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Storage Potential of Cold-hardy Apple Cultivars

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Abstract

The apple cultivars Fireside, Haralson, Honeygold, Regent, Cortland, Honeycrisp, and Delicious were harvested at up to three harvest dates in each of two years and fruit were stored for 9 months in air or controlled atmosphere (CA; 3% O_2 + 3% CO_2) storage. Fruit were sampled at harvest and at three month intervals for firmness, soluble solids content, titratable acidity, starch concentration, fresh weight loss, and decay. Responses to CA storage were generally favorable, though variable among harvest dates and seasons, for the cultivars in this study. CA storage helped maintain the quality of 'Fireside', 'Honeygold', 'Cortland', and 'Delicious' compared to air storage. 'Honeycrisp' fruit exhibited few differences between air and CA storage for the parameters measured and quality of the fruit was maintained at a high level under both regimes. 'Haralson' fruit exhibited poor long-term storage potential, including extensive decay after nine months, and did not benefit from the CA.

The apple industry in the upper midwestern US is based on several cultivars that are either unique to the region, such as Fireside, Haralson, Honeygold, Regent, and Honeycrisp™ (13), or cultivars such as Cortland that are more important here than in other production regions. These unique cultivars have permitted a healthy industry in a climatic region where it is difficult or impossible to produce cultivars such as 'Delicious', 'Golden Delicious', 'Gala', 'Braeburn' or 'Fuji', that dominate production elsewhere in the United States. Most apples produced in the region are marketed and consumed within three months of harvest. We wanted to determine whether controlled atmosphere (CA) storage would be useful in maintaining quality of regional cultivars during an extended marketing season.

Usual atmospheric modifications for extended storage of apples include normal O_2/elevated CO_2, reduced O_2/elevated CO_2, and reduced O_2/normal CO_2 (1). In CA storage, the rate of respiration, ethylene evolution and ethylene activity of the fruit are reduced, resulting in decreased postharvest loss (7). Also, the growth and development of microorganisms is suppressed under CA (21). Additional benefits of CA include delay of the climacteric (19), improved texture (12), reduced fruit weight loss (4), and reduced incidence and severity of decay through direct or indirect effects on postharvest pests (6).

Different apple cultivars have different optimal storage oxygen and carbon dioxide concentrations. Oxygen concentration seems to be the most important variable, with the critical O_2 and CO_2 concentrations varying between 1% and 3% (2, 10, 11, 18, and 23).

Relative maturity and harvest date can affect fruit storage quality. Mattheis et al. (14) reported that for 'Bisbee Delicious', firmness, soluble solids content, titratable

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acidity, and starch content were affected by harvest date. In 'Jonagold' apples, the greatest reductions in acidity and flesh firmness during air storage were found for fruit from late harvests compared to fruit from early harvests (5). Knee et al. (8) reported that firmness of 'Cox's Orange Pippin' apples was retained better during storage the closer the fruit was to the climacteric at the time of harvest. However, the relationship between harvest date and storage quality varied between growing seasons, even for fruit from the same orchards.

The objectives of our study were to investigate the effects of a CA storage regime on quality parameters of several apple cultivars grown in Minnesota. For cultivars with sufficient quantities of fruit available, three dates of harvest maturity were also compared.

Materials and Methods

In 1993 and 1994, fruit of 'Cortland' (Redcort strain); 'Delicious' (Starkspur Supreme strain), 'Honeycrisp', 'Haralson', 'Fireside', 'Regent', and 'Honeygold' , were harvested at the University of Minnesota Horticultural Research Center during the last week of September and the first 2 weeks of October. Trees of 'Cortland' were planted in 1980 on MM.111 rootstock at a spacing of 3.7 m x 5.5 m. Trees of 'Delicious' were planted in 1988 on M.7A rootstock at a spacing of 3.7 m x 6.7 m. Trees of 'Honeycrisp' were planted in 1989 on M.26 rootstock at a spacing of 2.6 m x 4.9 m. Trees of 'Haralson' were planted in 1984 on M.7 rootstock at a spacing of 3.7 m x 5.5 m. Trees of 'Fireside' were planted in 1990 on M.7 rootstock at a spacing of 2.5 m x 4.9 m. Trees of 'Honeygold' and 'Regent' were planted in 1987 on M.26 rootstock at a spacing of 3.1 m x 4.3 m.

Samples included fruit pooled from four to ten trees for each cultivar. Because of a limited availability of fruit, only one harvest date was chosen for optimal commercial fresh market flavor development for 'Delicious' and 'Honeycrisp', while three dates of harvest were chosen for the other cultivars. The three harvest dates included one date at the optimal commercial fresh market flavor development, one date earlier than optimal, and one date later than optimal. As relative maturity indices had not yet been developed for all the cultivars used, the optimal harvest date for flavor development for fresh consumption was estimated from preliminary studies in previous years by comparing fruit to the starch pattern index (a 1-6 scale with 6 representing low starch content) developed for 'Granny Smith' (16). Starch index values for optimal fresh market quality for 'Cortland', 'Fireside', 'Honeycrisp', and 'Honeygold' ranged between 4-5 while the range was 3-4 for 'Delicious', 'Haralson', and 'Regent' at harvest. These were the target values in each year for the second harvest while the first and third harvests were about one index point lower or higher, respectively.

Fruit were transferred to the laboratory approximately 2 hr after harvest and sorted. Sound fruit were stored in flow-through systems under controlled atmosphere (CA; 3% O_2 + 3% CO_2) or air for 9 months. Instead of 1-2% O_2, we used a conservative level of O_2 because we have no information on optimal CA conditions for the cultivars used in this study. Fruit were stored at 0°C in sealed, 114 L steel chambers (Greif Brothers, Kansas City, KS) purged with laboratory air (control) or an atmosphere mixed using CO_2, O_2, and N2 cylinders (CA) at flow rates of approximately 5 L/h. Laboratory air and the mixed atmosphere were humidified (RH > 95%) before entering the chambers. Oxygen and CO_2 concentrations in chamber outlets were measured with a portable O_2 and CO_2 analyzer (Nova 308, Nova Analytical Systems Inc., NY) and with precision detector tubes (Matheson Gas Products, NJ). Sixty fruit of each cultivar were used per treatment. Three fruit of each cultivar, harvest date, and treatment were sampled at harvest (zero time), and after 3, 6, and 9 months of storage, 'for firmness, soluble solids content, and titratable acidity.

Firmness. Firmness of each fruit was measured at two equatorial sites using fruit

Table 1. Quality of 'Cortland' fruit from three harvest dates, at harvest and after 9 months of air or CA (3% O_2 + 3% CO_2) storage at 0°C in 1993 and 1994, and analyses of variance due to year, harvest date, and storage. NA = apples not available from first harvest date in 1993.

Storage time and regime (mo)		Harvest date[Z]	Firmness (N) 1993	Firmness (N) 1994	Soluble solids content (°brix) 1993	Soluble solids content (°brix) 1994	Titratable acidity (% malic acid) 1993	Titratable acidity (% malic acid) 1994	Starch (g/100 gDW) 1993	Starch (g/100 gDW) 1994	Fresh weight loss (%) 1994	Decay at 9 mo[Y] (%) 1993	Decay at 9 mo[Y] (%) 1994
0		1	NA	68.9	NA	10.3	NA	0.54	NA	22.5	—		
		2	66.6	65.9	11.8	10.3	0.53	0.44	18.8	15.6	—		
		3	71.8	55.5	12.2	11.2	0.61	0.47	15.0	13.5	—		
3	Air	1	NA	39.3	NA	11.3	NA	0.32	NA	9.9	1.29		
		2	42.8	36.3	13.3	12.2	0.47	0.34	9.0	9.4	1.09		
		3	42.2	33.3	12.2	11.5	0.41	0.27	8.2	7.1	1.03		
	CA	1	NA	38.5	NA	12.2	NA	0.4	NA	20.0	0.46		
		2	44.8	57.0	14.3	12.0	0.47	0.37	11.6	10.4	0.72		
		3	45.5	41.5	11.5	12.2	0.44	0.35	12.0	7.8	0.90		
6	Air	1	NA	32.6	NA	11.2	NA	0.21	NA	8.2	2.89		
		2	41.5	34.8	12.5	11.7	0.29	0.21	6.4	6.3	1.61		
		3	45.2	31.8	10.0	10.8	0.21	0.20	6.5	5.4	1.32		
	CA	1	NA	36.0	NA	12.3	NA	0.19	NA	7.7	1.57		
		2	45.2	55.5	13.2	12.8	0.45	0.33	8.1	8.4	1.03		
		3	46.7	36.4	11.5	12.5	0.25	0.30	8.6	6.2	1.31		
9	Air	1	NA	34.8	NA	10.3	NA	0.15	—	—	3.72	42a	25a
		2	40.7	32.6	11.8	10.2	0.17	0.11	—	—	2.08	33a	21a
		3	37.8	28.9	10.8	11.2	0.16	0.10	—	—	1.97	0b	13a
	CA	1	NA	33.5	NA	11.7	NA	0.15	—	—	2.01	0b	21a
		2	48.2	52.6	12.2	11.2	0.27	0.25	—	—	1.20	0b	0b
		3	50.4	33.5	10.3	10.7	0.25	0.20	—	—	1.77	0b	0b
LSD (0.05)			5.8	5.9	1.2	1.0	0.05	0.04	4.5	0.8	0.41		

Analyses of variance

Source	Firmness	Soluble solids content	Titratable acidity	Starch
Year	**	+	**	**
Storage time (store)	**	**	**	**
Atmosphere (atmos)	**	**	NS	**
Harvest date (harv)	*	NS	NS	**
Year*store	*	**	**	*
Year*atmos	*	NS	+	+
Year*harv	**	NS	+	NS
Store*atmos	**	*	*	NS
Store*harv	*	+	NS	**
Year*store*atmos	NS	*	*	+
Year*store*harv	NS	NS	*	NS
Store*atmos*harv	NS	**	**	**
Year*atmos*harv	+	**	**	+
Year*store*atmos*harv	NS	**	**	NS

**,*,+ = significant at 1%, 5%, and 10%, respectively. NS = not significant.

[Z]The three harvest dates included one date at the optimal commercial fresh market flavor development, one date earlier than optimal,and one date later than optimal.

[Y]Treatments within columns not followed by the same letter are different according to chi-square contingency tests ($p \leq 0.05$).

pressure tester Effegi FT327 (McCormick Fruit Technology, Yakima, Washington) fitted with a 1.1 cm convex tip. Fruit were peeled before testing.

Soluble solids and titratable acidity. Soluble solids content and titratable acidity were determined using the procedures of Drake et al. (3). From each fruit, 20 g of tissue were homogenized in 80 ml distilled water for one min with a Brinkmann Polytron. A disposable pipette was used to transfer 1 ml of homogenate onto a hand-held refractometer for soluble solids determination, reported as °brix. Fifty ml of homogenate was put in a 100 ml beaker, stirred, and titrated to pH 8.1 with 0.1 N NaOH. The amount of 0.1 N NaOH used was multiplied by 0.06705 to obtain the percentage of malic acid (9).

Starch. Fruit were sampled for starch quantification at harvest and after 3 and 6 months of storage (preliminary tests indicated only trace amounts of starch remained after 9 months). Approximately 10 g of flesh from each of 3 fruit were freeze-dried immediately, then ground to a fine powder. For starch analysis, two subsamples (groups A & B) of 0.05 g of each sample were weighed into two culture tubes fitted with screw caps. Group A was used to measure free glucose while group B was used for quantitation of total glucose after hydrolysis of starch with (-amylase. The methods of Rasmussen and Henry (17) were used to hydrolyze starch into glucose except that, instead of termamyl amylase, porcine pancreas α-amylase (Sigma Chemical Co.) was used and tubes were capped and incubated at 55°C for 30 min. The final volume in group B tubes was 2.6 ml. Therefore, to each tube in group A, 2.6 ml deionized water was added. All tubes, groups A and B, were centrifuged at 1,775 x g and 10 ml of the supernatant was removed and diluted with deionized water to a final volume of 1.0 ml for glucose analysis. Two empty tubes were included for glucose blanks.

Glucose determinations were done according to the procedures of Nelson (15) and Somogyi (20). A standard curve was prepared using glucose as a standard (Sigma Chemical Co.). Absorbances at 540 nm of group A tubes were subtracted from that of corresponding group B tubes to determine apple tissue starch content. Percent recovery of starch was determined by analyzing two 0.05 g portions of corn starch (Sigma Chemical Co.) separately, but at the same time as the apple samples.

Fresh weight loss. In 1994, fruit were weighed individually after harvest, labeled, and stored. After 3, 6, and 9 months of storage, the same fruit were reweighed. Weight loss was expressed as a percentage of the original fresh weight of the fruit.

Decay. Decayed fruit were rare in the first 6 months of storage but were common in some treatments after 9 months. The number of fruit exhibiting decay were counted after 9 months of storage.

Statistical Analyses. The experimental design was completely randomized with a factorial arrangement of harvest date, storage treatments and sampling time for 'Fireside', 'Haralson', 'Honeygold', 'Cortland', and 'Regent'. A completely randomized design with a factorial arrangement of storage treatments, and sampling time was used for 'Honeycrisp' and 'Delicious'. Analyses of variance were done using the GLM procedure of SAS (SAS Institute, Inc., Cary, NC). Because of the interactions of many of the factors within year, data for each year were analyzed separately by cultivar. Means comparisons (LSD) were performed using Statistix 4.1 (Analytical Software, Inc., Tallahassee, FL). For percent decay, chi-square contingency tests were used to compare each pair of harvest dates or storage treatments for 'Fireside', 'Haralson', 'Honeygold', 'Cortland', and 'Regent', and to compare storage treatments for 'Honeycrisp' and 'Delicious'.

Results

Year, storage time, atmospheric treatment, and harvest date had significant effects on firmness, soluble solids content, titratable acidity, and starch content for almost all the cultivars (Tables 1-6). For most of the cultivars and attributes, interactions between year x storage time, year

Table 2. Quality of 'Fireside' fruit from three harvest dates, at harvest and after 9 months of air or CA (3% O_2 + 3% CO_2) storage at O°C in 1993 and 1994, and analyses of variance due to year, harvest date, and storage.

Storage time and regime (mo)		Harvest date[Z]	Firmness (N) 1993	Firmness (N) 1994	Soluble solids content (°brix) 1993	Soluble solids content (°brix) 1994	Titratable acidity (% malic acid) 1993	Titratable acidity (% malic acid) 1994	Starch (g/100 gDW) 1993	Starch (g/100 gDW) 1994	Fresh weight loss (%) 1994	Decay at 9 mo[Y] (%) 1993	Decay at 9 mo[Y] (%) 1994
0		1	94.8	71.8	16.8	12.7	0.39	0.30	19.5	13.4	—		
		2	81.8	76.3	14.8	13.7	0.43	0.36	18.9	11.2	—		
		3	87.4	73.3	14.3	12.8	0.27	0.29	15.3	9.2	—		
3	Air	1	69.6	60.0	14.2	12.2	0.18	0.13	11.6	6.4	1.09		
		2	60.7	57.8	14.2	11.3	0.25	0.14	16.0	6.6	1.23		
		3	60.0	55.5	14.0	13.3	0.22	0.14	11.3	6.3	1.56		
	CA	1	68.9	72.6	13.7	12.2	0.23	0.21	14.3	7.2	1.22		
		2	71.8	70.4	14.5	11.7	0.32	0.19	18.5	7.1	1.35		
		3	74.1	70.4	14.7	12.3	0.26	0.18	12.5	7.4	1.37		
6	Air	1	61.5	48.9	12.8	11.5	0.18	0.11	6.9	4.2	1.76		
		2	62.2	50.4	13.7	10.3	0.21	0.09	6.4	5.4	1.76		
		3	52.6	50.4	12.7	10.8	0.16	0.12	5.7	5.1	2.32		
	CA	1	65.9	60.7	13.7	12.2	0.26	0.24	9.8	4.5	1.68		
		2	74.1	68.1	12.5	10.7	0.22	0.14	8.8	6.8	1.85		
		3	65.9	62.9	14.5	11.7	0.25	0.19	6.5	6.6	1.71		
9	Air	1	59.2	42.2	12..5	10.3	0.15	0.08	—	—	2.21	0a	17
		2	56.3	41.5	12.5	10.3	0.14	0.19	—	—	2.30	25b	0
		3	54.1	45.2	14.0	10.2	0.12	0.12	—	—	3.03	29b	13
	CA	1	64.4	60.0	12.2	10.3	0.25	0.20	—	—	2.02	0a	4
		2	69.6	62.9	13.0	10.2	0.20	0.15	—	—	2.62	0a	0
		3	72.2	58.5	13.3	11.8	0.22	0.21	—	—	2.14	0a	4
LSD (0.05)			8.2	7.1	1.3	1.1	0.03	0.03	4.5	2.6	0.87		

Analyses of variance

Source	Firmness	Soluble solids content	Titratable acidity	Starch
Year	**	**	**	**
Storage time (store)	**	**	**	**
Atmosphere (atmos)	**	NS	**	+
Harvest date (harv)	**	**	**	*
Year*store	NS	**	**	**
Year*atmos	**	NS	**	NS
Year*harv	**	**	**	*
Store*atmos	*	NS	*	NS
Store*harv	**	**	**	+
Year*store*atmos	NS	NS	+	*
Year*store*harv	*	*	**	NS
Store*atmos*harv	NS	NS	+	NS
Year*atmos*harv	NS	NS	NS	NS
Year*store*atmos*harv	NS	*	*	NS

**,*,+ = significant at 1%, 5%, and 10%, respectively. NS = not significant.

[Z]The three harvest dates included one date at the optimal commercial fresh market flavor development, one date earlier than optimal,and one date later than optimal.

[Y]Treatments within columns not followed by the same letter are different according to chi-square contingency tests (p≤0.05).

Table 3. Quality of 'Haralson' fruit from three harvest dates, at harvest and after 9 months of air or CA (3% O_2 + 3% CO_2) storage at 0°C in 1993 and 1994, and analyses of variance due to year, harvest date, and storage. Due to extensive decay, data for other traits were not collected on fruit stored for nine months in air.

Storage time and regime (mo)		Harvest date[Z]	Firmness (N) 1993	Firmness (N) 1994	Soluble solids content (°brix) 1993	Soluble solids content (°brix) 1994	Titratable acidity (% malic acid) 1993	Titratable acidity (% malic acid) 1994	Starch (g/100 gDW) 1993	Starch (g/100 gDW) 1994	Fresh weight loss (%) 1994	Decay at 9 mo[Y] (%) 1993	Decay at 9 mo[Y] (%) 1994
0		1	78.1	73.3	11.2	10.0	0.94	0.64	25.9	24.7	—		
		2	72.2	63.7	10.3	10.5	0.91	0.72	23.5	20.0	—		
		3	72.2	63.7	11.2	10.3	0.75	0.68	15.6	12.7	—		
3	Air	1	72.6	62.2	11.8	11.8	0.68	0.69	11.5	10.2	1.79		
		2	62.9	65.9	10.3	13.2	0.56	0.59	9.9	10.1	2.12		
		3	61.5	49.6	10.7	10.2	0.56	0.46	9.8	8.5	1.66		
	CA	1	76.3	57.0	13.5	12.8	0.72	0.61	14.6	10.8	1.08		
		2	68.5	65.9	10.7	13.2	0.60	0.69	10.0	10.8	1.17		
		3	65.9	51.8	10.8	10.8	0.57	0.59	11.4	10.1	1.07		
6	Air	1	62.2	41.5	10.3	10.3	0.41	0.40	5.4	3.1	3.57		
		2	48.9	51.1	10.0	12.5	0.26	0.57	6.6	5.9	2.77		
		3	45.2	37.5	9.8	10.3	0.20	0.37	6.9	4.5	2.64		
	CA	1	62.2	49.6	11.0	11.3	0.44	0.34	5.6	3.6	2.57		
		2	49.6	62.9	10.0	13.5	0.44	0.55	6.7	7.7	1.88		
		3	46.7	52.3	10.0	10.3	0.38	0.30	6.5	8.8	1.61		
9	Air	1	—	—	—	—	—	—	—	—	—	46a	75a
		2	—	—	—	—	—	—	—	—	—	75a	58a
		3	—	—	—	—	—	—	—	—	—	62a	42a
	CA	1	41.5	27.8	11.0	10.8	0.23	0.13	—	—	—	15b	38a
		2	47.4	31.8	10.0	13.2	0.27	0.31	—	—	2.58	13b	0b
		3	44.4	41.5	10.5	10.2	0.25	0.27	—	—	2.14	25b	8b
LSD (0.05)			9.9	6.5	1.3	1.1	0.11	0.08	5.3	4.7	0.78		

Analyses of variance

Source	Firmness	Soluble solids content	Titratable acidity	Starch
Year	**	**	**	**
Storage time (store)	**	**	**	**
Atmosphere (atmos)	**	**	**	**
Harvest date (harv)	**	**	**	*
Year*store	**	**	**	NS
Year*atmos	NS	NS	NS	NS
Year*harv	**	**	**	NS
Store*atmos	**	**	**	**
Store*harv	*	**	**	**
Year*store*atmos	*	NS	NS	**
Year*store*harv	**	NS	NS	NS
Store*atmos*harv	NS	NS	NS	NS
Year*atmos*harv	NS	ND	*	NS
Year*store*atmos*harv	NS	NS	+	NS

**,*,+ = significant at 1%, 5%, and 10%, respectively. NS = not significant.

[Z]The three harvest dates included one date at the optimal commercial fresh market flavor development, one date earlier than optimal,and one date later than optimal.

[Y]Treatments within columns not followed by the same letter are different according to chi-square contingency tests ($p \leq 0.05$).

Table 4. Quality of 'Honeygold' fruit from three harvest dates, at harvest and after 9 months of air or CA (3% O_2 + 3% CO_2) storage at 0°C in 1993 and 1994, and analyses of variance due to year, harvest date, and storage.

Storage time and regime (mo)		Harvest date[Z]	Firmness (N) 1993	Firmness (N) 1994	Soluble solids content (°brix) 1993	Soluble solids content (°brix) 1994	Titratable acidity (% malic acid) 1993	Titratable acidity (% malic acid) 1994	Starch (g/100 gDW) 1993	Starch (g/100 gDW) 1994	Fresh weight loss (%) 1994	Decay at 9 mo[Y] (%) 1993	Decay at 9 mo[Y] (%) 1994
0		1	69.6	64.4	13.0	14.2	0.33	0.38	17.8	22.5	—		
		2	71.1	65.9	12.5	14.5	0.31	0.29	14.8	16.3	—		
		3	69.2	68.7	14.3	14.8	0.32	0.28	13.8	14.2	—		
3	Air	1	54.1	42.2	12.7	14.7	0.19	0.24	10.9	6.4	1.92		
		2	50.4	44.4	13.8	14.7	0.19	0.20	8.8	5.9	1.35		
		3	50.4	41.5	12.7	14.5	0.19	0.13	8.0	2.7	2.38		
	CA	1	54.8	53.3	11.2	14.7	0.22	0.25	13.7	7.7	1.19		
		2	56.7	62.9	14.2	15.5	0.22	0.30	10.5	7.2	1.00		
		3	55.5	60.0	12.5	15.0	0.21	0.25	11.5	1.0	0.76		
6	Air	1	50.4	44.4	12.0	12.8	0.14	0.11	6.0	2.4	3.78		
		2	44.4	40.0	12.3	14.3	0.11	0.11	7.9	2.6	1.90		
		3	45.2	36.3	12.3	14.3	0.13	0.10	5.1	2.3	3.50		
	CA	1	51.1	52.3	12.5	13.3	0.19	0.15	6.2	2.4	2.12		
		2	46.3	59.2	12.5	14.0	0.24	0.19	8.1	3.3	1.46		
		3	48.6	51.8	13.4	14.7	0.17	0.22	8.2	2.2	1.16		
9	Air	1	40.7	35.5	11.2	13.2	0.07	0.06	—	—	5.46	8a	4
		2	31.1	31.1	10.5	12.7	0.06	0.05	—	—	2.47	33b	0
		3	37.0	37.0	11.0	12.0	0.06	0.05	—	—	5.60	33b	13
	CA	1	49.6	38.2	11.8	13.0	0.09	0.11	—	—	2.54	0a	0
		2	49.6	49.6	12.2	14.3	0.14	0.16	—	—	1.80	0a	0
		3	51.1	36.3	11.8	14.3	0.11	0.16	—	—	1.41	0a	0
LSD (0.05)			5.5	5.3	1.8	1.0	0.05	0.01	4.0	4.2	0.99		

Analyses of variance Source	Firmness	Soluble solids content	Titratable acidity	Starch
Year	**	**	**	**
Storage time (store)	**	**	**	**
Atmosphere (atmos)	**	**	**	**
Harvest date (harv)	**	**	**	*
Year*store	**	**	**	NS
Year*atmos	NS	NS	NS	NS
Year*harv	**	**	**	NS
Store*atmos	**	**	**	**
Store*harv	*	**	**	**
Year*store*atmos	*	NS	NS	**
Year*store*harv	**	NS	NS	NS
Store*atmos*harv	NS	NS	NS	NS
Year*atmos*harv	NS	NS	*	NS
Year*store*atmos*harv	NS	NS	+	NS

**,*,+ = significant at 1%, 5%, and 10%, respectively. NS = not significant.

[Z]The three harvest dates included one date at the optimal commercial fresh market flavor development, one date earlier than optimal,and one date later than optimal.

[Y]Treatments within columns not followed by the same letter are different according to chi-square contingency tests (p≤0.05).

x harvest date, storage time x atmospheric treatment, and storage date x harvest date. Because the significance of these interactions differed by cultivar, they are discussed below by cultivar. Three- and four-way interactions were generally insignificant, except for soluble solids content, titratable acidity, and starch content for 'Cortland' and 'Fireside', and titratable acidity for 'Haralson', 'Honeygold', and 'Regent'.

When the fruit were placed in storage, starch concentrations were generally higher in earlier harvests but differences in firmness, soluble solids content, acidity, and dry weight were not consistent among cultivars or between the years of the study (Tables 1-6). In both years, firmness and acidity decreased with time in storage, especially under air, for all cultivars. In general, CA-stored fruit were firmer and had greater acidity than air-stored fruit. After 9 months of storage, acidity differences between the different dates of harvest were not significant in air storage for any cultivar.

Starch content decreased after 3 and 6 months of CA or air storage compared to the initial values at harvest but did not differ among harvest dates after 3, 6, and 9 months of CA or air storage. Percent dry weight decreased slightly during storage but no differences among harvest dates were observed. Fruit decreased in fresh weight as storage time increased and fresh weight losses were frequently greater in air storage. All cultivars, except Haralson, exhibited little or no decay in CA storage after 9 months while decayed fruit were common for all cultivars except Honeycrisp and Delicious in air storage.

Firmness of 'Cortland' fruit was maintained better in 1993 than in 1994, but in both years, firmness decreased substantially within 3 months of harvest (Table 1). In 1993, there were no significant differences in 'Cortland' for fruit firmness between the two harvests. In 1994, fruit from the second harvest date were substantially firmer at 3, 6, and 9 months under CA storage. The second 1993 harvest date had a greater soluble solids content than the third after 3, 6, and 9 months in CA storage. In air storage, the second harvest had a greater soluble solids content than the third harvest at 6 months. In 1994, no significant differences in soluble solids content of the different harvests were observed. Fruit from the second 1993 harvest had greater acidity than those from the third harvest at 3 and 6 months in air storage, and at 6 months in CA storage. In 1994, fruit from the second and third harvests had greater percent acidity than those from the first harvest at 6 and 9 months in CA storage. Starch content was lower in 1994 than in 1993. For both years, starch decreased less with CA compared to air. In 1993, starch content was similar for different harvest dates within a treatment at a particular storage time, but in 1994 there were significant differences between harvest dates. The first harvest of 'Cortland' in 1994 had much greater fresh weight loss in air storage than the other two harvests after 6 months.

'Fireside' fruit harvested in 1993 exhibited greater firmness, soluble solids content, acidity, and starch content than in 1994 (Table 2). In 1993, air-stored fruit from the first two harvest dates were similar in firmness to CA-stored fruit. In 1994, fruit from all three harvest dates were softer when stored in air rather than CA. In both years, acidity was maintained at higher levels under CA storage, but soluble solids content and starch were not affected by the storage atmosphere. Harvest date and storage conditions had no effect on fresh weight losses of 'Fireside'.

For 'Haralson' (Table 3), CA storage had no effect on maintaining firmness of fruit after 3 months, in either year, nor at 6 months in 1993. In 1993, the first harvest of 'Haralson' fruit was the firmest after 6 months regardless of storage conditions. In 1994, the first and second harvest dates had firmer fruit than the third harvest after 3 months of air storage while under CA storage, only the second harvest was firmer than the third harvest at 3 months. At 6 months in CA or air storage, the second harvest had the greatest firmness. Soluble solids content, acidity, and starch were not

Table 5. Quality of 'Regent' fruit from three harvest dates, at harvest and after 9 months of air or CA (3% O_2 + 3% CO_2) storage at O°C in 1993 and 1994, and analyses of variance due to year, harvest date, and storage.

Storage time and regime		Harvest date[Z]	Firmness (N)		Soluble solids content (°brix)		Titratable acidity (% malic acid)		Starch (g/100 gDW)		Fresh weight loss (%)	Decay at 9 mo[Y] (%)	
(mo)			1993	1994	1993	1994	1993	1994	1993	1994	1994	1993	1994
0		1	78.5	62.2	10.0	11.0	0.42	0.31	28.9	21.1	—		
		2	85.2	65.2	11.7	13.3	0.35	0.39	20.1	17.2	—		
		3	85.2	62.9	11.8	13.7	0.38	0.53	20.5	17.1	—		
3	Air	1	61.5	50.4	12.3	13.2	0.24	0.16	11.7	7.9	0.90		
		2	57.8	48.9	11.5	11.0	0.24	0.17	10.9	5.5	1.23		
		3	63.7	56.3	10.8	12.7	0.21	0.35	7.9	6.8	0.90		
	CA	1	62.2	54.8	11.3	13.3	0.26	0.21	14.7	9.1	1.19		
		2	62.9	49.6	11.3	12.5	0.25	0.23	11.6	10.5	1.07		
		3	69.6	52.6	11.7	14.2	0.23	0.35	11.6	7.8	0.91		
6	Air	1	51.8	37.8	10.5	10.7	0.21	0.09	6.8	4.6	1.49		
		2	55.5	32.6	10.0	11.2	0.14	0.11	7.2	4.9	1.99		
		3	54.1	38.5	10.2	11.3	0.15	0.25	6.9	5.4	1.82		
	CA	1	56.3	45.2	10.7	12.2	0.26	0.15	7.9	7.0	1.76		
		2	57.8	47.4	11.8	11.8	0.20	0.17	10.8	8.4	1.73		
		3	64.1	50.4	11.2	12.8	0.22	0.30	7.5	6.2	1.26		
9	Air	1	38.5	32.6	10.0	10.3	0.10	0.06	—	—	2.20	58a	38a
		2	39.3	30.4	10.0	10.2	0.09	0.05	—	—	2.92	46a	68a
		3	52.6	NA	10.0	NA	0.11	NA	—	—	—	42a	50a
	CA	1	54.1	34.1	10.2	12.3	0.13	0.17	—	—	2.31	0b	0b
		2	65.2	35.2	10.7	10.3	0.12	0.10	—	—	2.79	8b	4b
		3	70.4	35.5	10.8	10.8	0.17	0.21	—	—	1.85	0b	33a
LSD (0.05)			8.5	6.6	0.9	1.0	0.05	0.03	5.0	4.7	0.24		

Analyses of variance Source	Firmness	Soluble solids content	Titratable acidity	Starch
Year	**	**	**	**
Storage time (store)	**	**	**	**
Atmosphere (atmos)	**	**	**	**
Harvest date (harv)	**	**	**	+
Year*store	**	+	**	*
Year*atmos	*	*	*	NS
Year*harv	NS	*	**	+
Store*atmos	**	**	**	NS
Store*harv	+	**	**	*
Year*store*atmos	**	NS	+	NS
Year*store*harv	NS	*	*	+
Store*atmos*harv	NS	NS	NS	NS
Year*atmos*harv	NS	NS	*	NS
Year*store*atmos*harv	NS	NS	+	NS

**,*,+ = significant at 1%, 5%, and 10%, respectively. NS = not significant.

[Z]The three harvest dates included one date at the optimal commercial fresh market flavor development, one date earlier than optimal,and one date later than optimal.

[Y]Treatments within columns not followed by the same letter are different according to chi-square contingency tests ($p \leq 0.05$).

consistently affected by the storage regime. In 1994, the second harvest had the greatest acidity at 6 months in air and CA storage. Fruit harvested at different harvest dates did not differ significantly in fresh weight loss during the first 3 months under CA or air storage. However, at 6 months the first harvest had greater fresh weight loss than the third harvest. Most air-stored 'Haralson' fruit were decayed by 9 months of storage.

For 'Honeygold' fruit, CA reduced losses in firmness only after 9 months for 1993 harvests and after 3 and 6 months in 1994 harvests (Table 4). In 1993, fruit from the first harvest date were firmer than fruit from the second harvest date after 9 months under air storage but all harvest dates were similarly firm in CA. In 1994, harvest dates did not consistently differ from one another in firmness through the period under air storage. However under CA storage, the second harvest date had the greatest firmness at 6 and 9 months. Storage regime had no consistent effects on soluble solids content, acidity or starch concentrations. CA conditions reduced fresh weight loss after 6 and 9 months with the first and third harvests showing a greater response than the second harvest.

'Regent' fruit from all harvest dates were generally similar in firmness and soluble solids content through 9 months of storage (Table 5). Storage conditions did not affect firmness through 6 months in either year and only in 1993 were CA-stored fruit significantly firmer than air-stored fruit at 9 months. In 1993 at 6 months, the first harvest of 'Regent' fruit had the greatest percent acidity in air storage and was more acidic than the second harvest when kept in CA. In 1994, the third harvest had the greatest acidity at harvest, at 3 and 6 months in air or CA, and at 9 months under CA storage only. Decay was extensive in air stored fruit in both seasons, but only fruit from the last 1994 harvest had extensive decay in CA.

'Honeycrisp' seemed least responsive to storage conditions of all the cultivars. Fruit from CA storage were firmer than air-stored fruit in 1993 but not in 1994 (Table 6). In 1994, fruit from CA storage had less fresh weight loss at 6 and 9 months and greater acidity at 9 months than fruit from air storage. 'Delicious' fruit from CA storage exhibited less fresh weight loss and greater firmness and acidity compared to fruit from air storage (Table 6).

Discussion

Large effects due to storage time and harvest date were not unexpected as fruit were stored over a long period of time, and harvest dates were purposely chosen to be far apart. The CA conditions used in our study maintained quality of some cultivars, but the effects were not always consistent in both years. For example, 'Haralson' fruit after six months storage in 1994, from all harvests, had greater firmness under CA than in air, while in 1993, fruit from CA were not different from those stored in air. Likewise, for 'Regent' fruit at 6 months, only the third harvest had greater firmness in CA than in air storage in 1993 while all harvests were firmer under CA than in air in 1994. The inconsistencies between growing seasons may have been due to the climate conditions as the 1993 growing season was considerably wetter and cooler than the 1994 season. The inconsistent responses to storage conditions may have been due to variation in the maturity of the fruit or the small sample sizes. Although harvest was based on starch pattern ratings, we have limited knowledge of the relationship between starch patterns and relative maturity for these cultivars. Also, we have not determined the optimal harvest maturity or CA conditions for long-term storage of these cultivars.

Six months of CA storage resulted in maintaining quality of 'Haralson', 'Honeygold', and 'Regent'. After 6 months of storage, the fruit of 'Haralson', 'Honeygold', and 'Regent' started to deteriorate, and lost firmness, acidity, and flavor. After 9 months, CA-stored fruit from many of the harvest dates of 'Fireside', 'Cortland', and 'Delicious' still had significantly lower FW loss, higher firmness, and high-

Table 6. Quality of of fruit of 'Honeycrisp' and 'Delicious' at harvest and after 9 months of air or CA (3% O_2 + 3% CO_2) storage at 0°C in 1993 and 1994, and analyses of variance due to year, harvest date, and storage.

Storage time and regime (mo)	Cultivar	Firmness (N) 1993	Firmness (N) 1994	Soluble solids content (°brix) 1993	Soluble solids content (°brix) 1994	Titratable acidity (% malic acid) 1993	Titratable acidity (% malic acid) 1994	Starch (g/100 gDW) 1993	Starch (g/100 gDW) 1994	Fresh weight loss (%) 1994	Decay at 9 mo[Z] (%) 1993	Decay at 9 mo[Z] (%) 1994
0	Honeycrisp	76.6	79.2	11.8	12.5	0.67	0.54	13.2	7.8	—		
	Delicious	104	77.0	9.8	9.8	0.31	0.28	26.2	35.8	—		
3 Air	Honeycrisp	65.2	70.4	12.8	11.7	0.49	0.31	12.7	4.3	0.95		
	Delicious	82.9	64.4	11.7	11.8	0.25	0.15	12.6	12.0	1.31		
CA	Honeycrisp	77.0	72.6	11.8	12.3	0.49	0.41	11.3	6.6	0.95		
	Delicious	88.9	74.8	11.0	12.5	0.28	0.24	14.7	13.9	0.84		
6 Air	Honeycrisp	67.4	60.7	11.8	11.2	0.36	0.33	7.1	4.6	2.57		
	Delicious	82.2	44.4	10.8	12.2	0.19	0.13	9.9	7.3	1.93		
CA	Honeycrisp	74.8	60.0	11.7	12.3	0.42	0.35	7.6	5.7	1.42		
	Delicious	86.6	64.4	11.0	13.5	0.26	0.22	11.7	10.0	1.20		
9 Air	Honeycrisp	70.4	62.9	12.8	10.2	0.31	0.22	—	—	3.19	0	0
	Delicious	75.5	45.9	9.7	10.2	0.13	0.08	—	—	2.71	13	8
CA	Honeycrisp	80.0	59.2	11.5	11.2	0.36	0.36	—	—	1.72	0	0
	Delicious	90.4	55.5	10.8	12.3	0.26	0.24	—	—	1.55	0	4
LSD (0.05)		7.2	6.3	1.5	1.2	0.07	0.05	4.8	4.2	0.40		

Analyses of variance Source	Firmness Honeycrisp	Firmness Delicious	Soluble solids content Honeycrisp	Soluble solids content Delicious	Titratable acidity Honeycrisp	Titratable acidity Delicious	Starch Honeycrisp	Starch Delicious
Year	**	**	NS	**	**	**	**	NS
Storage time (store)	**	**	NS	**	**	**	**	**
Atmosphere (atmos)	+	**	NS	NS	*	**	NS	NS
Year*store	**	**	*	*	NS	NS	*	**
Year*atmos	NS	+	**	NS	NS	NS	NS	NS
Store*atmos	NS	**	NS	*	NS	**	NS	NS
Year*store*atmos	NS	NS	NS	NS	NS	NS	NS	NS

**,*,+ = significant at 1%, 5%, and 10%, respectively. NS = not significant.
[Z]Treatments did not differ for decayed fruit.

er acidity than comparable air-stored fruit. Incidence of decay was also suppressed by CA storage.

In our study, firmness of fruit varied considerably and, for some cultivars, was below 35 N at later storage times, especially in ambient atmosphere. Tong et al. (22) reported the consumer sensory evaluations in relation to firmness (measured by a texture analyzer) for some of the varieties we studied using fruit produced in Minnesota and stored for up to 6 months in ambient atmosphere at 0 to 2°C. 'Honeygold' fruit had substantially decreased overall liking and texture liking by consumers when puncture force was below approximately 25 N. 'Honeycrisp' and 'Delicious' fruit in the same study maintained high overall and texture likings by consumers for up to 6 months even though 'Honeycrisp' maintained puncture force above 35 N through the period while 'Delicious' fruit dropped from 38 to 26 N.

'Honeycrisp' exhibited few striking differences between air and CA storage for the parameters measured and quality of the fruit was maintained at a high level under both regimes. 'Haralson', currently the most widely grown cultivar in Minnesota, exhibited poor long-term storage potential and did not benefit from the CA regime used in this study. Thus, although CA may be useful for some Minnesota cultivars, it seems to be ineffective for 'Haralson' and unnecessary for 'Honeycrisp'.

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