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'Gala,' 'Braeburn,' and 'Fuji' Apples: Maturity Indices and Quality After Storage

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Abstract

Changes in apple maturity indices and fruit quality were measured weekly at harvest and after storage for 'Gala,' 'Braeburn,' and 'Fuji' apples. Fruits were evaluated on the day of harvest and after seven days at room temperature for internal ethylene concentration (IEC), skin color, firmness, starch index (SI), total soluble solids concentration (SSC), pH, and titratable acidity (TA). Color, firmness, SSC, and TA were again measured after 6, 12, 18, and 24 weeks for 'Gala,' and 8, 16, 24, and 32 weeks for 'Braeburn' and 'Fuji' held in cold storage at 0 ± 0.5C. Optimum harvest dates were determined retrospectively using consumer taste tests conducted approximately every four weeks for 'Gala' and every eight weeks for 'Braeburn' and 'Fuji.' Horticultural maturity of 'Gala' was attained 122 DAFB for long-term storage. On that date, SI was highly variable, SSC was at 11 °Brix, and IEC averaged one ppm, but fruit color was not fully developed. Later-harvested fruit had the best eating quality after short-term storage in October and November. 'Braeburn' picked 168 and 175 DAFB had the best storage potential. SSC was the most obvious maturity index in 1991. Fruit harvested 154 DAFB was already capable of producing autocatalytic ethylene when ripened seven days at 20C. SI increased too late (175 DAFB) to be used as a predictor of harvest. Fruit harvested before 168 DAFB developed scald and later harvested fruit had very low sensory ratings after 24 weeks in storage. IEC in 'Fuji' fruit stayed at low levels and without autocatalytic production and therefore could not be used as a physiological predictor of maturity. Obvious indices were the starch index and hue value of the ground color. The former increased suddenly and the latter decreased by 173 DAFB. Only fruit picked 173 and 180 DAFB were free from scald and retained good sensory quality after eight months storage.

Among the many new varieties of apples, 'Gala,' 'Braeburn,' and 'Fuji' have received special attention from growers in the main producing areas of the world. 'Gala' is the result of a cross between 'Kid's Orange Red' ('Cox's Orange Pippin' x 'Delicious') and 'Golden Delicious,' and originated in New Zealand in 1934 (6). 'Braeburn' is a chance seedling from 'Lady Hamilton' discovered in 1952 in the Nelson area of New Zealand (14). 'Fuji' was selected from a cross between 'Delicious' and 'Rall's Janet' in 1939 at the Morioka Research Station in Japan (6). All three varieties have numerous sports, mainly classified on the degree of red color. Increasing commercial production of these varieties in the Pacific Northwest has prompted interest in finding practical indices to predict optimum fruit quality for different storage durations.

Optimum picking date has been stated to be at the beginning of the respiratory climacteric in 'McIntosh' apple (22). In climacteric fruit, such as apple, the increase in ethylene production appears coincidentally with the increase of internal CO_2 (18). In practice, ethylene measurements are preferred to respiration rate, and a delay between detectable ethylene and the autocatalytic production has permitted adjustment of picking date for numerous cultivars (5, 12, 25). The year-to-year variation of ethylene production as well as the distinctive pattern for each cultivar has accounted for the

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lack of a single ethylene value as an index for maturity (3, 5). Although still under discussion, ethylene has been used as a physiological indicator of maturity and correlated with other parameters that are easier to measure in the field, such as starch index, "a" value for ground color, soluble solids, red color, and firmness (13, 23). Chlorophyll loss and increase of carotenoids has also been associated with the climacteric rise in 'Cox's Orange Pippin' apple (10). In the end, however, the true optimum harvest date can be assessed only after examining fruit out-of-storage (7, 11).

Maturity studies have often been complemented with taste panels in an attempt to define measurable indices for quality (4, 11, 19). A taste panel conducted by Knee and Smith (11) showed that a perceived decrease in acidity and a decrease in firmness accounted for the participants' ability to discriminate between stored fruit from different harvest dates.

In the work reported herein, physical and chemical changes occurring during the ripening process of 'Gala,' 'Braeburn,' and 'Fuji' apples were measured at harvest and after storage. Consumer taste tests evaluated quality, after storage, of fruit harvested at weekly intervals over a six-week period. These data were then used retrospectively to determine optimum picking dates for each variety.

Materials and Methods

Plant material

Fruits of 'Royal Gala,' standard 'Braeburn,' and 'Fuji' ('Moriho-fu #2' strain) were sampled weekly in a commercial orchard near Wenatchee, WA, on 15, 15, and 40 marked trees, respectively. The six-year-old 'Gala'/M.7 trees were trained to a vertical axis. 'Braeburn' trees were from scions that had been topgrafted four years earlier on three-year-old 'Delicious'/M.7 and 'Delicious'/M.106, and were free standing. 'Fuji'/M.26 trees were in their fourth leaf and trained to a vertical axis.

Fruits that appeared to be the most mature based on ground color and fruit size were picked on each sampling date. For each sampling, 20 fruits were evaluated on the day of harvest, and another 20 fruits were evaluated after seven days at 20C. An additional 220 fruits were kept in regular storage (0 ± 0.5C) for later evaluation as described in the storage study and for taste evaluation. Harvest dates for the three cultivars ranged from: 12 Aug. to 16 Sept. [108 to 143 days after full bloom (DAFB)] for 'Royal Gala,' 5 Sept. to 28 Oct. (133 to 186 DAFB) for 'Braeburn,' and 9 Sept. to 28 Oct. (138 to 187 DAFB) for 'Fuji.' Fruits of 'Braeburn' and 'Fuji' from the last sampling were exposed to a frost at -3C on the night before harvest; this occurred four and seven days after the date of the second to last harvest of 'Braeburn' and, 'Fuji,' respectively.

Maturity indices

Internal ethylene concentration (IEC) was quantified as described by Williams and Patterson (26). One ml of internal ethylene sampled from the core of individual fruits were analyzed on a Hewlett-Packard 5880 GC with a flame ionization detector. The glass column (30 cm, 0.32 cm i.d.) was packed with 80-100 mesh Porapack Q and held isothermally at 50C. Injector and detector temperatures were 150C and 200C, respectively. Gas flows for N_2 carrier, H_2, and air were 25, 20, and 340 ml·min^{-1}, respectively.

Color was measured with a Minolta CR-200 chromameter calibrated to a white standard illuminant condition C(6774K). Two readings were taken per apple on the spot containing the least (shaded, or ground side of the fruit) and the most (sun-exposed, or surface side of the fruit) red color. The tristimulus L^*, a^*, b^* measurement mode of the, CIE (Commission Internationale d'Eclairage) color space was used (15). Hue angle is reported and was calculated from the arctangent of

b^*/a^* (15). The sun exposed side was not considered as a maturity indicator since the red color varies with environmental factors (21) and is not representative of fruit maturity (24).

Firmness was measured on three pared sides of the fruit, avoiding the sun-exposed side, with an EPR-1 electronic penetrometer (Lake City Technical Products, Kelowna, BC, Canada) equipped with an 11-mm tip. The extent of fruit starch hydrolysis was estimated after staining a horizontal section of the fruit with a 0.5% iodine in potassium iodine solution and rated on a 1-6 scale (1 = full starch, 6 = clear of starch), as described in the Apple Maturity Program Handbook (2). Total soluble solids concentration (SSC) of the juice was measured with a handheld refractometer (Atago N1). Juice (10 ml) was titrated with 0.1N KOH to a malic acid endpoint of pH = 8.2 for titratable acidity (TA) measurements. Initial pH of the juice was also recorded.

Storage

Thirty fruits from each harvest date were removed from cold storage 6, 12, 18, and 24 weeks after harvest for 'Gala,' and 8, 16, 24, and 32 weeks after harvest for 'Braeburn' and 'Fuji.' Fifteen fruits were analyzed on the following day, and the other 15 fruits after 7 days at 20C. Color, firmness, SSC, and TA were quantified as previously described. Scald was rated on a 0-3 scale (none to severe). Other disorders were recorded.

Taste tests

A consumer taste test was conducted approximately every four weeks after final harvest for 'Gala' and every eight weeks for 'Braeburn' and 'Fuji,' fruits in the Sensory Science Laboratory at Oregon State University (Corvallis, OR). Fifty to 60 students and staff from Oregon State University participated in the tests. They were untrained, and different panelists participated in each panel. Only one variety was tasted per session. Twenty fruits from each harvest date were removed from storage and kept at 20C for four days prior to tasting. Six pieces of unpeeled apple, cut longitudinally and representing each harvest date, were presented to the panelists. Overall liking was rated using a nine-point hedonic scale where 1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely. Taste tests were conducted in individual booths under red lighting to mask the color variation of the fruit skin. Spring water (Aqua Cool, Portland, OR) was provided for rinsing between samples. Fruits were presented on a tray in a randomized, balanced, complete block design.

Statistical analysis

Maturity indices data of each cultivar are reported as means of 20 fruits with standard errors. The variability of IEC, the physiological indicator used for maturity, was analyzed through a stepwise multiple linear regression using the decimal logarithm of IEC as the dependent variable and the other maturity indices as independent variables. Analysis of variances (ANOVA) were performed on the data of each taste test session, with harvest date as the main effect and panelist as a blocking effect. Only statistically significantly different data are discussed. All statistical analyses were performed using the Statistical Analysis System (SAS Institute Inc., Cary, NC) (20).

Results

Maturity indices and fruit quality after storage

SI and IEC, which were measured only during the harvest period, are reported for the day of harvest and after seven days at 20C (Fig. 1). For other measurements at harvest and after storage, patterns in changes of fruit attributes after one and seven days at 20C were similar. Therefore, only the data obtained on the day of harvest and at the removal of the fruit from storage are reported.

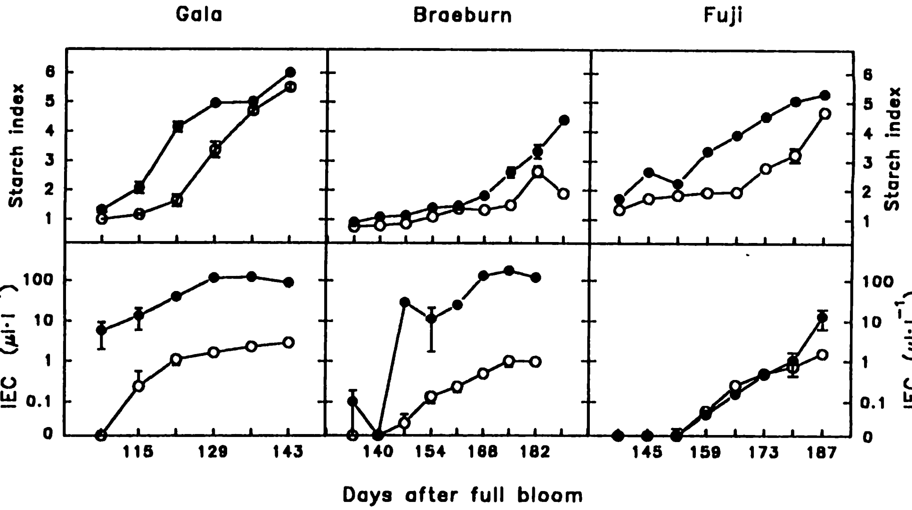

Figure 1. Changes in starch index and internal ethylene concentration (IEC), of 'Gala,' 'Braeburn,' and 'Fuji' fruit harvested on 6, 8, and 8 dates respectively, in 1991 at harvest (O) and after 7 days at 20C (●). Each point is a mean of 20 fruits and vertical bars represent ± SE.

Starch index (SI) increased in a sigmoidal fashion for 'Gala' during the period of sampling (Fig. 1). Little starch breakdown was observed at the early harvests of 'Braeburn' apples (SI = 1 from 133 to 147 DAFB). SI increased slowly from 154 to 168 DAFB. It remained low (Sl = 1.6) even in fruit ripened for seven days, until 175 DAFB where SI ranged from 3 to 4 after seven days at 20C. SI for 'Fuji' fruit increased significantly after 166 DAFB, although it had already increased in the fruits harvested 159 DAFB and ripened seven days (Fig. 1).

Internal ethylene concentration (IEC) at harvest reached the levels of 2.81, 1.00 and 1.5 $\mu l \cdot l^{-1}$ for 'Gala,' 'Braeburn' and 'Fuji,' respectively (Fig. 1). For the former two cultivars, ethylene production increased significantly (above 25 and up to 170 $\mu l \cdot l^{-1}$) for all but two dates, when fruit was allowed to ripen seven days at 20C, indicating autocatalytic ethylene production. For 'Fuji,' only fruits from the latest harvest date (187 DAFB) ripened for a week at 20C had an IEC greater than 10 $\mu l \cdot l^{-1}$.

Over the maturity range measurements, a*, a*/b*, and hue angle were highly correlated ($|r| > +0.97$) for both ground and surface color and in all three varieties (data not shown). Ground color L* variation was small over the maturity range studied, therefore, only the hue angle of the ground color is reported. For 'Gala,' ground color hue angle decreased rapidly at harvest, with an inflection point in the curve between 122 and 129 DAFB (Fig. 2). The green ground color observed during the first three harvests turned pale green to yellow in storage, as indicated by a decrease in hue angle values. There was no difference in ground color from harvest to storage for the fruit harvested after 129 DAFB. In general, for 'Braeburn' fruit, ground color hue angle decreased regularly at harvest and in storage. Variation between fruits was greater at the later harvests. Except for the two early harvests (147 and 154 DAFB) where fruit remained green, the ground color changed from pale green (at harvest) to yellow in storage. Surface color became visually more brilliant, the

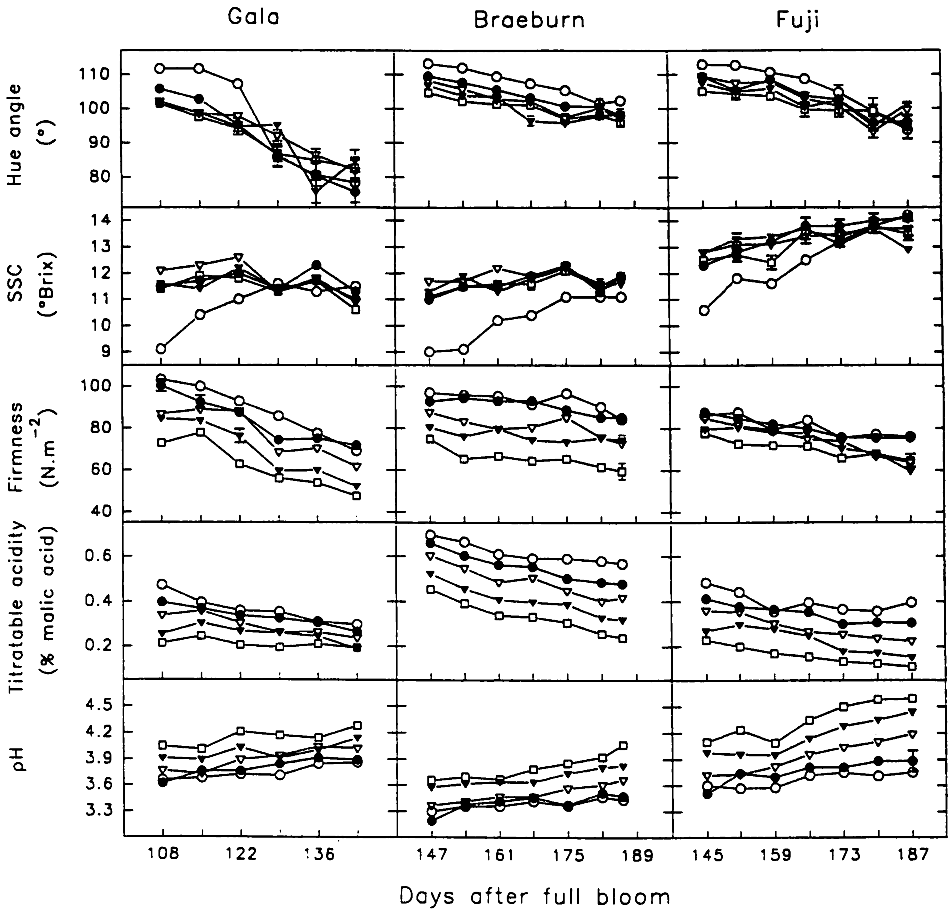

Figure 2. Fruit quality measurements of 'Gala,' 'Braeburn,' and 'Fuji' at harvest (○) and stored 6 (●), 12 (▽), 18 (▼), and 24 (□) weeks for 'Gala,' and 8 (●), 16 (▽), 24 (▼), and 32 (□) weeks for 'Braeburn' and 'Fuji,' in regular storage (0C), removed and held at room temperature for one day. Each point is a mean of 15 fruits and vertical bars represent ± SE.

dull red changing to orange-red. In 'Fuji,' no change in the ground color was visually perceived until 173 DAFB although hue angle decreased regularly after 159 DAFB. The decrease in ground color hue angle was higher after 173 DAFB. It became a lighter green at the end of the season, giving more brilliance to the red blush of the surface color. Changes of 'Fuji' fruit ground color hue angle after storage were similar to those observed on 'Braeburn.'

SSC for all three cultivars increased rapidly during the early harvest sampling periods. For 'Gala' fruit, SSC levelled off after it had reached 11.5 °Brix at 129 DAFB. SSC in 'Braeburn' increased rapidly between 154 and 161 DAFB and levelled off at 11 °Brix, after 175 DAFB. For 'Fuji' fruit, SSC increased steadily, reaching a final value of 14 °Brix. For 'Gala' and 'Braeburn,' SSC from the early harvests increased in storage to the values attained on the last harvests. In contrast

Table 1. Stepwise regression of log_{10} IEC (dependent variable) over SI, ground color hue angle, SSC, firmness, TA, and pH (independent variables) as measured at harvest for 'Gala,' 'Braeburn,' and 'Fuji' sampled on 6, 9, and 8 dates, respectively.

Cultivar	Model R^2	Variable entered (partial R^2)			
'Gala'	0.71	SI (.60)	SSC (.08)	pH (.02)	ground color hue angle (.01)
'Braeburn'	0.45	SSC (.42)	pH (.03)		
'Fuji'	0.80	SSC (.60)	water core (.17)	ground color hue angle (.03)	pH (0.01)

to 'Gala' and 'Braeburn,' the SSC of stored, early harvested 'Fuji' fruit (12.5 °Brix) never reached the level of the stored, late harvested fruit (13.5 °Brix).

Firmness decreased steadily at harvest and in storage for all three cultivars (Fig. 2). The overall loss of firmness was much less in 'Fuji' than observed for 'Gala' and 'Braeburn.'

Similarly, TA decreased and pH increased constantly over the harvest and storage seasons for 'Braeburn' and 'Fuji' only (Fig. 2). For 'Gala,' the loss of acidity as measured with TA was less for the late harvest dates than for the early ones. Fruit held in storage the longest (24 weeks) had low acidity (approximately 0.2% malic acid), with little differences between harvest dates. In contrast to TA, differences were observed in 'Gala' pH between harvest dates after 24 weeks in storage. pH for 'Braeburn' was lower at harvest and after 8 weeks of storage for all sampling dates. It increased after the longer storage durations (24 and 32 weeks). For 'Fuji' at harvest, TA decreased to its lowest value on 159 DAFB, followed by an increase of pH 166 DAFB (Fig. 2). TA was particularly low after 32 weeks in storage and for late harvested 'Fuji' fruits (0.1% malic acid).

For 'Gala,' variation in SI was related most closely with changes in IEC (Table 1). SSC, pH, and ground color hue angle were also significantly related to changes in IEC but were much less important. Only SSC and pH were significantly related to IEC in 'Braeburn.' For 'Fuji,' SSC and water core were the most closely related to IEC with slight but statistically significant contribution from ground color hue angle and pH (Table 1).

No storage disorders were observed on 'Gala' after 24 weeks in storage. Approximately 10% of 'Braeburn' fruit harvested after 168 DAFB had corky tissue in the flesh and brownheart, similar to brown water core but not limited to vascular bundles. In general, the percent of fruit with these disorders did not increase in long-term storage. Fruit harvested before 168 DAFB had increasing brownheart in storage. 'Braeburn' fruits harvested at 147, 154, and 161 DAFB had 10 to 80% of scald after 24 and 32 weeks in storage (17). 'Fuji' scald appeared after 16 weeks in storage. Among fruit stored for 32 weeks only two harvest dates, 173 and 180 DAFB, were scald-free.

Taste tests

Panelists usually do not use the two extreme ratings when using a category scale, saving them for "real extremes" (16). A rating of 5 in overall liking indicates no preference. Therefore, we chose arbitrarily a rating of 5.5 as the lowest limit for acceptability.

'Gala.' Ratings for overall liking decreased as the apples stayed longer in storage (Fig. 3). Fruit picked 129 DAFB and later had the best ratings in the first taste test (1 Oct.); however, harvest of 122 DAFB was not statistically different from them. After one and

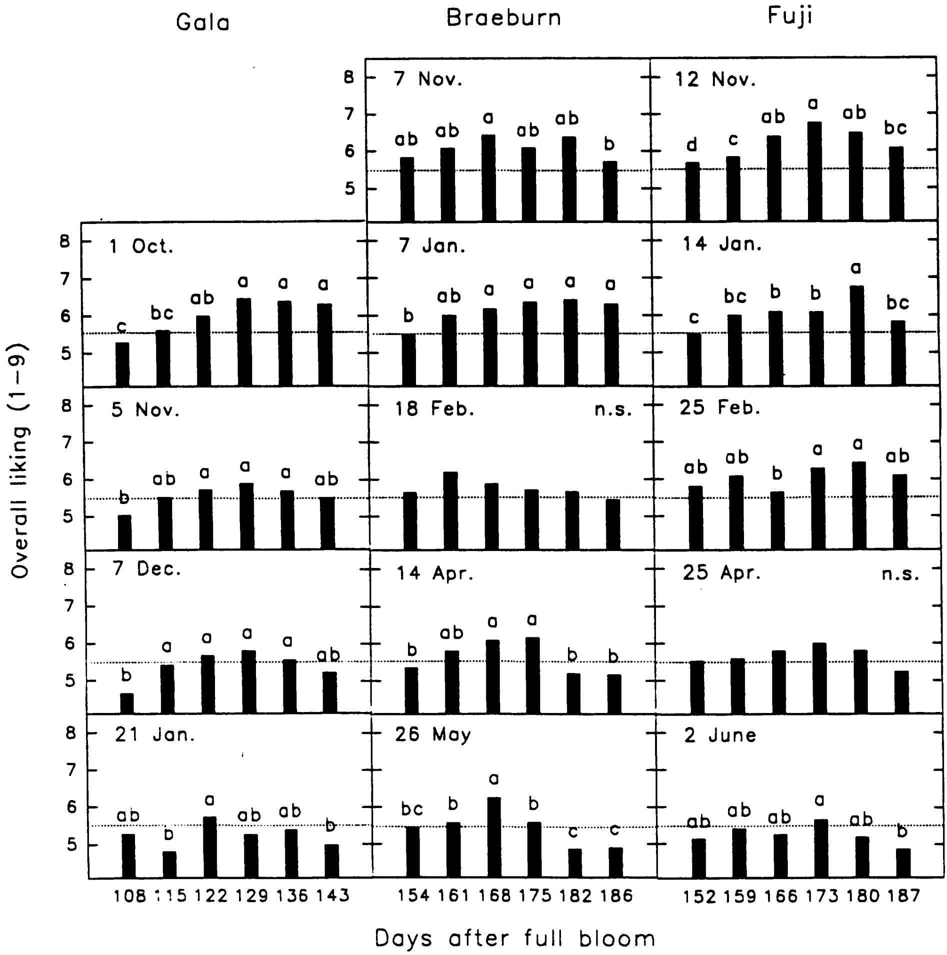

Figure 3. Sensory ratings for overall liking (9-point hedonic scale where 1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely) for 'Gala,' 'Braeburn,' and 'Fuji' apples harvested on 6 dates. Dates in figures indicate sensory evaluation date. Mean separations were by the Waller-Duncan k-ratio t-test, K = 100. Bars with the same letter are not significantly different from one another within a taste panel.

two months in storage (taste tests of 5 Nov. and 7 Dec.), fruit harvested late had a much lower liking rating. Preferences of fruit harvested from 122 to 136 DAFB were all rated greater than 5.5. On the last taste panel (21 Jan.), only fruit picked 122 DAFB was still acceptable (rating greater than 5.5), even though fruit harvested 108, 129 and 136 DAFB were not significantly different. Fruit from dates other than 122 DAFB was soft (below 60 N) or had developed an off-flavor.

'Braeburn.' The early taste panel (7 Nov.) rated the harvest of 168 DAFB as the best, yet there was little difference in overall liking between the dates, with the exception of the last harvest date (Fig. 3). The next taste panel (7 Jan.) preferred the later harvests to the early ones with a lower rating (below 5.5) being given to the

first harvest. No differences in liking were observed during the next panel on 18 Feb. The last two taste tests (14 Apr. and 26 May) revealed the limit of storability of 'Braeburn' apple in regular storage. Off-flavor was found in the early and late harvested fruits, and the late harvests were characterized by soft fruit. The most acceptable apples in the last taste test were those harvested on 168 DAFB (Fig. 3).

'Fuji.' As in 'Gala,' a decrease in the overall liking ratings was noted as fruit stayed longer in storage (Fig. 3). The early panel (12 Nov.) rated mid-season harvests, 166 to 180 DAFB as the best. Two months later (14 Jan.), only the harvest of 180 DAFB was rated better than the others. On the following taste test, harvest dates of 173 and 180 DAFB were still rated as the best. Yet, 152, 159 and 187 DAFB were not statistically different from them. No differences were noted between harvest dates on the 25 Apr. taste test. The overall liking ratings were very low on the last taste test. Only fruit harvested 173 DAFB had an overall liking above 5.5.

Discussion

Fruit quality after storage to confirm optimum picking date

Optimum harvest date, or horticultural maturity of 'Gala,' 'Braeburn,' and 'Fuji' apples was determined retrospectively with consumer taste test data and the presence of storage disorders. Consumer preferences were related to the changes of maturity indices at harvest. Fruit quality measurements after storage gave an indication of the stage of ripening of the fruit when tested.

IEC increased in 'Gala' fruit harvested 122 DAFB and held seven days at 20C, indicating the beginning of physiological ripening (Fig. 1). Concomitant with this ability to produce autocatalytic ethylene, an increase in starch breakdown was observed. SSC attained its final value of 11 °Brix but fruit color was not fully developed. Fruit harvested on that day retained its sensory quality longer (Fig. 3), indicating that if stored in regular atmosphere for a long-term storage, 'Gala' apples should be picked before optimum coloration occurs. Later harvested 'Gala' fruit (129 and 136 DAFB) developed full color and flavor, and was the best for short-term storage (November-December in regular storage). Fruit harvested last (143 DAFB) lost its quality in storage, and fruit harvested early (108 DAFB) never developed good sensory quality. SSC of early harvested fruit increased in storage to the same level as for the later harvests, suggesting that all fruits had the same starch reserves. Based on the regression of IEC with other measured indices, SI, SSC, pH, and hue angle ground color could be used to determine physiological maturity of 'Gala' apple (Table 1). In practice, starch index and ground color changes are the easiest to use in the field. To determine the start of harvest more accurately, sampling twice a week would be preferable for 'Gala,' since changes approaching harvest occur rapidly.

As determined by the taste panels, 'Braeburn' fruit harvested 168 DAFB were the most acceptable in the last two taste tests (14 Apr. and 26 May) (Fig. 3). Fruit harvested before 168 DAFB developed scald after 24 weeks in storage (17). Anet (1) determined that unripe fruit are more susceptible to scald symptoms. Late harvested fruit developed core cavities and brownheart in the flesh in approximately 10% of the apples (17). Therefore, 'Braeburn' fruit harvested 168 and 175 DAFB had the best storage potential. Later harvested fruit had the best eating quality for short-term storage. Fruit harvested early that had initiated ethylene production ripened in storage, resulting in large variability between apples within a sampling date. This could explain why no significant differences in overall liking were detected between the harvest dates during the sensory panel of 18 Feb. (Fig. 3). A significant change in SSC occurred before 168 DAFB (Fig. 2). pH had started to increase at 168 DAFB. IEC was 0.5 $\mu l \cdot l^{-1}$ on this date. Fruit harvested prior to this date was already capable of producing autocatalytic ethylene when held at room temperature (Fig. 1). Based on the rate of change during maturation, SSC was the best predictor of optimum harvest in this particular study. SSC and pH explained best the variability of IEC (Table 1). Although SI is commonly used in the field as a maturity index, it increased significantly on the sample harvested 175 DAFB and ripened for one week at 20C, which was already too late for long term storage. Ground color hue angle decreased regularly during the sampling season. The lightening in the shade of green was visible 161 DAFB, and could be used, in relation with other maturity indices, to explain to the pickers which fruit to harvest.

'Fuji' fruit harvested 173 and 180 DAFB was given the highest overall liking ratings across taste tests (Fig. 3). Only fruits picked on those dates were free of scald after eight months in storage (17). Significant changes in the maturity indices at these dates were the increase of SI and decrease of the hue angle of the ground color (Figs. 1 and 2). Some fruit started producing ethylene 166 DAFB (Fig. 1), but overall, IEC stayed at low levels. Autocatalytic production of ethylene was induced in 'Fuji' only on the last harvest date (187 DAFB). Autocatalytic production of ethylene can be initiated three to five days after harvest on fruit picked 174 DAFB (9). The increase observed in our sample might be the autocatalytic rise normally occurring in 'Fuji' fruit at that time (8, 9), or a response to frost exposure. Water core, normally produced in 'Fuji' fruit (6), was present on the last harvest date (187 DAFB). However, fruit from the last harvest were never rated high for overall liking (Fig. 3). Based on the regression model of the quality measurements to IEC, SSC, water core, ground color hue angle, and pH were the best indicators of physiological maturity (Table 1). However, because IEC remained low and water core appeared only on the last harvest, SI was the best indicator of horticultural maturity in this study. The highest quality stored fruit had a starch index above 2.5 at harvest. At 173 DAFB, the acidity of 'Fuji' fruit had levelled off and the highest SSC levels were measured.

The use of maturity indices

Visual changes in ground color were relevant for ripening in all three cultivars although the change was more in the quality of green (hue) for 'Braeburn' and 'Fuji,' opposed to the change of green to yellow for 'Gala.' Firmness, SSC, and TA are commonly used as quality descriptors. They could not be used as maturity indicators alone, but their changes during ripening provided valuable information. Since their change in storage is not constant from year-to-year and between varieties, quality after storage is not predictable (12). The sudden increase in 'Braeburn' SSC indicated changes in fruit maturation. SSC plateaued during the late sampling of 'Gala' and 'Braeburn,' indicating hydrolysis of fruit starch reserves. In this study, starch hydrolysis was a good indicator of maturity for 'Gala' and 'Fuji,' but not for 'Braeburn.' The fact that SI did not increase while SSC did in 'Braeburn' shows the limited value in measuring total starch content by the iodine test. In turn, SSC was the best maturity indicator for 'Braeburn.' IEC was a valuable physiological indicator for 'Gala' and 'Braeburn.' IEC is mostly useful when fruits are ripened at room temperature to verify the time of induction of autocatalytic ethylene production. Our data confirmed that 'Fuji' is a low ethylene evolver, and therefore could not be used as a predictor of harvest.

This study confirmed that there is no universal maturity index to rely upon harvesting fruit at the right time. Also, one cannot rely on one year of data, taken from one orchard. This study was aimed at initiating a database for the maturity of varieties which were still relatively unknown in the region. Recommendations to the growers through regional maturity programs are still justified. Results from the taste panels showed that untrained panelists could differentiate between harvest dates for their preference. Overall decrease of liking during the storage period for all varieties and harvest dates showed that consumers could perceive the loss of apple quality from harvest through storage.

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