Managing External Carbon Dioxide Injury With and Without SmartFresh™ (1-MCP)

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External carbon dioxide injury has long been a problem for varieties such as 'McIntosh', 'Empire' and 'Cortland'. Fruit that are kept "fresh" after harvest are particularly susceptible to injury and therefore it is not surprising that 1-MCP can increase risk. We have been developing strategies to help the New York apple industry avoid fruit losses from this injury.

External carbon dioxide injury is a skin disorder of apple fruit that occurs during storage, resulting in disfigured fruit that are unmarketable (Figure 1). The injury usually occurs on the unblushed side of the fruit and can range from barely noticeable to covering most of the skin in severe cases. It is manifested as light brown to colorless areas on the skin surface, and affected areas are irregularly shaped, rough and wrinkled (Figure 1). We have also found in trials that the initial injury develops on fruit during early storage periods and has a smooth and soaked appearance (Figure 2). The common injury symptoms presumably represent the same tissues that have dried out and collapsed.

The injury is usually associated with controlled atmosphere (CA) storage, but can occur during air storage of freshly harvested fruit packed quickly after harvest in poorly ventilated cartons. External carbon dioxide injury has long been a potential problem for storage operators in New York and elsewhere. Several varieties are susceptible to the disorder, including 'McIntosh', 'Cortland' and 'Empire', and in fact the Cornell recommendation for 'McIntosh' has long recognized this susceptibility. Although the 'McIntosh' variety benefits by having elevated carbon dioxide concentrations (3-5%) in the storage environment, our recommendation is to maintain these concentrations at 2% or less during the first 4-6 weeks of storage to minimize risk of disorder development. Little injury was seen in 'Empire' fruit until the early 1990s, when a recommendation to stop using the superficial scald inhibitor diphenylamine (DPA) resulted in losses of 20-40% in some storage rooms. Until that time, it was not appreciated that DPA not only prevented superficial scald, but also prevented external carbon dioxide injury. This discovery explains why we rarely observe external carbon dioxide injury in 'McIntosh' and never in 'Cortland' apples under commercial conditions. Occasional outbreaks of injury occur only in the Champlain Valley growing region of New York, where they typically do not apply DPA to 'McIntosh' apples, whereas 'Cortland' apples are always treated with DPA. Occasional severe injury in 'Empire' has occurred also in the Hudson Valley when fruit were not treated with DPA.

Studies by Jennifer DeEll and coworkers in Canada showed that the susceptibility of fruit to external carbon dioxide injury was greater in 'McIntosh' apples that were treated with SmartFresh™ technology. The technology is based on application of gaseous 1-methylcyclopropene (1-MCP) and has been widely incorporated by apple industries around the world because of its beneficial effects in maintaining quality, especially texture, throughout the whole marketing chain. Our early results, together with anecdotal reports from the New York apple industry, suggested that there may be increased susceptibility of 'Empire' apples to injury when treated with 1-MCP. We have carried out a series of experiments to investigate external carbon dioxide injury in this variety and to devel-

Figure 1. External carbon dioxide injury in 'Empire' apples.

Figure 2. Early symptoms of external carbon dioxide injury in 'Empire' apples before tissues have dried out.

op methods to control risk of injury development during storage. The information obtained for 'Empire' is likely to apply to all external carbon dioxide injury-susceptible apple varieties.

Experimental Outline

A series of experiments have been carried out using 'Empire' apples which include:

1. A study of the effects of carbon dioxide concentration and 1-MCP application on the incidence of external carbon dioxide injury.
2. An investigation of whether 1-MCP increases the period of highest susceptibility of fruit to injury.
3. An investigation of whether 1-MCP affects the decline in susceptibility to injury that occurs when fruit are kept in air before being exposed to CA storage.
4. A study of the effect of different DPA concentrations on external carbon dioxide injury.

The fruit used in these experiments were obtained from an orchard block with a known history of high susceptibility to external carbon dioxide injury. Except in the experiments in which different carbon dioxide concentrations were applied, a 5% concentration was used as a severe treatment to maximize the chances of injury. We assume that using fruit of high risk under high gas concentration conditions represent conditions greater than the worst-case scenario that could occur commercially.

All experiments were carried out at 35-36°F using flow-through systems in which fruit were treated in large glass jars (Figure 3). Each treatment had four replicates.

Increasing Carbon Dioxide and 1-MCP Treatment Increase External Carbon Dioxide Injury

Fruit were harvested and either treated or not treated with 1ppm 1-MCP after overnight cooling. Fruit were then exposed to 1%, 2.5% or 5% carbon dioxide (in 2% oxygen) for 20 weeks and evaluated after seven days at 68°F. External carbon dioxide injury occurred even at 1% carbon dioxide, but its incidence increased markedly in 2.5% and 5% carbon dioxide (Table 1). In all cases, treatment of fruit with 1-MCP increased the incidence of injury.

1-MCP Does Not Increase the Early Period of Risk in CA Storage

Fruit that were untreated or treated with 1-MCP were exposed to either 2.5% or 5% carbon dioxide (in 2% oxygen) for three week periods during 20 weeks of CA storage, either weeks 0-3, 4-6, 7-9 or 10-12. When not in elevated carbon dioxide, fruit were exposed to 1% carbon dioxide. For example, fruit treated with 5% carbon dioxide during weeks 4-6, were in a 1% concentration for weeks 0-3 and 7-20.

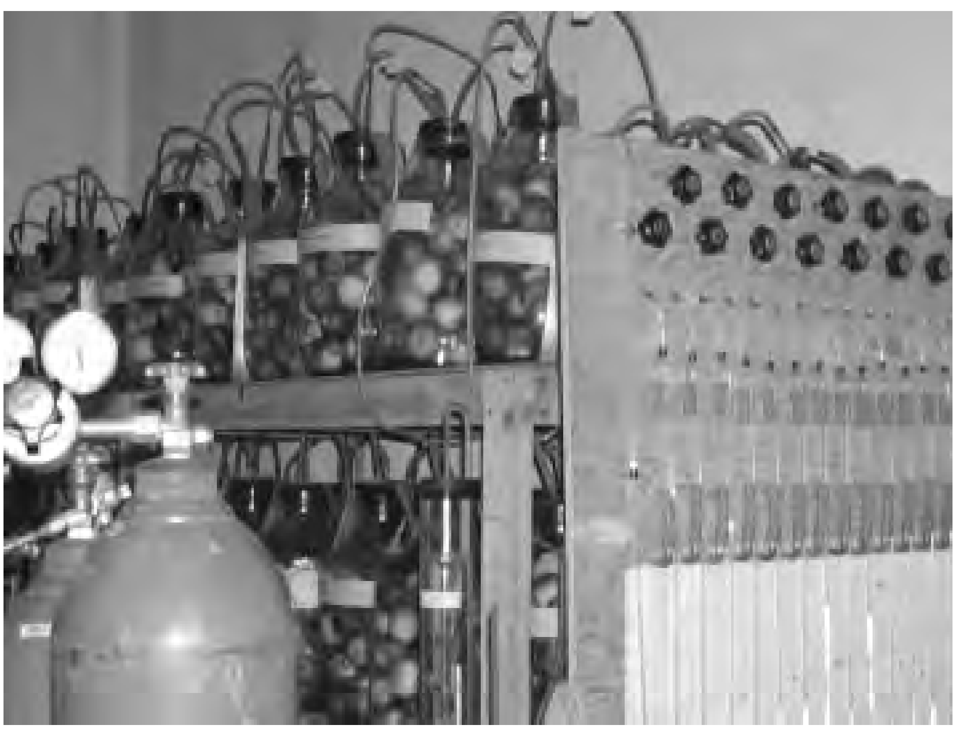

Figure 3. Experimental set up for treatment of fruit with 1%, 2.5% or 5% carbon dioxide (2% oxygen).

TABLE 1

External carbon dioxide injury (%) in 'Empire' apples either untreated or treated with 1ppm 1-MCP and exposed to 2.5 or 5% carbon dioxide (in 2% oxygen) for 20 weeks. Effects of carbon dioxide and 1-MCP are significant at P<0.001 and P=0.011, respectively.

	External carbon dioxide injury (%)	
Carbon dioxide (%)	- 1-MCP	+ 1-MCP
1	4	8
2.5	25	38
5	31	57

The highest injury incidence occurred during the first three weeks of exposure to either 2.5% or 5% carbon dioxide (Figure 4). While the injury levels were slightly higher in 1-MCP treated fruit than in untreated fruit, the time that fruit were most highly susceptible to injury was not extended by 1-MCP treatment.

1-MCP Prevents the "Adaptation" Period Between Karvest and CA Storage

Untreated fruit were exposed to 5% carbon dioxide (in 2% oxygen) after overnight cooling (1 day), or 2, 7 or 14 days after harvest. 1-MCP treated fruit were exposed to elevated carbon dioxide 2, 7 or 14 days after harvest. Fruit were stored for 10 weeks.

The susceptibility of untreated fruit to external carbon dioxide injury decreased rapidly to about 50% of the incidence at harvest to essentially none by day 14 (Figure 5). 1-MCP prevented that "adaptation" so that by day 14 there was no statistical reduction of injury.

DPA Eliminates Risk of External Carbon Dioxide Injury

Fruit were dipped in water, or 250, 500 or 1000ppm DPA on the day of harvest, cooled overnight and exposed to 5% carbon dioxide for 10 weeks. DPA at all concentrations completely eliminated external carbon dioxide injury (Figure 6).

Discussion

The observation that the risk of external carbon dioxide injury was increased by 1-MCP, led to our initial recommendation that carbon dioxide concentrations in the storage atmosphere

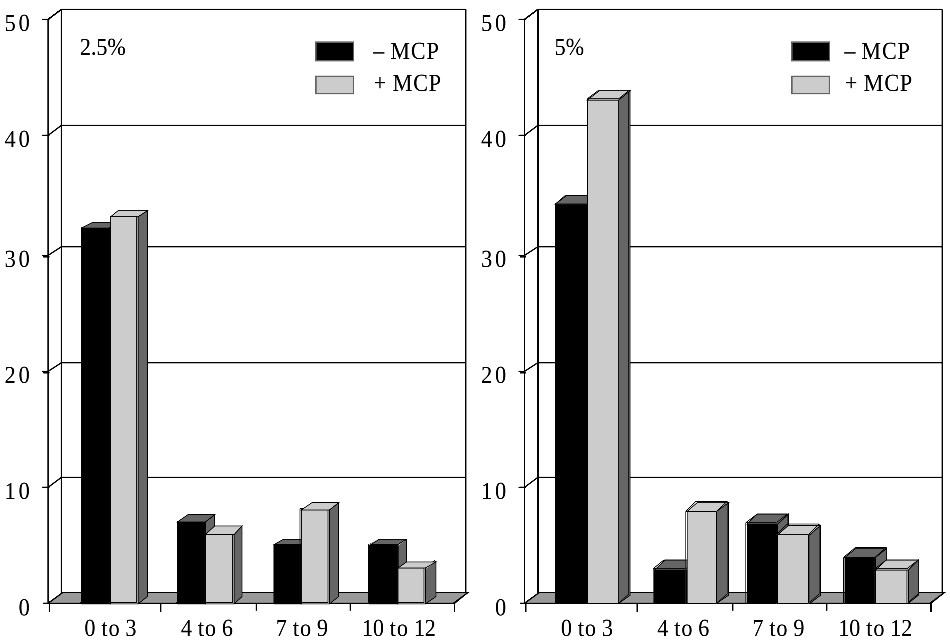

Figure 4. External carbon dioxide injury (%) of 'Empire' apple fruit either untreated or treated with 1ppm 1-MCP and exposed to 2.5% or 5% carbon dioxide (in 2% oxygen) for 3 week periods during storage.

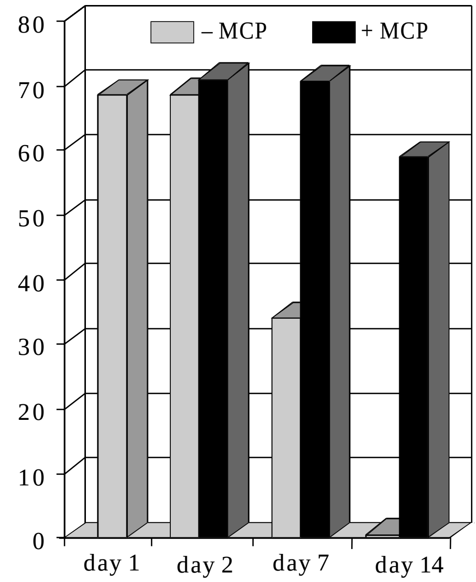

Figure 5. External carbon dioxide injury (%) in 'Empire' apples exposed to 5% CO2 one day after harvest, or untreated or treated with 1-MCP and exposed to CO2 2, 7 and 14 days after harvest.

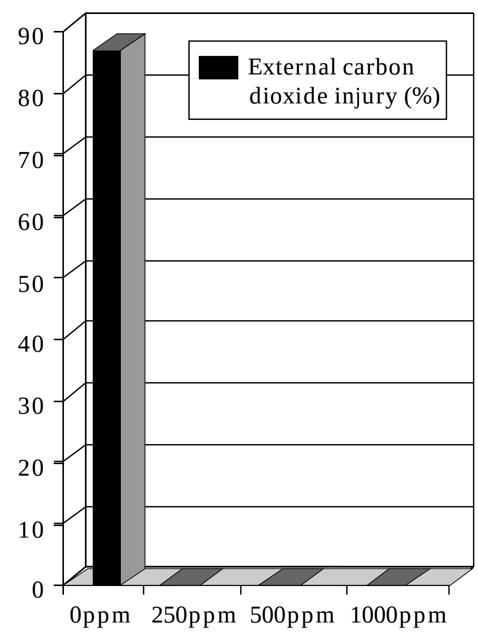

Figure 6. External carbon dioxide injury (%) of 'Empire' apples treated with water or 250, 500 or 1000ppm DPA and exposed to 5% carbon dioxide (in 2% oxygen) for 10 weeks.

should be kept to below 1% for the first 4-6 weeks of storage. However, even at this level, some injury risk exists and some storages reported unacceptable levels of injury when using this method. If carbon dioxide concentrations are reduced further, e.g. 0.5%, then injury might be further reduced. Nevertheless, it may be that reduced decay as a result of avoiding postharvest DPA offsets the losses due to external carbon dioxide injury found at low carbon dioxide concentrations in the storage, especially for storage of predominantly high colored fruit since injury usually occurs on the green or unblushed area of the fruit.

Our study indicates that the increased external carbon dioxide injury associated with 1-MCP treatment is not a result of greater risk periods, so we are not extending the length of the early period over which carbon dioxide concentrations should be kept low beyond the current recommendation of 4-6 weeks. It is important to understand that the period of injury risk is relatively short. How quickly should the carbon dioxide concentrations in the storage atmosphere be allowed to increase? Maintaining carbon dioxide in the storage environment between 2 and 3% is critical to maintain fruit firmness in fruit that are not 1-MCP treated, and therefore we like to see such levels within a couple months of storage. With 1-MCP-treated fruit, we have found that these higher carbon dioxide concentrations are not necessary to maintain firmness unless storage periods are beyond six months. However, in a CA room there is a chance that some fruit lots do not respond to 1-MCP as well as others; if this occurs then maintaining low carbon dioxide concentrations for extended periods could be detrimental to these fruit as they will soften prematurely.

Interestingly, however, our study shows that 1-MCP treatment increases the "adaptation" period prior to CA establishment. This is the time period between harvest and CA establishment during which fruit sensitivity to carbon dioxide decreases. When major losses were reported in the 1990s as a result of stopping DPA usage, the worst damage occurred in those storages that applied CA conditions within a few days of harvest – by doing things correctly, storage operators probably increased injury! In contrast, in those storage operations where application of CA conditions was delayed, there appeared to be less injury. The bottom line from our studies is that 1-MCP treated fruit maintain susceptibility to injury in the period after harvest and before CA establishment. Therefore, unless DPA is used to eliminate risk of injury development, storage operators need to be aware of the increased risk and manage to avoid fruit losses. It is dangerous to assume that risk is low because of the absence of external carbon dioxide injury in the last few years as seasonal variation can result in unexpected susceptibility.

In the foreseeable future, the no-risk solution to prevent external carbon dioxide injury development is DPA treatment after harvest. DPA is registered as an inhibitor of superficial scald and must be applied for that purpose under label restrictions. However, our results show that risk of external carbon dioxide injury is eliminated with a DPA treatment, even at concentrations as low as 250ppm. Therefore it may be possible to reduce costs associated with DPA treatment, especially as superficial scald susceptibility of 'Empire' apples is low. Some New York storage operators have employed DPA together with low carbon dioxide and delay treatments. If DPA is used, then no other methods are necessary to avoid external carbon dioxide injury.

Summary

1. Susceptibility of 'Empire' apples to external carbon dioxide injury is increased by higher carbon dioxide concentrations in the storage environments and further increased by prior treatment of fruit with 1-MCP.
2. The early period of fruit susceptibility to carbon dioxide is not lengthened by 1-MCP treatment and therefore it is not necessary to extend the time that carbon dioxide concentrations in the storage atmosphere must be kept low.
3. 1-MCP treatment prevents the "adaptation" period after harvest and before CA storage during which the susceptibility of fruit to carbon dioxide normally declines markedly. Therefore, special care by storage operators is required to avoid injury risk in 1-MCP treated fruit.
4. Two methods are available to minimize or prevent external carbon dioxide injury in apple fruit. The first is to maintain carbon dioxide concentrations below 1%, but some injury can occur if fruit are highly susceptible. The second is DPA treatment, which appears to completely eliminate risk of injury.

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Fanjaniaina Razafimbelo is a Ph.D. student doing research on the effects of 1-MCP on physiological disorders and on nutritional status of apple fruit. Jackie Nock is a Research Support Specialist and Chris Watkins is a Professor of Postharvest Science in the Department of Horticulture, Cornell University, Ithaca, NY.