Research Reports

Harvest Maturity and Storage Affect Quality of 'Cripps Pink' (Pink Lady®) Apples

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Summary. **Quality of 'Cripps Pink' apples (*Malus* ×*domestica*) harvested at a starch index of 2 and 4 was evaluated over three crop seasons. Apple quality was evaluated after harvest and after regular atmosphere (RA) and controlled-atmosphere (CA) storage at 1% O_2 and 1% CO_2, 1% O_2 and 3% CO_2, and 1% O_2 and 5% CO_2 (1 year only) at 1 ºC (33 to 34 ºF). Over three seasons, commercially acceptable fruit quality was achieved on either harvest date following both long-term RA and CA storage. Fruit size was not different between apples harvested at a starch index of 2 or 4. Firmness and acids remained at acceptable levels [62 N (14 lb) and ≥0.50%, respectively] in 'Cripps Pink' apples regardless of maturity, storage time or storage conditions. Delaying harvest after a starch index of 2 was achieved increased soluble solids concentration (SSC), SSC to TA (titratable acidity) ratio, peel color, malic acid and citric acid concentrations but decreased fructose content. 'Cripps Pink' apples responded well to CA storage conditions of 1% O_2 with 1% or 3% CO_2, but displayed significant firmness loss and greatly increased internal breakdown at 1% O_2 and 5% CO_2 at 1 ºC.**

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The 'Cripps Pink' (Pink Lady®) apple is growing in popularity in the United States; nearly 37 million lb (16.8 × 10^6 kg) were produced in 2000, primarily in the state of Washington. As volume has increased, interest has grown in suitable harvest maturity criteria and appropriate storage procedures to assure quality fruit. Fruit maturity at harvest has a major influence on both storability and poststorage quality of apples. At the present time, peel color, flesh firmness, soluble solids content, starch content and ethylene production are or have been used as indices of apple fruit maturity for scheduling harvest.

Several studies (Blanpied and Silsby, 1989; Lau, 1985; Lau and Looney, 1982; Meheriuk and Pruitt, 1973) have shown that the more rapidly the desired CA conditions are established, the better the quality of the fruit after storage. Even short delays between harvest and establishment of the proper storage atmosphere result in significant fruit quality loss during storage. Accurately determining proper harvest maturity for the CA storage of apples has been a major concern since the initiation of CA storage.

The optimum storage atmosphere conditions for maximum storage life and highest quality of apples depend both on cultivar and the fruit maturity status at harvest. Meheriuk (1993) reported that the preferred CA environment for the storage of 'Cripps Pink' was 2% O_2 and 1% CO_2. Investigators working with other apple cultivars have reported enhanced fruit quality when O_2 is held below 2% (Chen et al., 1985; Chapon, 1988; Curry, 1989). Other studies have reported enhanced fruit quality with CO_2 levels above 1% (Claypool, 1973; Drake and Eisele, 1997; Ke et al., 1990).

Starch content in the fruit flesh has long been used as an indicator of maturity for scheduling the harvest of apples (Beaudry et al., 1993; Drake and Kupferman, 2000; Lau, 1988; Poapst et al., 1959; Smith et al., 1979). Other researchers report that starch may not be a reliable indicator of apple maturity (Blanpied, 1974; Knee et al., 1989). Regardless of its limitations, starch clearing is one of the major indicators of fruit maturity used in the commercial apple industry today (Washington Apple Maturity Program, 1993). With the increasing importance of 'Cripps Pink' as a commercial cultivar in Washington state, determination of one or more appropriate indices of fruit maturity for that cultivar has become an important question needing resolution.

This study was initiated to examine fruit quality behavior of 'Cripps Pink' apples during and after regular and CA storage in relation to harvest date based on the use of the starch index as an indicator of harvest maturity.

Materials and methods

'Cripps Pink' apples growing on 'Malling 7a' (M.7a) rootstock were harvested over three crop seasons from a commercial orchard located in the vicinity of Wapato, Wash. Beginning in September, 10 apples were harvested each week from the same four trees in the orchard. Starch content of the harvested apples was determined by standard procedures using a starch index of 1 to 6 (Washington Apple Maturity Program, 1993). When the average starch index reached 2.0, 170 fruit (130 in years 2 and 3) were harvested from each of four other trees preselected for sufficient crop load to provide two harvest-date samples each year. When the average starch index reached 4.0 (10 to 15 d later, depending on season), 170 additional fruit (130 additional fruit in years 2 and 3) were harvested from the same four trees. At each harvest, fruit quality parameters (firmness, SSC, TA, peel color, and mean fruit weight) were determined immediately on 10 fruit

Table 1. Quality attributes averaged over 3 years for 'Cripps Pink' apples harvested at starch index of 2 or 4.

Starch index	Wt (g)[y]	Firmness (N)[x]	SSC[z] (%)	TA[z] (% malic acid)	SSC to TA ratio	Hunter color (peel) L*	a*	b*	Hue
2	152 a[w]	94.2 a	13.3 b	0.87 a	15.6 b	55.6 a	21.6 b	16.3 a	38.0b
4	156 a	90.0 b	14.4 a	0.79 b	18.3 a	52.1 b	28.4 a	11.7 b	22.3 a

[z]SSC = soluble solids concentration, TA = titratable acidity.
[y]28.4 g = 1.0 oz.
[x]4.45 N = 1.0 lb of force.
[w]Means in a column not followed by a common letter are significantly different by analysis of variance ($P \leq 0.05$).

from each tree. During the first year of the study, each fruit sample was subdivided and a subsample placed in both RA and three different CA storage conditions (1% O_2 and 1% CO_2, 1% O_2 and 3% CO_2, and 1% O_2 and 5% CO_2) at 1 °C. In the next 2 years the 1% O_2 and 5% CO_2 atmosphere was eliminated. After 90 or 180 d of RA and 90 or 180 d of CA storage, twenty fruit from each treatment and replication were removed and quality parameters evaluated on ten fruit. The remaining 10 fruit were held at ambient temperature for 7 d, after which quality was again evaluated. Poststorage quality factors evaluated were firmness, SSC, TA, peel color, individual carbohydrate (sucrose, glucose, fructose, sorbitol) and acid (malic acid, shikimic acid, citric acid, fumaric acid) concentrations, and internal breakdown.

Starch index was determined using a rating scale of 1 to 6 (Washington Apple Maturity Program, 1993). Firmness was determined at two locations per fruit with a texture analyzer (TA-XT2; Texture Technologies, Scarsdale, N.Y.) equipped with a 11.1-mm probe. Peel color was determined with a colorimeter (The Color Machine; Pacific Scientific, Silver Springs, Md.) using the Hunter L*, a*, b* system and calculated hue angle values (Hunter and Harold, 1987). SSC, TA, carbohydrates, and acids were determined from an aliquot of juice expressed from a composited sample of a cross-sectional tissue slice from each of the same 10 fruit. An Abbé type refractometer with a sucrose scale calibrated at 20 °C (68 °F) was used to determine SSC. TA was measured with a titrator (model TTT 85; Radiometer, Copenhagen, Denmark). Acids were titrated to pH 8.2 with 0.1 N sodium hydroxide and expressed as percent malic acid. Individual carbohydrates and acids were determined as described by Drake and Eisele (1999). Internal breakdown (discoloration and cavity formation) was evaluated by two laboratory personnel familiar with apple poststorage disorders. Analysis of variance was carried out using MSTAT-C (1988) with starch index (two levels) as the main plot and storage atmosphere (two levels) and ripening time (two times) as subplots where applicable. Means were separated using Tukey's test ($P \leq 0.05$).

Results and discussion

Harvest of 'Cripps Pink' apples in Washington state generally begins in late October, at which time weather factors may be as much or more of a concern than fruit maturity in harvest scheduling. Most apple cultivars are considered properly mature for CA storage at a starch index of 2 to 3 (Washington Apple Maturity Program, 1993). Over the 3 years of this study, 'Cripps Pink' apples reached a starch index of 2 between 20 and 25 Oct. and a starch index of 4 after 10 to 15 d more. The interval required for the starch index to change from 2 to 4 resulted in no detectable increase in fruit size (Table 1). However, delaying harvest from a starch index of 2 to 4 was associated with a decrease of 5% in firmness and 9% in TA. These changes would not represent a commercially significant reduction in fruit quality, given the high firmness level [90.0 N (20.2 lb)] and acid (0.79%) content of this cultivar at harvest, even at a starch index of 4.

Delaying harvest from a starch index of 2 to 4 was associated with a considerable increase in both peel color and SSC. The peel color change consisted of distinct changes in all color parameter values (L*, a*, b* and hue). The decrease in L* indicated development of a darker color. This change in L*, coupled with higher a*, lower b* and higher hue values, suggested a transition to a darker, more pink and less yellow-colored apple as the starch index changed from 2 to 4. A change of hue of

Table 2. Quality attributes after 90 or 180 d in regular atmosphere (RA) storage and 7 d ripening for 'Cripps Pink' apples harvested at starch index of 2 or 4.

Treatment	Firmness (N)[y]	SSC[z] (%)	TA[z] (% malic acid)	SSC to TA ratio	Hunter color (peel) L*	a*	b*	Hue	Internal breakdown (%)
Harvest (starch index)									
2	76.9 a[x]	14.8 a	0.58 a	26.4 a	50.1 a	30.0 a	15.9 a	28.1 a	0.0 b
4	68.2 b	14.2 b	0.53 b	27.3 a	51.3 a	28.2 a	15.6 a	29.1 a	6.2 a
RA storage (d)									
90	74.3 a	14.5 a	0.60 a	24.6 b	51.7 a	28.1 b	16.9 a	31.2 a	4.2 a
180	70.8 b	14.5 a	0.51 b	29.1 a	49.7 b	30.1 a	14.6 b	26.1 b	2.1 a
Ripe (d)									
0	75.4 a	14.5 a	0.60 a	24.8 b	50.3 a	29.0 a	15.1 b	27.6 a	0.0 b
7	69.7 b	14.5 a	0.51 b	28.9 a	51.1 a	29.2 a	16.4 a	29.7 a	6.2 a

[z]SSC = soluble solids concentration, TA = titratable acidity.
[y]4.45 N = 1.0 lb of force.
[x]Means in a column, within treatments, not followed by a common letter are significantly different by analysis of variance ($P \leq 0.05$).

this magnitude would be very visible to the human eye, given that a one unit change in hue value is considered visible (Hunter and Harold, 1987). SSC increased by 1% during the 10 to 15 d required for the starch index to change from 2 to 4. This increase in SSC, coupled with a decrease in TA, resulted in a significantly higher SSC to TA ratio for apples harvested at a starch index of 4. Consumer preference for apples is reported to improve with increased SSC to TA ratios (Boylston et al., 1994).

After RA storage, differences in firmness, SSC, TA and the SSC to TA ratio between fruit harvested at a starch index of 2 versus 4 were similar to differences in those same parameters at harvest (Table 2). After RA storage, no differences in any peel color parameter could be detected in fruit harvested at starch indices of either 2 or 4. Internal breakdown of fruit harvested at a starch index of 4 versus 2 was greater after both 90 and 180 d of RA storage. After the longer RA storage period and after 7 d of simulated shelf life, flesh firmness was reduced but the SSC to TA ratio was higher and peel color showed more pink color. Even after 180 d of RA storage and 7 d at room temperature, flesh firmness of the stored fruit remained excellent [69.7 N (15.6 lb)]. The increase in pink color was most probably due to a loss of chlorophyll during storage. Fruit from either 90 or 180 d RA displayed similar amounts of internal breakdown. Internal breakdown of the fruit was more evident after ripening. Apple quality attributes in other cultivars show similar changes with longer storage time and with ripening, but such cultivars rarely, if ever, demonstrate commercially acceptable levels of flesh firmness after 6 months in RA storage (Drake and Kupferman, 2000; Lau and Looney, 1982; Meheriuk and Pruitt, 1973).

As with apples from RA storage, apples harvested at a starch index of 4 and stored under CA conditions contained less acid and were not as firm as apples harvested at a starch index of 2 (Table 3). Color did not change and no internal breakdown was evident under the longer CA storage period, regardless of starch index at harvest. CA storage regime produced a minor difference in the SSC to TA ratio (+0.7 units) and a very distinct difference in color, particularly in L* and hue values. Apples stored in 3% CO_2 were darker in color with more pink than apples stored in an atmosphere of 1% CO_2. During the first year of this study, apples were also stored in an atmosphere of 1% O_2 and 5% CO_2. This storage atmosphere resulted in significant loss of firmness and increased internal breakdown regardless of harvest maturity or storage time (data not shown).

As CA storage time progressed from 90 to 180 d, there was no change in firmness, SSC or color, but TA decreased and SSC to TA ratio increased (Table 3). It is doubtful that this small decrease in TA (–0.05%), though statistically significant, would be detectable by the consumer. The same can be said for the increase in the SSC to TA ratio, which was only 2.3 units. A 7-d ripening period following CA storage resulted in decreased firmness and TA coupled with increased SSC and the SSC to TA ratio. Despite the small firmness loss during the ripening period [3.9 N (<1 lb)], the firmness value for apples stored in CA for 180 d and ripened for 7 d was well in excess of minimum commercial standards (62 N or 14 lb). In all instances in this study, the firmness of 'Cripps Pink' apples was excellent regardless of harvest date, time in storage, storage atmosphere, or ripening. Similarly, it is doubtful that the changes in SSC, TA and the SSC to TA ratio during the 7-d ripening period would be noticed by the average consumer.

Both carbohydrate and acid contents of 'Cripps Pink' apples changed with delayed harvest (Table 4). SSC, glucose, and fructose levels were lower and sorbitol higher at a starch index level of 4 versus 2. Sucrose content was not related to starch index at harvest. Storage atmosphere influenced only sorbitol content, which was higher when fruit were stored at 1% O_2 and 3% CO_2. Longer storage time under CA conditions resulted in higher glucose, fructose and sorbitol levels, but had no influence on SSC or sucrose. Apples harvested at a starch index of 4 had higher levels of malic acid, shikimic acid, and citric acid. An increase in the level of CO_2 in the CA atmosphere from 1% to 3% resulted in a decrease in the content of malic acid, citric acid, and fumaric acid. Seven days of ripening resulted in reduced malic acid and citric acid levels. Similar changes in individual carbohydrate and acid content related to time of harvest, storage atmosphere

Table 3. Influence of harvest time, controlled-atmosphere (CA) storage atmosphere, CA storage time and ripening time on 'Cripps Pink' apples, years 2 and 3.

Treatment	Firmness (N)[y]	SSC[z] (%)	TA[z] (% malic acid)	SSC to TA ratio	Hunter color (peel) L*	a*	b*	Hue	Internal breakdown (%)
Harvest (starch index)									
2	91.9 a[x]	14.7 a	0.64 a	23.2 b	52.2 a	25.9 a	15.4 a	31.1 a	0.0
4	85.2 b	14.7 a	0.63 b	23.7 a	52.5 a	25.7 a	14.8 a	30.4 a	0.0
CA atmosphere[w]									
1% O_2 + 1% CO_2	88.8 a	14.7 a	0.65 a	23.1 b	53.3 a	23.9 b	16.6 a	35.1 a	0.0
1% O_2 + 3% CO_2	88.3 a	14.7 a	0.63 b	23.8 a	51.4 b	27.8 a	13.6 b	26.4 b	0.0
CA storage (d)									
90	88.3 a	14.6 b	0.66 a	22.3 b	52.0 a	25.5 a	14.5 b	30.0 a	0.0
180	88.8 a	14.7 a	0.61 b	24.6 a	52.7 a	26.1 a	15.7 a	31.5 a	0.0
Ripe (d)									
0	90.5 a	14.6 b	0.69 a	21.3 b	52.5 a	25.4 a	15.2 a	31.2 a	0.0
7	86.6 b	14.8 a	0.58 b	25.6 a	52.1 b	26.2 a	15.0 a	30.4 a	0.0

[z]SSC = soluble solids concentration, TA = titratable acidity.
[y]4.45 N = 1.0 lb of force.
[x]Means in a column, within treatments, not followed by a common letter are significantly different by analysis of variance ($P \leq 0.05$).
[w]O_2 = oxygen, CO_2 = carbon dioxide.

Table 4. Carbohydrate and acid contents of 'Cripps Pink' apples as related to starch index at harvest, controlled-atmosphere (CA) storage condition and CA storage time.

Treatment	SSC[y] (%)	Carbohydrates (mg/100 mL)[z]				Acids (mg/100 mL)			
		Sucrose	Glucose	Fructose	Sorbitol	Malic	Shikimic	Citric	Fumaric
Harvest (starch index)									
2	12.9 a[x]	3.8 a	0.97 a	4.4 a	0.63 b	662.6 b	0.31 b	9.4 b	0.04 a
4	11.3 b	4.0 a	0.86 b	4.2 b	0.75 a	770.9 a	0.40 a	14.1 a	0.04 a
Controlled atmosphere[w]									
1% O_2 + 1% O_2	12.1 a	3.9 a	0.91 a	4.4 a	0.67 b	738.6 a	0.36 a	12.4 a	0.03 b
1% O_2 + 3% O_2	12.0 a	3.9 a	0.93 a	4.3 a	0.71 a	694.9 b	0.35 a	11.1 b	0.05 a
Controlled-atmosphere storage (d)									
90	11.9 a	4.1 a	0.79 b	4.1 b	0.59 b	784.9 a	0.34 a	12.7 a	0.03 b
180	11.6 a	4.0 a	0.98 a	4.6 a	0.83 a	648.7 b	0.34 a	10.7 b	0.03 b

[z]1.00 mg/100 mL = 10 ppm.
[y]SSC = soluble solids concentration.
[x]Means in a column, within treatments, not followed by a common letter are significantly different by analysis of variance ($P \leq 0.05$).
[w]O_2 = oxygen, CO_2 = carbon dioxide.

and storage and poststorage time were observed in a study with 'Jonagold' apples (Drake and Eisele, 1999).

Conclusions

Acceptable fruit quality can be achieved following long-term storage when 'Cripps Pink' apples are harvested at a starch index between 2 and 4 and stored under either RA or CA conditions. This harvest window of some 10-15 d, depending on the season, permits harvest scheduling to be based on other factors, such as weather conditions, which can be unfavorable at this time of year, or the desire for higher SSC and better fruit color, should either represent a marketing concern. The absence of a detectable fruit size increase over the 3 years of this study likely reflects the short day-length, cloudy weather, cold temperatures, increased risk of frost and deteriorating foliage typical in late fall in Washington, all of which significantly limit photosynthetic activity (Fujii and Kennedy, 1985). Firmness and acids remain at acceptable levels in 'Cripps Pink' apples from either long-term RA or CA storage. 'Cripps Pink' apples held in RA storage up to 180 d maintain acceptable poststorage quality. 'Cripps Pink' apples also respond well to CA storage conditions using 1% O_2 at between 1% and 3% CO_2.

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