Early Harvest is a Critical Factor in Decreasing Flesh Browning Development of 'Empire' Apples

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The 'Empire' apple is the second most commonly grown variety in New York State behind 'McIntosh'. Its popularity among consumers is largely due to excellent fresh eating qualities of the fruit with an excellent sugar/acid balance and good texture. It is also an ideal variety for the fresh cut slice industry, and an increasing share of total production has been diverted to meet this market segment. However, Empire apples are susceptible to development of a physiological storage disorder, firm flesh browning (Figure 1), which affects demand for fresh fruit by consumers and slicers. With this disorder, the flesh of the fruit is firm and moist despite being brown, in contrast to the soft browning that we normally associate with senescent breakdown. The disorder occurs in controlled atmosphere (CA) stored fruit and may develop in some orchard lots as early as May of the year following the harvest.

> "Firm flesh browning of 'Empire' apples is a major concern for growers and storage operators. In this study, the economic impact of harvest date on revenue based on percentage pack-out (fruit size/weight and red coloration) and flesh browning incidence was investigated using a budgeting model."

Occurrence of firm flesh browning can cause serious economic losses to stakeholders in the New York apple industry. These losses occur not only directly because of loss of marketability, but also indirectly because fear of browning development causes orchardists, storage operators and marketers to restrict storage periods and therefore to market the fruit within a shorter time frame. Flesh browning has been especially problematic for the fresh cut industry since any internal browning, even if slight, is unacceptable. Minor flesh browning in whole fruit may not be detected by the consumer, but modern sorting lines with internal quality assessment can detect internal defects regardless of fruit use.

It has long been assumed that flesh browning is a chilling injury. Scientists at Cornell University have shown that storage temperatures of 35 to 36°F reflect a compromise between chilling injury at lower temperatures and faster softening at warmer temperatures. However, browning development sometimes increases after postharvest treatment of fruit with 1-MCP at the warmer temperatures, and appears similar in nature to the browning observed at lower temperatures. To date, no postharvest treatments or storage regimes have successfully controlled flesh browning (James et al. 2010a). However, it is generally recognized that browning occurs more frequently in later-harvested 'Empire' apples (James et al. 2010b).

Figure 1. Flesh browning in 'Empire' apples that develops during controlled atmosphere storage.

The objective of this experiment was to evaluate the effects of harvest date on flesh browning, and to do that we harvested a week earlier (September 21, 2012) than the "normal harvest date" (September 28) for the orchard block, plus one week later (October 5). Fruit quality of untreated and 1-MCP-treated fruit was assessed after storage in CA at 33 and 36°F for 9 months. The fruit were harvested from an orchard with a high density planting system, which allows most fruit to be well exposed and color is developed more evenly and uniformly. A full economic analysis was carried out to compare the effects of early harvest having lower quality, as judged by pack-outs based on fruit size and color, with later harvests with higher pack-outs, but potentially greater loss of fruit due to disorder development. This study has been published in full (Doerflinger et al. 2015) and only the main findings are presented here.

Material and Methods

'Empire' trees grown on M9 rootstocks, planted in 2007 in a 2 ft x 10 ft spacing high density planting (2150 trees per acre), commercial orchard in Wolcott, New York, were used for this experiment. 25 bins of fruit were harvested on September 21st (H1), 28th (H2), and October 5th (H3) in 2012. To provide fruit for three harvests, every third section demarcated by a fence post in each row was strip-picked by a commercial harvest crew. The total area harvested was one acre per harvest.

The harvested bins were labeled and stored in commercial cold storage at 32°F in Wolcott, NY, until they were sorted

on a commercial sorting line in November 2012. During the commercial harvest, 16 plastic half bushel containers of approximately 40 fruit each plus four replicates of 10 fruit for maturity analysis, were taken randomly from each treatment and transported to the postharvest laboratory at Ithaca for analysis and storage.

At harvest, internal ethylene concentration (IEC), firmness, titratable acidity (TA), soluble solids concentration (SSC), starch pattern index (SPI) and delta absorbance (I_{AD}) measurements were carried out on each replicate of ten fruit according to standard methods. After storage, fruit firmness, SSC, and TA were measured as before on four replicate sets of 10 fruits at 1 and 7 days after storage at 68°F. On day 7, all remaining fruit were assessed for external and internal disorders.

For storage, fruit were divided into treatment replicates consisting of four containers for each ±1-MCP treatment (SmartFresh™) and storage temperature. Fruit were then cooled overnight at either 33 or 36°F. Half the fruit at each temperature were treated with 1 ppm 1-MCP for 24 hours, and allowed to vent for another 24 hours. Containers with untreated and treated fruit were placed into experimental CA chambers fitted with a circulating fan system (Storage Control Systems, Sparta, MI) and stored at 2% O_2 and 2% CO_2.

For pack-out assessment, the fruit from the commercial cold storage were graded on a sorting line (GREEFA Geosort, Geldermalsen, Netherlands) that was equipped with iQS III for external defects and iFA for internal defects. Exact numbers of fruit in each grade were recorded separately for each of the three harvest dates, to evaluate changes in potential income due to changes in fruit size and color over the time of the experiment.

For the economic analysis, an enterprise budgeting model was developed that considers the revenue flows and costs of producing, storing, and marketing apples. The model employed a spreadsheet framework to quantify the revenue and cost implications for fruit harvested in three different time periods.

The model takes into account production costs for a fully established orchard, including costs for pest and weed management, hand and machine labor, and several more aspects of production per acre. Approximate costs were calculated based on costs per acre taken from a workbook developed by DeMarree et al. (2010) for a high density 'Gala' planting in New York State and adjusted for 'Empire' production with 2150 trees per acre.

Results

Harvest and storage quality. The IECs in fruit indicated that they were preclimacteric at the first harvest, but then concentrations increased each subsequent week (Table 1). Over the three harvest dates, fruit firmness and acidity decreased, and starch hydrolysis increased, as indicated by higher SPI values. Neither SSC, nor the I_{AD} values that indicate chlorophyll content, were affected by harvest date. Of the quality parameters that were measured, only flesh firmness is shown here (Table 2). Flesh firmness was affected by harvest date, reinforcing the well-known adage that fruit for long term storage should be harvested first. However, the third harvest date was only one week later than the "normal" harvest date, although yields in 2012 were lower than normal and this may have impacted optimal harvest timing. After 1 day of shelf life, firmness was higher in H1 and H2 harvested fruit compared with H3.

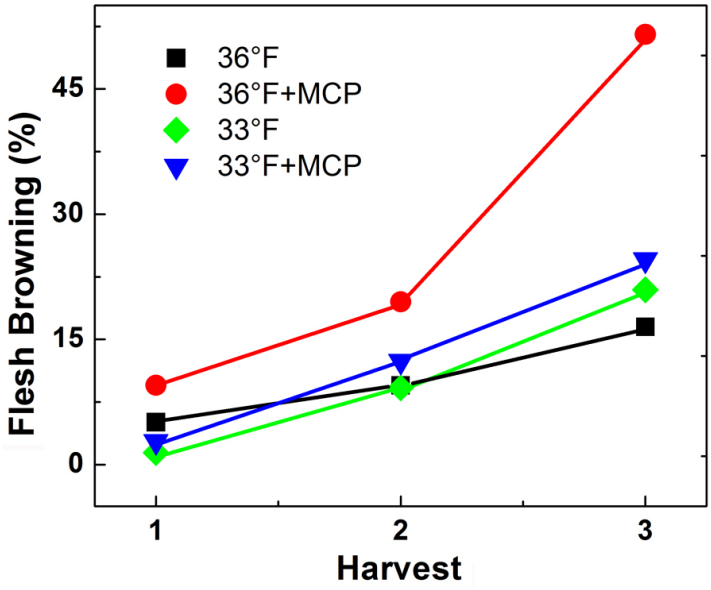

Figure 2. Flesh browning incidence of 'Empire' apples harvested on September 21 (H1), September 28 (H2) and October 5 (H3), treated with 1-MCP, and stored in controlled atmosphere storage for 9 months plus 7 days at 68°F.

Marketing to a fresh cut provider would not be possible for the non 1-MCP-treated fruit from H3 since the fresh cut industry requires a minimum firmness of 14 lb-f to guarantee good quality cut produce. After 1 day, even 1-MCP-treated fruit of H3 only barely reached the minimum required firmness after storage. Certain export markets also require minimum standards for fruit firmness, which would most likely not be reached by fruit harvested at H3.

Fruit firmness at H1 and H2 was greater at a storage temperature of 33°F than 36°F, and softening was minimal during the shelf life period, especially for fruit from H1, even without 1-MCP. In informal taste tests with growers, storage operators and field men, the eating quality of H1 fruit was highly ranked, with no difference detected between fruit untreated or treated with 1-MCP.

The most significant disorder found in these fruits was flesh browning, and an interaction of harvest date and 1-MCP was found (Figure 2). Browning increased with later harvests, and more so in fruit treated with 1-MCP. However, it is important to note that browning was low at H1, regardless of storage temperature and 1-MCP treatment.

Cost model and fruit pricing. The information shown in Table 3 provides much of the detail used in our budget model to calculate the profits associated with each of the three

Table 1. Internal ethylene concentration (IEC), flesh firmness, soluble solids concentration (SSC), titratable acidity (TA), starch pattern index (SPI) and delta absorbance (I_{AD}) of 'Empire' apples at three harvests.

Harvest date (2012)	IEC (ppm)	Firmness (lb-f)	SSC (%)	TA (%)	SPI (1-8)	I_{AD}
Sept 21 (H1)	0.33	17.3	13.6	0.50	3.4	1.22
Sept 28 (H2)	1.28	16.7	14.2	0.42	3.7	1.22
Oct 5 (H3)	18.83	16.1	14.2	0.43	4.7	0.95
***P*-values**	**0.0103**	**0.0032**	**ns**	**0.0033**	**0.0006**	**ns**

harvest dates. The production costs are based on those used in the analysis by DeMarree et al. (2010) for high density 'Gala' production; the costs for marketing and storage follow those used by the Ag Profit budget template 1022 (Oregon State University) and Gallardo and Galinato (2012). In our model, the costs per acre are specific to the number of trees per acre and for 'Empire' apples. However, the model can be generalized and extended to consider the costs for alternative orchard systems and for different varieties.

To calculate revenue, we calculated average prices for each grade and size using 10 recent years of 'Empire' market prices. Because of the low yields in 2012, we assumed that fruit prices were 150% of the average 10-year values that we calculated (Table 4). By comparing the 10 year average price data to the available 2012 'Empire' market price data, we see the 2012 prices were between 135 and 175% higher. Data suggest that this is a conservative assumption for the 2012 prices, but was performed to prevent overestimation of revenue in 2012. Furthermore, this assumption was made in the analysis for all three harvest dates, and adjustments in this assumption do not change the general pattern of our results. The calculations are carried out based on 25 harvested bins per acre to account for the 50% lower yield in 2012. A planting of 2150 trees per acre of 'Empire' averages approximately 50 bins in "normal" years. The costs for one acre are $4,325 without application of storage or 1-MCP. Including costs for storage materials increases the total costs to $4,770 and $4,533 with and without 1-MCP, respectively (Table 3).

Changes in Apple Size and Grade Distribution. Prices for various fruit grades per box were based on the average price between 2002 and 2011, and the average price was then used to estimate the market prices in 2012 (based on a 50% premium on the 10-year average price). In our analysis, we assume two sets of prices for fruit that comes out of storage. In the first case, we assume that prices are constant throughout the year using the prices shown in Table 4 (that is, prices are the same for fruit sold in the fall or for fruit that had been stored and sold in spring). In the second case, we consider the effects when the prices for fruit that come out of storage are 10% higher than fruit sold in the fall (see Table 5).

Fruit size and color changes over the time of the experiment are shown by the distribution of marketable Extra Fancy and Fancy fruit (Table 4). At the third harvest (H3), almost 80% of the fruit from the air-stored field bins were Extra Fancy, compared

Table 2. Flesh firmness of 'Empire' apples with and without 1-MCP treatment at harvest and stored in CA conditions for 9 months. Fruits were measured after 1 and 7 days at 68°F.

Harvest date (2012)	Treatment	Firmness (lb-f)* 1 d	7d
Sept 21 (H1)	36°F	16.5 a	15.7 ab
	36°F + 1-MCP	16.6 a	16.0 ab
	33°F	17.1 a	16.8 a
	33°F + 1-MCP	16.9 a	16.8 a
Sept 28 (H2)	36°F	15.4 ab	15.6 ab
	36°F + 1-MCP	15.6 ab	16.7 a
	33°F	16.1 ab	15.3 ab
	33°F + 1-MCP	16.2 a	16.7 a
Oct 5 (H3)	36°F	11.4 c	9.8 c
	36°F + 1-MCP	14.3 b	13.9 b
	33°F	11.4 c	11.6 c
	33°F + 1-MCP	14.3 b	14.7 ab

*means with differences in letters are significantly different at P = 0.05 within each evaluation day.

Table 3. Estimated costs for management, production, harvest, storage, and marketing of 28 tons production for a one-acre orchard block with approximately 2150 trees (costs for 1-MCP treatment are not considered in base costs).

Name	$/unit	Units/acre	$/acre
Labor (bin)	36.49	25	912.00
Seasonal quality control (hour)	11.47	5	57.00
FT* truck/tractor driver (hour)	17.54	5	88.00
FT tractor driver (hour)	14.37	5	72.00
PT* truck/tractor Driver (hour)	12.71	5	64.00
Interest on operating capital (acre)	724.46		724.00
Disease control (Fungi, Insect/mite, Herbicides) (acre)	263.00		263
Chemical thinners (acre)	185.00		185
Fruit thinning/return bloom (acre)	90.00		90
Fertilizer (acre)	113.00		113
Total overhead expense (acre)	600.00		600
Average equipment investment replacement-1 year-1 (acre)	220.00		220
Operators' management only (acre)	372.00		372
Total annual equipment expense (acre)	280.00		280
Marketing, & packaging (bin)	285.00		285
Sorting & Storing Bins (Ap) (bin)	208.00		208
1-MCP (SmartFresh) (bin)	9.50	25	237.50
Costs per acre for fresh marketed fruit:			4,325
Costs per acre for fruit marketed after 9 months CA-storage:			4,533
With 1-MCP treatment			4,770

* FT, Full time; PT, Part time

Table 4. Unit prices per box (40 lb) for an average year and 2012, a low cropping year, and pack-out for fruit (25 bins) at harvest.

# fruit per box (unit)	Avg fruit wt (g)	$ per unit (10-yr avg)	$ per unit (2012)	Pack-out Sept 21 (H1) (# of fruit)	Pack-out Sept 28 (H2) (# of fruit)	Pack-out Oct 5 (H3) (# of fruit)
Extra Fancy						
163	116	13.02	19.39	5,529	5,569	4,244
150	128	14.13	21.05	7,186	7,664	6,704
138	136	13.37	19.93	7,676	8,837	8,650
125	153	13.64	20.32	7,697	9,378	10,551
113	167	18.00	26.82	6,080	8,031	9,688
100	190	17.38	25.90	3,301	4,628	5,939
88	215	18.08	26.94	1,103	1,651	2,255
80	238	18.68	27.84	304	473	773
72	264	18.87	28.12	84	107	182
64	298	20.86	31.08	8	18	22
bag 2½ lb	126	14.12	21.05	2,823	2,525	1,437
bag 2¾ lb	114	12.48	18.59	3,091	2,821	1,935
% total fruit				**62.6**	**73.1**	**79.8**
Fancy						
138	136	8.55	12.74	2,966	1,884	1,118
125	153	8.30	12.37	3,113	1,923	1,288
113	167	6.43	9.58	2,102	1,379	1,071
100	190	7.96	11.86	984	749	575
88	215	6.57	9.78	361	225	167
80	238	7.54	11.23	35	52	47
bag 2½ lb	126	10.60	15.79	4,997	3,008	1,388
% total fruit				**20.3**	**13.0**	**8.6**
Commercial/Juice						
1000		4.00	5.96	12,280	9,815	7,574
% total fruit				**17.1**	**13.9**	**11.5**
Total number of fruit				**71,720**	**70,737**	**65,608**

Table 5. Revenue due to harvest date and marketing strategy; marketing strategies at harvest or after nine months in CA storage based on percentage loss due to flesh browning for fruit storage at 33 or 36°F with and without 1-MCP treatment; for losses due to storage disorders, it was assumed that all grades and counts would be affected evenly. A 10% price premium is assumed for fruit marketed in June.

	Revenue per acre ($)		
Fruit marketed	**Sept 21 (H1)**	**Sept 28 (H2)**	**Oct 5 (H3)**
At harvest	**4,223**	**5,195**	**5,526**
After 9 month in storage (June)			
36°F	3,289	3,823	2,104
36°F + 1-MCP	2,509	2,759	-1,127
33°F	3,910	3,959	1,892
33°F + 1-MCP	3,148	3,167	1,342
Assuming 10% price increase in June			
36°F	4,107	4,694	2,800
36°F + 1-MCP	3,271	3,545	-737
33°F	4,792	4,844	2,566
33°F + 1-MCP	3,976	3,996	1,984

with 63% and 73% for H1 and H2, respectively. The time a fruit grows on the tree will influence fruit size and coloration of the fruit and, therefore, will influence the pack-out for a given crop. Based on pack-out data at harvest, or shortly thereafter, increases in size and color (or fruit in the category of Extra Fancy) are desirable. However, there is a potential economic tradeoff from delaying harvest. Delaying harvest to obtain larger fruit may increase the likelihood that the stored fruit will develop physiological disorders, and this has the capacity to decrease the overall value of the crop.

The increase of fruit in the Extra Fancy category, with a bigger diameter and lower fruit count per box, is greatest at the last harvest date (Table 4). Smaller fruits as well as fruit of good size, with slight defects/imperfections of shape or coloration, typically are packed in pre-packed bags of 2.5 lb. The amount of fruit sorted into this category was much higher in H1 and decreased over the next two harvests. Fruit with less coloring may qualify as Extra Fancy, but market demand for less colored fruit (that only marginally reach a minimum color standard) is lower and often leads to this fruit being marketed in the pre-packed bags.

Economic Effects of Harvest Dates and Storage Methods. The net economic effects of delayed harvest for a one acre high density 'Empire' orchard block are shown in Table 5. If fruit are marketed directly in the fall or after a relatively short period of time in storage (air or CA), there are net benefits associated with later harvest dates. More specifically, our results show an increase of more than $1,000 per acre for fruit from H3 compared with that from H1, due to the higher amount of larger fruit in the Extra Fancy category. This assumption is based on calculations assuming every fruit could be sold in its category for the assumed prices shown in Table 4. For example, an individual fruit sorted into an Extra Fancy 100-count box would be sold for $0.259 per fruit given a box price of $25.90 and 100 fruit per box. The results also show that there would be a net loss from marketing late harvested fruit after long term storage (Table 5). Even when we assume higher prices for fruit stored long term, we still see a significant net loss in H3. In addition, if a substantial share of the H3 fruit exhibit poor quality with suboptimal flavor, it can lead to consumer disappointment that can last for a long time. The income increase from H1 to H2 is relatively small after storage, in part because flesh browning incidences are much lower for fruit harvested early and stored at the lower temperature.

Decreased revenue for 1-MCP-treated fruit compared with untreated fruit is the result of two factors. First, there is a slightly higher percentage of flesh browning and other disorders in the 1-MCP-treated fruit, and second, there are slightly higher costs (an increase of approximately $240 per acre) associated with 1-MCP treatment. However, the treated fruit that were not affected by the disorders exhibited more marketable levels of acidity and firmness, and therefore were of higher quality and will likely have received higher prices in the market. Although we did not model the effects of this higher quality fruit with higher prices, we expect that this consideration may generate additional revenue that may equal or exceed the increased cost of approximately $240 per acre associated with treating the fruit. Additional research that provides specific measures of fruit quality is needed to better understand the relationship between 1-MCP treatments and grower profitability for selected harvest dates across different varieties.

Summary

This study reveals that a primary tool to manage flesh browning of 'Empire' apples is harvest date. Harvesting fruit a week before the "normal optimum" (H1) resulted in low disorder incidence and high fruit quality including firmness (Table 2) and SSC and TA (data not shown). At this early harvest, there was a small effect of 1-MCP on enhancing browning at 36°F, but not 33°F (Figure 2). By H3, the effect of 1-MCP on increasing flesh browning of fruit stored at 36°F was very noticeable. Perhaps more significantly, the incidence of flesh browning in fruit stored at 33°F increased with advancing harvest date, but was little affected by 1-MCP treatment. This is the first time that an interaction between harvest date and storage temperature has been identified.

There is an economic tradeoff between harvest date and profitability for 'Empire' apples. There are net benefits associated with later harvest dates for fruit that is marketed earlier in the season. However, these benefits disappear for fruit that is stored long-term because of greater risk of flesh browning development. The revenue earned for more saleable fruit with less size and less color outweighs the benefits of greater size and more color with a higher incidence of flesh browning. Overall, harvesting the fruit as early as one week prior to the conventionally accepted harvest date sacrifices skin color and fruit size, but can yield higher profits for industry stakeholders if fruit are stored for extended periods (nine months) in CA storage.

Thought be given to modifying current storage recommendations. Perhaps the fear of chilling injury for fruit stored at 33°F is overstated, especially if fruit are treated with 1-MCP. The degree of this concern varies from orchard block to orchard block, with fruit from some blocks developing injury at low storage temperatures. These results do help explain the variations in flesh browning incidence in response to 1-MCP; clearly enhanced browning can result from later harvest dates. Our subsequent trials that have attempted to replicate the results described here, and expanded to include Harvista and ReTain treatments,

have not shown such strong harvest date effects. It is possible that we have not selected an early enough harvest date because the size and color are not adequate for high enough pack-outs.

Our tentative recommendation is to harvest as soon as possible for long term storage, even at the risk of sacrificing fruit size and color. Should low storage temperatures of 33°F be tried? Yes, but only with a strict monitoring system that allows the storage operator to detect any signs of browning development during storage.

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