Using the Streif Index as a Final Harvest Window for Controlled-atmosphere Storage of Apples

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Abstract. A final harvest window (FHW), expressed as Streif Index coefficients [firmness/(percentage soluble solids concentration × starch index)], was developed for identifying maximum fruit quality for straains of ‘McIntosh’, ‘Cortland’, and ‘Jonagold’ apples (Malus ×domestica Borkh.) following 8 months of controlled-atmosphere (CA) storage. The Streif Index was calculated during nine preharvest (twice per week) intervals and four-weekly harvests over three seasons. The relationship between Streif Index (dependent variable) and day of year (independent variable) of the preharvest and harvest samples was then derived by negative first-order linear regression equations that had parameter estimate (b), probability values ≥0.0001 for all of the straains. Apples from the four harvest periods were stored in standard CA storage for 8 months and then subjected to a 7-day shelf-life test at 0 °C followed by 5 days at 20 °C. Poststorage quality data were categorized and combined to produce an overall fruit quality rating scale. For each strain, the final harvest [i.e., day of year (X)] was identified as that which directly preceded at a 10% drop in the poststorage fruit quality rating compared with the first harvest rating. The FHW, expressed as Streif Index coefficients via the regression of Streif Index (Y) on day of year (X), was then calculated as the 3-year final harvest mean with the upper and lower window limits being determined by the standard deviation of the mean. The lower to upper FHW boundaries ranged from 4.18 to 5.34, 4.12 to 5.46, 4.51 to 5.68, 5.23 to 5.99, and 1.38 to 2.34 for Redmax, Marshall and Summerland ‘McIntosh’, Redcort ‘Cortland’ and Wilmuta ‘Jonagold’, respectively. The practical utility of the Streif Index method lies in the ease with which apple fruit maturity at harvest can be evaluated for its suitability for long-term CA storage.

To ensure the highest fruit quality at the end of long-term controlled-atmosphere (CA) storage, apples must be harvested when mature but not when fully ripe. If harvested too early they are often small, have reduced flavor and color, may fail to fully ripen, and are more susceptible to scald and bitter-pit. Conversely, apples harvested when over-mature are vulnerable to mechanical injury and disease, develop off-flavors, and often have a higher occurrence of watercore and senescent breakdown (Meheriuk et al., 1994). Hence, determination of an optimal harvest period is critical for growers to maximize poststorage fruit quality and minimize losses.

Although numerous methods have been developed in the past, no single test has proven solely adequate for assessing the physiological maturity of fruit. Combining several indices should be superior to a single test, as each provides information about the apple’s physiological state, and collectively, should reduce fruit-to-fruit, seasonal, and location-related variability (Kingston, 1991). The Streif Index is comprised of three maturity measurements (firmness, percentage soluble solids concentration, and starch conversion) (Streif, 1983, 1996) and has been successfully used to estimate the time of optimum harvest for various apple cultivars in Germany (Streif, 1996; Wilcke, 1996), the Netherlands (de Jager and Roelofs, 1996), Hungary (Mérész et al., 1996), and Poland (Rutkowski et al., 1996). Streif (1996) showed that over an 8-year period, the Index values in the Bodensee area of Germany were specific for each cultivar and were not strongly dependent upon orchard influences or climatic conditions.

In much of this recent research, the Streif Index has been used to identify a single optimum harvest from data collected over several consecutive experimental years. These single-point models could be improved if the Streif Index were used to describe a harvest window that more realistically paralleled fruit maturaion, i.e., apples develop optimal quality for storage over a period of time. Additionally, a harvest window would be a useful tool for growers by describing a period of a few days, rather than a single date, for harvest management of any single cultivar.

Relatively little work has been done to utilize the Streif Index as a maturity indicator in apple growing regions within North America. Within eastern Canada, we have observed that growers would benefit more from a maturity guide that aids in assessing when to conclude rather than when to begin harvest so that over-mature fruit could be excluded from long-term storage. Hence, the objectives of this research were: 1) to develop the Streif Index as a physiological indicator of apple maturity =5 weeks prior to and during harvest; and 2) to superimpose a final harvest window upon the Streif Index to delimit the harvest period within which poststorage fruit quality is highest.

Materials and Methods

Experimental data were collected in the Annapolis Valley of Nova Scotia during three consecutive years (1995–97) on three cultivars/five strains of apples: ‘McIntosh’ (Summerland, Redmax, and Marshall), ‘Cortland’ (Redcort), and ‘Jonagold’ (Wilmuta). Trees were selected at three grower sites for the ‘McIntosh’ and at four sites for the ‘Cortland’ and ‘Jonagold’ strains.

To relate the Streif Index to day of year, 10 apples from each sampling site were randomly collected at nine preharvest intervals (twice per week) =5 weeks prior to harvest and once per week during the 4-week harvest period. Starch-to-sugar conversion was evaluated on a 1 (100% starch) to 9 (0% starch) scale for each apple using the McIntosh Starch Test Guide (Phillips and Poapst, 1972), while firmness (N) and percentage soluble solids concentration (SSC) were calculated as averages for the 10-apple sample. A Ballauf penetrometer (Ballauf, Laurel, Md.) with an 11-mm-diameter tip was used to assess fruit firmness, while juice SSC was determined with a handheld refractometer (Atago Co., Tokyo). Titratable acidity (TA) was determined from the same 10-apple composite sample by titrating 2 mL of apple juice with 0.1 mol·L–1 sodium hydroxide and was expressed as malic acid equivalents (g·L–1) (DeEll and Prange, 1998).

Fruit samples for quality measurements at harvest and for standard CA (SCA) storage were collected each week for 4 weeks (Table 1). The first and last harvests were regarded as early and late, while the middle two were considered optimal for the traditional Annapolis Valley harvest period. On each sampling day, one representative bushel (~20 kg) of apples was selected from each site with 10 fruit being evaluated for starch-to-sugar conversion, firmness, and SSC.
The remaining fruit were then stored in SCA for 8 months at 3.5 °C, 2.5 kPa O₂, and 4.5 kPa CO₂ (‘McIntosh’ and ‘Cortland’) or at 0 °C, 2.5 kPa O₂, and 4.5 kPa CO₂ (‘Jonagold’).

Following 8 months of storage all apples were held for 7 d at 0 °C followed by 5 d at 20 °C. Means for firmness, SSC, and TA were determined from a 10-apple sample, while percentage of healthy fruit (absence of core and cortical browning, senescent breakdown, and rots) was determined from a 50-apple sample (Streif, 1996). In addition, a taste-test was conducted with members of the Nova Scotia Fruit Growers Association and with employees at the Agriculture and Agri-Food Canada, Atlantic Food and Horticulture Research Centre, in Kentville, N.S. Tasters sampled fruit from each of the four harvests and rated the overall sensory quality (texture and flavor) on a hedonic scale ranging from 1 (dislike extremely) to 9 (like extremely) (Table 2) (Land and Shepherd, 1984). The poststorage (firmness, SSC, TA, percentage of healthy fruit) and sensory data were then categorized and additively combined to provide an overall poststorage fruit quality rating of the individual apple strains for each of the four harvests (Table 3) (Streif, 1996).

The Streif Index coefficient, calculated as the quotient of [firmness/(SSC × starch index)] (Streif, 1996), was derived for every sampling of fruit during the nine preharvest and four harvest periods. The relationship between the Streif Index (dependent variable) and day of year (independent variable) of the preharvest and harvest samples was characterized by negative first-order linear regression equations (PROC REG; SAS Institute, 1990). For each strain, the day of year that directly preceded at least a 10% drop in poststorage fruit quality (approaches industry standards) compared with the 1st harvest rating (highest), was determined by the final harvest (Table 3). The final harvest window (FHW) was then calculated as the 3-year final harvest mean, with the upper and lower window limits being determined by the standard deviation, and was expressed as Streif Index coefficients via the regression equations relating the Streif Index (Y) to day of year (X). Following the research precedent to date, the Streif Index units of N (SSC)⁻¹ were dropped in this study, resulting in the FHW boundaries being delineated as Streif Index coefficients.

**Results and Discussion**

In recent years, there has been an increased research effort to develop models for determining optimum harvest dates for important apple and pear (Pyrus sp.) cultivars (Beaudry et al., 1993; Blankenship et al., 1997; de Jager and Roelofs, 1996). In the present study, we have focused on developing a final harvest window for three economically important cultivars (five strains) grown in eastern Canada. The change of emphasis from the conventional “when-to-begin” to “when-to-conclude” harvest occurred as we realized that very little work had been done in developing end-of-harvest models with long-term CA storage in mind. For optimum fruit quality following storage, each cultivar must be harvested within a relatively flexible time period (e.g., 7 d); if harvest is delayed beyond a critical endpoint, the quality of fruit in long-term storage rapidly deteriorates (as our data indicate). In this study, we sought to identify that critical end-of-harvest period.

Past studies that have focused on identifying an optimum harvest period based upon postharvest quality measurements have usually taken one of two approaches: 1) to mathematically link the harvest and postharvest quality variables directly by regression or correlation statistics (Blankenship et al., 1997; Evensen et al., 1993); or 2) to identify the optimum harvest period retrospectively by determining from which harvest the highest postharvest fruit quality was obtained (Lau, 1988; Plotto et al., 1995; Stow, 1995). With the former method, the goal is to regress or correlate harvest and postharvest fruit quality attributes (e.g., firmness, SSC, starch conversion) so that a large portion of the statistical model’s variation is explainable. The a priori assumption is that these maturity measurements change linearly and consistently as maturity advances so that the relationships between dependent and independent variables can be mathematically modelled. However, a major problem often encountered with these models is that the coefficients of determination (R²) are usually <50%, indicating that a large proportion of the model’s variation cannot be explained by the selected variables, casting doubt on their suitability as harvest predictors. In a recent study, Blankenship et al. (1997) developed a predictive maturity equation for poststorage firmness of ‘Fuji’ and found that although their best-fitting regression models had statistically significant parameter estimates, R² values accounted for only 24% to 34% of the total variation.

In this present study, the latter retrospective approach was used for identifying the final harvest window. A negative first-order regression between the dependent (Y) and day of year (X) was calculated for the three ‘McIntosh’ strains (Fig. 1), for Redcroft ‘Cortland’ and for Wilmuta ‘Jonagold’ (Fig. 2). No marked improvements were observed by fitting the data to second or third-order polynomial models. Coefficients of simple determination (r²) ranged from 0.71 to 0.88, indicating that the model parameters accounted for a relatively large proportion of the total variation present. Once the Streif Index trends were established, the final harvest window was superimposed on the regression lines for each of the five strains by converting the standard deviation of the average final harvest day of year into Streif Index coefficients (Table 3). The advantage of this approach lies in the comprehensive assessment of poststorage fruit quality firmness, SSC, TA, percentage of
ments from the pool of variables if elimination of economically important quality seeks to find the least number of variables that classically relate pre- and poststorage fruit quality ranking. In contrast, models that mathematically facilitate the numeric ranking of the influential several harvests on the overall condition of fruit after storage. Then, the optimum result is a broad description of fruit quality that w Indicates the average harvest (day of year) y Sum of the firmness, soluble solids concentration (SSC), titratable acidity (TA), healthy fruit, and sensory rating scale data for each harvest. z Numbers represent average poststorage rating scales. Refer to Table 2 for rating scale details.

258 ± 2.29° 2.55 0.89 1.78 7 4.37 16.59 4.37 ± 0.58
265 ± 2.29° 1.77 0.78 1.67 5.89 4.77 14.88 2.98 ± 0.58
272 ± 2.29° 1.11 0.89 1.44 3.89 4.69 12.02 1.21 ± 0.58
279 ± 2.29° 0.78 1.22 1.22 1.56 4.35 9.13 –0.56 ± 0.58

*Numbers represent average poststorage rating scales. Refer to Table 2 for rating scale details.

For 'McIntosh', 'Cortland', or 'Jonagold' apples designated for long-term CA storage (e.g., 8 months), maximum poststorage fruit quality will be obtained when harvest is concluded within the specified FHW (Figs. 1 and 2). Fruit may be picked prior to the harvest windows and be of superior quality at the termination of extended CA storage; however, if harvest is delayed beyond the window, poststorage quality will decline as the fruit become over-mature.

The results of this 3-year study demonstrate that the Streif Index is a reasonably consistent descriptor of physiological maturity when fruit are measured across the latter part of the growing season and during harvest. The superimposition of a final harvest window on each strain’s Streif Index graph facilitates the practical utilization of valuable poststorage quality data in determining the suitability of fruit for long-term CA storage. The Index values appeared to be relatively independent of variations in growing season and orchard location within Nova Scotia’s Annapolis Valley; hence, the FHW values reported herein would ostensibly be applicable for growing regions in the Northeast, i.e., eastern Canada and New England. However, we recommend that Streif Index models for important local cultivars be developed for each distinctly different growing region (e.g., regions having warm vs. cool autumn nights, and vs. humid climates).
Literature Cited


Land, D.G. and R. Shepherd. 1984. Scaling and


