Managing External Carbon Dioxide Injury During Storage: A Sequel

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A new technology in which diphenylamine (DPA) can be applied by thermofogging in the storage room will soon be available for New York storage operators, raising questions of the importance of the timing of SmartFresh (1-methylcyclopropene or 1-MCP) treatment relative to DPA treatment. In addition, we have found that temperature management of fruit after harvest may be a critical risk factor for those storage operators who prefer not to use either DPA drenching or thermofogging.

External carbon dioxide injury is a skin disorder of apple fruit that occurs during storage, resulting in disfigured fruit that are unmarketable. The injury is usually associated with controlled atmosphere (CA) storage, and it 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'. This risk varies considerably among orchard blocks and may also vary from season to season. The new technology, SmartFresh, based on the ethylene inhibitor 1-methylcyclopropene (1-MCP), can increase the susceptibility of fruit to external carbon dioxide injury.

In a recent article in the *New York Fruit Quarterly*, (Razafimbelo et al., 2006), we described several important factors associated with risk of external carbon dioxide injury developing during storage, as well as methods that storage operators can use to eliminate or reduce this risk. There are essentially two methods for the industry to consider.

The first method takes advantage of the powerful effect of the postharvest antioxidant, diphenylamine (DPA), used routinely by storage operators to prevent development of superficial scald. If fruit are treated with DPA to prevent scald, then an additional benefit is that external carbon dioxide injury is completely controlled. We have shown that this control can occur at concentrations as low as 250ppm. DPA is registered as an inhibitor of superficial scald and must be applied for that purpose under label restrictions, but if fruit are treated with DPA no "special precautions" in handling practices or storage atmospheres are necessary to avoid external carbon dioxide injury.

The second method is non-chemical, avoiding use of postharvest DPA drenching and associated use of fungicides, by maintaining carbon dioxide concentrations in the storage atmosphere below 1% for the first four to six weeks of storage. However, even at this level, some injury can occur in very susceptible situations and some storages report 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. However, maintaining such low carbon dioxide concentrations is not always practical. Other strategies to reduce risk of injury could include avoiding lots of fruit from orchards with a history of greater susceptibility. These are often, but not always, poor colored fruit since injury usually occurs on the green or unblushed area of the fruit.

Here we report two additional aspects related to control of external carbon dioxide injury that are important for safe implementation of either method. The first concerns the new DPA application technology known as thermofogging that will soon become available to the New York apple storage industry (Sanderson, 2005). The second concerns how the temperature of fruit after harvest may markedly affect the susceptibility of fruit to injury.

Thermofogging Of DPA – How Soon Must Fruit Be Treated After Harvest With and Without Smartfresh?

The Issue. Under present apple handling conditions, fruit are drenched or dipped in DPA at the time of arrival of bins of fruit at the storage facility. Fruit are then moved into the controlled atmosphere (CA) storage rooms and when the rooms are full, they are closed. Fruit are either untreated or treated with SmartFresh technology before the atmospheres are established.

If the new thermofogging technology is used, DPA will be applied when the rooms are closed, rather than at the time of arrival of fruit at the storage facility (Figure 1). The industry has asked, which should be applied first, DPA or Smartfresh? Also, is there a risk of reduced effectiveness resulting from the delayed DPA application?

Pace International LLC, recommends that the initial application of DPA should be made within seven days, but no later than 10 days after harvest for optimal scald control. There is no conflict with SmartFresh application and DPA for scald control since SmartFresh decreases the rate of scald development. In contrast, because SmartFresh increases the development of external carbon dioxide injury, the timing of the two processes may be much more critical.

The Approach. We applied DPA to Empire apples exposed to elevated carbon dioxide atmospheres at various intervals after harvest. We wanted to use the most abusive conditions that could occur while fruit are being accumulated in the CA storage rooms. A 5% concentration of carbon dioxide (in air) was chosen for this experiment. Although this level is very high, it represents atmospheres that have been measured during loading of CA storage rooms. In addition, the fruit tested in this experiment were harvested from an orchard block with a history of high susceptibility to external carbon dioxide injury.

Fruit were cooled overnight and then either untreated or treated with 1ppm 1-MCP. Additional samples were also treated with DPA on the day of harvest, and either untreated or treated with 1-MCP. The fruit were exposed to the elevated carbon dioxide at 35-36°F using a flow-through system in which fruit were stored in plastic pails, each containing about 50 fruit. Each treatment consisted of four replicates.

After one, two, four, six or eight days, fruit either untreated or treated with 1-MCP were removed from the flow boards, dipped in 1000ppm DPA for 1 minute, returned to the plastic pails and exposed once again to 5% carbon dioxide. The dipping treatment was assumed to produce results equivalent to thermofogging.

All fruit were removed from the carbon dioxide treatments 14 days after initiation of the experiment, and evaluated for injury.

Results. The only disorder that was detected on the fruit was external carbon dioxide injury. There was a dramatic effect of both SmartFresh treatment and timing of DPA treatment on the incidence of injury (Figure 2).

No injury was detected in samples exposed to the high carbon dioxide environment during the first four days without DPA, whether treated with SmartFresh or not. However, injury was visible in both SmartFresh and control samples when treatments were delayed six and eight days. The SmartFresh samples resulted in far more injury than the untreated samples (9% vs. slight on day 6, and over 25% vs. 10% on day eight).

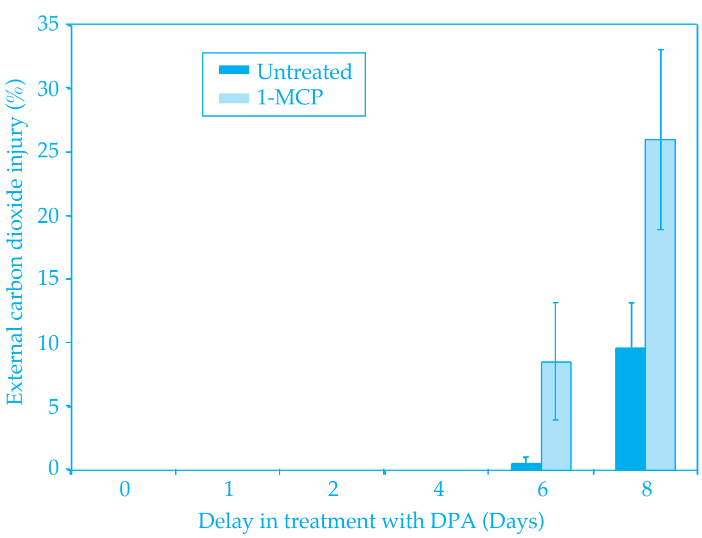

Figure 2. The incidence of external carbon dioxide injury in Empire apple fruit that were untreated or treated with SmartFresh and kept in 5% carbon dioxide (in air) for 14 days at 36°F. Fruit were removed from the 5% carbon dioxide atmosphere and treated quickly with 1000ppm DPA either on day one, two, four, six or eight and returned to the high carbon dioxide atmosphere.

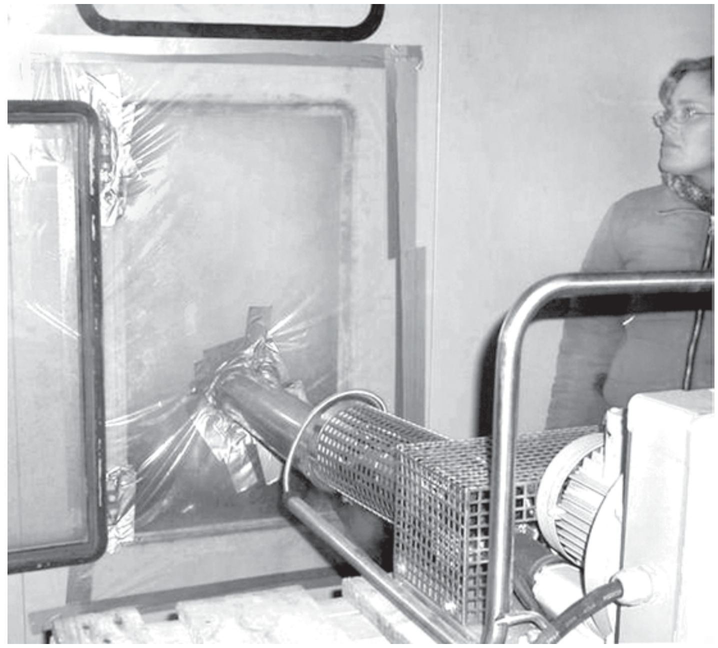

Figure 1. Thermofogging of a CA storage room with DPA. Photo provided by Pace International, LLC. Artwork, photographs and designs may not be copied, reproduced or used in any way without written authorization from Pace International, LLC.© 2007 Pace International LLC - All Rights Reserved

Fruit that were treated with DPA on the day of harvest, with or without subsequent SmartFresh treatment, and exposed to 5% carbon dioxide for the 14-day period, had no visible external carbon dioxide injury. Fruit without DPA treatment had 19% and 49% injury if untreated or treated with SmartFresh, respectively, at the same time (data not shown).

Conclusions. We have shown again that SmartFresh increases the risk of external carbon dioxide injury, and that DPA has a powerful protective influence by preventing development of the injury. However, delays before DPA application reduced effectiveness of the treatment. In interpreting these results it is important to recognize that we did everything that we could to maximize the risk of external carbon dioxide injury by using highly susceptible fruit together with high carbon dioxide concentrations during exposure. Therefore, the injury levels obtained in this experiment likely represent the maximum damage that would result under a worst case scenario. It is important to note that even following the extreme conditions used in the experiment, the injury to fruit without SmartFresh treatment was negligible when DPA treatment was delayed for six days, while the SmartFresh samples resulted in only 9% to this very susceptible fruit at the same time. Because the incidence of injury is correlated to carbon dioxide concentrations in the atmosphere, the results highlight the importance of maintaining low concentrations of the gas in the storage room during loading. Good fruit cooling practices, especially the temporary distribution of incoming fruit among available storage rooms to speed field heat removal, is necessary. Carbon dioxide levels during loading can be controlled by providing sufficient ventilation or by early addition of lime to the room.

We conclude that delaying DPA treatment of fruit up to seven days would result in negligible risk of external carbon dioxide injury development in Empire apples, and under normal circumstances may be even longer. If any appearance of the disorder is unacceptable, then shorter delays may be necessary, but dependent on the sensitivity of the fruit and control of carbon dioxide in the storage atmosphere.

It should be noted that for the 2006/2007 season, Pace international LLC, treated nine rooms of varieties susceptible to carbon dioxide injury (Empire, McIntosh and Cortland) in New York State with DPA by thermofogging. All rooms were treated with 1-MCP a few days prior to DPA thermofogging, and visual inspections revealed little or no external carbon dioxide injury.

How Important Is Temperature Management for Smartfresh Treated Fruit?

The Issue. AgroFresh provides guidelines for the period of time between harvest and application of Smartfresh. While the 7-day guideline for Empire in New York State is manageable for large operators, the SmartFresh guidelines are sometimes difficult for storage operators who are unable to fill rooms quickly, or who may wish to fill single rooms with several varieties. In addition, rapid filling of rooms especially during warm weather may exceed the cooling capacity of some storages, resulting in slow field heat removal.

Therefore, we have been investigating the responses of McIntosh and Empire to a strategy where the focus is on treating fruit with SmartFresh as soon as possible after harvest and then applying CA storage conditions after delayed time periods. Several storage operators have built rooms specifically for this purpose or have used treatment pods. The main finding of this work will be reported in a future issue of the *New York Fruit Quarterly*. However, we want to report an important finding that may explain why high levels of external carbon dioxide injury have sometimes occurred in non-DPA treated fruit, even when carbon dioxide levels have been kept low during the earlier part of the storage. In the study reported here we show that temperature management may be critical to avoid injury to fruit that has not been treated with DPA.

The Approach. Fruit used in this experiment were obtained from the Cornell Orchard at Ithaca. Fruit were divided into replicates of 50 fruit and cooled overnight to 36, 45 or 55°F. Fruit were then either untreated or treated with 1ppm 1-MCP for 24 hours. On day two following harvest (i.e. as soon as the fruit were ventilated after 1-MCP treatment), untreated and treated samples were cooled to 36°F before atmospheres of 2% oxygen and 2% carbon dioxide were established. Similar samples were cooled and placed under the same CA conditions following day seven and 14 days after harvest. Fruit were stored in CA for eight months, and quality was assessed after seven days at 68°F.

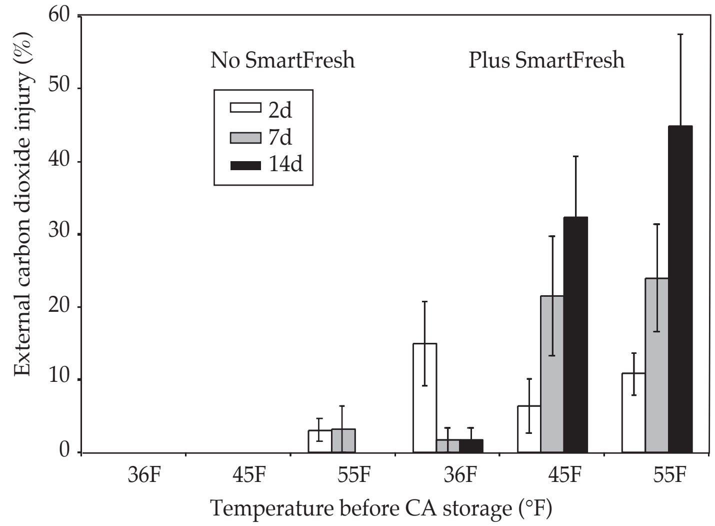

Figure 3. External carbon dioxide injury in Empire apple fruit harvested and then treated with Smartfresh after cooling overnight to 36, 45 or 55°F. Fruit were then moved to 36°F storage, cooled and CA (2% oxygen and 2% carbon dioxide) established two days after harvest, or kept at warmer temperatures for 7 and 14 days before cooling to 36°F and application of CA.

Results. The effects of keeping fruit at different temperatures before CA on external carbon dioxide injury were twofold. First the levels of external carbon dioxide injury were much higher in SmartFresh-treated apples than in untreated apples (Figure 3). The second was that the fruit temperature after SmartFresh treatment profoundly affected the incidence of injury and that this increased incidence was directly related to the time that the fruit was kept at these temperatures. While there was little effect at 36°F, carbon dioxide injury in the other samples was increased by lengthening the delay in CA establishment, and elevating holding temperatures during the delay. It appears that if fruit are not cooled after SmartFresh treatment and before application of CA there is a massive increase in the risk of external carbon dioxide injury development.

Conclusion. The take home message from this experiment is that in the absence of DPA treatment, if storage operators employ a strategy whereby fruit are treated with SmartFresh quickly after harvest, good temperature management of the treated fruit is critical. The highest temperature used in the study (55°F) may represent an extreme case, but a temperature of 45°F in a storage that is filled quickly and lacks sufficient refrigeration capacity seems quite likely. An interesting aspect of this study is that fruit from the orchard block that we used rarely developed external carbon dioxide injury as shown by negligible levels in fruit cooled after harvest and stored under CA conditions. Clearly even a "low risk" orchard can develop problems if temperature management is poor!

Putting it Together

These data, together with those reported earlier by Razafimbelo, Nock and Watkins (2006), show that:

1. Empire fruit (and other varieties such as McIntosh and Cortland) can be highly susceptible to external carbon dioxide injury. Susceptibility can vary with orchard block location but is increased by postharvest exposure to carbon dioxide in the storage atmosphere.
2. Fruit treated with SmartFresh have a greater susceptibility to development of external carbon dioxide injury, perhaps because the fruit is kept "fresher" or closer to the ripening stage at the time of harvest, and as a result, is slower to decrease sensitivity to injury. Injury occurs within the first few weeks of storage.
3. If DPA is used to control superficial scald development, an additional benefit of preventing external carbon dioxide injury results, even at DPA concentrations as low as 250ppm.
4. Delaying DPA treatment after harvest, as would be necessary for thermofogging treatments, is still effective. We suggest that DPA treatment up to seven days from harvest may

be satisfactory (for control of external carbon dioxide injury, though not necessarily scald). The safe period is likely to be even longer if sensitive blocks are avoided and if carbon dioxide levels during loading are controlled by either good ventilation or the addition of lime.

5. External carbon dioxide injury can be avoided or reduced without DPA treatment, but special care is essential to avoid carbon dioxide accumulation during filling of rooms and during the first four to six weeks of storage. Good cooling of fruit is essential if there are delays between SmartFresh treatment and the application of CA conditions.

References

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