Rapid Application of SmartFresh™ (1-MCP) to Apples After Harvest is More Important Than Rapid CA

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In the last several years, we have accumulated a considerable body of information to help New York growers and storage operators exploit SmartFresh™ technology. This new technology has had a major effect in improving the quality of our fruit in the marketplace. This improvement has been especially valuable after the fruit leaves the storage facility since loss of quality during subsequent shipping and handling operations is out of the control of the storage operator and shipper, and sales are driven by quality at the point of consumption. Loss of quality is a problem for apples worldwide, but it has been a major issue for New York growers since many of our varieties soften rapidly after harvest.

> **"SmartFresh™ is a technology that has resulted in much better quality of fruit of some varieties in the marketplace, but we are still learning to use it to obtain maximum benefits for storage operators and consumers. In this article, we address the issue of whether it is better to apply SmartFresh™ as rapidly as possible after harvest and then be less concerned about rapid CA. This is an important question, especially for storage operators who cannot fill rooms quickly. Our results show that with rapid SmartFresh treatment, it is safe to delay CA storage application. However, if fruit are not cooled properly, and have not been treated with diphenylamine (DPA), there is increased potential for external carbon dioxide injury."**

SmartFresh™ technology is based on an inhibitor of ethylene perception known as 1-methylcyclopropene (1-MCP). Ethylene is the plant growth regulator that controls many aspects of ripening and senescence. In the case of apples, ethylene is closely linked with the rate of fruit softening. Thus a major benefit of SmartFresh™ is that it slows down softening of the fruit.

SmartFresh™ is usually applied to bins of fruit in air-tight storage rooms, and fruit are then stored in air or controlled atmosphere (CA) storages for periods that are appropriate for the variety and harvest date. Depending on the variety, the beneficial effects of SmartFresh™ can be reduced with extended storage.

Ethylene is produced naturally by the apple and its measurement is an important part of tracking fruit maturity during the harvest period. In general, fruit which produce lower levels of ethylene (i.e. early in the harvest window for any variety) tend to store longer with or without SmartFresh™. As a result, early harvested fruit are better candidates for long-term storage. SmartFresh™ also works best when fruit are not producing ethylene. Therefore, the internal ethylene concentration (IEC) of the fruit at the time of harvest is the first major factor that can affect the efficacy of SmartFresh™ application.

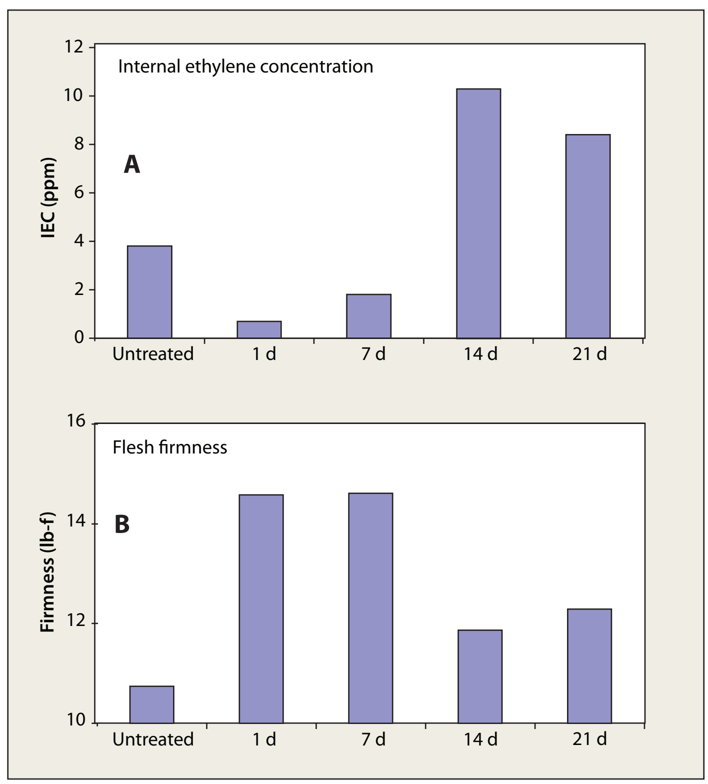

Figure 1. Internal ethylene concentration (ppm) of Jonagold apples at harvest and after storage in air for 1, 7, 14 and 21 days before treatment with 1-MCP (A) and flesh firmness (lb-f) after CA at 33°F storage for 5 months (B).

It is often not always recognized that ethylene continues to be produced by the fruit after harvest. Initially, rapid cooling helps to slow down ethylene production. However, ethylene production by the fruit increases in storage, the timing of which is affected by fruit maturity. Figure 1A shows data for an experiment with Jonagold apples. The IEC in the fruit was measured for up to 21 days after harvest while they were kept in cold air storage. After seven days, the IEC increase indicates that postharvest ripening has become less controllable. This type of change is also the basis for why rapid CA has been recognized as an important method to maintain fruit quality. Rapid CA, in which oxygen levels around the fruit are reduced to less than 5% in seven days, was rarely used 30 years ago. However, rapid CA now has become the industry standard, at least for large storage operations. The IEC of the fruit also affects the response of fruit to SmartFresh™ as illustrated in Figure 1B. A reduced SmartFresh™ firmness response in Jonagold was associated with increased IEC at the time of treatment.

The effects of both maturity and delays after harvest provide the basis for SmartFresh™ use recommendations provided by AgroFresh, Inc. The recommendations list maximum number of days between harvest and treatment, as well as other specific handling recommendations for important varieties. It is interesting to note that in Canada the maximum period between harvest and treatment is three days for all varieties, established by the federal Pest Management Regulatory Agency.

The AgroFresh recommendations are guidelines that necessarily average the interactions between maturity of fruit at harvest and subsequent changes in IEC during storage, but the situation in the field can be more complex. An apple harvested at the early part of the harvest window may take seven days or longer before ethylene production increases. As a result, the "degrees of freedom" for management of early picked apples may be quite high. However, an apple harvested at the end of the harvest window may take only a day or two to show increased ethylene production or, worse yet, may already be producing high amounts when harvested. In addition, commercial storage operators have to contend with a lot of variability in the maturity of fruit from different orchard blocks. These differences are likely to become greater and more critical with a later harvest date. Therefore, it is likely that a management protocol that emphasizes rapid SmartFresh™ treatment of fruit after harvest is desirable.

Also, as we have described in previous *NY Fruit Quarterly* articles (Razafimbelo et al., 2006; Watkins and Nock, 2007), rapid CA may make some storage disorders worse, especially external carbon dioxide injury in SmartFresh™ treated fruit. Strategies for reducing these risks may involve less emphasis on rapid CA as well as control of carbon dioxide levels in the storage.

The objective of the research presented here was to determine if rapid SmartFresh™ treatment (within two days of harvest) would then permit a more relaxed approach to the time taken to establish CA conditions. This research was carried out over two seasons. In the first year (Experiment 1), we examined the effect of delayed CA in McIntosh and Empire fruit grown in two regions. In the second year (Experiment 2), we addressed the issue of temperature effects if field heat were not removed quickly following harvest.

Methods

Experiment 1

McIntosh apples were harvested in the Champlain and Western New York region, while Empire fruit were harvested in the Hudson valley and Western New York during the normal window for CA storage (Table 1). Three orchard blocks were harvested for each variety in each region, transported back to the storage facility at the Cornell Orchards in Ithaca, cooled overnight to 36°F, and treated with 1 ppm 1-MCP, generated from SmartFresh™ powder, for 24 hours. Fruit were then either placed into CA storage conditions immediately (two days after harvest) or after 7 and 14 days after harvest. Rogers McIntosh from the Champlain were stored in 2% carbon dioxide for the first four weeks, and then 5%, in 2% oxygen at 38°F. Marshall McIntosh from western New York were stored under the same carbon dioxide regime, but in 4.5% oxygen. Empire apples from the Hudson Valley and Western New York were stored in 2% carbon dioxide and 2% oxygen at 36°F. Fruit were stored for six months and evaluated after one and seven days at 68°F.

Table 1. Maturity and quality factors in the McIntosh and Empire apple fruit used in Experiment 1.

Variety	Region	IEC (ppm)	Starch index	Firmness (lb-f)	Soluble solids (%)
McIntosh	Champlain	14.95[z]	5.6	15.2	12.0
	Western NY	42.80	5.7	14.8	12.1
Empire	Hudson Valley	1.62	4.4	16.9	11.5
	Western NY	0.83	5.2	15.8	11.1

[z] Each mean is the average of 3 orchard blocks in each region.

Experiment 2

McIntosh apples from Apple Acres Orchard and Empire apples from Cornell Orchards were harvested, and stored overnight at 36, 45 or 55°F. Fruit were then treated with 1 ppm 1-MCP at each respective temperature for 24 hours and kept at these temperatures for 2, 7 or 14 days. All fruit were then held at 36°F overnight before CA storage regimes were established. Fruit were stored for 4.5 and 8.5 months and evaluated after one and seven days at 68°F.

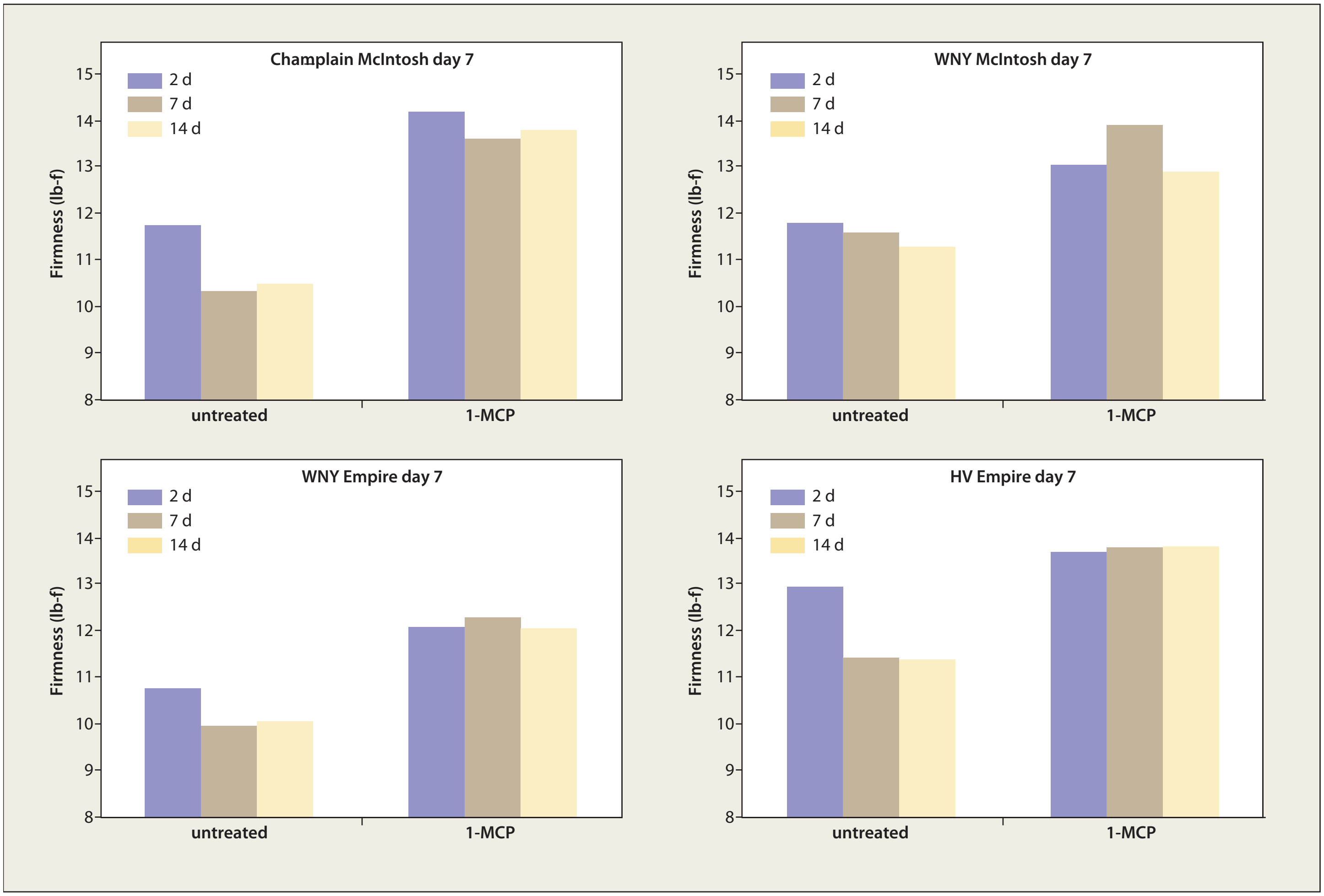

Figure 2. Flesh firmness of McIntosh (Champlain and Western New York), and Empire (Western New York and Hudson Valley) fruit stored in CA for 6 months plus 7 days at 68°F. Fruit were either untreated or treated with 1ppm 1-MCP and then kept at 38°F (McIntosh) or 35°F (Empire) for 2, 7 or 14 days before application of CA conditions. Fruit were obtained from three orchard blocks in each region.

Results and Discussion

Experiment 1

Although fruit were evaluated after one and seven days at 68°F, only the results for a seven- day shelf life are shown here (Figure 2). For both varieties and growing regions:

1. Fruit treated with SmartFresh™ were firmer than untreated fruit.
2. Fruit without SmartFresh™ treatment (untreated) typically were softer with increasing delays after harvest before CA storage.
3. SmartFresh™-treated fruit did not show greater softening with increasing delays between harvest and CA storage.

No major effects of treatments on storage disorders or decay were found in this experiment. These results strongly suggest that the application of SmartFresh™ within a couple days of harvest reduces the need to apply rapid CA. This means that if it is more appropriate for some operations to fill rooms over longer periods of time, then it is possible to achieve this if facilities for quick treatment of small volumes of fruit are available. Concern has been expressed that quality of some fruit lots may be compromised if there are variable fruit maturities and therefore variable responses of fruit to SmartFresh™. For example, if a given orchard lot of fruit did not respond to SmartFresh™, then that fruit will be much softer if CA application is delayed. This is a factor that should be considered in a storage operation, especially towards the end of the harvest window. The risk of quality loss in non-responsive fruit will be greater with longer storage periods, and therefore it is likely that large storage operations that are trying to maximize storage potential will apply both rapid SmartFresh™ treatment and rapid CA. Interestingly, rapid SmartFresh™ treatment and more relaxed CA application seems ideally suited to smaller size operations with a goal of short to medium term CA storage length.

These results also highlight the importance of rapid CA after harvest for maintaining fruit quality for fruit that are not treated with SmartFresh™. Although delays between two and seven days were not examined, clear loss of firmness was found between these two times. Delays of CA application beyond a few days after harvest can result in significant loss of firmness.

Experiment 2

McIntosh apples were already producing climacteric levels, with internal ethylene concentrations (IECs) of

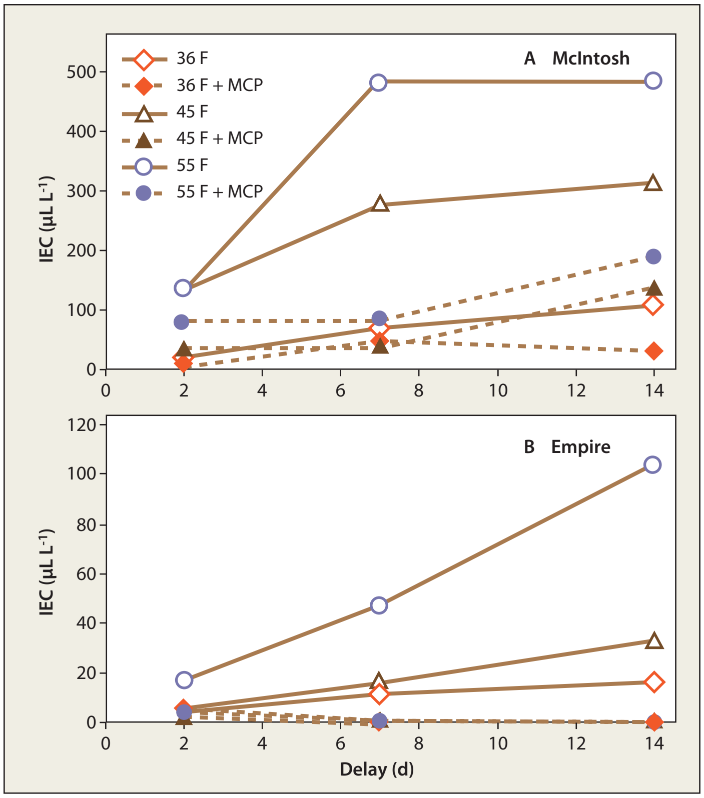

Figure 3. Internal ethylene concentrations of McIntosh and Empire apples either untreated or treated with 1ppm 1-MCP and kept at 36, 45 or 55°F.

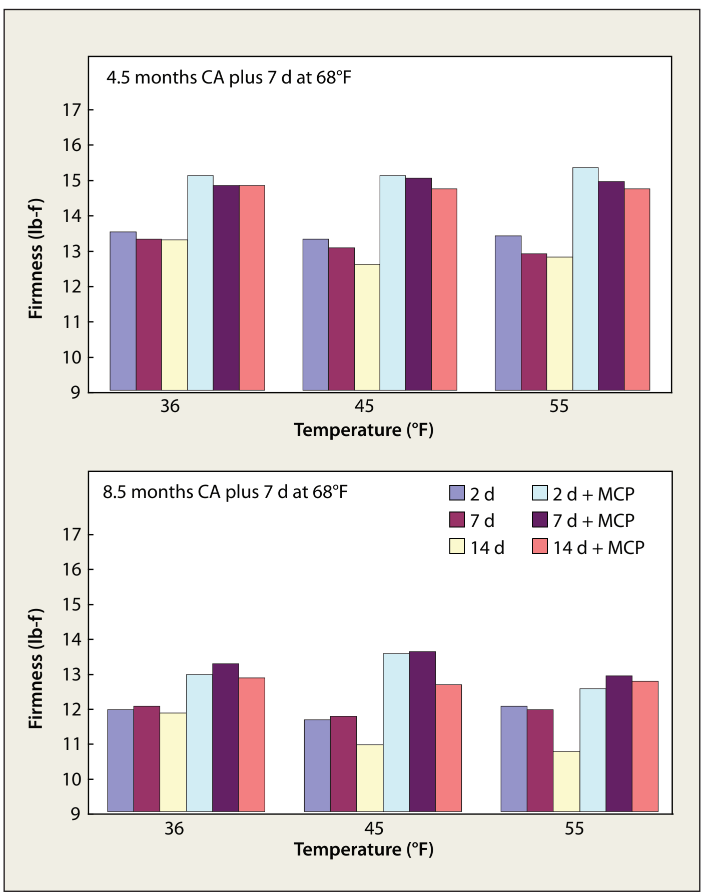

Figure 4. Flesh firmness (lb-f) of McIntosh apples treated with 1-MCP after overnight cooling to 36, 45 or 55°F and then maintained at these temperatures for 2, 7 or 14 days before storage in CA at 36°F for 4.5 or 8.5 months plus 7 days at 68°F.

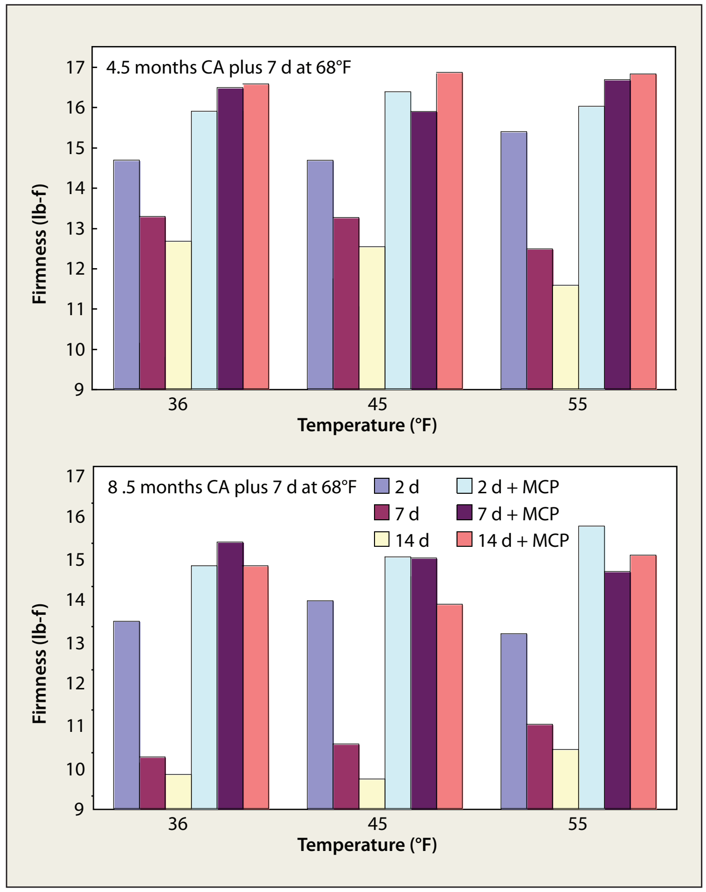

Figure 5. Flesh firmness (lb-f) of Empire apples treated with 1-MCP after overnight cooling to 36, 45 or 55°F and then maintained at these temperatures for 2, 7 or 14 days before storage in CA at 36°F for 4.5 or 8.5 months plus 7 days at 68°F.

116 ppm, at the time of harvest, while Empire apples were producing relatively low ethylene levels as indicated by IECs of 7 ppm.

SmartFresh™ markedly inhibited the IEC of McIntosh apples despite the high levels at harvest (Figure 3 A). However, for this variety higher IECs were found in both untreated and treated fruit with higher delay temperatures and delays. In Empire, application of SmartFresh™ within a day of harvest completely stopped increases in ethylene production at all temperatures (Figure 3 B). However, the IEC of untreated fruit increased and was stimulated further by increased holding temperatures. Fruit also softened at the higher storage temperatures on day 14 (data not shown).

Both McIntosh and Empire apples were softer after 8.5 months of CA storage than after 4.5 months, irrespective of treatment (Figures 4 and 5). Empire fruit without SmartFresh™ and with delays softened more than McIntosh, but SmartFresh™ treated fruit were always firmer than untreated fruit. The benefits of SmartFresh™ in maintaining firmness were also apparent even in fruit that had been kept at warmer temperatures prior to CA storage.

However, major effects of SmartFresh™ and delay at the different temperatures were found in this experiment.

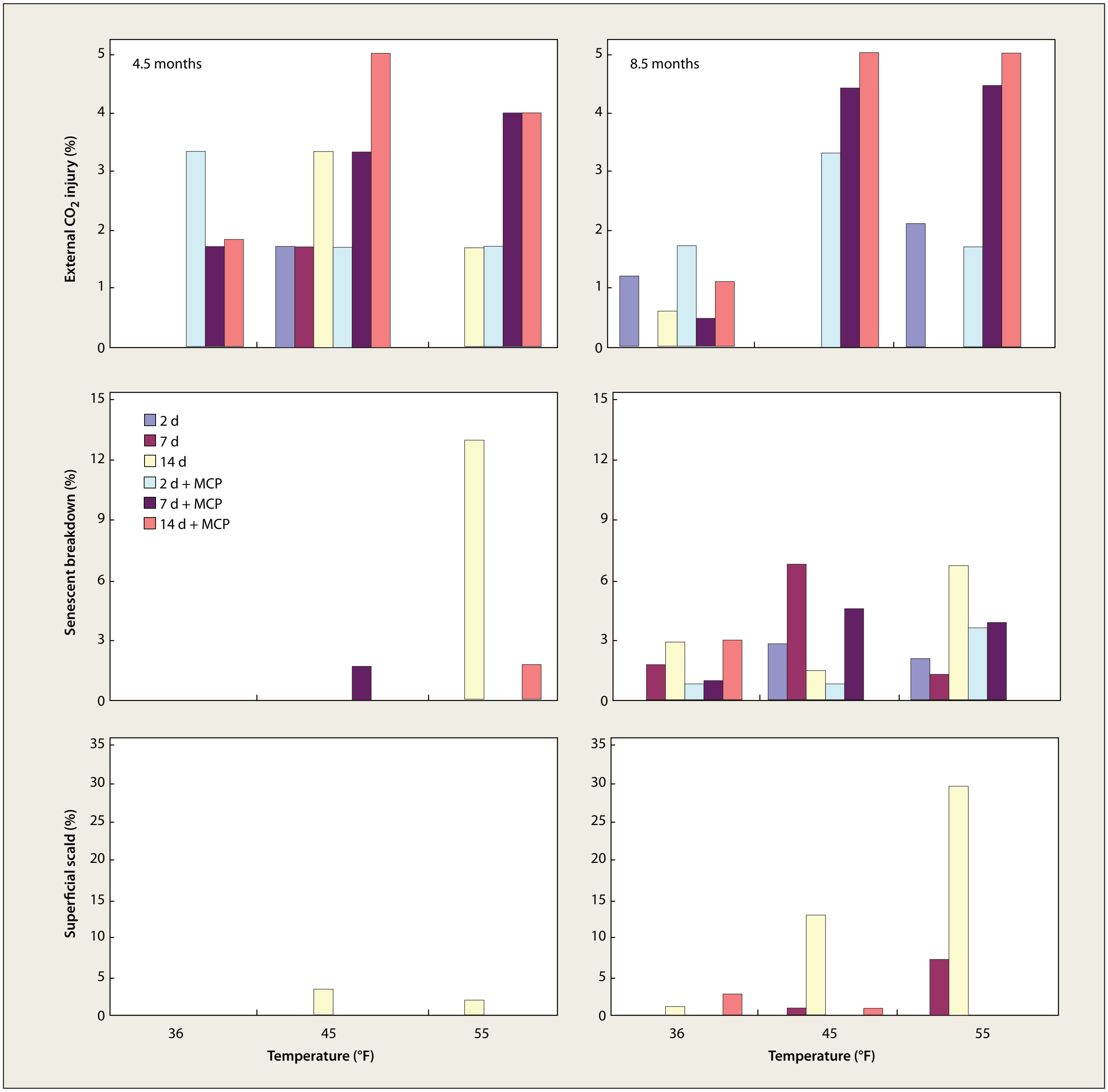

Figure 6. External carbon dioxide injury, senescent breakdown and superficial scald incidence in McIntosh apples treated with 1-MCP after overnight cooling to 36, 45 or 55°F and then maintained at these temperatures for 2, 7 or 14 days before storage in CA at 36°F for 4.5 or 8.5 months plus 7 days at 68°F.

In McIntosh, the incidence of external carbon dioxide injury was low but increased with higher temperatures before CA storage after both 4.5 and 8.5 months (Figure 6). Senescent breakdown and superficial scald were highest in untreated fruit kept at 55°F, and to a lesser extent at 45°F.

In Empire, SmartFresh™ treatment resulted in lower levels of senescent breakdown and decay, but higher levels of flesh browning (Figure 7). An effect of delay that was spectacular and unexpected was the increased external carbon dioxide incidence in MCP treated apples kept at warmer temperatures prior to CA storage. This effect was surprising as the fruit in the Empire orchard block that we used have a history of low susceptibility to carbon dioxide injury, as was shown by fruit kept at 36°F before CA storage.

Increased risk of carbon dioxide injury would not be a problem for fruit treated with diphenylamine (DPA) to avoid storage scald. However, the results demonstrate that proper cooling is critical for fruit that has not received DPA treatment. It is possible that this observation explains why some Empire apples have had high instances of carbon

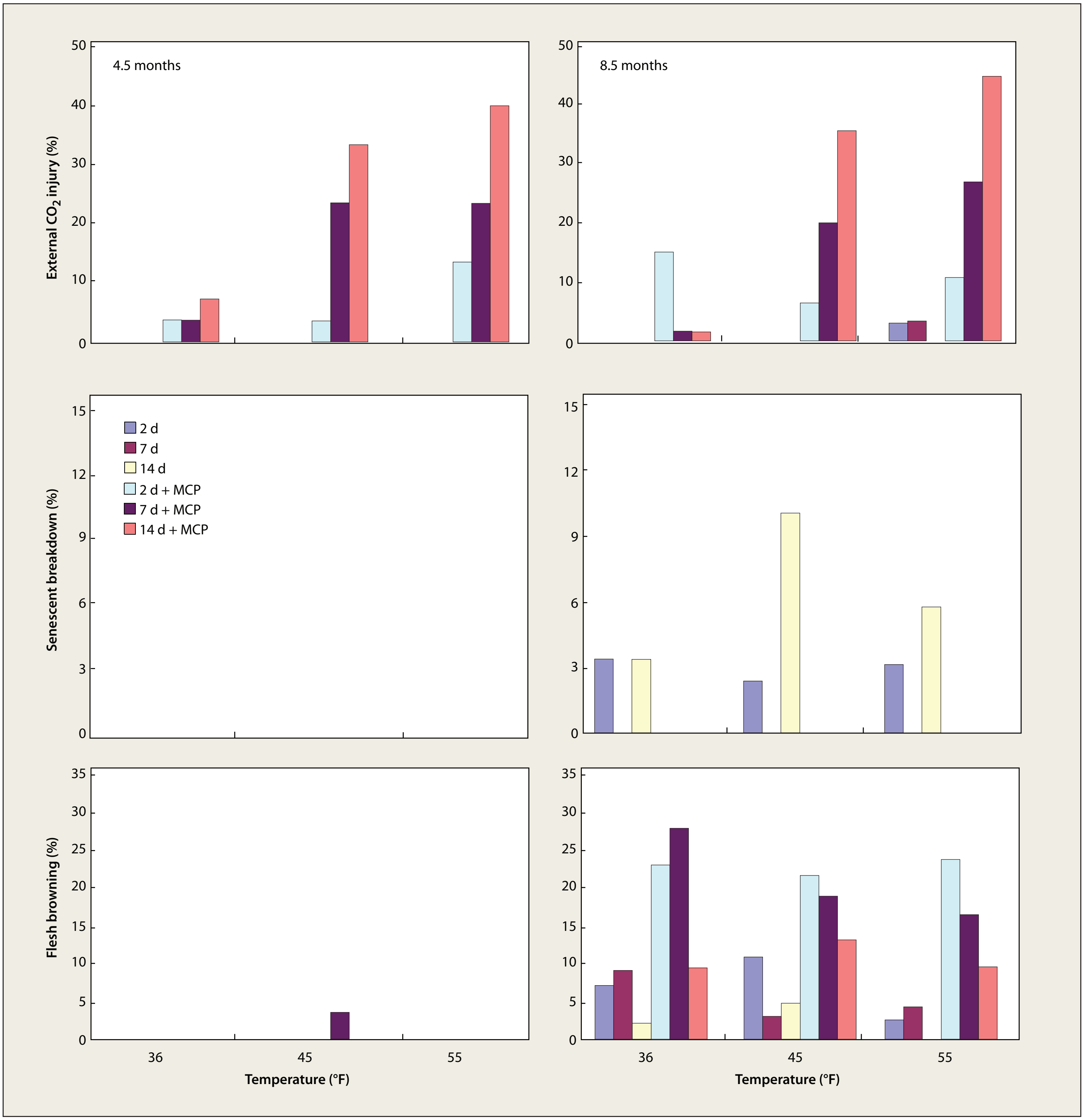

Figure 7. External carbon dioxide injury, senescent breakdown and flesh browning incidence in Empire apples treated with 1-MCP after overnight cooling to 36, 45 or 55°F and then maintained at these temperatures for 2, 7 or 14 days before storage in CA at 36°F for 4.5 or 8.5 months plus 7 days at 68°F.

dioxide injury, even when the levels of the gas in the storage atmosphere have been kept at 1% or lower. Although carbon dioxide injury in McIntosh was not high in this experiment, the variety is also susceptible to this disorder. Therefore, we urge that care be taken to manage cooling after SmartFresh™ treatment if fruit have not been treated with DPA.

A feature of this experiment was the observation that flesh-browning levels started to decline with increasing delays before CA storage. As part of a New York Farm Viability Institute grant to find solutions for flesh browning issues in Empire apples, we included a three week delay at 35°F before CA storage. Unfortunately the results (Figure 8) showed that while the incidence of flesh browning was markedly reduced in untreated fruit, fruit treated with SmartFresh™ had high levels similar to those found without a delay treatment. Fruit with delay treatments were also unacceptably soft, even with SmartFresh treatment. Delayed treatments also resulted in higher levels of senescent breakdown, although these levels were lower in SmartFresh™-treated fruit. External carbon dioxide injury was, as expected by previous results, much lower in delayed treatments.

Aside from increased susceptibility to carbon dioxide injury if fruit were not cooled properly before CA application, the experiments did not reveal any additional risks associated with the strategy of delaying application of CA conditions in fruit treated with SmartFresh™. However, it is important to recognize that CA delay strategies could have a downside in lots of fruit that did not respond well to SmartFresh™. In that case, a severe penalty in terms of fruit condition should be expected for such fruit. Although we do not know the actual risk in commercial practice, we suggest that delays be avoided in fruit harvested late in the harvest window, especially if considerable block-to-block variability in fruit condition is observed.

Summary and Conclusions

This study illustrates some important messages for New York storage operators, both small and large scale.

1. For storage operators who are not using SmartFresh™, the importance of rapid CA after harvest for maintaining fruit quality is reinforced. Delays of CA application beyond a few days after harvest can result in significant loss of firmness. The loss of fruit quality will be greater with increasing length of CA storage.
2. Rapid application of SmartFresh™ technology maximizes the positive responses of fruit to treatment. The effect is likely to be true for fruit stored in air as well as in CA. Rapid SmartFresh™ treatment allows later application of CA storage atmosphere without loss of quality, but note point 4 below.
3. Strategies for applying SmartFresh™ to smaller quantities of fruit have, and will continue to be devised by storage operators around the state. Decisions about the investment involved should take into account the length of expected storage. For example, a storage that is operating for only four months may not need to utilize faster SmartFresh™ application than recommended by AgroFresh, whereas an operation planning an eight month storage period or longer should actively consider rapid SmartFresh application.
4. Our results show that delayed CA storage after 1-MCP application can greatly aggravate the risk of external carbon dioxide injury if temperatures of the fruit after treatment remain high. It would be nice to think that temperatures of 45, and especially 55 °F, are excessive and would never occur for extended time periods in commercial practice. Unfortunately, they are not unreasonable for rapidly filled rooms with inadequate cooling capacity. However, remember that the risk of external carbon dioxide injury is eliminated if fruit have been treated with DPA for control of storage scald.

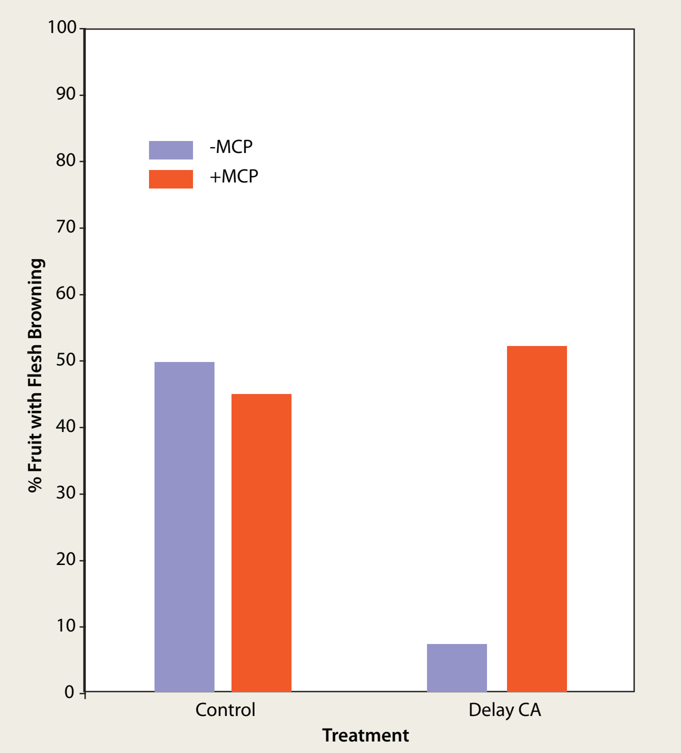

Figure 8. Flesh browning (%) in Empire apples either untreated or treated with 1ppm 1-MCP and stored immediately in CA or after 3 weeks in air at 36°F.

Acknowledgements

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Literature Cited

Razafimbelo, F., Nock, J., Watkins, C. 2006. Managing external carbon dioxide injury with and without SmartFresh™ (1-MCP). *New York Fruit Quarterly* 14(3): 7-10.

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Chris Watkins is a professor in the Department of Horticulture and leads Cornell's postharvest physiology program. Jackie Nock is a research support specialist who works with Dr. Watkins. Hannah James has a postdoctoral position in the Watkins laboratory supported by the New York Farm Viability Institute to help develop solutions for flesh browning in McIntosh and Empire apples.