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An Evaluation of Harvest Indices for 'McIntosh' Apples in Two Orchards

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Abstract. **Harvest indices were measured in 2 mature bearing orchards of 'McIntosh' apple (*Malus domestica*, Borkh.) in 2 seasons. Full bloom dates differed between the 2 orchards by 4 days in one season and 7 days in the other. Heat-unit accumulation during the growing season differed between the 2 orchards by 27%. The onset of the accelerated rate of ethylene production (AREP) began 133 days past full bloom in both orchards. The first significant increase in skin anthocyanin occurred before the AREP in the higher elevation orchard and after the AREP in the lower elevation orchard. Changes in flesh firmness, soluble solids, acidity, and skin chlorophyll were not significantly different before and after the AREP. The optimum harvest dates, evaluated by poststorage analysis, were on the AREP in the higher elevation orchard and after the AREP in the lower elevation orchard.**

The need for proper timing of apple harvesting to insure maximum quality and storage life has long been recognized. Many harvest indices have been used in an attempt to determine the optimum harvest period. However, seasonal variability and variations in orchard conditions limit the reliability of most indices for optimum harvest. Nevertheless, one or more of these indices are generally used to determine when to pick. The purpose of this study was to examine the usefulness of several harvest indices for 'McIntosh' apples in 2 closely situated, but environmentally different orchards.

Two 'McIntosh' orchards in Onondaga County, N.Y. were selected for this study. Orchard "A" was planted at an elevation of 482 m in 1971 on Malling-Merton 106 rootstocks at a spacing of 4.6 × 7.3 m. Orchard "B", located 3.2 km away, was planted at an elevation of 195 m in 1956 on Malling 7 rootstocks at a spacing of 6.1 × 8.5 m. Full bloom was considered to be the day when 80% of the blossoms on the north side of the trees were open, and bees were working actively. Thermographs and matched maximum-minimum thermometers to calibrate the thermographs were used to monitor temperature in both orchards from tight cluster until after harvest. The mean temperature during the growing season was 1.7°C higher in the orchard at the lower elevation than that in the higher elevation during both seasons. The optimum harvest date for storage was predicted for both orchards using bloom date and temperature data in the formula for Central New York 'McIntosh' apples developed by Blanpied and Ben-David (2).

To minimize differences in nutritional status between the 2 orchards, leaf samples were taken in mid-August from 20 trees at each location for nutrient element analysis. Then, 6 trees of similar nutritional status were selected for study at both locations.

Apples were harvested on 7 or 8 dates at 3–4 day intervals centered around the predicted optimum harvest date. A 40-apple sample of well-exposed apples was picked at random from the periphery of each of the 6 trees at each orchard on each harvest date. Twenty apples from each sample were placed in cold storage (0°C). The other 20 apples were used to measure flesh firmness, soluble solids, total acidity, anthocyanin concentration, and ethylene evolution on the day after harvest.

Flesh firmness was measured with an Effegi pressure tester as previously described (3). One test was made on each of 15 fruits from each of the 6 tree replicates. Wedge-shaped sections from these 15 fruits were juiced in an Acme Supreme Juicerator. Soluble solids of each juice sample was measured with a hand-held refractometer, and total acidity was measured by titrating 50 ml of juice with a 0.1 N NaOH solution to pH 8.

One disc (7 mm diameter) was cut from the reddest portion of the skin from each of the 15 apples from each of the 6 replicate trees. Anthocyanin was extracted by placing the 15 discs into 10 ml of 0.1 N HCl in methanol and storing the samples at −18°C until the end of the harvest period. Absorbance was then measured at 528 nm with a Beckman DU-8 spectrophotometer. Anthocyanin concentration was determined by using a molar extinction coefficient of 4.62×10^4 (9) and was expressed as nanomoles per cm^2 of apple skin. The skin chlorophyll content was measured as absorbance of these extracts at 653 nm. Several absorbance readings were also taken at 650 and 665 nm to combine the equations listed by Holden (7) into a single equation which uses a single absorbance reading at 653 nm. The following equation was developed to determine chlorophyll concentration of the extracts: chlorophyll (mg/liter) = $24.88 \times A^{653}$.

Ethylene evolution was measured by placing the remaining 5 apples from each of the 6 tree replicates into respirometer jars flushed with ethylene-free air (200 cc/min) at 20°C. The ethylene concentration in 1-ml samples of the jar effluents was measured with a Varian Aerograph Series 1800 fitted with an activated alumina column and flame-ionization detector.

In mid-February, the samples were removed from cold storage and held at room temperature (20°C) for one week to simulate market holding conditions. Then, a poststorage evaluation of the apples was made to determine the condition of the apples and the optimum harvest dates. Five apples from each of the 6 trees from each harvest (30 apples per harvest date) were evaluated by 7 experienced panelists, who ranked the apples by harvest dates for taste (texture and flavor) and appearance (red color, ground color, and brightness of the color).

Selection of the optimum harvest date was based on firmness, panel evaluation scores, and incidence of disorders. Often, the differences in flesh firmness were small, and incidence of disorders were either very low or lacking. In these instances, the selection

Table 1. Poststorage evaluations of 'McIntosh' apples harvested from Orchard "A" in Fall 1980 (Feb. 1981).

Harvest date	Firmness (kg)	Panel Evaluation Scores[z]			Disorders %
		Eating	Appearance	Sum	Fungal rots
Sept. 23	3.9	49	49	98	0
26	3.8	25	30	55	0
30	3.8	18	20	38	0
Oct. 3	3.7	14	8	22	0
7	3.7	17	19	36	0
10	3.6	32	30	62	3
14	3.6	41	40	81	8

[z] Low score preferred.

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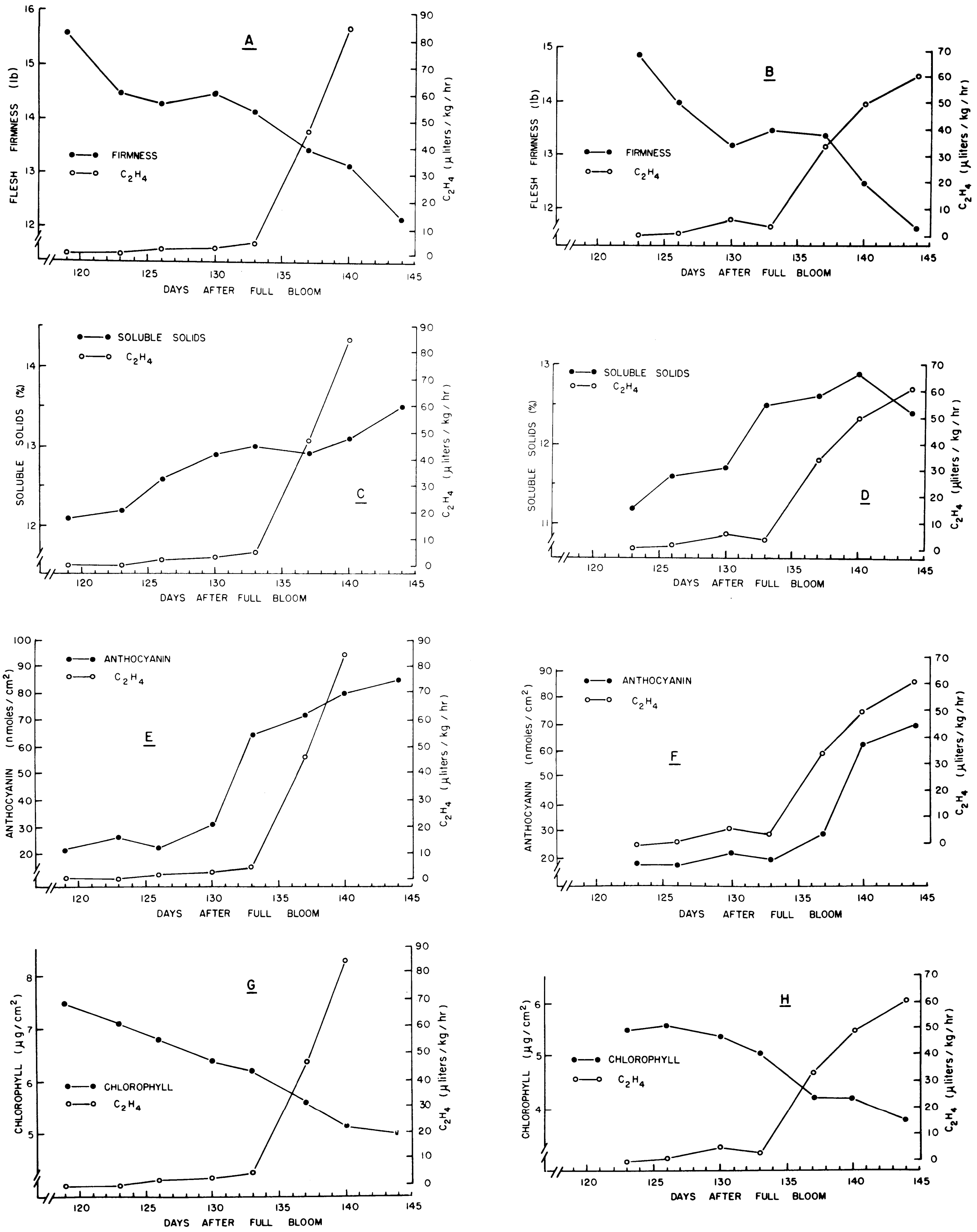

Fig. 1. Changes in firmness (A & B), soluble solids (C & D), anthocyanin (E & F), and chlorophyll (G & H) in relation to the curve for accelerated rate of ethylene production on Orchard "A" (left) and Orchard "B" (right) orchards. Points on ethylene curves represent average of ethylene production during the 72-hr period following harvest.

of optimum harvest date was based primarily on panel evaluation scores. For example, the harvest date in 1980 for Orchard "A" which had the best eating quality was also the date for the best appearance (Table 1). Storage disorders were lacking on this date, also. Firmness differed by only 0.3 kg among all 7 harvest dates. Thus, Oct. 3 was clearly the optimum harvest date for Orchard "A" in 1980.

The Orchard "B" trees were in full bloom on May 16, 1980, but full bloom of Orchard "A" trees was delayed until May 23 by the cooler climate. The date on which the accelerated rate of ethylene production (AREP) began was considered to be the harvest in which the rate of ethylene production increased significantly during the period from 24 to 48 hours after harvest. The actual (by postharvest analysis) and predicted (2) optimum harvest dates and the AREP date for Orchard "A" were Oct. 3, 6, and 3, 1980, respectively, and for Orchard "B" were Sept. 30, 27, and 26, 1980, respectively. Thus, the actual optimum harvest dates could have been estimated reasonably (± 4 days) using either Blanpied and Ben-David's formula (2) or the AREP.

A statistical comparison of the harvest indices for the 2 orchards on their respective optimum harvest dates is summarized in Table 2. Orchard "A" apples had significantly higher values for firmness, anthocyanin, and chlorophyll. There was no significant difference in soluble solids and total acidity. Orchard "B" apples produced significantly more ethylene than Orchard "A" apples on their respective optimum harvest dates because they were further along on the AREP curve.

It has long been recognized that seasonal and orchard variability limits the reliability of many harvest indices (1, 6, 11). The data in Table 2 clearly indicate that there were no absolute values which could have been assigned to the optimum harvest date. While absolute values may be useful for assessing fruit quality, they are of lesser value in determining the optimum harvest date. Often, the indices for when to pick are referred to as "maturity indices". However, the term "maturity index" may not be an accurate description. According to Lott's terminology (8) there is only one stage of maturity, i.e., apples are either mature or not. Immature apples do not have the capacity to ripen properly off the plant, and maturity is not attained until the ripening processes begin. A sharp rise in the production rate of ethylene has been interpreted as the indicator of the beginning of ripening (4, 5). Immature apples produce ethylene at very low rates. Thus, the onset of an AREP marks the attainment of maturity.

In this study, AREP occurred on 133 days past full bloom in both orchards. This suggests that the apples in both orchards reached maturity on or about 133 days past full bloom. If we choose to call "maturity indices" the changes in firmness, soluble solids, chlorophyll, and acidity, then there should be a noticeable acceleration in their rate of change when maturity is reached. Indeed, Olsen (as interviewed by Shelton) (10) suggested such changes in harvest indices were associated with the attainment of maturity.

However, data in the present study indicated that these changes began while the apples were immature and continued at the same rate after ripening was initiated (Fig. 1). There were no apparent, abrupt rate changes of these indices, as suggested by Olsen (10), which would be associated with the attainment of maturity. There was no apparent abrupt change in the rate of decrease of firmness which could be associated with AREP in either orchard (Fig. 1A, B). Likewise, soluble solids increased at a fairly steady rate before and after AREP in both orchards (Fig. 1C, D). The abrupt change in anthocyanin content was related to temperature and not to the AREP. The rapid increase in anthocyanin occurred before the AREP in Orchard "A" (Fig. 1E) and after the AREP in Orchard "B" (Fig. 1F). The decrease in chlorophyll was nearly linear both before and after AREP in both orchards (Fig. 1G, H). The changes in acidity were too small and too variable to be of much value as an index of maturity or of the optimum harvest date. Hence, the term "maturity index" may not accurately describe the variables measured in this study.

"Harvest index" seems to be a more appropriate term. The only true index of apple maturity was the onset of the AREP (4, 5). AREP is clearly an indicator that maturity had been reached. However, this study indicated that AREP is not an absolute "harvest index". The data from this study showed that the optimum harvest date for apples of Orchard "A" was at AREP, but the optimum harvest date for apples of Orchard "B" did not occur until after AREP, when the apples were significantly advanced on the AREP curve.

Thus, the absolute values of harvest-index measurements made near harvest may be useful for determining fruit quality but not for determining when to pick. While absolute values and relative changes in these indices may be helpful in selecting the harvest date, their reliability has not been demonstrated for New York 'McIntosh' apples.

Table 2. The levels of harvest indices of Orchard "A" and Orchard "B" 'McIntosh' apples at their optimum harvest dates.

Harvest index	Orchard "A"	Orchard "B"	Significance
Firmness (kg)	6.5	6.1	*
(after storage)	3.7	3.3	**
Soluble solids (%)	13.0	12.6	NS
Anthocyanin (nmoles/cm^2)	65.2	29.1	**
Chlorophyll (μg/cm^2)	6.16	4.21	**
(after storage)	5.31	3.83	**
Total acidity (mg malate/ml)	5.88	5.68	NS
(after storage)	2.68	2.68	NS
C_2H_4 (μl/kg-hr)	6.2	35.0	**
Days from AREP to OHD[z]	0	4	*

[z] Number of days from the beginning of accelerated rate of ethylene production (AREP) to the optimum harvest date (OHD).

[NS, *, **] Nonsignificant (NS) or significant at 5% (*) or 1% (**) level.

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