commercial). Adjuvant concentration as explained in Table 1. Fruit was treated commercially with NAA on July 24, 2007 and remaining treatments on July 27, 2007. Commercial harvest would have occurred on 8/16/07.

As shown in Figure 9, the best treatment to control fruit drop was NAA. However, 1-MCP appeared also to provide benefits when compared with the control treatment (without MCP or NAA) or adjuvant alone. Whether 1-MCP and NAA would have a synergistic effect still remains to be determined. In this experiment, trees were not sampled for firmness and/or harvested at any time to allow natural fruit drop to occur. However, according with data collected in our previously discussed experiment performed in the same orchard, harvest would have occurred at 17-18lbf on 8/16/2007.

Ripening Effects After 4.5 or 4 Months Storage*: Firmness, Respiration Rate, Ethylene Production, and Physiological Disorders after storage at 30°F*

Figure 10 shows firmness values after 4.5 and 4 months of cold storage. Those treatments for which 1-MCP was applied at 18-19lbf remained firmer after cold storage at both harvest times. However, there was no delay in ripening when fruit was ripened after cold storage (Figure 11). The untreated control fruit from harvest 1 had higher firmness values after storage and ripening (Figure 11). This pattern might be associated with the high incidence and severity of internal breakdown in fruit from this treatment (see Figure 14 and 15).
External color was also evaluated after storage and ripening (data not shown). Most of the 1-MCP treated fruit developed full yellow color; however less than 20% or 10% of H1 or H2 fruit, respectively, that had been treated with 1-MCP had a slight delay in color development after 4 days of ripening at 68F, especially for those fruit

treated with 1-MCP at 18-19 lbf. These fruits eventually developed full color after 1-2 additional days in the ripening room.

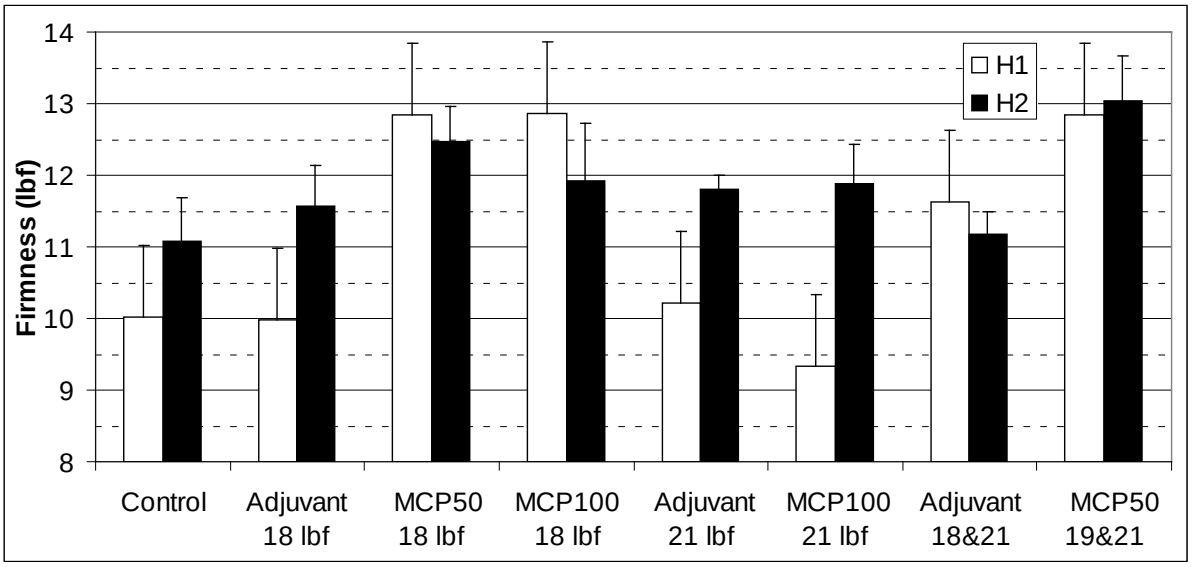

Figure 10. Firmness after 4.5 m (H1) and 4m (H2) cold storage at 30F of Bartlett pears harvested on August 20 (H1) and August 30, 2007 (H2).

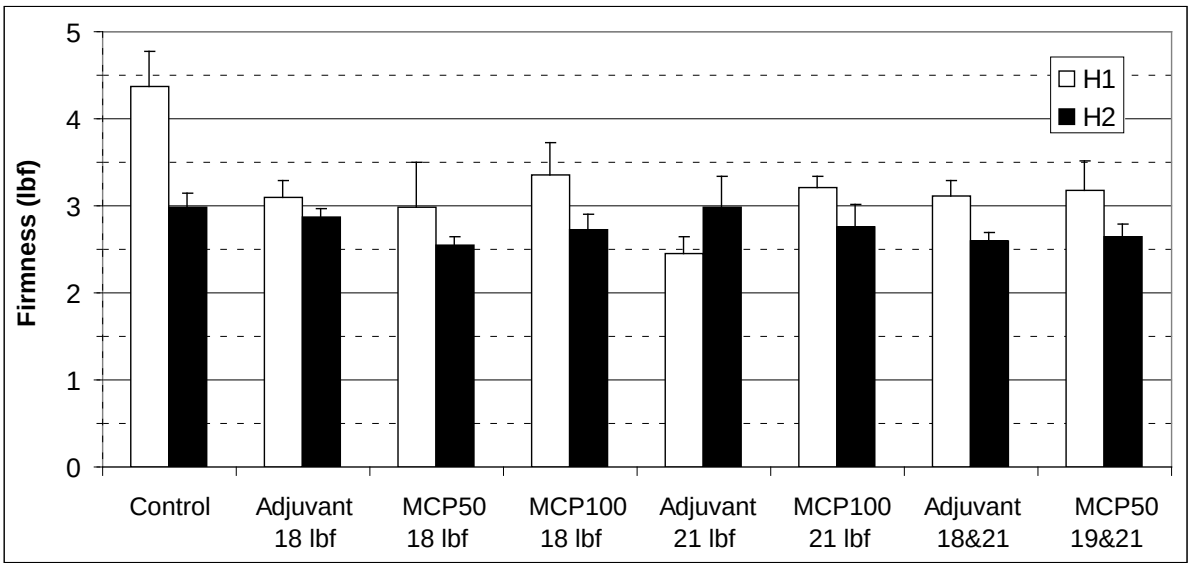

Figure 11. Firmness after 4.5 (H1) or 4 m (H2) cold storage at 30F plus 4 days ripening at 68F.

Figures 12 and 13 show the respiration and ethylene production values during ripening after cold storage. Especially in fruit harvested one week after treatment (H1), those fruit treated with adjuvant or 1-MCP at 18-19 lbf presented slightly lower respiration rates. A similar situation was observed with ethylene production; however, 1-MCP treated fruit at 18-19 lbf maturity exhibited lower ethylene production than their adjuvant counterparts. This effect on respiration and ethylene production was

not observed clearly in these same treatments harvested later on August 30, 2007 (H2).

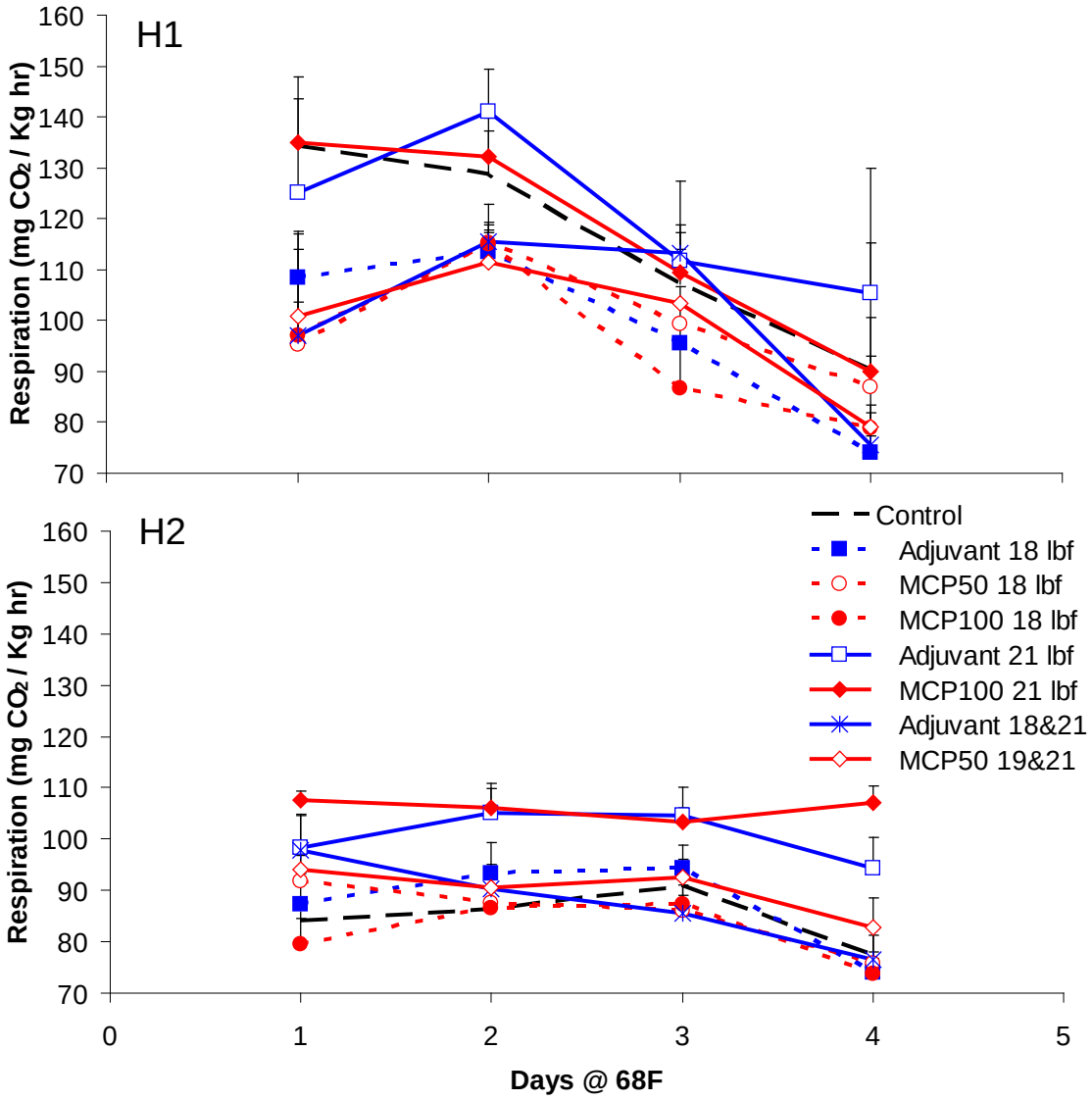

Figure 12. Respiration rate of fruit from each treatment after 4.5 or 4 months cold storage at 30F and during ripening at 68F of California ‘Bartlett’ pears harvested on August 20 (H1) and August 30, 2007 (H2).

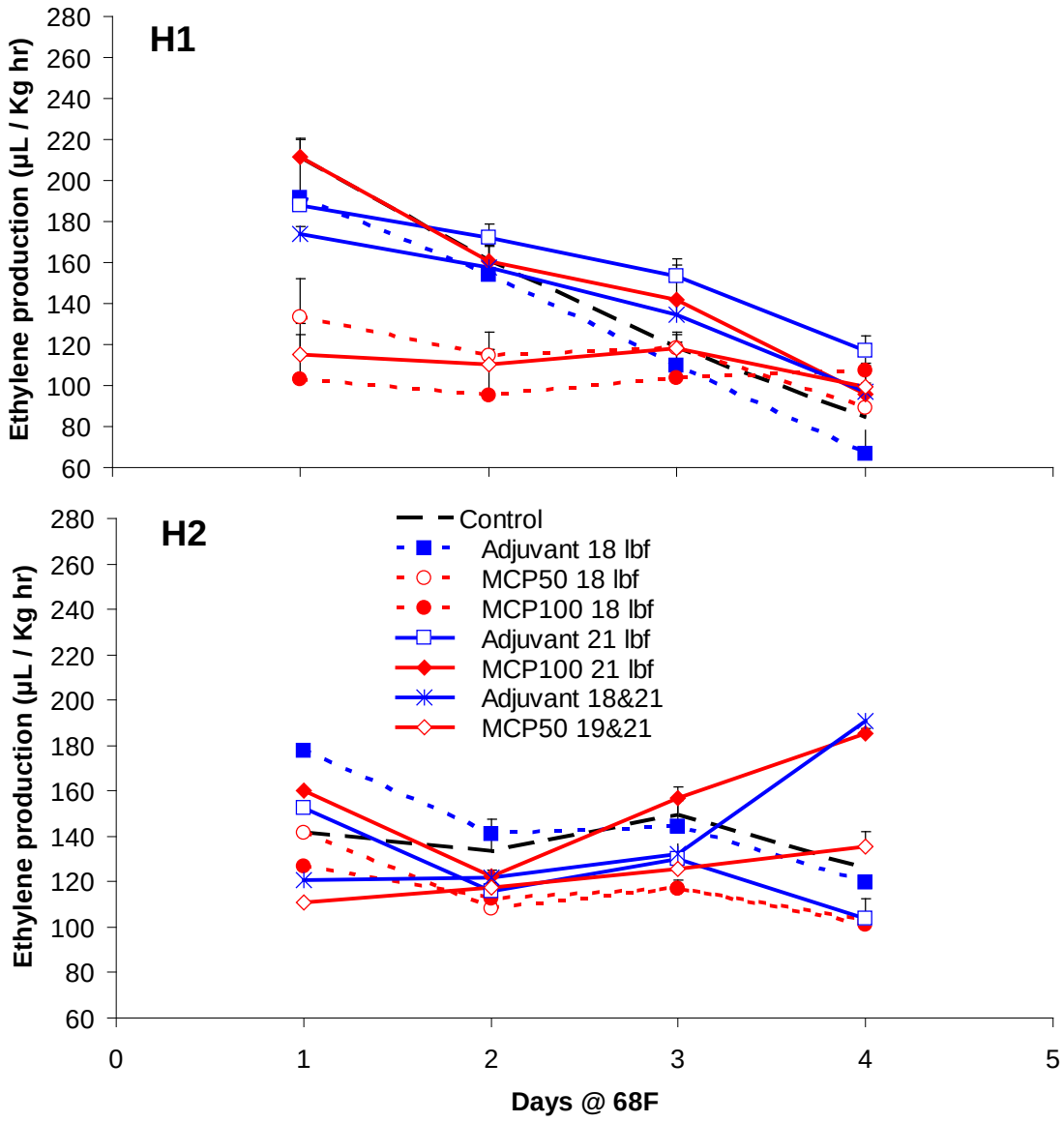

Figure 13. Ethylene production of fruit from each treatment after 4.5 or 4 months cold storage at 30F and during ripening at 68F of California 'Bartlett' pears harvested on August 20 (H1) and August 30, 2007 (H2).

In this experiment, fruit treated with 1-MCP at 18-19 lbf had a lower incidence and severity of internal breakdown and storage scald than the control fruit. However, for some evaluations, some of the fruit treated with adjuvant only at 18-19 lbf or 21lbf showed some control of these physiological disorders, suggesting that both the 1-MCP and adjuvant might play a role in the control of these disorders.

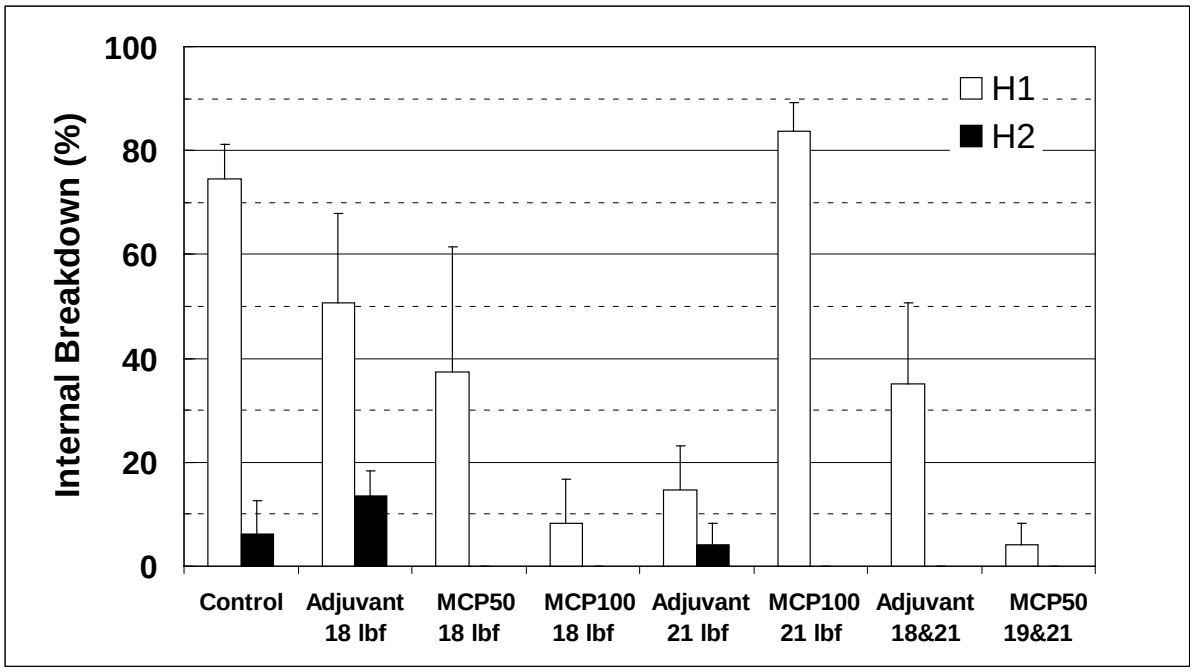

Figure 14. Internal breakdown incidence by treatment after 4.5 and 4 months of cold storage at 30F and 4 days ripening at 68F of California 'Bartlett' pears harvested on August 20 (H1) and August 30, 2007 (H2).

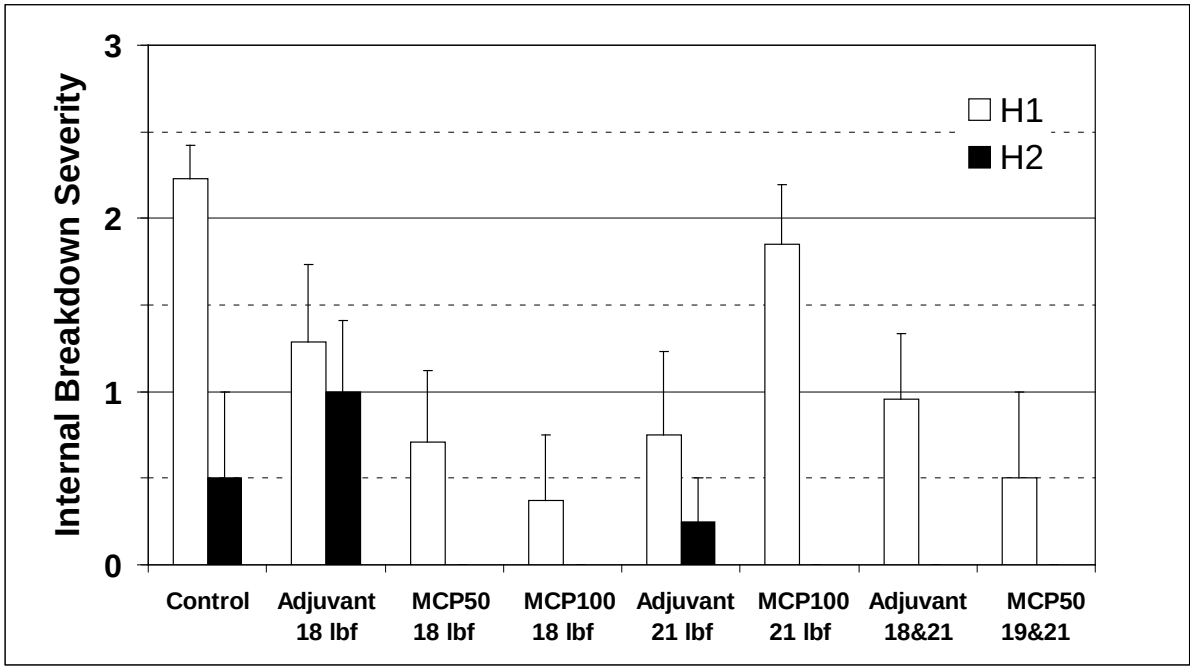

Figure 15. Internal breakdown severity by treatment after 4.5 and 4 months cold storage at 30F and 4 days ripening at 68F of California 'Bartlett' pears harvested on August 20 (H1) and August 30, 2007 (H2). The following hedonic scale was used: 0=none; 1=slight damage; 2=moderate damage; 3=severe damage.

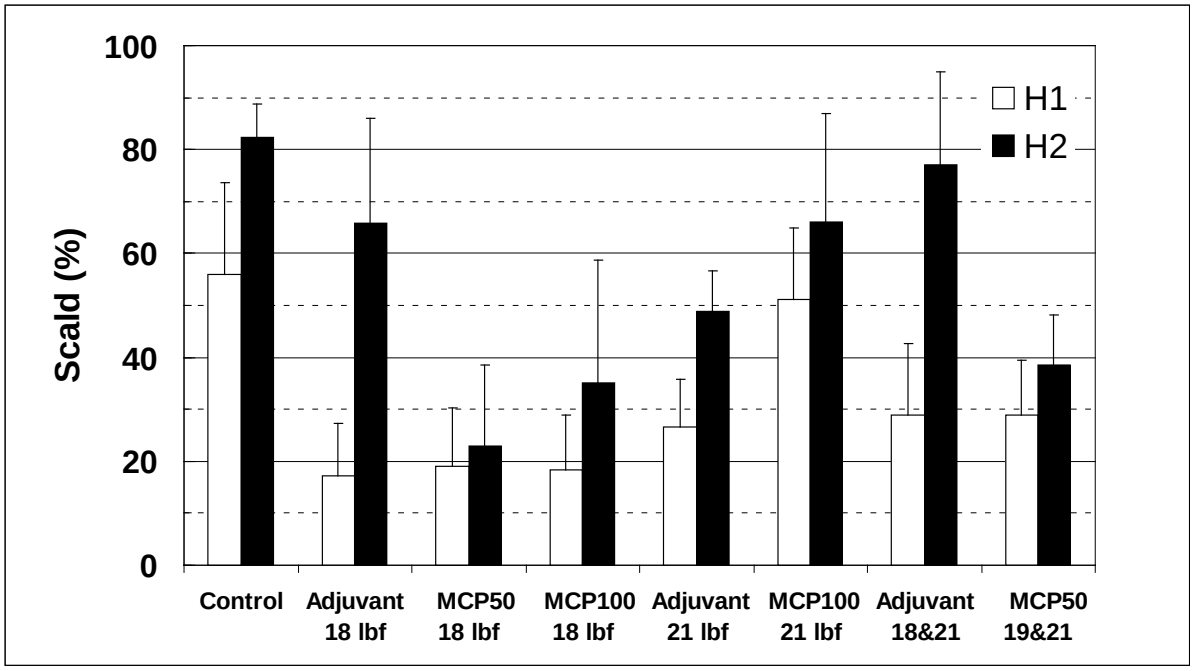

Figure 16. Scald incidence by treatment after 4.5 and 4 months cold storage at 30F and 4 days ripening at 68F of California 'Bartlett' pears harvested on August 20 (H1) and August 30, 2007 (H2).

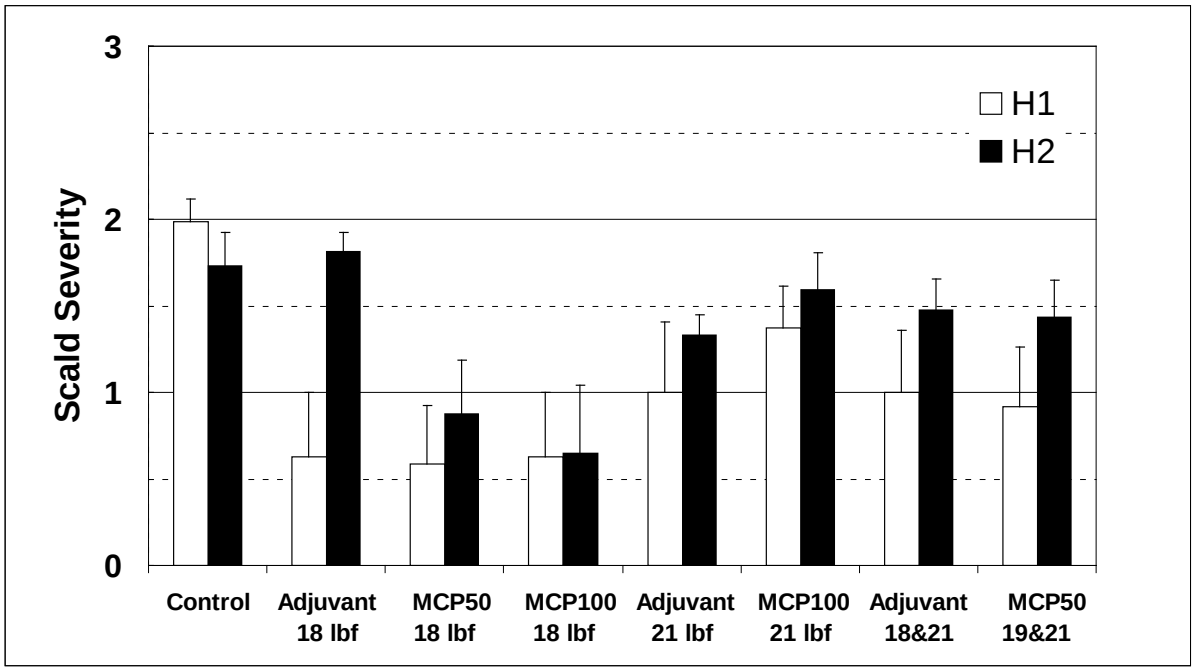

Figure 16. Scald severity by treatment after 4.5 and 4 months cold storage at 30F and 4 days ripening at 68F of California 'Bartlett' pears harvested on August 20 (H1) and August 30, 2007 (H2). The following hedonic scale was used: 0=none; 1=slight damage; 2=moderate damage; 3=severe damage.

Conclusions

Treatment with 1-MCP provided approximately 1 to1.5lbf higher firmness on the tree compared with untreated fruit on the same date. 1-MCP treatments applied at 18lbf had a much greater effect in slowing fruit softening on the tree than treatments applied at 21lbf, likely because of the long time between treatment and harvest for the 21lbf fruit. Doubling the application time (21 and 19lbf maturity) or increasing the 1-MCP concentration (50 vs. 100 mg/L) did not appear to have a consistent effect on the rate of fruit ripening after harvest and/or after cold storage, or on scald and internal breakdown control after cold storage. 1-MCP significantly reduced fruit drop compared to untreated trees; however, NAA was still the best treatment to control fruit drop.

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Quality evaluations after 4.5 and 4 months of cold storage at 30F indicate that, regardless of harvest time, fruit that were treated with 1-MCP at 18-19lbf were more firm immediately after cold storage, but these fruit were able to ripen normally after 4 days at 68F. Some portion of the fruit showed a delay in yellow color development of approximately 1 to 2 days. 1-MCP treatment applied at 18-19lbf also decreased scald and internal breakdown incidence and severity compared with untreated fruit, regardless of harvest time.

From this and our previous trials in 2006, 1-MCP has been demonstrated to maintain higher fruit firmness during maturation on the tree compared with untreated fruit for approximately 1 to 2 ½ weeks after application time. The effect on ripening immediately after harvest depends on the interval between application and harvest period. The fruit seems able to recover normal ripening capacity after different combinations of harvest time and storage duration. For the coming season, it would be interesting to determine whether the firmness maintenance period can be extended with multiple applications closer to harvest. We would also like to determine the effect of 1-MCP on subsequent ripening at harvest and after shorter storage periods (1-3 months) than those evaluated in our 2006 and 2007 trials.

Acknowledgement

We thank Andy Scully from Scully Packing Co.'s for providing the orchard and logistic help for this experiment. We also thank AgroFresh™ for providing the 1-MCP formulation (Harvista™) and financial support,and Amanda Kane, Cornelia Sieber-Davis, Sarah Nave and, Steve D'Agostini, from the University of California Cooperative Extension, Lake and Mendocino County, for field assistance during the experiment. Thanks also to the California Pear Advisory Board for partial financial support of this project.