

## **Toward Optimizing CA Storage of Honeycrisp Apples: Minimizing Prestorage Conditioning Time and Temperature (Originally published in the October 2014 NY Fruit Quarterly)**

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The Honeycrisp apple continues to be a popular and valuable addition to the varietal mix of apples grown in the U.S. Significant production acreage can now be found in Michigan, Minnesota, New York, Nova Scotia, Ontario, and Washington. Honeycrisp is one of the most profitable apples grown on a per fruit basis and the number of bearing acres is increasing dramatically each year. As the planted acreage continues to grow, the need to extend the marketing season intensifies.

Unfortunately, however, high sensitivity to a number of storage disorders makes long-term storage a serious challenge. Important among these are the chilling injuries soggy breakdown and soft scald (Watkins and Rosenberger, 2000; Watkins et al., 2004, 2005). Delayed cooling or prestorage conditioning of 'Honeycrisp' appears to be effective in controlling soft scald and soggy breakdown (Watkins and Rosenberger, 2000; Watkins and Nock, 2003; DeLong et al., 2004; Watkins et al., 2004, 2005). Successful prestorage conditioning temperatures range from 50-60 °F and 4-7 days in duration (Beaudry et al., 2010).

It has recently been realized that Honeycrisp apples are also sensitive to injury while being stored under controlled atmospheres (Beaudry and Contreras, 2009). This CA-related injury is, in some cases, very similar in appearance to soggy breakdown. It is characterized by brown lesions/patches in the fruit cortex, often with irregular edges and sometimes with the inclusion of lens-shaped openings in the brown lesions (Fig. 1). Unlike soggy breakdown, CA injury does not seem to have a strong scent of fermentation associated with the visible symptoms.

Honeycrisp is not alone in its sensitivity to CA injury. Many fruit cultivars develop physiological disorders in response to low O<sub>2</sub>, elevated CO<sub>2</sub> or a combination of both (Pierson et al., 1971). Injury can be manifested as large or small brown lesions, the largest of which are frequently surrounded by a narrow band of healthy tissue at the periphery of the fruit skin, and resemble soggy breakdown (Pierson et al., 1971). CO<sub>2</sub> can cause an injury described as 'brown heart', which is exacerbated by low O<sub>2</sub> (Plagge, 1929). Affected fruit are described as possessing small lesions of brown flesh distributed randomly between the skin and the core (Snowdon, 1990). Initially, the injured tissue is firm and moist, but after prolonged storage they become spongy and dry developing cavities, or lens-shaped voids (Plagge 1929; Snowdon, 1990).

Recently, we reported that the controlled atmosphere injury, like chilling injury, is suppressed by prestorage conditioning treatments (Contreras et al., 2014). We also found that a prestorage

treatment with ~1000 ppm diphenylamine (DPA) would essentially eliminate CA-related injury. The prestorage conditioning treatments evaluated were 5 days at either 50 or 68 °F. The higher temperature appeared to provide more protection than the lower temperature. This was somewhat unfortunate in that the lower temperature provides good control of chilling injury and it would be convenient if the lower temperature conditioning treatment could serve the purpose of suppressing chilling injury as well as CA injury.

In order to explore the relationship between the temperature of the conditioning period, its duration and its effectiveness at suppressing CO<sub>2</sub> injury, we devised an experiment that exposed Honeycrisp fruit to several temperature/duration combinations. We proposed that a shorter duration preconditioning period at higher temperatures (68 or 77 °F) could be just as effective as a longer treatment at lower temperatures (e.g., 50 or 60 °F). An additional advantage of a shorter treatment period would be more efficient handling of the fruit prior to storage; if we could develop a 3-day protocol, for instance, . Our concern, however, was that the more 'intense' conditioning treatments might negatively affect quality, so we performed sensory analysis using a trained panel to evaluate the impact of the conditioning treatments on quality and measured the volatile profile of treated fruit to detect "off flavors".

For this project, our working hypothesis was that there exists an optimal preconditioning time-temperature combination for the suppression of CA injuries. However, this result must be interpreted in view of enhancement of any undesirable side-effects of the treatment combinations.

We conducted an experiment to:

- 1) Identify the most effective and most rapid pre-storage conditioning regimen for CA storage to minimize CA injury
- 2) Determine the impact of these conditioning regimens on undesirable disorders (e.g., bitter pit and decay)
- 3) Determine the impact of conditioning treatments on sensory quality.



Figure 1. Internal controlled atmosphere injury from low O<sub>2</sub> and elevated CO<sub>2</sub>. Injury can be in small patches or large sections, depending on severity (left). The disorder can lead to the formation of more typical CO<sub>2</sub> injury (right) with time.

In 2013, we secured fruit from 6 orchards from across the state of Michigan. Since the intent was to try to determine the optimal prestorage conditioning treatment, a range of treatment

temperatures and durations was created. Fruit were subjected to 0, 1, 3, 5, and 7 days holding at 3, 10, 15, 20, and 25 °C (38, 50, 59, 68, 77 °F, respectively), then held under CA conditions (3% O<sub>2</sub> and 3% CO<sub>2</sub> at 3°C) expected to induce CA injury. After 4 months, the fruit were assessed for the incidence and severity of CA injury, bitter pit, decay, firmness, soluble solids, aroma volatiles and titratable acidity. In addition, we determined the impact of the treatments on the sensory perception of 'ripeness' as determined by a trained panel.

Conditioning temperature and duration did not affect fruit firmness following 4 months storage either the day after removal or after a 7-day simulated retail period at 68 °F, but conditioning at temperatures 10 °C and above reduced the incidence of decay (Figure 2). Importantly, bitter pit was mild to moderate, depending on the grower, but unaffected by preconditioning (data not shown).

Conditioning reduced the incidence of CA injury at all temperatures. The effectiveness of the treatment was improved by increasing the temperature and the duration of the treatment. At 38 °F, 7 days of conditioning reduced sensitivity to CA injury marginally. Conditioning at 50 °F was slightly better, but not as effective as was hoped. At least 3 days at 68 to 77 °F were required to successfully suppress CA injury (Figure 3). What this means is that a shorter, 3-day prestorage holding period at a minimum of 20 °C can be used by apple storage operators to protect Honeycrisp apple from CA injury. Storage operators can, therefore, use their space more efficiently than previously thought, with a shorter turn-around time than the 5 days previously thought necessary for conditioning. In addition, storage operators should be able to apply the prestorage conditioning treatments to control CA injury without fear of inducing unwanted, deleterious disorders like bitter pit and decay.

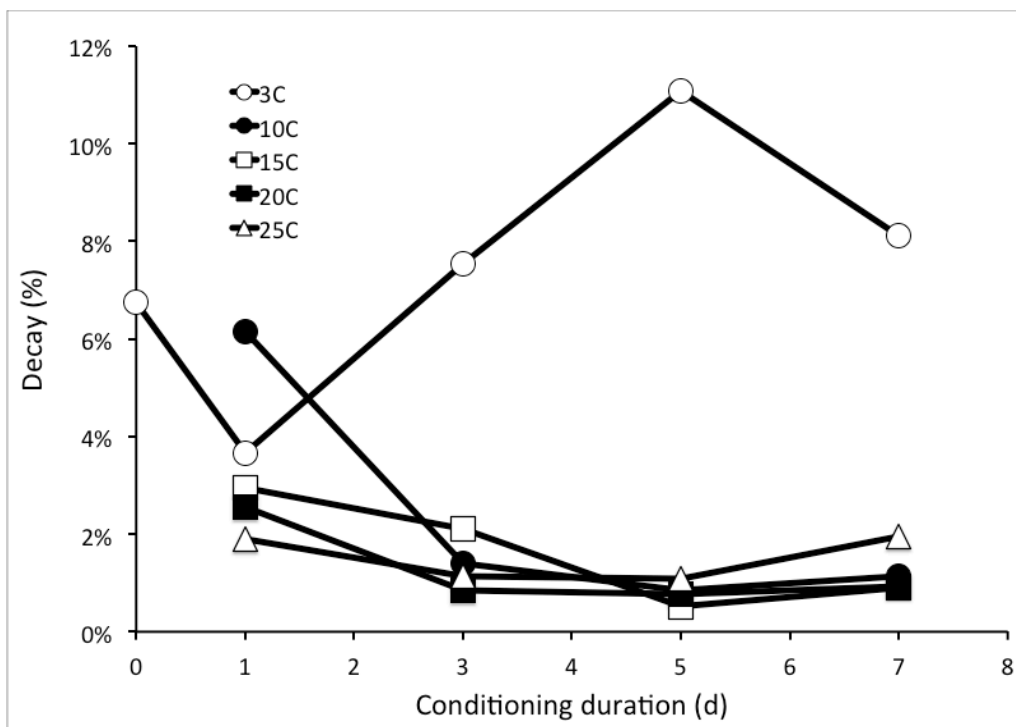


Figure 2. Increasing the duration and the temperature of the prestorage conditioning treatment reduced decay. Decay was highest for the fruit 'conditioned' at 3 °C.

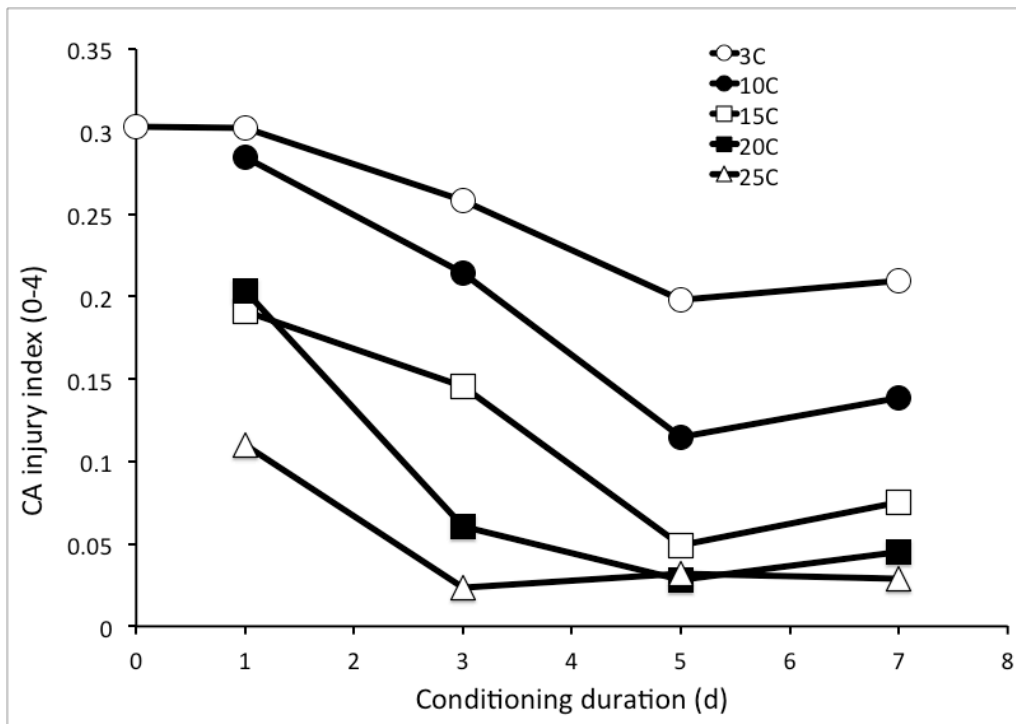


Figure 3. Increased duration of the conditioning period and increased conditioning temperature both contribute to reducing susceptibility of the fruit to CA storage injury.

In an earlier study in 2012, we used a consumer sensory panel to determine if they perceived a decline in quality over time and could discern differences in quality due to conditioning treatments (5 days at 50°F) applied. Fruit were evaluated after 1, 3, and 6 months storage in CA (3% CO<sub>2</sub> and 3% O<sub>2</sub>) or in air. A total of 78 panelists evaluated fruit on each date and a trained panel evaluated specific attributes of flavor and condition. The consumer panel could not differentiate between the various treatments or the storage durations, suggesting that the uninformed consumer is not able to readily perceive any differences in fruit ripeness (data not shown). We considered the idea that the consumer panel may have been unbiased since they were informed that the tasting was for Honeycrisp fruit and the favored opinion of that variety may have lead to higher ratings than we might otherwise expect. However, a trained panel was easily able to distinguish differences in ripeness as a function of storage duration. Even the trained panel, however, was not able to clearly distinguish between conditioning treatments.

In the 2013 study, the trained sensory panel again had difficulty distinguishing between conditioning treatments. In this case, they were presented with fruit from four different conditioning treatments differing in 'intensity' with regard to temperature and duration: 0 days conditioning; 5 days at 50 °F, 5 days at 68°F, and 7 days at 77 °F. The panel was asked to judge ripeness, greasiness, tartness, strength of aroma and firmness. The sensory panel could not detect an effect of conditioning treatment on any one of these characteristics, but we did find that

conditioning treatment affected a ripeness index, which we calculated as the sum of sensory scores for aroma and greasiness divided by the tartness score. However, the effect was very slight and statistical tests could not demonstrate which treatment differed from the others. Further, we found that prestorage conditioning duration and temperature did not affect titratable acidity (data not shown) and so would be unlikely to affect the perception of tartness, which is consistent with our sensory data. Increasing the intensity of the conditioning treatment increased the synthesis of fermentation volatiles such as ethanol and ethyl esters in Honeycrisp fruit (Fig. 5). However, other aroma compounds were not appreciably affected. The sensory data suggest that the more intense preconditioning treatments do have the potential to compromise perceived quality, albeit only slightly, so that the conditioning temperature and its duration should be kept at their respective minimums. In this case, the conditioning temperature should probably remain near 20 °C and be applied for no more than 3 to 5 days.

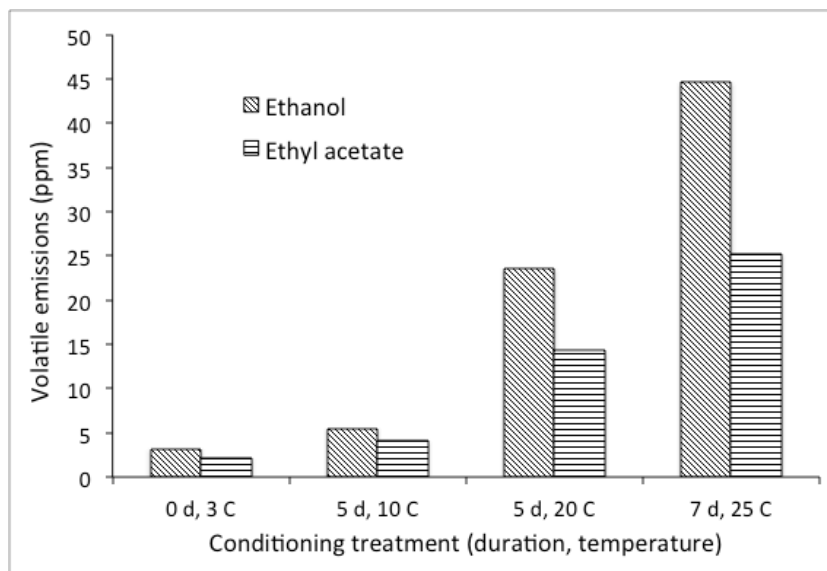


Figure 5. Increasing the intensity of the prestorage conditioning treatment by increasing temperature and the duration of the treatment enhanced the production of volatiles related to fermentation, which are associated with over-ripeness.

## Summary

The findings demonstrate to our apple storage industry that Honeycrisp fruit can be stored safely in CA if the fruit are preconditioned properly, thus extending the marketing season and protecting the value of the harvested crop beyond its normal marketing period.

the data from 2013 suggest that apple storage operators may be able to use a shorter, 3-day prestorage holding period (at a minimum of 20 °C) to protect Honeycrisp apple from CA injury without risk of increased incidence of other storage disorders and with minimal impact on fruit flavor.

Our current recommendation for CA storage is to keep CO<sub>2</sub> low in the first month of storage, much in the same way as for Empire, and then allow the CO<sub>2</sub> levels to increase. Our recommended storage temperature remains 38°F for the moment, but with conditioning, somewhat lower temperatures may be successful as well. We recommend some form of protection from CA injury and we have previously had very good success for three successive years (Contreras et al., 2014) with 5 days at 68 °F. However, the more recent data shared here

suggests a shorter conditioning period may be similarly effective, but additional testing is required at this point since this represents only a single year's data. It is also worth noting that DPA is very effective at suppressing CA injury in Honeycrisp and would certainly be able to substitute for a preconditioning treatment in terms of controlling this disorder. However, since DPA has only a very slight suppressive effect on chilling injury (Watkins et al., 2004), a minimal prestorage conditioning treatment (5 days at 50°F) is still advisable in air or CA storage. Another alternative to CA storage is the use of 1-MCP to suppress ripening. Results so far have been quite favorable, but there may be a slight enhancement of sensitivity to CO<sub>2</sub> injury. For this reason, we strongly recommend monitoring CO<sub>2</sub> levels during room loading and the initial cooling period, venting the room if necessary.

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