HORTSCIENCE 33(2):302–304. 1998.

Harvest Indices, Storability, and Poststorage Refrigeration Requirement of 'Sunrise' Apple

O.L. Lau[1]
Industry Research Program, Okanagan Federated Shippers Association. c/o Agriculture and Agri-Food Canada, Pacific Agri-Food Research Centre, Summerland, B.C. V0H 1Z0, Canada

W.D. Lane
Agriculture and Agri-Food Canada, Pacific Agri-Food Research Centre, Summerland, B.C. V0H 1Z0, Canada

Additional index words. postharvest physiology, *Malus ×domestica*, controlled atmosphere, flesh firmness, physiological disorders

Abstract. **Starch index and seed color are useful harvest indices for 'Sunrise' apple (*Malus ×domestica* Borkh.). Increases in starch index value (≈1.4 units per week) and percent brown seed color (≈27% per week) were linearly correlated with harvest time and paralleled the increase in percent ripe fruit. 'Sunrise' was best picked, within a 1-week harvest window, at starch index values between 2.5 and 3.5 on a 0–9 scale, percent brown seed color of 30% to 50%, and flesh firmness of 69 to 73 N. Firmness loss was comparable to other apple cultivars during harvest (≈5 N per week) and during air or CA storage. However, 'Sunrise' fruit lost 18 to 27 N firmness during a 7-d 20 °C poststorage shelf-life test, resulting in fruit that was well below 49 N, the minimal firmness for consumer acceptance. Fruit previously stored at 0 °C had a shelf-life of 3 to 4 d at 20 °C, even though the fruit was picked at the correct maturity and had 70 to 74 N firmness at the end of storage. To ensure good eating quality, fruit must be held continuously at 0 °C until consumption. Firmness loss during shelf-life tests was higher for fruit harvested at starch index values between 1.3 and 2.4 and held in 0 °C air for 3 to 12 d (13 to 24 N firmness drop) than for fruit left on the tree and harvested at starch index 2.9 (10 N firmness drop). Fruit held in storage for 1 to 3 months were susceptible to flesh browning, flesh breakdown, core browning, stem-end browning, and storage rots. Early-picked (starch index <2.4) fruit held in CA for 1 month developed skin disorders resembling those of CO_2 injury and scald.**

'Sunrise' is a summer apple developed at Agriculture and Agri-Food Canada, Summerland, B.C. (Lane et al., 1996). Good taste, bright color, distinctiveness of appearance from other cultivars (20% to 80% bright pinkish red on a pale yellow background), and good horticultural traits are the cultivar's primary attributes. When picked at proper maturity and consumed quickly, 'Sunrise' is a high-quality eating apple for its season: crisp and juicy, sweet without an acidic taste, and mild in flavor.

The objectives of this study were to establish useful harvest indices for 'Sunrise' apple and to assess storage potential and shelf-life of this cultivar in relation to harvest maturity and storage regime.

Received for publication 10 Mar. 1997. Accepted for publication 27 Aug. 1997. Contribution No. 1016 Agriculture and Agri-Food Canada, Pacific Agri-Food Research Centre, Summerland, B.C. This work was supported in part by an Okanagan Valley Tree Fruit Authority grant awarded to O.L. Lau. Appreciation is extended to R. Yastremski, P. Schofield, L. Ostergaard, C. Holmes, J. Dodd and S. Horton for their capable assistance. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.
[1]To whom reprint requests should be addressed.

Materials and Methods

1991 experiment (3- and 3.5-month storage). 'Sunrise' apple samples (70 fruit each; 10 fruit for prestorage fruit maturity measurement and two replicates of 30 fruit for two storage treatments) were harvested at 7-d intervals between 14 Aug. and 11 Sept. from each of five mature trees in a test block at Agriculture and Agri-Food Canada, Pacific Agri-Food Research Centre. Following harvest, 10 apples per sample were evaluated for internal ethylene concentration (IEC) by gas chromatography, flesh firmness with a Magness–Taylor pressure tester, red skin color by visual estimation, starch index value by staining with I_2-KI, and seed color by visual estimation according to methods described previously (Lau, 1985, 1988). Starch index values of 0, 1, 2, 3, 4, 5, 6, 7, 8, and 9 represent 0%, 10%, 17%, 26%, 38%, 51%, 67%, 78%, 85%, and 99%, respectively, of the cross-sectional area of fruit clear of starch. For storage, fruit were cooled overnight at 0 °C before placement of samples in 0 °C air or CA cabinets (1.2 kPa O_2 + 1.5 kPa CO_2 established within approximately 1 d of sealing), with ≈90% to 92% relative humidity. Flesh firmness and incidence of storage disorders (Lau, 1988) were evaluated on 30 fruit stored in air for 3 months or in CA for 3.5 months at 0 °C and held an additional 7 d in air at 20 °C.

1992 experiment (30- and 50-d storage). 'Sunrise' apple samples (70 fruit each; 10 fruit for maturity determination and two replicates of 30 fruit for storage study) were obtained at 10-d intervals between 20 July and 9 Aug. from each of six groups of 2- to 3-year-old trees in two commercial orchards (three groups per orchard). Maturity and quality and maturity measurements, and storage procedures and treatments were as described for 1991. After 30 and 50 d in air or CA storage at 0 °C and 7 d in air at 20 °C, each storage sample was examined for flesh firmness and incidence of storage disorders

1993 experiment (3- to 24-d storage). 'Sunrise' apples (90 fruit each; 10 fruit for maturity evaluation and four replicates of 20 fruit for two storage treatments and two examination dates) were harvested from 3- to 4-year-old trees from six commercial orchards at 3-d intervals between 2 Aug. and 14 Aug. in 1993. Maturity and quality evaluations and storage procedures and treatments were as described for 1991 and 1992. Each storage sample was assessed for flesh firmness and incidence of storage disorders upon removal from the air and CA storage on 14 Aug. (after 0 to 12 d) and 26 Aug. (after 12 to 24 d) and again on 21 Aug. and 2 Sept. (after 7 d in 20 °C air).

Data analysis. Data for flesh firmness and disorder were subjected to analysis of variance (ANOVA; SAS, 1989) to test for a harvest date and storage treatment interaction. The contrast option in the GLM procedure (SAS, 1989) was used to determine significance of the trend of response of flesh firmness and storage disorders to harvest date. Percent values were square root arcsin transformed before variance analysis.

Results and Discussion

Changes in starch index, percent ripening fruit, percent seed color, flesh firmness, and skin color during harvest. An increase in starch index (≈1.4 index number per week), percent ripening fruit (fruit with IEC >1 $\mu L \cdot L^{-1}$; ≈10% per week) and percent brown seed color (≈27% per week), and a decrease in flesh firmness (≈5 N per week) was observed in 'Sunrise' apples during maturation and ripening in 1991–93 (Fig. 1; Tables 1 and 2). Starch index values were correlated with percent ripening fruit and percent seed color. Also, the initial increase in starch index occurred 2 to 14 d before the increase in percent ripening fruit (Fig. 1). The results suggest that starch index is a simpler and more practical harvest predictor than IEC. An association between the timing of ethylene production and the increase of starch index at harvest time has been reported for 'Jonagold' and 'McIntosh' apples (Lau, 1988, 1989).

'Sunrise' fruit were 25% to 50% red in color at harvest, depending on exposure to the sun and local weather conditions preceding harvest. A hot July in 1994 (mean temperature of 23.9 °C compared to 20.9 °C in 1991, 20.3 °C in 1992, and 17.6 °C in 1993) resulted in 'Sunrise' fruit that ripened quickly and soft-

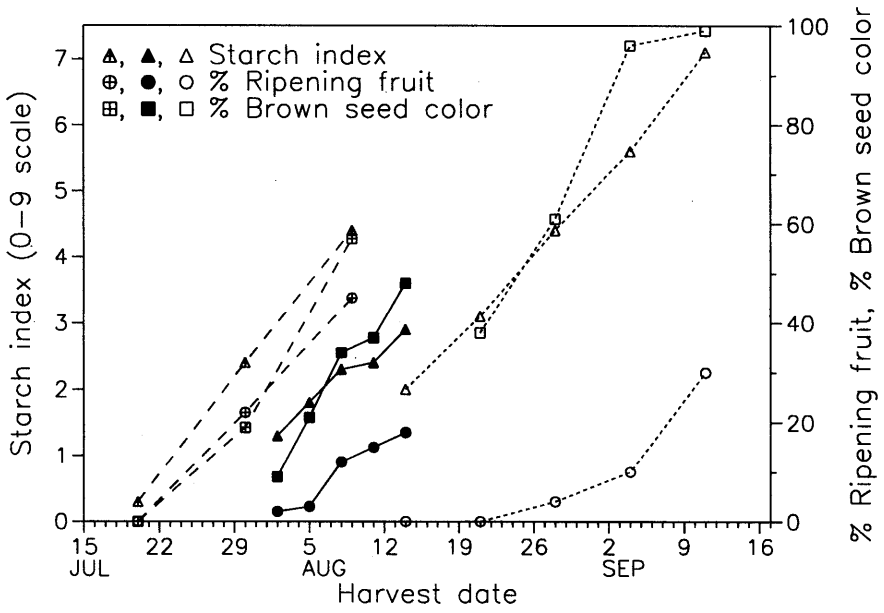

Fig. 1. Changes in starch index value, percent ripening fruit (fruit with internal ethylene concentration >1 $\mu L \cdot L^{-1}$) and percent brown seed color in 'Sunrise' apples during maturation and ripening [1991: open symbols (n = 5); 1992: crossed symbols (n = 2 × 3); 1993: closed symbols (n = 6)].

ened excessively prior to the development of sufficient red color (data not shown). Skin color and flesh firmness are not true indicators of the maturity of apple fruit, as they vary considerably with orchard and season (Lau, 1985, 1989).

Poststorage flesh firmness and shelf life. 'Sunrise' fruit picked at starch index values between 2.3 and 2.9 had a satisfactory flesh firmness of 70 to 74 N upon removal from 0 °C air storage after 12 to 18 d (Table 1). However, the fruit lost 27 to 29 N firmness during the shelf-life test (Table 1) compared with only 4 to 7 N firmness decrease in other apple cultivars during the same period (Lau and Meheriuk, 1994). After the shelf-life test, 'Sunrise' fruit from air storage were well below the minimal acceptable firmness of 49 N regardless of harvest maturity and type and length of storage (Tables 1, 2, and 3). Fruit held in CA were ≈5 N firmer than fruit held in air (Tables 1 and 2). In 1993, for example, fruit picked on 8 Aug. (starch index 2.3) and held in 0 °C air and CA for 6 d lost 20 N and 12 N, respectively, during the shelf-life test. Those held in air and CA for 18 d lost even more firmness, 29 and 21 N, respectively, during the same period (Table 1).

Table 1. Effect of harvest date and storage regime on flesh firmness, storage rots, and skin disorders in 'Sunrise' apples held for 0 to 24 d in air or CA[z] at 0 °C, and 7 d in air at 20 °C (1993[y], n = 6 commercial orchards).

			Flesh firmness (N)								Storage rots (%)				Skin disorders (%)			
			After 0–12 d at 0 °C				After 12–24 d at 0 °C				0–12 d at 0 °C		12–24 d at 0 °C		0–12 d at 0 °C		12–24 d at 0 °C	
Harvest date	Starch index (0–9) at	Flesh firmness (N) at	At removal 14 Aug.		+7 d 20 °C 21 Aug.		At removal 26 Aug.		+7 d 20 °C 2 Sept.		+7 d 20 °C 21 Aug.		+7 d 20 °C 2 Sept.		+7 d 20 °C 21 Aug.		+7 d 20 °C 2 Sept.	
(Aug.)	harvest	harvest	Air	CA	Air	CA	Air	CA	Air	CA	Air	CA	Air	CA	Air	CA	Air	CA
2	1.3 ± 0.8	75 ± 5	73	70	48	61	76	75	49	56	2	1	2	0	0	0	0	26
5	1.8 ± 0.9	74 ± 5	72	69	49	57	76	74	47	53	1	0	0	1	0	0	0	32
8	2.3 ± 1.2	72 ± 5	72	69	51	57	74	72	45	51	5	0	4	3	0	0	3	20
11	2.4 ± 1.0	69 ± 6	68	66	55	61	72	71	45	53	0	1	5	2	0	0	0	5
14	2.9 ± 1.2	68 ± 4	67	67	57	57	70	70	43	49	1	1	4	8	0	0	0	3
Harvest date			L*	NS	L*	NS	L***	L***	L***	L**	NS	NS	NS	L*	NS	NS	NS	L***
Storage (air vs. CA)			***		***		**		***		NS		NS		NS		***	
Harvest date × storage			NS		**		NS		NS		NS		NS		NS		*	

[z]CA = 1.2 kPa O_2 + 1.5 kPa CO_2.
[y]July was wet and cool.
NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively; L = linear.

Table 2. Effect of harvest date and storage regime on flesh firmness and storage disorders in 'Sunrise' apples held for 30 and 50 d in air or CA[z] at 0 °C, and 7 d in air at 20 °C (1992; n = 6 groups of trees from 2 commercial orchards).

	Starch index (0–9)	Flesh firmness (N)			Flesh breakdown (%)		Core browning (%)		Stem-end browning (%)		Storage rots (%)		Skin disorders (%)	
Harvest date	Harvest	Harvest	Air	CA	Air	CA	Air	CA	Air	CA	Air	CA	Air	CA
After 30 d in 0 °C storage + 7 d in 20 °C air														
20 July	0.3 ± 0.3	84 ± 5	49	57	0	1	0	0	1	4	2	3	3	13
30 July	2.4 ± 1.2	77 ± 4	45	52	1	1	0	0	0	0	3	6	0	0
9 Aug.	4.4 ± 1.2	66 ± 7	39	41	8	5	1	8	0	0	11	7	0	0
Harvest date			L**	L***	L**	NS	NS	L*	NS	L*	L**	NS	NS	Q**
Storage (air vs. CA)			**		NS		NS		NS		NS		*	
Harvest date × storage			NS		NS		NS		NS		NS		**	
After 50 d in 0 °C storage + 7 d in 20 °C air														
20 July			50	58	0	0	0	0	0	0	3	4	0	12
30 July			43	45	3	2	0	2	0	0	8	7	0	0
9 Aug.			39	40	5	8	1	13	0	0	16	17	0	0
Harvest date			L***	L***	NS	L*	NS	L*	NS	NS	L**	L*	NS	Q***
Storage (air vs. CA)			**		NS		*		NS		NS		***	
Harvest date × storage			*		NS		NS		NS		NS		***	

[z]CA = 1.2 kPa O_2 + 1.5 kPa CO_2.
NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively; L = linear, Q = quadratic.

Table 3. Effect of harvest date on flesh firmness and storage disorders in 'Sunrise' apples after 3-month air[z] storage or 3.5-month CA[y] storage at 0 °C, plus 7 d in air at 20 °C (1991; n = 5 single trees).

Harvest	Starch index (0–9)	Flesh firmness (N)			Flesh browning (%)		Flesh breakdown (%)		Core browning (%)		Stem-end browning (%)		Storage rots (%)		Skin disorders (%)	
date	Harvest	Harvest	Air	CA	Air	CA	Air	CA	Air	CA	Air	CA	Air	CA	Air	CA
14 Aug.	2.0 ± 0.3	72 ± 2	47	57	0	3	32	0	6	0	17	4	18	20	0	8
21 Aug.	3.1 ± 0.5	77 ± 3	43	53	0	2	33	0	3	0	16	2	17	24	0	18
28 Aug.	4.4 ± 0.7	69 ± 2	42	48	0	3	17	0	11	0	20	5	13	12	0	3
4 Sept.	5.6 ± 0.7	63 ± 4	42	41	0	15	14	3	0	0	7	3	14	20	0	13
11 Sept.	7.1 ± 0.6	59 ± 3	41	37	0	43	14	7	0	0	6	0	15	15	0	14
Harvest date			L^{***}	L^{***}	NS	Q^{**}	L^{**}	NS	q^{*}	NS	L^{***}	NS	NS	NS	NS	NS

[z]Fruit were examined on 26 Nov.
[y]CA = 1.2 kPa O_2 + 1.5 kPa CO_2. Fruit were examined on 12 Dec.
NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively; L = linear, Q = quadratic, q = quartic.

Short (<7 d) shelf-life at 20 °C is the most significant weakness of 'Sunrise' apples.

Fruit held in CA at 0 °C for 0 to 12 d and 12 to 24 d lost ≈10 N (5 to 12 N) and 20 N (19 to 21 N) of firmness, respectively, during the shelf-life test (Table 1). However, firmness loss during the shelf-life test was 14, 12, 10, and 3 N greater, respectively, for air-stored fruit picked on 2, 5, 8, and 11 Aug. (held at 0 °C air for 12, 9, 6, and 3 d) than for fruit left on the tree until 14 Aug. (0 d in 0 °C air). This was possibly due to a "tree" effect (Burg and Burg, 1964) inhibiting ripening in late picked fruit, and/or a "chilling" effect (Knee et al., 1983) stimulating ripening in early picked fruit.

Storage disorders. In 1992, late-picked fruit (starch index >4.4) held in storage for longer than 1 month were susceptible to flesh breakdown, core browning, and storage rots (Table 2). Prolonged storage of fruit from the 1991 season increased the incidence of flesh breakdown, core browning, stem-end browning, and storage rots in air-stored fruit and flesh browning and storage rots in CA-stored fruit (Table 3). Storage in CA did not prevent these disorders and increased the incidence of skin disorders (resembling scald and CO_2 injury) in early-picked (starch index <2.4) fruit stored longer than 1 month (Tables 1 and 2).

In summary, 'Sunrise' fruit are best picked within a 1-week harvest window when the starch index is between 2.5 and 3.5, the percent brown seed color is between 30% to 50%, and the flesh firmness is between 69 to 73 N. Storage life is estimated to be 2 to 3 weeks in air storage and 1 month in CA storage. Shelf-life (20 °C in air) is a maximum of 3 to 4 d. Flesh firmness after a 7-d shelf-life test is often well below the minimum acceptable level of 49 N, even if the fruit are picked at the correct maturity, held in CA, or have a high flesh firmness of 70 to 74 N on removal from storage. 'Sunrise' fruit must be packed and shipped within 1 month of harvest. Refrigeration is required to conserve firmness until consumption.

Literature Cited

Burg, S.P. and E.A. Burg. 1964. Evidence for a natural occurring inhibitor of fruit ripening. Plant Physiol. 39(Suppl):x.

Knee, M., N.E. Looney, S.G.S. Hatfield, and S.M. Smith. 1983. Initiation of rapid ethylene synthesis by apple and pear fruits. J. Expt. Bot. 34:1207–1212.

Lane, W.D., R.A. MacDonald, O.L. Lau, and K.O. Lapins. 1996. Sunrise apple. Can. J. Plant Sci. 76:165–167.

Lau, O.L. 1985. Harvest indices for B.C. apples. B.C. Orchardist 7(7):1A–20A.

Lau, O.L. 1988. Harvest indices, dessert quality, and storability of 'Jonagold' apples in air and controlled atmosphere storage. J. Amer. Soc. Hort. Sci. 113:564–569.

Lau, O.L. 1989. Harvest indices for British Columbia-grown apples, p. 115–120. In: J.K. Fellman (ed.). Proc. 5th Intl. Controlled Atmosphere Res. Conf., Wenatchee, Wash.

Lau, O.L. and M. Meheriuk. 1994. The effect of edible coatings on storage quality of McIntosh, Delicious and Spartan apples. Can J. Plant Sci. 74:847–852.