Maturity and Storage Quality of 'Honeycrisp' Apples

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SUMMARY. 'Honeycrisp' apples (*Malus × domestica*) were harvested over 3-week periods in 2001 and 2002. Maturity and quality indices were determined at harvest. Fruit quality was evaluated after air storage [0.0 to 2.2 °C (32 to 36 °F), 95% relative humidity] for 10–13 weeks and 15–18 weeks for the 2001 and 2002 harvests, respectively. Internal ethylene concentrations (IEC), starch indices (1–8 scale), firmness and soluble solids content (SSC) did not show consistent patterns of change over time. Starch hydrolysis was advanced on all harvest dates, but it is suggested that a starch index of 7 is a useful guide for timing harvest of fruit in western New York. After storage, firmness closely followed that observed immediately after harvest, and softening during storage was slow. No change in SSC was observed during storage in either year. Incidence of bitter pit and soft scald was generally low and was not affected consistently by harvest date. The incidence of stem punctures averaged 18.5% over both years, but was not affected by harvest date. Development of stem end cracking in both years, and rot development in one year, increased with later harvest dates. A panel of storage operators, packers, growers, and fruit extension specialists evaluated the samples for appearance and eating quality after storage, and results suggested that a 2-week harvest window is optimal

for 'Honeycrisp' apples that are spot picked to select the most mature fruit at each harvest.

'Honeycrisp' is a new apple cultivar that has been widely planted by growers in New York in recent years. The cultivar has outstanding flavor and texture characteristics at harvest and during air storage (Luby and Bedford, 1992; Tong et al., 1999) and growers have been paid two to three times more per box for 'Honeycrisp' than for any other cultivar. However, industry confidence in 'Honeycrisp' has been negatively affected by susceptibility of the cultivar to bitter pit and by sporadic development of off-flavors, soft scald, and soggy breakdown during storage of the fruit (Greene and Weis, 2001; Rosenberger et al., 2001). In addition, fruit pack-out percentages have been reduced due to susceptibility of the fruit to stem punctures, cuts, and stem-end splitting, which occur at various stages of the handling process. For the most part, the physiological disorders appear to be manageable. Bitter pit is a calcium-related disorder (Ferguson and Watkins, 1989) and can be controlled by a preharvest calcium spray program (Rosenberger et al., 2004). Off-flavor development and occurrences of soggy breakdown and soft scald are associated with later harvest dates and storage of fruit close to 0 °C (Tong et al., 2003; Watkins et al., 2004a). In contrast, little is known about harvest and storage factors that affect susceptibility of 'Honeycrisp' to stem punctures, cuts, and stem-end splitting.

Information about the proper harvest timing, maturity, and quality indices of 'Honeycrisp' is not available. In a separate study, the relationships among these indices and development of soft scald at different storage temperatures have been investigated (Watkins et al., 2004a). The objective of the current study was to relate a number of maturity and quality indices to acceptable harvest periods for fruit grown in western New York.

Materials and methods

Four blocks of 'Honeycrisp' growing in the western New York area were chosen for the study. Tree ages ranged from 4 to 9 years, and the same orchards were used in both years of the trial. Five trees in each

orchard block were designated for this experiment and were not harvested by the growers. Between 50 to 55 fruit without external blemish, such as bitter pit, were harvested from each block of trees every 3 to 4 d over a 3-week period in 2001 and 2002. Except for the first harvest date each year when fruit were poorly colored, only fruit with commercially acceptable red color (>50%) were harvested on each occasion. The first harvest was on 4 Sept. in 2001, but 10 Sept. in 2002, due to a later season.

Ten fruit were used to assess IEC, starch pattern indices, firmness, and SSC on the day of harvest. The IEC was determined by withdrawing a 1-mL gas sample from the core of each apple fruit. The sample was injected into a gas chromatograph (Shimadzu CG-8A, Shimadzu Corp., Kyoto, Japan) equipped with a stainless steel column packed with 60/80 mesh alumina F-1 (2 m × 4 mm i.d.), and a flame ionization detector. The starch index was rated according to the Cornell Starch Chart (Blanpied and Silsby, 1992), where 1 = 100% staining and 8 = 0% staining. Firmness was measured on opposite pared sides of each fruit using an EPT-1 pressure tester (Lake City Tech. Products, Lake City, B.C., Canada) fitted with a 11.1-mm-diameter probe, and the expressed juice was used for SSC measurement with a refractometer (Atago PR-100, Atago Co., Tokyo).

The remaining fruit were placed in air storage (95% relative humidity) at a commercial facility. The storage temperature was maintained at 2.2 °C during the first month in storage, then decreased over a 2-week period to reach 0.0 to 1.1 °C (32 to 34 °F). Fruit were removed from storage on 2 Dec. 2001, and 6 Jan. 2003, representing storage periods of 10–13 weeks and 15–18 weeks for the 2001 and 2002 harvests, respectively. After fruit were removed from storage, they were held at 21.1 °C (70 °F) for 3 d and 10 fruit were assessed for firmness and SSC as described above. Relative humidity was not measured during this time. The incidence of disorders and defects, including bitter pit, soft scald, decay, stem punctures, stem-end splitting, and decay, was then determined on the remaining fruit.

To obtain estimates of acceptable and best harvest dates for poststorage fruit quality, fruit were rated for ap-

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pearance and eating quality by panels comprised of 16 (2001 harvest) or 18 (2002 harvest) storage operators, packers, growers, and extension fruit specialists.

The panelists judged each harvest date sample within each orchard block as acceptable or not acceptable, and then ranked the top three samples for each individual orchard block. Any fruit with the above visible disorders or blemishes were excluded. A harvest date was deemed acceptable if 70% or more of the panelists judged the sample as "acceptable." Best harvest dates were based on those dates that were rated most consistently among fruit from a given orchard block.

All analyses were carried out with harvest date as the main effect and orchards as replicates. Data were subjected to analysis of variance (Minitab

software v. 11.12; Minitab, State College, Pa.). Linear, quadratic, and cubic contrasts were used to determine the significance of trend responses of maturity and quality factors to harvest date.

Results and discussion

HARVEST MATURITY AND QUALITY. At the first harvest date in both years, IEC of fruit were at levels that are normally considered to be climacteric, but IEC did not increase in an autocatalytic pattern over time (Table 1). These IEC patterns are generally consistent with those found in other studies of 'Honeycrisp' (Tong et al., 2003; Watkins et al., 2004a), suggesting that the cultivar has unique ethylene physiology characteristics. Flesh firmness decreased by 10.68 N (2.4 lbf) from 4 to 25 Sept. in 2001, and 8.01

N (1.8 lbf) from 10 Sept. to 1 Oct. in 2002 (Table 1). SSC increased over time in 2001, but not in 2002. The starch indices already averaged 5.7–5.9 units at the first harvest dates, approximately equivalent to 60% of starch clearing from the equatorial region of the fruit (Blanpied and Silsby, 1992).

STORAGE QUALITY. Storage periods were 10–13 weeks and 15–18 weeks for fruit from the 2001 and 2002 harvests, respectively. Fruit were softer with advancing harvest date (Table 2), paralleling the pattern of firmness readings taken in the fall with each sequential harvest (Table 1). However, the loss of firmness during storage averaged only 0.89 N (0.2 lbf) in 2001 and 3.11 N (0.7 lbf) in 2002. The slow rate of softening during storage of 'Honeycrisp' is a feature of the cultivar (Tong et al., 1999). The

Table 1. Maturity and quality factors of 'Honeycrisp' apple fruit harvested from four western New York orchard blocks in 2001 and 2002, measured on the day of harvest.

Harvest date (2001)	Ethylene ^z (μL·L ⁻¹)	Firmness ^y (N)	SSC ^x (%)	Starch index ^w (1–8)	Harvest date (2002)	Ethylene ^z (μL·L ⁻¹)	Firmness ^y (N)	SSC ^x (%)	Starch index (1–8)
4 Sept.	12	71.2	12.9	5.7	10 Sept.	20	71.3	13.3	5.9
8 Sept.	17	69.0	13.4	6.2	14 Sept.	31	69.3	13.3	6.2
12 Sept.	27	65.9	13.1	7.2	17 Sept.	35	65.9	13.2	7.3
15 Sept.	21	64.7	13.3	7.6	21 Sept.	59	64.1	13.5	7.8
20 Sept.	17	63.4	13.6	7.8	24 Sept.	34	63.5	13.5	7.8
25 Sept.	17	60.6	14.3	8.0	28 Sept.	12	60.3	13.4	8.0
					1 Oct.	29	63.5	13.3	8.0
Harvest date	Q*	L***	L*	L***, Q**	Harvest date	Q*	L***, Q*	NS	L***, Q*

^z1 μL·L⁻¹ = 1 ppm.

^y1.0 N = 0.225 lbf.

^xSSC = soluble solids concentration.

^wCornell starch chart: 1 = no starch hydrolysis; 8 = 100% starch hydrolysis.

NS, *, ***, ****Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively; L, Q = linear or quadratic, respectively.

Table 2. Quality factors of 'Honeycrisp' apple fruit harvested from four western New York orchard blocks in 2001 and 2002, and stored at 0.0 to 2.2 °C (32 to 36 °F), 95% relative humidity, until 2 Dec. and 6 Jan., in 2001 and 2003, respectively, plus 3 d at 21.1 °C (70 °F).

Harvest date 2001								Harvest date 2002							
Firmness ^z (N)	SSC ^y (%)	Bitter pit (%)	Soft scald (%)	Stem punctures (%)	Stem-end splitting (%)	Decay (%)		Firmness ^z (N)	SSC ^y (%)	Bitter pit (%)	Soft scald (%)	Stem punctures (%)	Stem-end splitting (%)	Decay (%)	
4 Sept.	70.7	13.2	6	0	15	1	0	10 Sept.	67.9	13.0	7	1	28	2	2
8 Sept.	69.8	13.5	3	0	8	0	0	14 Sept.	65.8	13.2	11	1	16	2	2
12 Sept.	65.7	13.5	2	0	15	1	1	17 Sept.	63.2	13.4	3	1	17	4	0
15 Sept.	63.4	13.5	5	3	20	2	1	21 Sept.	60.8	13.4	1	0	18	2	0
20 Sept.	61.1	13.7	7	4	24	8	2	24 Sept.	60.6	13.4	3	1	21	2	2
25 Sept.	59.6	14.0	3	2	19	16	5	28 Sept.	58.9	13.6	3	1	19	23	3
								1 Oct.	58.4	13.5	2	1	17	23	4
Harvest date	L*	NS	C*	L*	NS	L***, Q**	L**	Harvest date	L***	NS	L*	NS	NS	L***, Q**	NS

^z1.0 N = 0.225 lbf.

^ySSC = soluble solids concentration.

NS, *, ***, ****Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively; L, Q, C = linear, quadratic, and cubic, respectively.

reasons for the greater softening in fruit from the 2002 harvest compared with the 2001 harvest are not certain, but may be related to additional month of storage. SSC of fruit after storage were similar to those at harvest, and were not affected by harvest date (Table 2).

Bitter pit incidence was variable in 2001, but was higher in fruit from the first two harvest dates in 2002 (Table 2). Bitter pit incidence was related to orchard block, however, ranging from 2% to 28% depending on the orchard (data not shown). The wide variation in the occurrence of bitter pit between orchard blocks is quite common and typically depends on factors such as crop load, soil water status, soil fertility and calcium availability, and the use of foliar calcium sprays (Ferguson and Watkins, 1989). The incidence of bitter pit was greatly reduced in blocks where preharvest calcium sprays were used, as demonstrated by Rosenberger et al. (2004).

No soggy breakdown (internal browning in the absence of external symptoms) was observed in either year. Soft scald incidence increased slightly in later-harvested fruit in 2001, but no effect of harvest date was detected in 2002 (Table 2). The incidences were low compared with those found in other studies (Watkins et al., 2004a, 2004b), possibly because of the higher initial storage temperatures used in this study. Susceptibility of fruit to soft scald (and soggy breakdown) can be greater with later harvest dates and lower storage temperatures (Watkins et al., 2004a).

Stem punctures were high in both years, averaging 17% and 20% in 2001 and 2002, respectively, but incidence was not affected by harvest date (Table 2). Two characteristics of 'Honeycrisp' predispose fruit to stem punctures: 1) stems of the cultivar are very rigid and thick, and some apples produce long stems that puncture other fruit during fruit-to-fruit contact in the picking basket or bin; 2) some fruit have very short stems that detach from the spur inside the stem bowl of the apple. The sharply pointed bud located on the spur just above the fruit pedicel can puncture the skin in the stem bowl or shoulder when the apple is twisted from the spur during harvest. This type of puncture often goes undetected at harvest or when fruit are packed soon after harvest. However, such wounds ultimately become infected by fungi

causing a visible black mark during storage and potentially leading to decay. With this type of defect, the apple is usually culled during packing.

The incidence of stem-end splitting increased markedly for fruit from the later harvest dates of both years. Stem-end splitting was also detected while the fruit were on the tree, and was particularly noticeable on late harvested fruit after heavy rain events. Stem-end splitting appears to be related to continuing fruit growth where the cuticle cannot keep up with the rate of expansion. Opara et al. (2000) found that stem end splitting was associated with irrigation, especially as fruit maturity advances.

The occurrence of stem punctures and stem-end splitting was not evaluated at harvest, often being difficult to detect at this time. Also, in the first season we were not aware of how extensive this problem could be, and in the second season, we wanted to evaluate the effect of these injuries on fruit in storage, especially in relation to decay.

The incidence of blue mold decay caused by *Penicillium expansum* was slightly higher in the later harvest date in 2001, but not 2002. Where present, the decays occurred in fruit that had cracks or stem punctures. Storing fruit with considerable amounts of cracks and punctures is likely to result in a higher incidence of decay in storage and lower pack-out percentages.

2001							
							1
2	3	4	5	6	7	8	
9	10	11	12 BHD	13	14	15 BHD	
16	17	18 BHD	19	20	21	22	
23	24	25	26	27	28	29	
30	1	2	3	4	5	6	

Fig. 1. The acceptable harvest period for apple fruit from four 'Honeycrisp' orchard blocks in western New York in 2001 ranged from 8 to 20 Sept. The single best harvest dates (BHD) occurred on 12 Sept. (one block), 15 Sept. (two blocks), and 18 Sept. (one block). Fruit from individual blocks remained in acceptable condition for an average of 11 d.

BEST HARVEST DATES. The evaluation panels noted that fruit harvested too early lacked flavor and was too green to have satisfactory appearance (data not shown). Some late harvested fruit were considered overmature and typically had off-flavors or poor texture.

In 2001, the best harvest dates for the four orchard blocks based on panel evaluations occurred between 12 and 20 Sept. (Fig. 1). The acceptable harvest period ranged from 8 to 20 Sept., but only lasted for a period of 11 d, on average, for individual blocks. Fruit matured later in 2002, and the best harvest dates ranged from 24 to 28 Sept. (Fig. 2), suggesting a maturity delay of 7 to 10 d compared with 2001. The acceptable harvest period occurred between 14 Sept. and 1 Oct., considerably longer and later than the previous year, and averaged 13 d for individual blocks. Even though the single best harvest dates occurred in late September in 2002, fruit was acceptable for harvest much earlier than those dates.

HARVEST INDICES AND BEST HARVEST DATES. The maturity and quality indices examined in this study had limited usefulness for determining harvest dates for 'Honeycrisp' in western N.Y. Although significant IEC were detected, they did not change over time in a climacteric pattern, as described for many other cultivars (Blanpied and Silsby, 1992; Lau, 1985). The starch indices were high, and close to maximum values during the optimum harvest season in this

2002							
1	2	3	4	5	6	7	
8	9	10	11	12	13	14	
15	16	17	18	19	20	21	
22	23	24 BHD	25	26	27	28 BHD	
29	30	1	2	3	4	5	

Fig. 2. The acceptable harvest period for apple fruit from five 'Honeycrisp' orchard blocks in western New York in 2002 ranged from 14 Sept. to 1 Oct. The single best harvest dates (BHD) occurred on 24 Sept. (two blocks), and 28 Sept. (two blocks). Fruit from individual blocks remained in acceptable condition for an average of 13 d.

region. For 'Honeycrisp' in western New York, best maturity for harvest was associated with 7 or higher on the Cornell Starch Chart. SSC changed only slightly throughout the harvest period, and that change was inconsistent from year-to-year. Although fruit softened over the harvest period, the loss of firmness during storage was relatively small. Both firmness and SSC can be influenced by factors such as shade and nitrogen levels (Jackson et al., 1977; Lau, 1985; Wargo et al., 2004). Within-block comparisons of firmness, soluble solids, and eating quality for the various harvest dates indicated that fruit should be harvested with a minimum of 60 N (13.5 lbf) firmness and 13% SSC for best poststorage eating quality (Wargo, unpublished data).

GENERAL COMMENTS. 'Honeycrisp' is an apple that can develop a bright appearance about the time that varietal flavor develops. However, this association is dependent on seasonal influences. In 2001 (cool harvest weather), acceptable fruit color developed well in advance of acceptable fruit flavor whereas in 2002 (a poor coloring year), flavor was present before good color. In the Hudson Valley, a poorer coloring region of New York (Stover et al., 2003), fruit flavor can develop prior to adequate color development.

Growers are finding that 'Honeycrisp' needs to be spot picked sequentially to obtain best quality. In this respect, 'Honeycrisp' is similar to 'Gala', which is also harvested on the basis of ground color (Brookfield et al., 1993). However, as with 'Gala', 'Honeycrisp' fruit that have acceptable color must be harvested in a timely manner to avoid problems with over-maturity.

Based on the results from this trial, we conclude that growers have approximately 2 weeks to harvest fruit in acceptable condition. This should allow enough time to make the two to four sequential spot pickings required for this cultivar. Later-harvested fruit can be overmature and at higher risk for stem-end splitting, injuries during

harvest and postharvest disorders. However, the absence of useful harvest indices to supplement visual observations in the orchard creates difficulties for the industry because fruit sometimes are harvested before varietal flavor has developed due to concerns about off-flavor and disorder development in later-harvested fruit (Watkins et al., 2004a). Early harvesting compromises the unique flavor of the 'Honeycrisp' apple that contributes to its popularity.

Care is needed when harvesting and handling 'Honeycrisp' to minimize skin punctures. There is no easy solution to this problem, but growers should supervise pickers closely for unacceptable amounts of punctures. If pickers are paid hourly, they should be allowed to harvest fruit at a pace that will minimize rough handling. 'Honeycrisp' should be handled like other easily damaged cultivars, such as 'McIntosh', and while this may slow the rate of harvest, it should lead to better pack-out percentages and greater profitability.

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