Use of Maturity Indices for Predicting Poststorage Firmness of 'Fuji' Apples

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Additional index words. postharvest physiology, *Malus domestica*, storage, harvest maturity

Abstract. 'Fuji' apples (*Malus domestica* Borkh.) were harvested at three maturities for three consecutive seasons. Fruit firmness, soluble solids concentration, starch-iodine index (SI), and internal ethylene concentration were measured at harvest. Fruit were stored in 0 °C air storage for 8 months. Fruit firmness and other maturity indices were measured monthly during storage. Using a stepwise regression procedure, harvest maturity indices were used to predict firmness after air storage. When all maturity indices measured were represented in the model, $R^2 = 0.29, 0.34$, and 0.26 at 4, 6, and 8 months, respectively. Use of only SI and fruit firmness in the model gave R^2 values of $0.25, 0.29$, and 0.24 for 4, 6, and 8 months, respectively. Although R^2 values were low, they were highly significant. The model using fruit firmness and SI resulted in the best fit. Thus, an equation was developed using months of air storage, firmness, and SI at harvest. Actual firmness values correlated fairly well with predicted firmness values, usually within ≈ 5 N. On Washington apples, predicted values were 4.3 and 3.7 N too low compared to actual firmness values after 3 or 5 months' storage. In 1993, when predicted and actual firmness values were compared for Pennsylvania apples, predicted values ranged from 2.6 to 8.3 N too high after 3 months' storage, depending on harvest date. In 1994, Pennsylvania fruit stored 4 months had predicted values 0.5 N too high to 6.3 N too low, depending on harvest date. It may be possible to develop and refine models for an apple variety that would be applicable to several regions.

'Fuji' apples recently have gained popularity in the United States. Although not an attractive fruit, the high degree of flesh firmness and soluble solids concentration (SSC) make for an apple with exceptional consumer acceptance. Maturity indices of 'Fuji' have been reported (Jobling et al., 1993; Jobling and McGlasson, 1995). Plotto et al. (1995) reported that optimal quality for Washington apples was obtained for fruit harvested 173 to 180 d after full bloom. In New Zealand, background color was the best indicator of fruit maturity (Watkins et al., 1993). 'Fuji' retains flesh firmness during prolonged periods in air storage, unlike other commercially available apples that require controlled atmosphere (CA) to maintain acceptable quality. Flesh firmness retention makes 'Fuji' an ideal apple for marketing, because it can be left on retail shelves at room temperature without a significant reduction in fruit quality.

In 'York Imperial' apples, a processing variety, regression models were used successfully to target apples suitable for storage

(Evensen et al., 1993). In 'York Imperial', fruit firmness and SSC were the best indicators to use to judge fruit maturity. Because of some of the unique characteristics of 'Fuji', growers have difficulty deciding when to harvest fruit for maximum storage life while maintaining fruit quality. The objective of our study was to determine which fruit maturity characteristics at harvest could best be used to predict fruit firmness after refrigerated storage.

Materials and Methods

'Fuji' apples were harvested in three consecutive seasons from the Mountain Horticultural Crops Research Station, Fletcher, N.C. In each season, fruit were harvested on three harvest dates. The decision to begin harvest was based on the commencement of starch degradation. Fruit were harvested and transported to Raleigh, N.C., for analysis at harvest and after subsequent 0 °C air storage. Fruit were placed in plastic liners, then stored in fiberboard boxes. The following characteris-

tics were measured on a 15-fruit sample at harvest and monthly for an 8-month storage period: fruit firmness (F) (N), internal ethylene concentration (E) ($\mu\text{L}\cdot\text{L}^{-1}$), SSC (%), starch-iodine index (SI) (1 to 9). Fruit firmness was determined on peeled fruit using a Univ. of California firmness tester equipped with an 11-mm-diameter plunger; data were recorded in pounds and then converted to Newtons. Two readings per fruit were taken and averaged. SSC was determined with a digital refractometer. Internal ethylene was determined by inserting a needle in the calyx end of the fruit. A gas sample was withdrawn, analyzed by gas chromatography, and then ethylene was quantified by comparison to a certified standard. SI was determined using a 1 to 9 scale, with 1 representing no starch conversion in the apple interior, and 9 being no starch left in the apple interior (Saltveit and Hale, 1982). As a general indicator of fruit quality, maturity indices were determined for the middle of the three harvests (Table 1). A stepwise regression procedure (version 6.04; SAS Institute, Cary, N.C.) was used to analyze data. All data were entered along with firmness values at 4, 6, and 8 months' storage for the 3 years. Firmness was selected because it was the best indicator of fruit quality after storage. The model was first constructed using all harvest characteristics, then characteristics were individually omitted until the point was reached where omission of any more characteristics would significantly reduce the R^2 of the model. In this way, it was possible to judge which characteristics at harvest were most valuable in predicting fruit firmness in storage. With this procedure, an equation was generated that allowed prediction of firmness after a selected storage time (in months), based on fruit firmness and SI measured at harvest.

Results and Discussion

The R^2 values from the stepwise regression were low, however, they were statistically significant (Table 2). The highest R^2 value was 0.34, using all indices after 6 months' storage. Interestingly, little variability is accounted for by using all the maturity indices, which indicate that major factors that determine fruit maturity are unaccounted for by the commonly used maturity indices. The comparable R^2 values were slightly lower at 4 and 8 months. All three-way combinations, other than the combination SI, SSC, and E, yielded similar results. Two characteristic combinations had only slightly lower R^2 values than three char-

Received for publication 22 Dec. 1995. Accepted for publication 25 Feb. 1997. We would like to thank George Greene, Pennsylvania State Univ., Biglerville, and James P. Mattheis, USDA/ARS, Wenatchee, Wash., for their assistance and allowing us to test our model on their data. Use of trade names does not imply endorsement of the products named or criticism of similar products not named. 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.

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Table 1. Mean values for selected maturity indices for the second of three harvests of 'Fuji' apples in North Carolina. No significant differences were detected between harvests within each year; therefore, only the data for the second harvest are presented.

Year	Fruit maturity index		
	Firmness (N) ^a	Soluble solids concn (%)	Starch-iodine index (1-9) ^b
1991	81.8	16.2	8.4
1992	70.7	17.0	6.7
1993	68.5	13.1	5.8

^aFruit firmness: N/4.44 = lb force.

^bBased on a scale from 1 to 9, where 1 = all starch and 9 = no starch.

Table 2. Prediction value of harvest characteristic variables for determining fruit firmness of 'Fuji' apples after 4, 6, and 8 months' air cold storage.

Variables ² in model at harvest	R ² after storage period (months) indicated		
	4	6	8
F	0.18	0.23	0.20
SI	0.11	0.10	0.07
SSC	0.09	0.11	0.02
SI, F	0.25	0.29	0.24
F, E	0.22	0.28	0.20
SSC, F	0.21	0.24	0.22
SI, E	0.17	0.17	0.07
SSC, E	0.15	0.15	0.07
SI, SSC	0.14	0.11	0.09
SI, F, E	0.27	0.33	0.24
SI, SSC, F	0.26	0.29	0.24
SSC, F, E	0.25	0.29	0.22
SI, SSC, E	0.19	0.19	0.09
All (P value < 0.0001)	0.29	0.34	0.26

²F = fruit firmness; SSC = soluble solids concentration; SI = starch-iodine index; E = internal ethylene concentration. All = F, SSC, E, SI, and a term for SI squared.

acteristic combinations, with the following characteristic combinations providing the best fit: SI and F, F and E, or SSC and F. Based on R^2 , the SI and F combination was slightly better than the other two characteristic combinations. We, therefore, chose it to be the basis for the models presented below. Additionally, SI and F are easy characteristics to measure and do not require specialized equipment. If only one index could be used for predicting poststorage firmness, firmness at harvest would be the best choice. However, fruit size is known to affect fruit firmness, with larger fruit often being softer. Fruit size may account for some of the variability in this study.

Prediction equations for firmness of 'Fuji' after air storage were generated based on SI and F at harvest. A slight modification of the formulas might be necessary if the 1 to 8 point, rather than 1 to 9 point, starch scale is used

(Blanpied and Silsby, 1992). "Months" is the number of months in air storage. F and SI are the values at harvest. The equation we used to predict firmness after air storage is: predicted firmness (N) = $-1.6 + -1.08(\text{months}) + 0.82(\text{F in N}) + 2.5(\text{SI})$.

In Fig. 1, predicted values are shown with actual F values for the stored fruit. In 1991, 1992, and 1993, correlation coefficients of 0.64, 0.69, and 0.43, based on SI and F, were obtained, respectively. Despite the fairly low correlation coefficients, predicted values were usually within 5 N ($\pm 6\%$ to 7%) of actual values (Fig. 1). The starch term in the equation is positive. When SI was in the 4–6 range at harvest, predictions were the most accurate. When the harvest SI was numerically low, predicted F values tended to be lower than actual values. Apples with high SI at harvest had predicted F values that were too high.

Fig. 1. Predicted and actual fruit firmness values for 'Fuji' apples stored for 8 months in air for predicted 1991 (□), actual 1991 (■), predicted 1992 (Δ), actual 1992 (▲), predicted 1993 (○), actual 1993 (●).

These discrepancies may be caused by the small range of the starch indices used in the original data set.

To evaluate how these formulas would predict F of stored fruit in other apple production regions, we tested the model using 2 years of data from Washington state after apples had been stored 3 or 5 months in air storage (J. Mattheis, personal communication) and from Pennsylvania, including several harvest dates, after 3 or 4 months of similar storage (G. Greene, personal communication). Based on 1993 Washington harvest data and F data after 3 months' cold storage, predicted F was 4.3 N too low. On a sample stored 5 months, the predicted value was 3.7 N too low. Washington apples were at ≈ 80 N and in the middle SI range at harvest. For 'Fuji' grown in Pennsylvania and harvested weekly for 4 weeks in 1993, the differences between predicted and actual F after 3 months' storage were 8.3, 6.5, 5.1, and 2.6 N too low. In 1994, the model for apples harvested during 3 consecutive weeks and then stored 4 months, predicted values that were 0.5 N too high, and 1.1 and 6.3 N too low. The Pennsylvania apples ranged from ≈ 82 - to 65-N firmness, and 2 to 7 in SI at harvest, over the 2 years and all harvest dates.

Although firmness is not an adequate maturity indicator alone to determine optimal harvest due to year-to-year fluctuation, it can be used with SI to obtain a good prediction of poststorage firmness in 'Fuji' apples. Using additional indices did not greatly improve the predictive value of our regression equation. Plotto et al. (1995) also reported that SI was a adequate indicator for 'Fuji' maturity, based on a 1-year study. Our equation based on 3 years suggests that both SI and F might be used to predict fruit firmness after refrigerated air storage. The model may be applicable to several geographic areas.

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