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Postharvest Performance of 'Minneiska' Apple, a Progeny of 'Honeycrisp'

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Abstract

'Minneiska', a cross between 'Honeycrisp' and 'Minnewashta' (Zestar!®), was the first commercialized progeny of the 'Honeycrisp' apple. The effects of harvest date and storage under air for 3 and 6 months, and controlled atmosphere (CA) conditions for 4 and 8 months, at 0 °C, on 'Minneiska' fruit firmness were tested at multiple locations in Michigan, Minnesota, and New York over two years. Harvest date affected flesh firmness, starch pattern index, soluble solids concentration, internal ethylene concentration, and percentage of red blush at harvest. Harvest date affected all quality attributes of fruit after air and CA storage, except for flesh firmness 7 d after removal from air storage. Fruit stored under CA for 8 months developed CO_2 injury and senescent breakdown. Fruit treated with 1-methylcyclopropane retained firmness during 6 months of storage. All attributes varied by year and orchard. Harvest date did not affect sensory panelists' liking of Minnesota-grown fruit. Although stored fruit developed decay and shriveling, no or low incidences of soft scald and soggy breakdown were observed. In general, 'Minneiska' fruit maintained good firmness and soluble solids concentration for up to 3 months when stored in air and for 4 months in CA conditions of 1.5-2.5% O_2 and 1.5-2.5% CO_2.

Introduction

'Honeycrisp', an apple cultivar known for its long-lasting crisp texture and juiciness, has become popular due to consumer demand. Since its release in 1991, 'Honeycrisp' has been incorporated into many apple breeding programs. The first commercial cultivar released with 'Honeycrisp' in its pedigree was 'Minneiska'. Fruit of this cultivar reaching acceptable wholesale quality is marketed as SweeTango®. The other parent of 'Minneiska' is 'Minnewashta', marketed as Zestar!® apple. This study was performed to characterize postharvest quality of 'Minneiska' in multiple environments early in commercialization.

Aspects of the postharvest performance of 'Honeycrisp' that could also be a concern for 'Minneiska' include the uneven maturation of fruit, resulting in the need for multiple harvests, as well as susceptibility to several storage disorders (DeEll, 2005; Wargo and Watkins, 2004). Assessment of fruit maturity and determining when to harvest 'Honeycrisp' apples can be problematic. Commonly used maturity indices, such as flesh firmness, internal ethylene concentration (IEC), soluble solids concentration (SSC), and starch pattern index (SPI), are of limited use with 'Honeycrisp' (Wargo and Watkins, 2004; Watkins et al., 2005). It is not known how useful these criteria are for 'Honeycrisp' progeny.

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Furthermore, 'Honeycrisp' fruit are susceptible to the physiological disorders soggy breakdown and soft scald, which are considered to be low temperature disorders, and are associated with more mature fruit, but can often be controlled by a conditioning treatment before storage (Watkins et al., 2005; Moran et al., 2010). 'Honeycrisp' fruit are usually subjected to a conditioning treatment to reduce incidence of the disorders. Controlled atmosphere (CA) storage and 1-methylcyclopropene (1-MCP) treatment are increasingly used to maintain quality in long-term storage of 'Honeycrisp' apples, although care is needed to prevent development of CO_2 injuries (DeLong et al., 2006; DeEll et al., 2016; Contreras et al., 2014). Postharvest interventions to offset disorder incidence may also be needed for 'Honeycrisp' progeny.

'Minneiska' ripens about 2-3 weeks ahead of 'Honeycrisp' and preliminary evaluations in breeding trials has shown that it typically had a more intense flavor due to higher SSC and titratable acidity than 'Honeycrisp', and did not store as long as 'Honeycrisp' under ambient cold storage without 1-MCP treatment. In light of known positive and negative postharvest traits of 'Honeycrisp', this study was undertaken to characterize postharvest quality of 'Minneiska' fruit grown in different environments and stored under different regimes. Consumer acceptance as a function of harvest date of this new cultivar was also determined.

Materials and Methods

Postharvest storage studies were conducted in 2008 and 2009 in Michigan, Minnesota, and New York (Table 1). Replications of all postharvest treatments could not be done in each state due to differing and limited availabilities of fruit among states and orchards within states, typical for a newly commercialized cultivar.

Michigan. Fruit were harvested in 2008 from a commercial orchard (Wittenbach, Belding, MI). Limitations in fruit availability severely curtailed storage analysis. Fruit were used to assess the efficacy of CA storage and the long-term storability of the fruit. Fruit were harvested on a weekly basis and brought to Michigan State University the morning of harvest. Fruit were segregated into four lots of forty fruit each and a fifth lot of 20 fruit. The fifth lot was used for maturity analysis the day after harvest (10 fruit) and 7 d later (remaining 10 fruit, kept at 20 °C). Maturity analyses included internal ethylene concentration, flesh firmness, SPI (1-8 scale, Blanpied and Silsby, 1992), and soluble solids concentration (SSC). IEC was measured on 1-mL gas samples taken from each fruit, using a Carle 100 AGC gas chromatograph equipped with an activated alumina (2 m x 2 mm, i.d.) column and flame ionization detector. Firmness was measured on opposite, paired, and peeled sides of fruit using a drill stand-mounted penetrometer (Effegi FT-327, McCormick Fruit Tree Inc., Yakima, WA) fitted with an 11.1 mm-diameter probe. SSC was measured on expressed juice using a refractometer (PR-100, Atago Co. Ltd., Tokyo, Japan).

Two of the 40-fruit lots were placed in air storage at 0 °C; one lot for 3 months and the other for 6 months. The two remaining 40-fruit lots were stored under CA conditions of 1.5% O_2 and 3% CO_2 at 0 °C for 4 and 8 months. Fruit removed after each storage period were held for 7 d at 20 °C in large, low-density polyethylene bags to reduce moisture loss. Following removal, 10 fruit from each lot were assessed for IEC, firmness, and SSC. The remaining fruit were assessed for external and internal disorder incidence.

In 2009, fruit were harvested from three commercial orchards, one in Deerfield, MI and two in Belding, MI. Fruit harvested on three weekly harvests were received from each orchard. At each harvest, fruit were distributed in eight lots of forty fruit each and a ninth lot of 20 fruits. Maturity analysis at harvest and after 7 d at 20 °C was assessed on the lot of 20 fruit as described above for the 2008 season. The eight lots of forty fruit were cooled overnight to 0 °C. Four of

Table 1. Locations, number of harvests, treatments used, and measurements made in 2008 and 2009.

Year	State	Orchards	Number of Harvests	Storage Time in Air	Storage Time in Controlled Atmosphere	1-Methyl-cyclopropane Used	Harvest Indices	Traits Measured After Storage
2008	Michigan	One commercial orchard	4	3 & 6 months	1.5% O_2 + 3% CO_2; 4 months, Not analyzed	No	Internal ethylene concentration (IEC), firmness, starch pattern (SPI), soluble solids concentration (SSC), percent redness, fresh weight	IEC, firmness, SSC, percent redness, fresh weight, disorders
	Minnesota	Horticultural Research Center	4	3 & 6 months	Not tested	Yes	IEC, firmness, SPI, SSC	Firmness, SSC, disorders
	New York	One commercial orchard	4	3 months	2.5% O_2 + 2.5% CO_2; 4.5 months Not analyzed	Yes	IEC, firmness,SPI, SSC, percent redness, weight	IEC, firmness, disorders
2009	Michigan	Three commercial orchards, including 2008 orchard	3	3 & 6 months	1.5% O_2 + 3% CO_2; 4 months	Yes	IEC, firmness, SSC, percent redness, weight	IEC, firmness, SSC, percent redness, weight, disorders
	Minnesota	Horticultural Research Center	4	3 & 6 months	Not tested	Yes	Firmness, SPI, SSC	Firmness, SSC, disorders
	New York	Three commercial orchards, including 2008 orchard	3	Not tested	2.5% O_2 + 2.5% CO_2; 4.5 months	Yes (with CA)	IEC, firmness, SPI, SSC	Firmness, disorders

the 40-fruit lots were treated with 1 $\mu L \cdot L^{-1}$ 1-MCP for 24 h within the first 7 d after harvest. The four remaining lots were untreated. Half of the untreated and 1-MCP treated fruit were stored in air at 0 °C, whereas the other half was stored in an atmosphere of 1.5% O_2 and 3% CO_2 at 0 °C. Quality analyses were at 3 and 6 months for air-stored fruit, and 4 and 8 months for the CA-stored fruit. Fruit quality was assessed after storage removal as described above.

Minnesota. Fruit were harvested once a week over 4 weeks in 2008 and 2009 from the Horticultural Research Center in Chanhassen, MN. The first harvest occurred when fruit background color started to turn from green to yellow. Fruit were brought to campus the day of harvest and segregated into three lots. The first lot was used for quality analysis at harvest. The quality parameters that were measured were IEC, firmness, SPI (1-8 scale), and SSC, except that IEC was not measured for the first harvest in 2009. The other two lots were air stored at 0 °C, where one lot was treated with 1 $\mu L \cdot L^{-1}$ 1-MCP for 24 h. In 2008, 20 fruit were assessed at harvest, while 10 fruit were tested in 2009 at harvest. In both 2008 and 2009, six batches of 10 fruit each were treated with 1-MCP in 17-L boxes and then stored at 0 °C. Six more batches of 10 fruit each were enclosed in 17 L boxes but not treated with 1-MCP, and then stored at 0 °C. Fruit were removed from storage after 3 and 6 months, and assessed for disorders, firmness, and SSC after 1 and 7 d at 20 °C.

IEC was measured on 1-mL gas samples using a Hewlett-Packard 5880 gas chromatograph equipped with a flame ionization detector and 80/100 Porapak Q (1.8 m x 2.1 mm, i.d.) column (Supelco, Bellefonte, PA). Firmness and SPI were measured using the

same methods as for Michigan fruit. SSC was measured using a hand-held refractometer (ATC-1E, Atago Co. Ltd., Tokyo, Japan).

New York. In 2008, fruit were harvested from a commercial orchard once a week from Sept. 2 to Sept. 22. Twenty fruit were assessed at harvest for IEC, % blush, weight, firmness, SSC, and SPI (1-8 scale). The remaining fruit were divided into 4 groups of 60 fruit each. Two groups were placed in air storage, and two in an atmosphere of 2% O2 and 2% CO2, both at 0.5 °C. Half of each lot in air or CA storage (30 fruit) was treated with 1 $\mu L \cdot L^{-1}$ 1-MCP after overnight cooling at 0.6 °C. Air-stored fruit were assessed after 3 and 6 months, while CA-stored fruit were evaluated after 4 and 8 months of storage.

In 2009, 60 fruit were harvested on Sept. 3, 10, and 17, from each of three commercial orchards. IEC, firmness, SPI, and SSC were measured on 20 fruit from each orchard on each harvest date. Two lots of 40 fruit each were placed in CA (2.5% O_2 and 2.5% CO_2). One lot was treated with 1-MCP after overnight cooling at 0.5 °C. After 5 months of storage, 20 fruit from each 1-MCP and CA combination were assessed for firmness, SSC, TA, and disorders after 1 or 7 d at 20 °C.

IEC of 1-mL gas samples taken from each apple was measured with a Hewlett-Packard 5890 series II gas chromatograph equipped with a stainless steel column (2 m x 2 mm, i.d.) packed with 60/80 mesh alumina F-1 and a flame ionization detector. Firmness was measured using a mechanized pressure tester (EPT-1, Lake City Tech. Products, Lake City, Canada), on opposite, paired, and peeled sides of fruit with an 11.1 mm-diameter probe. SSC was measured on expressed juice using a refractometer (PR-100, Atago Co. Ltd., Tokyo, Japan).

Statistical analyses. Harvest data from MN, NY, and MI were analyzed using linear mixed models that could handle the nested and unbalanced data sets (lmer function) for R statistical software version 3.1.0 (R Development Team, 2010). The statistical model for the effects of harvest date on a trait (firmness measured 1 day after harvest, starch pattern index, IEC, SSC, peel redness, and weight) was

$T = \alpha + \varepsilon$ where T = measured trait, α = harvest as an ordered factor, and ε = residual effects. Year, state, and orchard (nested in state) were modeled as random terms. ANOVA with Satterthwaite approximation for degrees of freedom was used to check the significance of the fixed effect.

For storage experiments with 1-MCP under normal atmosphere, only data for the same orchards were analyzed by multifactor ANOVA with year, location (orchard nested in state), harvest, 1-MCP treatment, storage duration (3 or 6 months), and days after removal from storage as factors. Multiple interactions with Year and other factors were significant, so data for 2008 were subsequently analyzed separately from the 2009 data. Data were not balanced, so the lm function prior to ANOVA was used to analyze all data using R statistical software. Data collected from refrigerated air treatments were analyzed as split-split-split plot designs. The 2009 CA storage experiment, with or without 1-MCP treatments, was analyzed as a split plot design with Michigan and New York as the blocks, 1-MCP treatment as the plots, CA storage as the sub-plots, and replication by orchard. When applicable, means were compared using Tukey's HSD tests at the 5% level.

Consumer preference. In 2008, subjects (N = 115) were recruited from a database of students and staff at the University of Minnesota who had expressed an interest in participating in sensory tests. Panelists were 18 years or older, had no food allergies, and were consumers of apples. They were paid for participating.

Apple samples from four harvest dates, one week apart, were used for this study. All fruit were harvested from the Horticultural Research Center in Chanhassen, MN. The first harvest occurred when fruit background color started to turn from green to yellow. Fruit were stored in air at 0 °C until assessed

by the consumer panel, so the first harvest was stored for 4 weeks, while the last harvest was stored for 1 week. All harvest dates were assessed by the consumer panel at the same time. Fruit were cored and each apple was cut into 16 pieces, which were then immediately dipped in a commercial anti-browning solution (Ball Fruit Fresh®, Jarden Home Brands, Daleville, IN) to prevent enzymatic browning. Panelists received the apple pieces in 59 mL clear soufflé cups at room temperature.

Participants first selected the apple varieties they most frequently consumed and the one they liked best from a list of 14 varieties. They also indicated their apple consumption frequency between the months of Sept. to Dec. Subjects then evaluated the 4 apple samples in replicate using serving orders balanced for tasting order and carryover effects. All samples were served blinded with a 3-digit code. Subjects tasted one set of the four samples and rated them for overall liking, flavor liking, juiciness liking, and texture liking. Ratings were made on labeled affective magnitude scales (left-most end labeled strongest dislike imaginable; right-most end labeled strongest like imaginable). Immediately after tasting the first set, the participants tasted a second set (replicate) of the same 4 samples in a different balanced order.

Data were analyzed using a mixed model analysis of variance (SAS Proc Mixed; SAS, Cary, NC) with overall liking, flavor liking, texture liking, and juiciness liking as dependent variables and product, taste position, and replicate as predictors. A level of significance of 0.05 was used to determine if the apple samples differed. This analysis of variance was repeated for only the samples tasted in the second replicate (the 5^{th}-8^{th} samples each person tasted).

Results and Discussion

Harvest indices. Attributes measured in common across all locations at harvest were flesh firmness, starch pattern index, SSC, and IEC (Table 1). Harvest date affected all of these attributes, as well as peel redness. Of the measured attributes, only firmness differed among states, and in general, was greater for MI-grown fruit compared with those grown in MN or NY. MI-grown fruit were firmer

Table 2. Maturity indices for 'Minneiska' apples measured in 2008 and 2009 for orchards (one per state) common to both years. Harvest dates for MI-grown fruit were 8/26, 9/2, 9/5, and 9/12 in 2008 and 8/31, 9/7, and 9/14 in 2009. MN-grown fruit were harvested on 9/12, 9/18, 9/25, and 10/2 in 2008 and 9/9, 9/11, 9/17, and 9/24 in 2009. NY-grown fruit were harvested on 9/2, 9/8, 9/15, and 9/22 in 2008 and 9/3, 9/10, and 9/17 in 2009. ----- = not measured. N = Newton.

Year	Harvest	Firmness (N)			Starch Pattern Index			Internal Ethylene Concentration ($\mu L \cdot L^{-1}$)			Soluble Starch Conc. (%)		
		MI	MN	NY	MI	MN	NY	MI	MN	NY	MI	MN	NY
2008	1	71.8	68.2	65.5	2.0	3.1	5.6	0.3	1.1	0.97	14.9	13.8	14.0
	2	87.4	69.7	66.4	4.0	4.0	5.4	0.7	2.8	1.10	15.5	14.7	14.4
	3	81.5	59.3	69.3	6.0	5.4	6.5	1.6	4.6	4.29	16.3	15.4	15.5
	4	87.2	55.7	56.4	6.1	6.4	8.0	2.0	9.1	2.32	16.8	16.3	13.7
2009	1	70.0	73.7	71.5	-----	3.8	3.1	0.0	-----	0.1	12.8	15.0	12.8
	2	70.1	69.8	63.8	-----	4.4	4.5	0.4	-----	0.2	14.1	16.3	12.1
	3	64.4	69.8	62.9	-----	5.5	6.1	1.0	-----	0.2	15.6	16.8	13.2
	4	-----	62.9	-----	-----	6.0	-----	-----	-----	-----	-----	17.4	-----

in 2008 than in 2009, and firmness increased with harvest date in 2008, whereas it decreased with later harvests in MN and NY (Table 2). The softening of MN- and NY-grown fruit was similar to that of other apple cultivars, such as 'Cripps Pink' (Drake et al., 2002) or 'Sunrise' (Lau and Lane, 1998), which can soften by about 5 N per week delay in harvest.

The SPI increased with harvest and was greater in 2008 for NY-grown fruit than in 2009 (Table 2). It was generally similar across locations. The IEC was greater in 2008 than in 2009, and increased with later harvests in 2008, but not 2009. Similar to 'Honeycrisp' (Wargo and Watkins, 2004), 'Minneiska' did not exhibit a large autocatalytic increase in IEC, although 'Minneiska' IEC was lower than that reported for 'Honeycrisp'. In general, IEC of 'Minneiska' fruit did not differ significantly across locations. SSC was less in 2008 than in 2009 for MN-grown fruit, but greater in 2008 than in 2009 for NY-grown fruit. It was generally similar across locations, averaging approximately 16%, although slightly greater in 2009 for MN-grown fruit than MI- or NY-grown fruit. SSC tended to increase with later harvest. Both SPI and SSC were similar to that of 'Honeycrisp' (Watkins et al., 2005).

Percent redness increased with harvest date for MI-grown, but not NY-grown fruit (Table 3). Red coloration of MI-grown fruit ranged between 5% and 90%, increasing from 53 to 88% as harvest date was delayed. Fruit fresh weight was greater for NY-grown fruit from the second and third harvests compared with MI-grown fruit, but did not differ between harvests within an orchard. Weight of MI-grown fruit increased 15% from 151 g to 174 g over the four harvest dates.

Air storage. Data were obtained from three orchards in 2008 and two orchards in 2009, resulting in multiple interactions between year and various other factors. Data for 2008 were thus analyzed separately from 2009 data. Orchard and Harvest Date were sources of variation for firmness measured 1 or 7 d after removal from storage, SSC, and IEC in 2008 ($p < 0.005$ for all but SSC in which $p = 0.01$ for Harvest Date). In 2009, only firmness measured 1 d after removal from storage and SSC were affected by Orchard and Harvest Date ($p < 0.001$ for both traits). Storage Duration was also a source of variation for firmness measured 1 d after removal from storage in 2009 and measured 7 d after removal from storage ($p < 0.001$) in both 2008 and 2009. 1-MCP treatment significantly affected firmness measured 1 d after removal from storage in 2009 ($p < 0.001$). Traits that were affected by 1-MCP in both 2008 and 2009 were firmness 7 d after removal from storage ($p < 0.001$ for both traits in both years), SSC ($p = 0.08$ in 2008 and 0.03 in 2009), and IEC ($p < 0.001$ in 2008 and = 0.09 in 2009).

Firmness measured 1 d after removal from storage tended to decline with increasing harvest date in 2008, but not in 2009 (Table 4), while that measured 7 d after removal varied less with harvest date in both years (Table 5). Firmness measured 1 d after 3 months of storage of MI-, but not MN- or NY-grown fruit, remained above 66 N across most harvest dates in 2008. MI- and NY-grown fruit of some harvest dates in 2008 also exhibited

Table 3. Redness and fruit weight of apples harvested from MI and NY orchards at harvest. Variation between years was insignificant, so data were aggregated for both years. Harvest dates for MI-grown fruit were 8/25, 9/2, 9/5, and 9/12 in 2008 and 8/31, 9/7, and 9/14 in 2009. MN-grown fruit were harvested on 9/12, 9/18, 9/25, and 10/2 in 2008 and 9/9, 9/11, 9/17, and 9/24 in 2009. NY-grown fruit were harvested on 9/2, 9/8, 9/15, and 9/22 in 2008.

Harvest	Redness (%)		Fruit Weight (g)	
	MI	NY	MI	NY
1	50.8	69.5	168.7	177.6
2	70.8	88.0	159.3	205.2
3	63.5	85.8	155.6	198.5
4	87.5	76.3	181.0	190.2

Table 4. Firmness measured 1 day after transfer to room temperature of 'Minneiska' fruit after 3 and 6 months of air storage with or without 1-MCP treatment for fruit harvested from the same orchards in 2008 and 2009. Harvest dates for MI-grown fruit were 8/26, 9/2, 9/5, and 9/12 in 2008 and 8/31, 9/7, and 9/14 in 2009. MN-grown fruit were harvested on 9/12, 9/18, 9/25, and 10/2 in 2008 and 9/9, 9/11, 9/17, and 9/24 in 2009. NY-grown fruit were harvested on 9/2, 9/8, 9/15, and 9/22 in 2008 and 9/3, 9/10, and 9/17 in 2009. Numbers with differing small letters within a column for each year or capital letters within a row are significantly different at p = 0.05. Lack of lettering indicates no significant differences. ----- = not measured.

Year	Harvest	Firmness after 1 day (N)									
		3 months						6 months			
		MI		MN		NY		MI		MN	
		-MCP	+MCP	-MCP	+MCP	-MCP	+MCP	-MCP	+MCP	-MCP	+MCP
2008	1	80.1 A	-----	61.6 aB	64.6 aB	60.7 B	63.7 B	74.0 abA	-----	51.5 abC	62.0 B
	2	68.6 A	-----	55.9 bB	55.1 bB	61.8 C	64.2 C	80.8 aD	-----	56.5 aB	62.4 C
	3	77.8 A	-----	55.4 bB	52.1 bB	65.6 C	66.0 C	71.7 abA	-----	57.2 aB	60.7 B
	4	82.5 A	-----	51.4 bB	55.4 bC	59.5 C	60.5 C	62.8 bD	-----	47.6 bB	57.1 C
2009	1	61.4 A	64.8 A	55.7 A	64.5 A	-----	-----	52.4 AB	62.1 A	41.8 B	59.4 A
	2	56.4 B	64.9 B	49.6 A	66.0 B	-----	-----	56.5 AB	59.7 AB	41.5 C	55.1 ABC
	3	-----	-----	54.7 AB	62.8 A	-----	-----	53.7 AB	59.6 AB	48.2 B	53.4 AB
	4	-----	-----	53.1 A	67.2 B	-----	-----	-----	-----	45.6 A	63.8 B

Table 5. Firmness measured 7 days after transfer to room temperature of 'Minneiska' fruit after 3 and 6 months of air storage with or without 1-MCP treatment for fruit harvested from the same orchards in 2008 and 2009. Harvest dates for MI-grown fruit were 8/26, 9/2, 9/5, and 9/12 in 2008 and 8/31, 9/7, and 9/14 in 2009. MN-grown fruit were harvested on 9/12, 9/18, 9/25, and 10/2 in 2008 and 9/9, 9/11, 9/17, and 9/24 in 2009. NY-grown fruit were harvested on 9/2, 9/8, 9/15, and 9/22 in 2008 and 9/3, 9/10, and 9/17 in 2009. Numbers with differing capital letters within a row are significantly different at p = 0.05. Lack of lettering indicates no significant differences. ----- = not measured.

Year	Harvest	Firmness after 7 days (N)									
		3 months						6 months			
		MI		MN		NY		MI		MN	
		-MCP	+MCP	-MCP	+MCP	-MCP	+MCP	-MCP	+MCP	-MCP	+MCP
2008	1	78.0 C	-----	45.1 A	57.6 B	56.9 B	55.9 aB	71.8 C	-----	45.3 A	55.0 B
	2	72.4 B	-----	50.4 A	58.1 A	66.1 AB	67.4 bB	70.1 B	-----	48.3 A	54.9 A
	3	70.8 B	-----	52.7 A	57.9 A	68.2 B	68.4 bB	71.9 B	-----	46.5 A	54.1 A
	4	64.8 B	-----	44.3 A	60.9 B	58.9 B	62.5 abB	61.7 B	-----	41.2 A	51.9 B
2009	1	51.9 AB	53.6 B	50.8 AB	70.4 C	-----	-----	35.5 A	51.7 AB	44.8 AB	55.6 B
	2	55.2 ABC	65.4 BC	48.2 AB	64.7 C	-----	-----	48.8 AB	57.6 BC	39.6 A	53.5 AB
	3	56.3	61.1	49.1	58.2	-----	-----	47.0	55.0	47.0	56.7
	4	-----	-----	49.2 A	64.1 B	-----	-----	-----	-----	-----	-----

Table 6. Soluble solids concentration (SSC) measured 1 day after transfer to room temperature of 'Minneiska' fruit after 3 and 6 months of air storage with or without a 1-MCP treatment for fruit harvested in 2008 and 2009. Harvest dates for MI-grown fruit were 8/26, 9/2, 9/5, and 9/12 in 2008 and 8/31, 9/7, and 9/14 in 2009. MN-grown fruit were harvested on 9/12, 9/18, 9/25, and 10/2 in 2008 and 9/9, 9/11, 9/17, and 9/24 in 2009. NY-grown fruit were harvested on 9/2, 9/8, 9/15, and 9/22 in 2008 and 9/3, 9/10, and 9/17 in 2009. ----- = not measured.

Year	Harvest	SSC (%)									
		3 months						6 months			
		MI		MN		NY		MI		MN	
		-MCP	+MCP	-MCP	+MCP	-MCP	+MCP	-MCP	+MCP	- MCP	+MCP
2008	1	16.4	-----	16.7	16.8	14.1	15.1	14.8	-----	15.9	16.3
	2	16.1	-----	16.6	16.9	14.9	16.7	15.8	-----	16.8	16.8
	3	17.0	-----	17.5	17.1	16.5	16.7	16.3	-----	16.3	16.7
	4	15.1	-----	16.6	17.1	14.9	15.0	16.2	-----	16.7	17.2
2009	1	14.1	14.4	16.8	16.7	-----	-----	14.9	14.1	16.7	17.7
	2	14.3	14.9	17.3	17.2	-----	-----	14.8	15.8	17.3	17.4
	3	-----	-----	17.7	17.6	-----	-----	15.4	16.1	17.5	18.0
	4	-----	-----	18.2	18.6	-----	-----	-----	-----	17.9	19.3

firmness above 66 N when measured 7 d after 3 months of storage. It was observed that the fruit had a tendency to shrivel during the 7-day holding period, which likely resulted in higher firmness values. Fruit stored for 6 months were generally softer than those held only 3 months without 1-MCP treatment. Firmness did not differ between 1-MCP-treated and non-treated fruit one day out of storage after 3 months in 2008, but this varied with harvest date. 1-MCP treatment effects on fruit firmness measured 1 or 7 d after removal from storage were more noticeable in 2009. Flesh firmness measured 7 d after removal was lower, SSC was higher, and IEC comparable to that reported for stored 'Honeycrisp' fruit (Watkins et al., 2005).

Aggregated across orchards, SSC tended to increase slightly with harvest date (Table 6). Fruit treated with 1-MCP did not exhibit different SSC than untreated fruit. MN-grown fruit had slightly greater SSC than MI- or NY-grown fruit.

IEC of fruit held for 3 or 6 months in air storage increased during a 1-day holding period out of storage (Table 7), compared to freshly harvested fruit (Table 2). 1-MCP treatment suppressed this increase. IEC of MI-grown fruit from the first 2009 harvest that had been treated with 1-MCP was exceptionally high. Two fruit from this lot accumulated over 100 $\mu L \cdot L^{-1}$ of ethylene during the 1-day holding period, for unknown reasons.

CA storage. Orchards within either MI or NY were significant ($p = 0.05$) sources of variation for firmness measured 1 or 7 d after removal from storage, SSC, and IEC (data not shown). After 4 months of CA storage, firmness 1 d after removal from CA was similar across harvest dates in MI-grown fruit (Table 8). Fruit from the first harvest at one orchard was firmer than that of the other orchards, but there were no differences among subsequent harvests. Variation among orchards was not detected for NY-grown fruit.

CA-stored fruit tended to be firmer after 4 months than fruit held 3 months in air when fruit were analyzed 7 d after removal from storage (Table 10, compared with Table 5). Fruit from one orchard were firmer than those at the other two orchards. 1-MCP treatment and storage duration did not affect firmness of CA-stored fruit when measured after 7 d. SSC after CA storage was similar to that at

Table 7. Internal ethylene concentration (IEC) measured 1 day after transfer to room temperature of 'Minneiska' fruit after 3 and 6 months of air storage, or 4, 4.5, and 8 months under controlled atmospheres with or without a 1-MCP treatment for fruit harvested from the same orchards in 2008 and 2009. MI-grown fruit were stored for 4 or 8 months under 1.5% O_2 + 3% CO_2. NY-grown fruit were stored for 4.5 months under 2.5% O_2 + 2.5% CO_2. Harvest dates for MI-grown fruit were 8/26, 9/2, 9/5, and 9/12 in 2008 and 8/31, 9/7, and 9/14 in 2009. NY-grown fruit were harvested on 9/2, 9/8, 9/15, and 9/22 in 2008 and 9/3, 9/10, and 9/17 in 2009. ----- = not measured.

Year	Harvest	IEC ($\mu L \cdot L^{-1}$)											
		3 months, -CA				6 months, -CA		4 months, +CA		4.5 months, +CA		8 months, +CA	
		MI		NY		MI		MI		NY		MI	
		-MCP	+MCP	-MCP	+MCP	-MCP	+MCP	-MCP	+MCP	-MCP	+MCP	-MCP	+MCP
2008	1	59.0	-----	4.7	5.4	86.1	-----	0.5	-----	0.6	0.5	1.0	-----
	2	73.8	-----	50.5	2.8	64.0	-----	0.1	-----	1.4	0.9	0.2	-----
	3	37.2	-----	86.8	3.0	43.7	-----	0.1	-----	4.4	1.0	0.4	-----
	4	56.8	-----	81.6	3.1	32.1	-----	0.8	-----	5.7	0.7	0.3	-----
2009	1	38.0	0.2	-----	-----	13.8	71.5	0.01	0.02	-----	-----	0.03	0.0
	2	30.3	0.3	-----	-----	33.4	1.2	0.1	0.08	-----	-----	0.1	0.1
	3	25.7	1.3	-----	-----	17.2	0.6	0.1	0.2	-----	-----	-----	0.2

Table 8. Firmness measured 1 day after removal from storage of 'Minneiska' fruit harvested from MI and NY orchards in 2009 and stored under CA with or without 1-MCP treatment. MI-grown fruit were stored for 4 or 8 months under 1.5% O_2 + 3% CO_2. New York-grown fruit were stored for 4.5 months under 2.5% O_2 + 2.5% CO_2. Harvest dates for MI-grown fruit were 8/31, 9/7, and 9/14. NY-grown fruit were harvested on 9/3, 9/10, 9/17. Numbers with differing small letters within a column or capital letters within a row are significantly different at p = 0.05. Lack of letters indicates no significant differences. ----- = not measured.

Storage Time (mo)	Harvest	MI						NY					
		Orchard 1		Orchard 2		Orchard 3		Orchard 1		Orchard 2		Orchard 3	
		-MCP	+MCP	-MCP	+MCP	-MCP	+MCP	-MCP	+MCP	-MCP	+MCP	-MCP	+MCP
4 /4.5	1	73.8 aAB	74.6 AB	81.3 BC	82.8 aC	63.6 A	60.7 A	70.9	69.3	68.1	67.3	71.5 a	70.0
	2	60.3 a	61.2	73.3	67.8 a	65.1	63.1	69.5	69.5	65.5	65.8	67.6 a	65.3
	3	63.5 a	62.8	67.7	64.8 b	58.5	58.9	67.0	68.0	63.4	64.1	61.9 b	66.0
8	1	66.0 a	65.4	-----	-----	56.3	61.6	-----		-----		-----	
	2	64.5 a	60.6	-----	-----	55.1	61.1	-----		-----		-----	
	3	48.4 bA	63.4 AB	-----	-----	-----	71.1 B	-----		-----		-----	

harvest (Table 9). There was variation in SSC among fruit from different MI orchards. Differences in SSC were not biologically significant among NY-grown fruit. IEC of MI-grown fruit was still quite low after CA storage in 2009 (Table 10), very near that at harvest, and did not vary by orchard, unlike that of other apple cultivars (Testoni and Zerbini, 1989). The only increase in IEC was observed for the third harvest for Orchard 1, in which fruit had been treated with 1-MCP and stored for 8 months. Internal disorders of CA-stored fruit were common and included vascular browning, core browning and browning of the cortex, likely due to CO_2 injury. The fruit from the last harvest (Sept.

Table 9. Soluble solids concentration measured 1 day after removal from storage of 'Minneiska' fruit harvested from MI and NY orchards in 2009 and CA-stored with or without 1-MCP treatment. MI-grown fruit were stored for 4 or 8 months under 1.5% O_2 + 3% CO_2. NY-grown fruit were stored for 4.5 months under 2.5% O_2 + 2.5% CO_2. Harvest dates for MI-grown fruit were 8/31, 9/7, and 9/14. NY-grown fruit were harvested on 9/3, 9/10, 9/17. Numbers with differing capital letters within a row are significantly different at p = 0.05. There were no significant differences among harvested dates. ----- = not measured.

Storage Time (mo)	Harvest	MI						NY					
		Orchard 1		Orchard 2		Orchard 3		Orchard 1		Orchard 2		Orchard 3	
		-MCP	+MCP	-MCP	+MCP	-MCP	+MCP	-MCP	+MCP	-MCP	+MCP	-MCP	+MCP
4/4.5	1	-----	-----	16.0B	-----	15.5B	14.3A	15.5	14.6	12.5	13.0	13.3	13.1
	2	16.4B	16.3B	15.0A	15.9AB	15.9A	15.6AB	15.1	14.9	13.4	13.3	13.3	13.6
	3	17.3B	16.0AB	16.7B	16.3B	16.3A	16.8A	14.8	15.0	13.3	12.9	13.7	13.7
8	1	16.0B	16.6B	-----	-----	15.5B	14.4A	-----	-----	-----	-----	-----	-----
	2	16.2B	16.4B	-----	-----	14.2A	15.8AB	-----	-----	-----	-----	-----	-----
	3	16.4B	16.8B	-----	-----	-----	14.7A	-----	-----	-----	-----	-----	-----

Table 10. Firmness measured after 7 days and IEC measured after 1 day removal from storage of 'Minneiska' fruit harvested from MI orchards in 2009 and stored for 4 or 8 months under 1.5% O_2 + 3% CO_2 with or without 1-MCP treatment. Numbers with differing small letters within a column or capital letters within a row are significantly different at p = 0.05. Lack of letters indicates no significant differences. ----- = not measured.

Storage Time (mo)	Harvest Date	Firmness after 7 days (N)						Internal Ethylene Concentration ($\mu L \cdot L^{-1}$)					
		Orchard 1		Orchard 2		Orchard 3		Orchard 1		Orchard 2		Orchard 3	
		-MCP	+MCP	-MCP	+MCP	-MCP	+MCP	-MCP	+MCP	-MCP	+MCP	-MCP	+MCP
4	Aug 31	63.4b	63.8	66.2	67.5	70.2b	65.8	0.42	0.11	0.11	0.05	0.01	0.02
	Sept 7	67.0b	69.0	73.8	75.2	67.0b	66.4	0.04	0.03	0.01	0.01	0.15	0.08
	Sept 14	68.0bABC	69.3ABC	71.8BC	74.4C	58.2aA	62.3B	0.33	0.25	0.24	0.25	0.14	0.19
8	Aug 31	62.9b	65.7	-----	-----	71.3b	65.8	0.35	0.17	-----	-----	0.03	0.01
	Sept 7	64.5bA	71.0 A	77.3 B	78.1B	64.6bA	65.0A	0.07	0.39	-----	-----	0.11	0.12
	Sept 14	56.5a	62.8	-----	-----	-----	66.7	0.16	0.93	-----	-----	-----	0.22

12) had the greatest percentage of internal injury.

Disorders. MI-grown fruit stored for 8 months in CA storage after 1-MCP treatment developed flesh breakdown. In 2008, the percentages of fruit developing this disorder were 5%, 6%, and 14% of fruit from the first, second, and third harvests, respectively. In 2009, fruit from one, but not the other two orchards, and not the orchard used in 2008, developed senescent breakdown after CA with 1-MCP treatment. The percentages of fruit from this orchard showing the disorder were 44%, 16%, and 94% for the first, second, and third harvests, respectively. In 2009, there was a great amount of shriveling and disease after 6 months of storage in MI-grown fruit (data not shown). Following storage, lenticels became much more noticeable and were considered to be a defect in some cases. In 2008, 28% of fruit from the third harvest and stored in air for 3 months developed lenticel breakdown. None of the air-stored fruit showed this disorder after 6 months, highlighting lot-to-lot variability. The percentage of fruit exhibiting lenticel breakdown under CA storage was less than 4%. In 2009, lenticel breakdown was 0-12%, varying by orchard and harvest date. Significant (5-12%) lenticel breakdown was observed only for air-stored fruit after 3 months. Unlike its 'Honeycrisp' parent (Tong et al., 2003), no

fruit developed soft scald and less than 1% of fruit showed soggy breakdown in both 2008 and 2009.

Decay incidence varied with orchard in NY. Water core was observed in some fruit, but this also varied by location. Fruit showed a low (< 1%) incidence of brown core in 2008. In 2009, 13-20% of fruit from one harvest date at each orchard (affected harvest date differed by orchard) exhibited brown core after 4.5 months of CA storage with 1-MCP treatment. Fruit stored under CA without 1-MCP treatment did not exhibit brown core. Only minor instances of vascular breakdown and water core breakdown were observed in 2009, while vascular breakdown was common in fruit harvested in 2008. Shriveling was more prominent in later harvests. Senescent breakdown was observed in 22% of fruit stored in air in 2008, and in 10-20% of fruit from one, but not the other two orchards, stored under CA. In 2009, 10% of fruit of two different harvest dates of one orchard and one harvest date of a different orchard exhibited soggy breakdown. Fruit from the third orchard did not develop soggy breakdown. No soft scald was observed in 2008 or 2009, so delayed cooling is not necessary for this cultivar (DeLong et al., 2004).

Consumer study. The objective of this part of the study was to compare the effects of harvest date on consumer liking of 'Minneiska'. Consumers who participated in the panel did not represent all Americans, given that they were recruited from among students and staff at the University of Minnesota. Compared to the larger U.S. adult population, they were most likely younger, better educated, and had a high familiarity with 'Honeycrisp' apples.

The consumers judged 'Minneiska' samples from the four harvest dates as not different in overall liking, flavor liking, texture liking or juiciness liking (Fig. 1). However, there was a large bias for participants to give high ratings to the first sample they tasted, a common observance in taste testing. Thus, data from the first 4 samples (rep 1) were discarded, and data were reanalyzed using only the second replicate. Even with the new analysis, harvest date did not influence sensory quality ratings (Fig. 1). However, most of the liking ratings trended upwards with later harvest dates. Be-

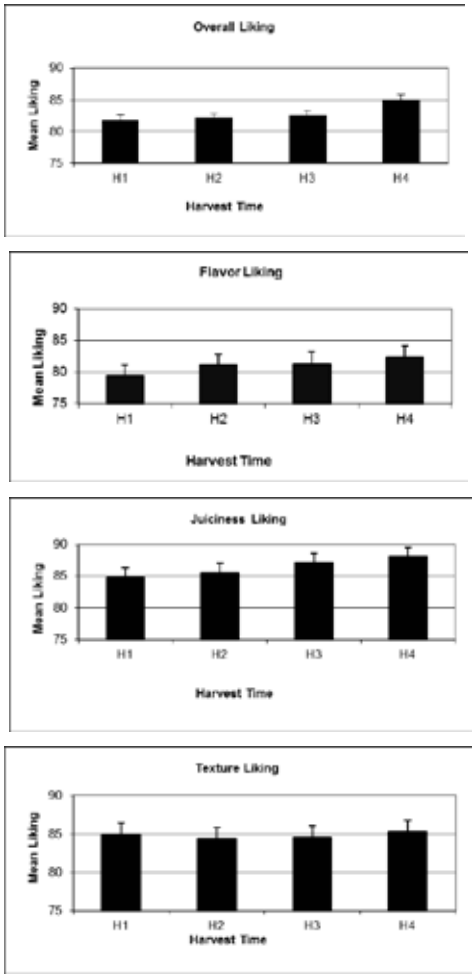


Fig. 1. Mean ratings (error bars represent standard errors) of 'Minneiska' apple samples (from the second replicate only) for overall liking, flavor liking, juiciness liking, and texture liking over 4 harvest dates. Liking ratings are on a scale of 0 = greatest possible dislike, 13 = dislike extremely, 25 = dislike very much, 39 = dislike moderately, 53 = dislike slightly, 60 = neither like nor dislike, 67 = like slightly, 81 = like moderately, 93 = like very much, 104 = like extremely, 120 = greatest possible like.

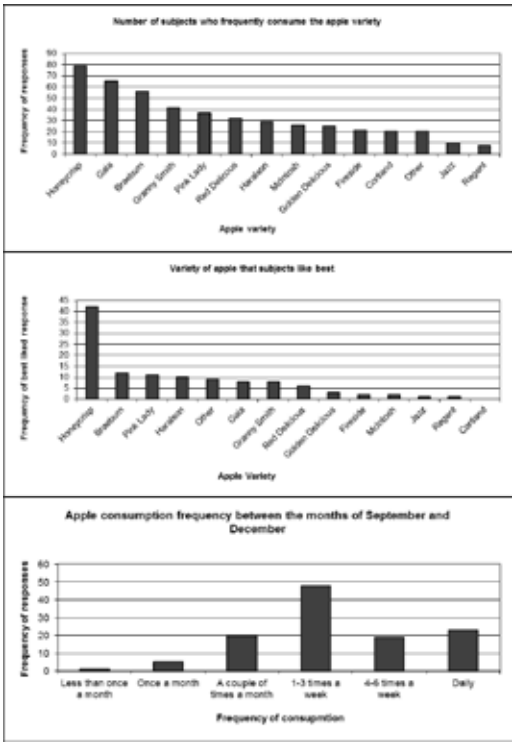


Fig. 2. Frequency of responses to the questions of what apple varieties participants frequently consumed, what apple cultivar subjects liked best, and how often they consumed apples between September and December.

cause the taste testing occurred after the fourth harvest time, and because the apples from the earlier harvest times were not stored under controlled atmosphere conditions, apples from the earlier harvest dates may have continued to mature after picking, minimizing the sensory differences among the harvest dates. Participants rated 'Honeycrisp' apples as the cultivar they most frequently consumed and the one that they like best (Fig. 2). The majority of participants consumed apples 1-6 times per a week.

Like 'Honeycrisp', 'Minneiska' fruit did not produce high amounts of ethylene at harvest, so IEC is not a good indicator of ripeness of this cultivar. Fruit firmness at harvest and after storage could decrease with increasing harvest date, so 'Minneiska' harvest should start once peel redness has reached an acceptable level. Harvest date effects on firmness of stored fruit and on SSC varied by year and location, so growers will need to be aware of trends for their particular orchards and adjust harvests accordingly, especially if storing fruit for a long time. To maintain fruit firmness over the long term (e.g., 6 months), fruit should be treated with 1-MCP or kept under CA conditions. 1-MCP treatment provided maintenance of firmness under either air or CA storage. Without 1-MCP treatment, stored fruit firmness can become unacceptably low (< 50 N). Overall, CA storage maintained flesh firmness, but fruit were susceptible to CO_2 injury if stored for 8 months. Stored 'Minneiska' did not develop significant soft scald or soggy breakdown, suggesting that it did not inherit the tendency to develop these disorders from 'Honeycrisp'. Development of other storage disorders and efficacy of postharvest storage treatments were subject to environmental variation, as demonstrated by differences between years and among orchards, so growers will need to watch for problems specific to their particular orchards.

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Disclosure: JJL and DSB are entitled to royalties from the 'Minneiska' cultivar described in this paper. The University of Minnesota also has a royalty interest in 'Minneiska' and related intellectual property. These relationships have been reviewed and managed by the University of Minnesota in accordance with its Conflict of Interest policies.

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About The Cover

Included in this issue are biographies describing the lives, adventures and lasting contributions of five American Fruit Explorers: counter clockwise starting at the top left: John Bartram, Niels Ebbesen Hansen, Frank Nicholas Meyer, Walter Tennyson Swingle, and David Grandison Fairchild.