Internal Browning in Empire Apples in Relation to Harvest Date

Hannah James, Jacqueline F. Nock and Chris B. Watkins
Department of Horticulture
Cornell University, thaca, NY

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Firm flesh browning (Figure 1) has been a major limitation to controlled atmosphere (CA) storage of Empire apples for many years. Development of browning in this variety has proven especially difficult for the industry because the timing of its onset and its severity can vary greatly from year to year. Therefore an uncertain risk is faced by the industry on an annual basis, which makes marketing planning problematic. Typically, browning problems are greater in years where temperatures in July and August are cooler than normal.

> **"Flesh browning in some apple varieties continues to be a major concern for the New York Industry. Our recent research has shown the importance of harvest date as a major factor in susceptibility of Empire apples to browning. The take home message is that the risk of browning increases greatly with advancing harvest date."**

The browning has been assumed to be a result of chilling injury. Therefore, the recommendation to New York storage operators has been to store fruit at 35-36ºF, especially in longer term CA storage in order to avoid browning development. Higher temperatures such as 38ºF have been discouraged because fruit softening is greater and fruit can develop senescent breakdown (a dry type of browning with little free juice). In addition, past research has shown that the carbon dioxide level during CA storage can have a major effect on the firm flesh browning of Empire apples, with greater incidence as the carbon dioxide level is increased (Figure 2A). At the same time, however, the presence of carbon dioxide is important in order to maintain flesh firmness (Figure 2B), so the recommendation for standard CA storage has been to use 1-2% carbon dioxide. The recommended oxygen level is 2%, although storage operators have used both lower and higher levels successfully, depending on whether the storage atmospheres are maintained manually or monitored by computer.

In addition to development of flesh browning, core browning can occur in both air and CA storage, but tends to be more of a problem for air-stored fruit. Both disorders affect not only the fresh apple industry, but the utility of the Empire apple for fresh cut slice production as well.

As part of an extensive series of trials funded by the NY Farm Viability Institute and the NY State ARDP to develop methods to reduce losses of fruit caused by internal browning—especially flesh browning—we have investigated the effects of harvest date on fruit stored in air, and in CA storage in different carbon dioxide levels over two years. In each year, fruit were harvested from trees that were untreated or from trees treated with ReTain or Harvista (a pre-harvest formulation of 1-methylcyclopropene – 1-MCP) at the Lansing Orchard at Cornell University. The ReTain and Harvista treatments were applied two weeks and one week, respectively, prior to first harvest each year, to three (2007) and four (2008) replicate sets of trees. Fruit were harvested and harvest indices measured (Table 1) at three week intervals in 2007 and four week intervals in 2008.

The fruit were cooled overnight and either untreated or treated with 1ppm SmartFresh (1-MCP) for 24 hours. Fruit were then stored in air at 33°F, or CA storage with 2% oxygen at 35°F. In 2007, the carbon dioxide levels in CA storage were maintained at 1, 2 or 3%, while in 2008, the carbon dioxide levels were maintained at 0.5 or 2%. Air stored fruit were assessed at 2, 4 and 6 months in 2007 and only at six months in 2008. CA stored fruit were assessed at 7 and 9.5 months in 2007, and at 10 months in 2008. Firmness and other quality attributes were assessed 1 and 7 days after removal of fruit to 68°F. Disorder incidence was

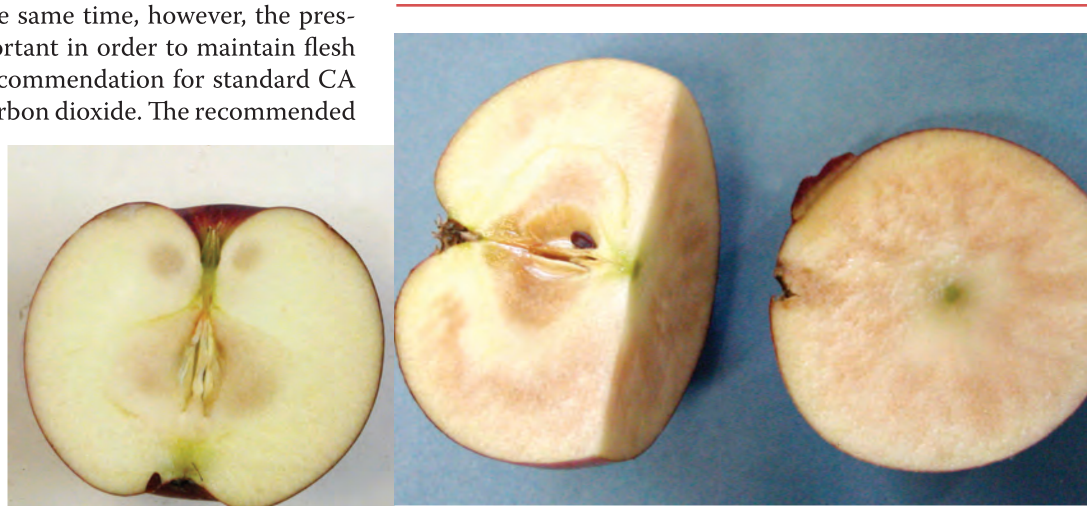

Figure 1. Firm flesh browning in Empire apples. The left picture shows the browning type that is restricted to the stem end shoulder region of the fruit. The right picture shows severe flesh browning.

Table 1. Internal ethylene concentration (IEC), starch index, flesh firmness and soluble solids concentration (SSC) of Empire apples untreated or treated with ReTain or Harvista (2 weeks and 1 week, respectively) prior to the first harvest in 2007 and 2008.

Harvest	IEC (ppm)			Starch index			Firmness (lb-f)			SSC (%)		
date	Untreated	ReTain	Harvista	Untreated	ReTain	Harvista	Untreated	ReTain	Harvista	Untreated	ReTain	Harvista
2007												
Oct 2	2.3	0.8	0.3	3.9	3.4	3.6	16.0	16.6	16.2	13.5	13.1	12.8
Oct 9	8.4	1.1	0.3	4.7	4.3	4.6	16.1	16.6	16.2	13.5	13.6	13.6
Oct 16	4.6	0.4	0.4	5.3	4.7	4.9	14.7	15.2	14.9	13.7	13.2	13.0
2008												
Sept 17	0.4	0.4	0.5	4.3	3.8	4.0	15.8	15.9	16.0	11.7	11.6	11.8
Sept 24	0.7	0.7	0.6	5.1	4.8	4.1	15.0	15.5	15.3	11.8	11.9	11.8
Oct 1	1.5	0.5	0.5	5.8	5.2	5.0	14.9	15.0	15.0	12.1	12.1	12.0
Oct 8	0.9	0.8	0.8	6.2	5.8	6.0	14.8	15.3	15.3	12.4	12.3	12.1

assessed on day seven. Only internal browning disorders are reported here.

Harvest Indices

Fruit were harvested on Oct 2, Oct 9 and Oct 16 in 2007 (Table 1). The internal ethylene concentrations (IEC) were affected only by treatment, averaging 0.7ppm and 0.3 ppm in the ReTain and Harvista treatments, respectively compared to 5.1ppm in the untreated fruit. Starch rating increased with advancing harvest date from an average of 3.6 units on Oct 2 to 5.0 on Oct 16, and overall, was lower in ReTain (average 4.1 units) and Harvista (average 4.4 units) than untreated fruit (4.6 units). Fruit softened from an average of 16.3 lb-f on Oct 2 to 14.9 lb-f on Oct 16. The treatments were not significantly different. The soluble solids concentrations (SSC) were not statistically affected by harvest date or treatment, but averaged 13.6, 13.3 and 13.1% for untreated, ReTain and Harvista treated fruit, respectively.

In 2008, there was no effect of harvest date or treatment on the IEC (Table 1). The starch index increased with advancing harvest date from 4.0 units on Sept 17 to 6.0 units on Oct 8. The starch index was affected by treatment, being lower in ReTain (4.9 units) and Harvista (4.8 units) than in the untreated fruit (5.3 units). Fruit softened over time, but averaged 15.1, 15.4 and 15.4 lb-f in untreated, ReTain and Harvista treatments, respectively. The SSC increased with advancing harvest date, but there was no effect of treatment. The percentage blush averaged 84, 90, 94 and 95% for fruit harvested on Sept 17, Sept 24, Oct 1 and Oct 8, respectively, but no effect of treatment was detected (data not shown).

Internal Browning After Storage

2007: In 2007 fruit were stored in 1, 2 and 3% carbon dioxide (Figure 3). After 7 months of storage, the effect of carbon dioxide level on flesh browning was significant but relatively small

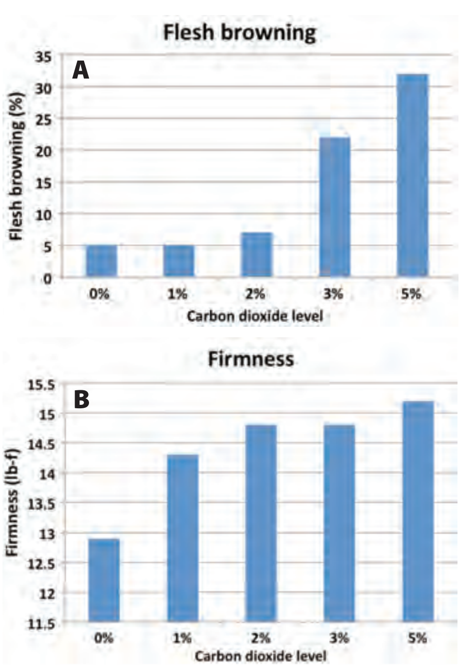

Figure 2. The effect of carbon dioxide in the storage atmosphere on flesh browning (A) and flesh firmness (B) of Empire apples. Fruit were stored in controlled atmosphere storage with a range of carbon dioxide levels (in 2% oxygen) for 8 months plus 7 days at 68°F.

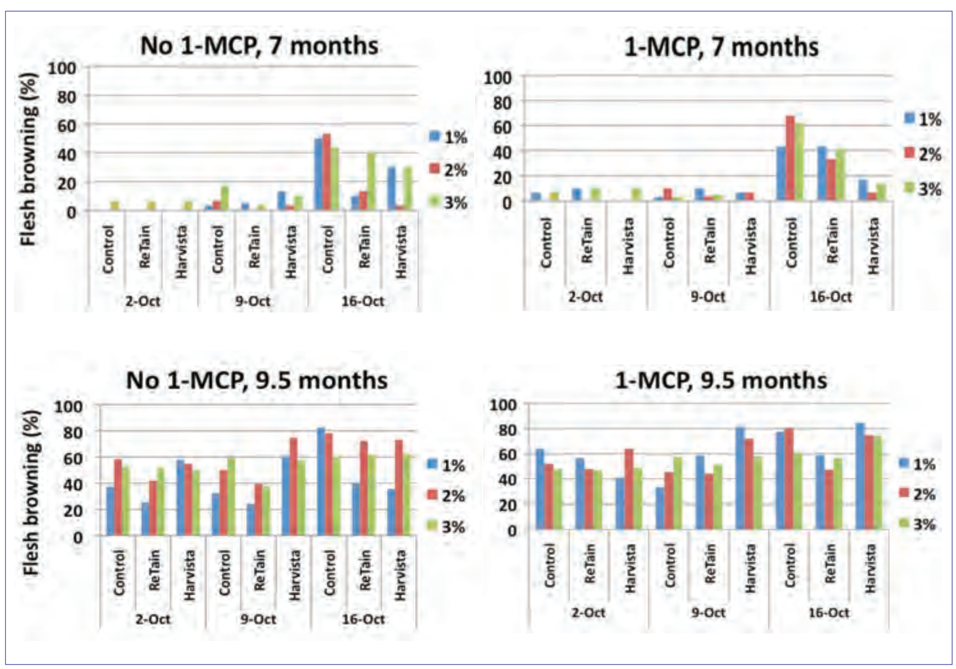

Figure 3. Flesh browning in Empire apples harvested from untreated, ReTain and Harvista treated trees at three weekly intervals, either untreated or treated with SmartFresh (1-MCP), and stored in 1, 2 or 3% carbon dioxide (in 2% oxygen) at 35°F for 7 or 9.5 months (2007).

overall, averaging 14, 12 and 17% for 1, 2 and 3% carbon dioxide respectively. Flesh browning occurred at low levels and inconsistently in fruit from the first two harvests, averaging 4 and 6% for fruit harvested on Oct 2 and Oct 9, respectively, but for fruit harvested on Oct 16, the incidence increased to an average of 53% in fruit from untreated trees compared with 30 and 17% in ReTain and Harvista treatments. SmartFresh treatment increased flesh browning incidence in the ReTain treated fruit, but not in the untreated or Harvista treated fruit.

Flesh browning incidence was markedly higher across all harvest dates after 9.5 months of CA storage, but overall was higher with advancing harvest date; 50, 52 and 66% in fruit harvested on Oct 2, 9 and 16, respectively. SmartFresh increased flesh browning in fruit stored in 1% (44% without SmartFresh and 62% with SmartFresh), but not 2% or 3% carbon dioxide.

In air storage, no significant disorders developed until 6 months. At that time, core browning incidence was greater in fruit harvested on Oct 16 than on Oct 2 in fruit from untreated and ReTain treated trees, but not in the Harvista treatment (Figure 4A). SmartFresh treatment further reduced core browning in fruit harvested on Oct 2 and 16, but not Oct 9.

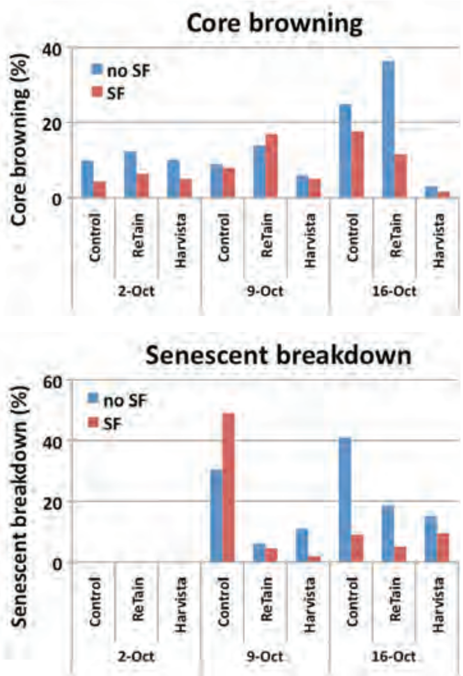

Figure 4. **Core browning and senescent breakdown in Empire apples (2007) harvested from untreated, ReTain and Harvista treated trees at weekly intervals. Fruit were then untreated or treated with SmartFresh (SF), and stored in air at 33ºF for 6 months plus 7 days at 68ºF.**

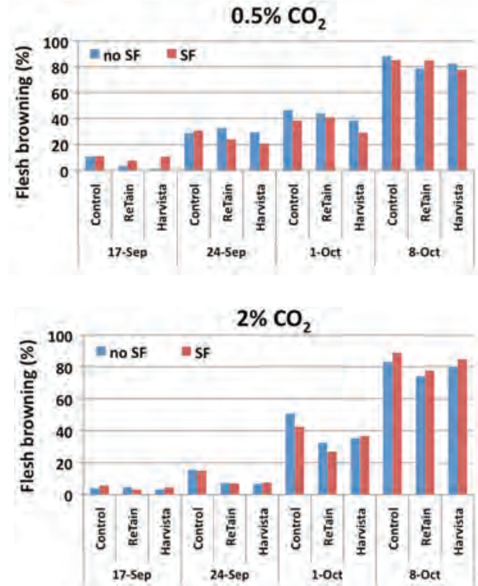

Figure 5. **Flesh browning in Empire apples (2008) harvested from untreated, ReTain and Harvista treated trees at weekly intervals, either untreated or treated with SmartFresh (SF), and stored in 0.5 or 2% carbon dioxide (in 2% oxygen) at 35ºF for 9.5 months plus 7 days at 68ºF.**

No senescent breakdown was detected in fruit harvested on Oct 2, but incidence of the disorder increased in fruit harvested on Oct 9 and 16, and to a greater extent in fruit from untreated than ReTain and Harvista treated trees (Figure 4B). SmartFresh treated fruit had lower senescent breakdown with the exception of the control treatment harvested on Oct 9.

2008: In 2008, we compared 0.5% and 2% carbon dioxide atmospheres for fruit from four harvests. The first harvest was about two weeks earlier than in 2007 (Table 1). Fruit were stored for 10 months and evaluated after seven days at 68°F. Again, there was a clear trend of increasing browning with advancing harvest date (Figure 5), with an average of 6%, 19%, 38% and 82% for fruit harvested on Sept 17, Sept 24, Oct 1 and Oct 8, respectively. Neither ReTain nor Harvista treatments before harvest affected browning incidence. There was slightly less browning in fruit stored in 2% carbon dioxide (33%) than 0.5% carbon dioxide (39%), but no other effects such as SmartFresh treatment or any interactions between factors were statistically significant.

Core browning incidence was less than 0.5% for the first three harvests, but increased to 32% for fruit harvested on October 8. Core browning in fruit harvested on that date averaged 45% and 19% in 0.5% and 2% carbon dioxide, while incidence averaged 25% with SmartFresh treatment compared with 38% without treatment (data not shown).

In contrast to CA-stored fruit, core-browning incidence in air storage during 2008 was much greater in earlier harvested than later harvested fruit (Figure 6). Core browning was affected greatly by both pre- and postharvest treatment with 1-MCP. Overall, the incidence was 61, 55 and 17% without SmartFresh treatment, and 3, 3 and 2% with SmartFresh treatment, for untreated, ReTain and Harvista treated fruit, respectively.

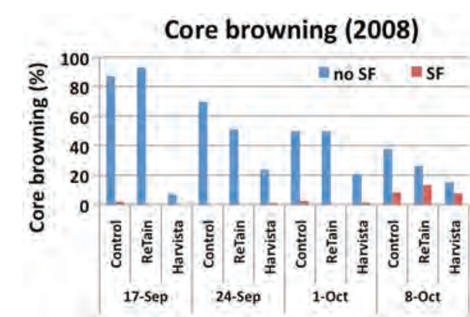

Figure 6. **Core browning in Empire apples (2008) harvested from untreated, ReTain and Harvista treated trees at weekly intervals. Fruit were then untreated or treated with SmartFresh (SF), and stored in air at 33ºF for 6 months plus 7 days at 68ºF.**

Conclusions

These experiments have tested the effects of harvest date, SmartFresh treatment, and storage in air and CA on internal browning of Empire apples. Maturity was influenced by use of ReTain, a pre-harvest treatment used extensively by the New York apple industry to manage harvest, and Harvista, a pre-harvest 1-MCP formulation that is likely to become available to the industry in the near future. Our primary focus is on firm flesh browning as development of this disorder during CA storage is a major limitation to extending the storage season for the variety. There was considerable variation in maturity between the two years, and while IEC of the fruit remained low even in untreated fruit in 2008, the starch indices and firmness indicated that fruit were more mature at comparable harvest times (early October) in 2008 than in 2007. Also, we started harvest in the first year later than optimal because we were focused on understanding the interactions between browning, SmartFresh and carbon dioxide levels in the storage atmosphere. In 2008, we started the experiment two weeks earlier than in 2007 in order to better understand the maturity effects. The fruit responses to storage in both air and CA were quite distinctive, but the results indicate that:

1. Harvest date has an overwhelming effect on susceptibility of fruit to firm flesh browning. Early harvest is a key to extending the storage potential of the Empire apple. The effect of harvest date was shown in both years, but most clearly in 2008 when two earlier harvest dates compared with 2007 were used.
2. The effects of ReTain and Harvista on the incidence of firm flesh browning are generally small, in comparison with the large effect of harvest date.
3. Carbon dioxide levels in the storage atmosphere affect the incidence of firm flesh browning. When levels of 1, 2 and 3% were compared in 2007, a carbon dioxide level of 1% tended to result in lower browning incidence for the longer CA storage period, but in the following year, 0.5% carbon dioxide resulted in higher browning incidence than 2% carbon dioxide in the earlier harvested fruit. We recommend that the carbon dioxide concentrations in the storage atmosphere are maintained between 1 and 2%. Note, however, that to avoid external carbon dioxide injury, it may be necessary to control carbon dioxide levels at 1% or less for the first 4-6 weeks if SmartFresh treated fruit are stored without prior diphenylamine (DPA) treatment.
4. The effects of SmartFresh treatment on the susceptibility of the fruit to firm flesh browning were inconsistent. No effects were detected in 2008, but SmartFresh increased the incidence in fruit of some treatments in 2007.
5. Both pre- and postharvest SmartFresh treatments markedly reduced core browning incidence.

In summary, the effect of harvest date is a major factor in the susceptibility of the Empire apple to firm flesh browning. Our data suggest that the risk of browning increases by 2-3 fold with each week of harvest. Several storage operators are testing the effects of earlier harvest dates on storage browning in Empire apples, but more work is required on a statewide basis, both pre- and postharvest to better manage harvest periods for the Empire variety.

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Hannah James is a postdoctoral associate who works with Chris Watkins on fruit browning, **Jacqueline Nock** is a research technician who works with Chris Watkins on post harvest storage of fruits and **Chris Watkins** is a professor and associate director of Cornell Cooperative Extension who leads Cornell's program in postharvest biology of fruit crops.