Towards Controlled Atmosphere Storage for Honeycrisp Apples

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It is not surprising that Honeycrisp remains one of the most profitable apples for New York growers. The flavor and texture are outstanding and as a result consumers seek out the variety. The texture, and to a lesser extent, the flavor, is maintained during long-term storage even in air storage. From the onset of its planting in New York, however, Honeycrisp has presented an almost bewildering range of storage disorders. These have included soft scald, soggy breakdown, low temperature breakdown, senescent breakdown, bitter pit, lenticel spots, skin wrinkling, and storage rots.

"Although most New York grown Honeycrisp apples are marketed in the short term, increasing volumes of fruit will soon require use of controlled atmosphere (CA) storage to maintain optimum fruit quality. No CA recommendations are yet available for New York, but this article describes progress on CA storage of this important variety."

In our first series of studies, we discovered that 38°F is the best temperature to minimize low temperature injuries, and that a conditioning period of 7 days at 50°F will minimize the risk of soft scald and soggy breakdown even in late harvested fruit. Unfortunately, the conditioning treatment can exacerbate development of bitter pit in the variety, and so calcium spray programs as well as other preharvest management techniques must be employed to reduce fruit losses from pitting. These studies have been reported to New York growers at various venues, including articles in the New York Fruit Quarterly (Watkins and Nock, 2003).

Although Honeycrisp can store well in air, it is generally recognized that loss of acidity can result in decreasing fruit quality over time. Therefore, there has been interest in developing controlled atmosphere (CA) storage regimes to maintain fruit quality for extended periods during storage. Our first attempts to store Honeycrisp in CA conditions demonstrated that development of disorders under CA could be devastating, but we carried out these trials without the now standard conditioning treatment of 7 days at 50°F. Successful CA storage has been reported for fruit grown in Nova Scotia (2.5% oxygen/2.5% carbon dioxide at 38°F after conditioning, but susceptibility of Honeycrisp fruit from other regions to disorders under CA conditions have led to reluctance on our part, and that of our colleagues in Ontario and Michigan, to make CA recommendations. Therefore, in the last two years, we have been focused on answering the question: "Can we safely store New York-grown Honeycrisp apples under CA conditions?"

Materials and Methods

The work reported here is based only on western New York fruit. In year 1 (2009), we obtained fruit from 6 orchard blocks, harvested at commercial quality criteria of red coloration, and delivered to two major storage operations. Three blocks (1, 2 and 3) were harvested on September 24, and the other three were harvested on September 25. Fruit for the experiments were transported to Ithaca on the 25th and harvest indices were assessed on the same day. After a conditioning period of 7 days at 50°F, the fruit were cooled overnight to 38°F, and stored in one of 6 atmospheres:

1. 1.5% oxygen/1.5% carbon dioxide
2. 3% oxygen/1.5% carbon dioxide
3. 4.5% oxygen/1.5% carbon dioxide
4. 1.5% oxygen/3% carbon dioxide
5. 3% oxygen/3% carbon dioxide
6. 4.5% oxygen/3% carbon dioxide

These atmospheres represent a range of treatments that would be expected to result in quite dramatic differences if applied to an apple variety such as 'McIntosh', 'Empire' or 'Delicious'. Fruit were stored for 6 months and quality assessed after 4 days at 68°F.

In year 2 (2010), a smaller range of atmospheres were tested (2% oxygen/2% carbon dioxide; 3% oxygen/0.5% carbon dioxide; 3% oxygen/1.5% carbon dioxide) and the effects of SmartFresh (1-MCP) were also evaluated when applied either before or during the last day of the conditioning period (on day 6).

Fruit were obtained from three orchard blocks on September 17, and harvest indices measured on the following day. Fruit were stored for 6 months and quality assessed after 4 days at 68°F.

Flesh firmness was measured with an electronic pressure tester, and soluble solids concentration (SSC) and titratable acidity on homogenized flesh samples using a digital refractometer and an automatic titrator, respectively. Each fruit was examined carefully for external disorders and rating for presence or absence of greasiness (slipperiness to the touch), before being sliced for assessment of any internal disorders.

Table 1. Internal ethylene concentration (IEC), flesh firmness, titratable acidity, soluble solids concentration (SSC) and starch pattern indices of Honeycrisp apples in 2009.

Orchard block	IEC (ppm)	Firmness (lb)	Titratable acidity (%)	SSC (%)	Starch index (1-8)
1	0.4	14.1	0.216	11.1	6.9
2	3	15.2	0.303	11.4	7.1
3	28	13.7	0.280	11.5	7.0
4	20	14.9	0.361	10.8	6.9
5	14	15.2	0.386	12.6	7.4
6	11	13.1	0.272	10.8	7.0

Results

Effects of storage atmosphere (2009). The harvest indices of fruit from the six orchard blocks varied greatly, except for the starch indices, for which differences among blocks were not significant (Table 1). A striking feature that appeared to relate to informal flavor assessments was the titratable acidity, which ranged from 0.22% to 0.39%.

CA storage did not affect flesh firmness, but it did affect SSC and TA. Although there was wide variation among fruit from orchard blocks, the data were combined for all orchards for the sake of clarity (Figure 1A-C). The variation of SSC was relatively small compared with that for TA. Fruit from the 1.5% oxygen/1.5% carbon dioxide, 3% oxygen/1.5% carbon dioxide and 3% oxygen/3% carbon dioxide treatments had the highest acidity. Fruit from blocks 1 and 3, and to a lesser extent block 6, had low SSC and TA values after storage. These low values were associated with bland flavor that was detected by informal sensory analyses by growers and storage operators.

Of the physiological disorders, the one of most concern was internal carbon dioxide injury, characterized by the frequent presence of cavities with or without flesh browning (Figure 2). As is typical for disorders, the incidence of injury ranged widely. In this experiment, the average injury was as little as 1% in fruit from block 1 to as much as 17% in fruit from block 5. In this article, we present the average internal carbon dioxide injury across all blocks (Figure 3). There was no significant effect of oxygen concentration, but injury averaged 10% in fruit stored with 3% carbon dioxide compared with 5% in fruit stored in 1.5% carbon dioxide. Internal carbon dioxide injury remains the major limiting factor to CA storage of 'Honeycrisp' as also shown in the 2010 experiment.

The incidences of soft scald, core browning and senescent breakdown were negligible. Bitter pit and decay varied by orchard but did not exceed 5% overall, and were not affected by atmosphere (data not shown).

The percentage of fruit with greasiness varied greatly, with less than 1% in fruit from Orchard block 2, to 35% in fruit from orchard block 4. Over all treatments, however, the greasiness incidence was lower in 1.5% oxygen than 3 and 4.5% oxygen, and in 3% than 1.5% carbon dioxide (Figure 4).

Effects of storage atmosphere and SmartFresh (2010). Fruit were harvested on September 17, but may have been harvested too late for optimum CA storage. 2010 was a difficult year for the industry in terms of color development, as maturity was more advanced than indicated by fruit color. Fruit from orchard 1 had already been spot picked once, but fruit from orchards 2 and 3 were first pick fruits. The IECs and starch indices were in the normal range of western New York 'Honeycrisp' fruit at harvest (Table 2) but flesh firmness was low, especially in blocks 1 and 3, even given the unreliability of the firmness tester for this variety.

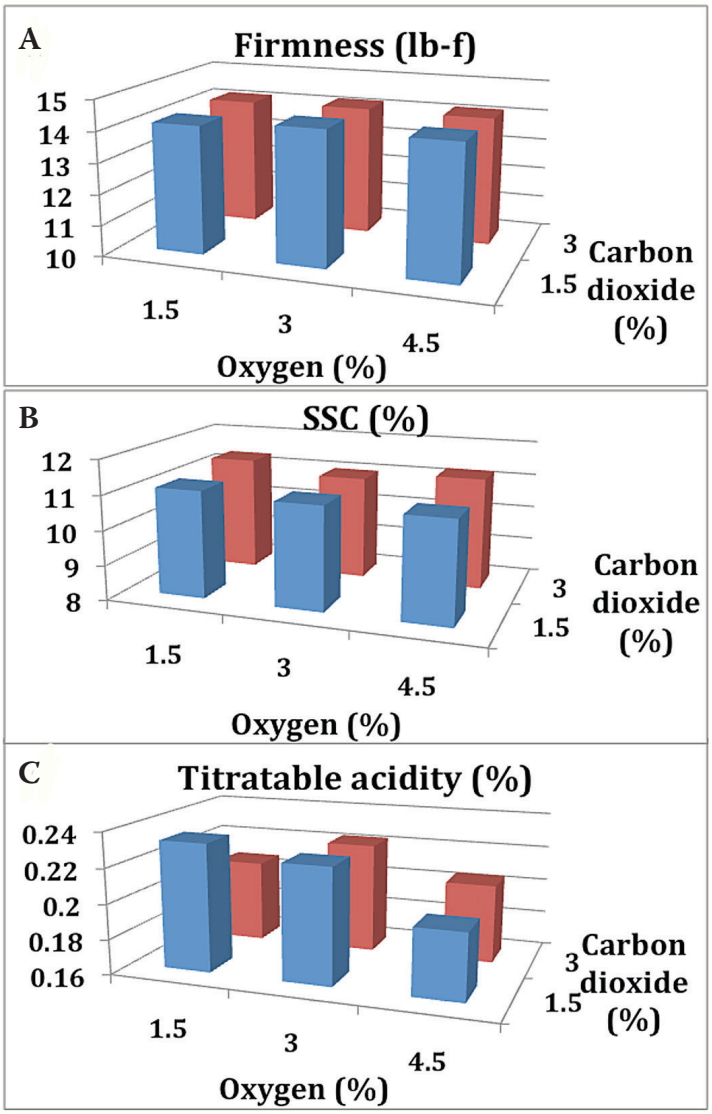

Figure 1. Flesh firmness, soluble solids concentration (SSC) and titratable acidity of 'Honeycrisp' fruit from six Western New York orchards stored in CA storage for 6 months plus 4 days at 68°F (2009 harvest).

Figure 2. Internal carbon dioxide injury of 'Honeycrisp' apples with characteristic cavities in the flesh.

Titratable acidity and SSC were lowest in fruit from block 1 (Table 2).

After storage, the IEC of fruit treated with SmartFresh was lower than untreated fruit, regardless of time of treatment, but no quality factors were affected consistently by storage atmosphere or SmartFresh treatment (data not shown). These results are similar to those found in other studies where we have found little effect of SmartFresh on firmness, acidity or SCC of Honeycrisp fruit stored in CA.

However, SmartFresh had marked effects on storage disorders, and timing of treatment could also be important. The first thing to notice is the significant block-to-block variation in CO_2 injury (Figure 5). Fruit from block 1 had essentially no internal CO_2 injury or senescent breakdown, in contrast to the high levels in fruit from blocks 2 and 3.

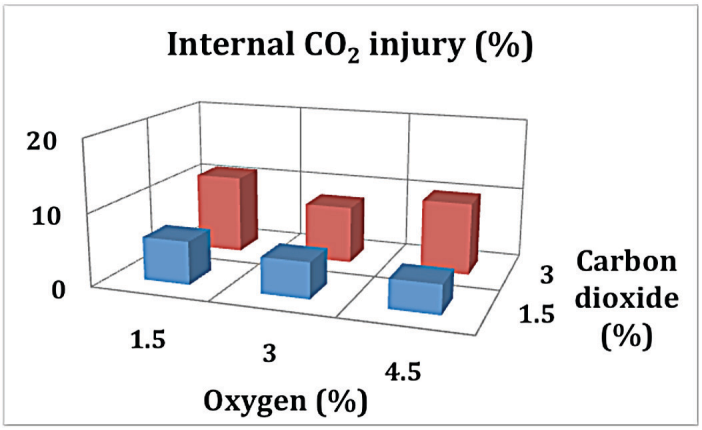

Figure 3. Internal carbon dioxide injury (%) in 'Honeycrisp' fruit from six Western New York orchards stored in CA storage for 6 months plus 4 days at 68°F (2009 harvest).

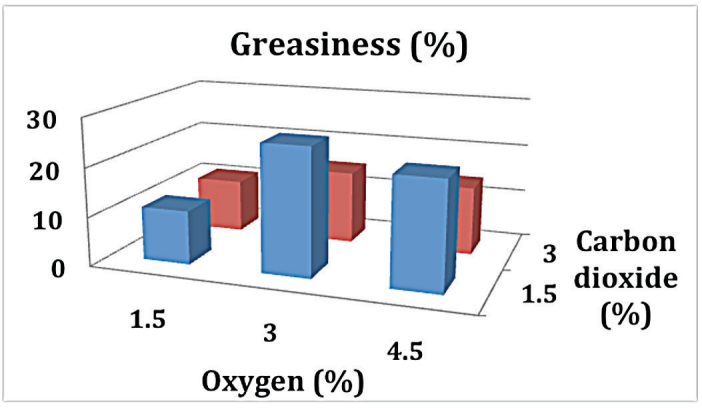

Figure 4. Greasiness (%) of 'Honeycrisp' fruit from six Western New York orchards stored in CA storage for 6 months plus 4 days at 68°F (2009 harvest).

Table 2. The internal ethylene concentration (IEC), flesh firmness, titratable acidity, soluble solids concentration (SSC) and starch pattern indices of Honeycrisp apples in 2010.

Orchard block	IEC (ppm)	Firmness (lb)	Titratable acidity (%)	SSC (%)	Starch index (1-8)
1	32	12.5	0.299	10.7	7.8
2	14	14.3	0.347	11.8	7.9
3	14	12.6	0.322	11.3	7.9

There was a negligible effect of SmartFresh on internal carbon dioxide injury with the exception of fruit treated with SmartFresh on day 1 and then stored in a 2% oxygen/2% carbon dioxide atmosphere (Figure 5). This type of result is similar to earlier finding with 'McIntosh' and 'Empire' where higher levels of external carbon dioxide injury were found in fruit that were treated with SmartFresh and kept at warmer temperature prior to application of CA storage (Watkins and Nock, 2007). It is still

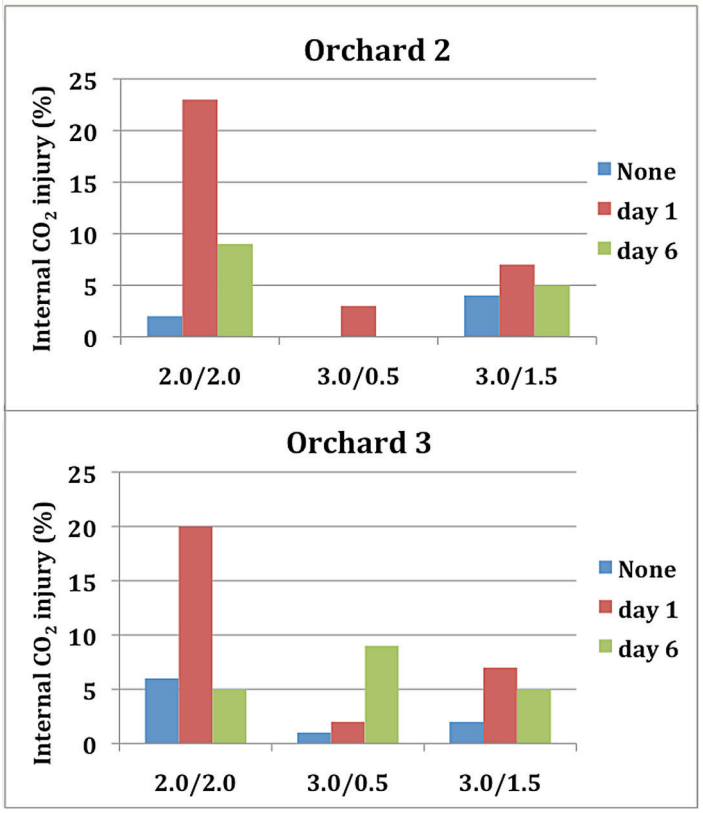

Figure 5. Internal carbon dioxide injury in 'Honeycrisp' apples from two Western New York orchards (2010 harvest) untreated or treated with SmartFresh on day 1 or day 6 of the conditioning period. Fruit were stored in 2.0%/2.0%, 3.0%/0.5%, or 3.0%/1.5% oxygen/carbon dioxide for 6 months followed by 4 days at 68°F. Orchard 1 had negligible disorder occurrence.

Figure 6. Senescent breakdown of 'Honeycrisp' apples.

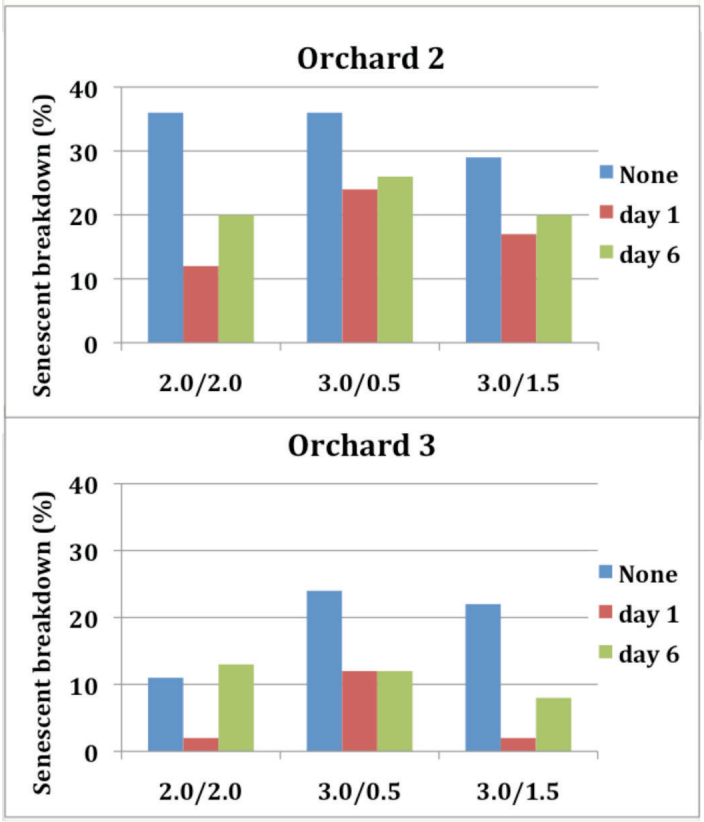

Figure 7. Senescent breakdown in 'Honeycrisp' apples from two Western New York orchards (2010 harvest) untreated or treated with SmartFresh on day 1 or day 6 of the conditioning period. Fruit were stored in 2.0%/2.0%, 3.0%/0.5%, or 3.0%/1.5% oxygen/carbon dioxide for 6 months followed by 4 days at 68°F. Orchard 1 had negligible disorder occurrence.

unclear why this phenomenon happens, but we suspect that the solution is to delay application of CA storage for several days after the conditioning period.

Senescent breakdown (Figure 6) was usually decreased by SmartFresh treatment, and more effectively if fruit were treated on day 1 (Figure 7). It is notable that we only detected high incidences of senescent breakdown in the 2010 harvest season, possibly because as mentioned above, fruit were more mature that in the previous season.

The percentage of fruit that developed greasiness during storage was also usually reduced and more effectively, if fruit were treated with SmartFresh on day 1 (Figure 8).

Summary

CA storage has significant benefits on 'Honeycrisp' apple quality. However, an unusual feature of 'Honeycrisp' is lack of great difference in firmness, acidity and SSC among the wide range of atmospheres from 1.5% to 4.5% oxygen, with 1.5% and 3% carbon dioxide. With other varieties of apple, we would expect a significant loss of these attributes as the oxygen concentration increased, especially at the lower carbon dioxide concentrations.

Although the experiments described here did not involve air storage for comparison, we know from our other studies that acidity and SSC levels are maintained higher in CA- than air-stored fruit. Also, SmartFresh treatment of air-stored fruit can be as effective as CA storage in maintaining these attributes for at least several months.

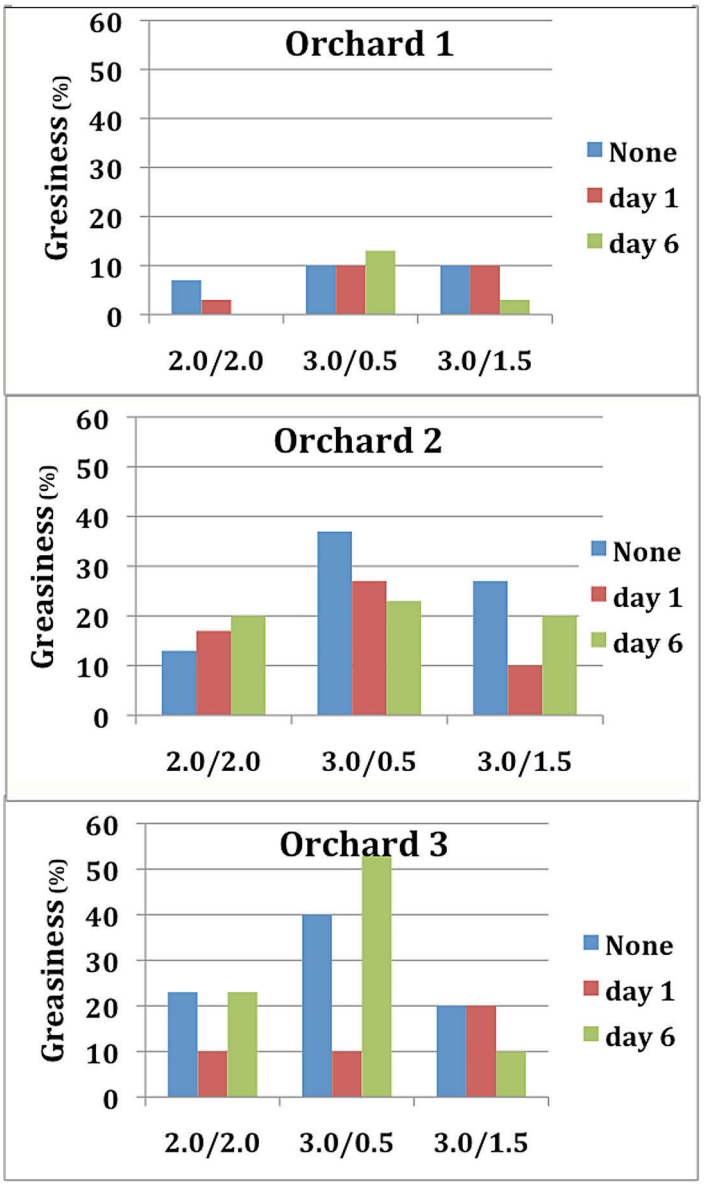

Figure 8. Greasiness of 'Honeycrisp' apples from three Western New York orchards (2010 harvest) untreated or treated with SmartFresh on day 1 or day 6 of the conditioning period. Fruit were stored in 2.0%/2.0%, 3.0%/0.5%, or 3.0%/1.5% oxygen/carbon dioxide for 6 months followed by 4 days at 68°F.

Internal carbon dioxide injury remains the limiting factor in CA storage of 'Honeycrisp' apples. Although there was a wide range of fruit susceptibility to injury, no factors that enable prediction of risk to injury have been identified. We are currently working on testing conditioning and delay treatments that may eliminate risk of injury, but until this goal is reached we cannot make firm recommendations for the New York industry.

CA storage reduced development of greasiness of the fruit, but the higher carbon dioxide concentrations that decreased incidence the most, increased development of internal carbon dioxide injury.

Fruit used in these experiments were picked according to commercial color standards, but the quality of the fruit was variable. To some extent, we believe that this reflects differences in crop load, mineral nutrient content and irrigation levels. Previous work has shown that crop load is a dominant factor in determining eating quality, fruit color, and soluble solids (Robinson and

Watkins, 2003). When crop load is too high, good fruit quality and color do not develop. In addition fruit mineral content and irrigation have a significant connection to fruit quality and storage disorders (Robinson and Lopez, 2009). When nitrogen level is high there are more storage disorders while when potassium level is high there are fewer disorders. Dry early and mid-seasons can increase the level of bitter pit presumably due to reduced calcium uptake by the plant in dry soils. It is likely that the development of CA storage recommendations will need to take into account crop load, fruit mineral content and irrigation.

Acknowledgements

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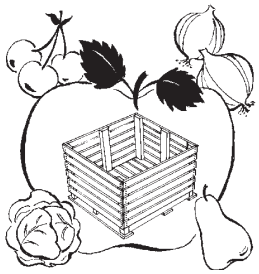

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