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Predictions of Quality by Preharvest Fruit and Leaf Mineral Analyses in 'Starkspur Golden Delicious' Apple

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Abstract. **Forward stepwise multiple regression equations were developed from seasonal leaf and fruit mineral analyses to predict quality parameters for 'Starkspur Golden Delicious' apple (*Malus domestica* Borkh.) during 1980–82. Quality parameters were evaluated both at harvest and after 6 months of 0°C storage. Soluble solids, skin ground color, and titratable acidity were strongly predictable as early as June or July. However, an August analysis was most predictive. For titratable acidity, a combination of both leaf and fruit minerals produced stronger predictions than leaf or fruit minerals alone in each individual year. Soluble solids, skin ground color, and bitterpit were more accurately predicted by fruit analyses. Fruit size was important in regression equations for firmness, but was not essential for other parameters. Although between-year predictions were not as good as within-year predictions, regression equations could successfully place fruit in high or low categories for most quality parameters.**

Although leaf analysis is a diagnostic tool for optimizing mineral nutrition in fruit trees, it correlates weakly with fruit quality (3, 9). Fruit analysis may be more useful in estimating quality (3, 5) and storage disorders (1, 4, 6, 9, 10). Mineral analyses of both fruit and leaves will become increasingly popular. Recent advances in analytical equipment allow multi-element analyses on a single sample; thus, mineral contents of fruit and leaves can be determined routinely at a fraction of the time and cost traditionally associated with mineral analyses. Understanding relationships between postharvest quality and preharvest variables may make management decisions easier. Early season predictions of poststorage firmness, ground color, and bitterpit can be valuable. An early identification of fruit likely to be low in soluble solids or titratable acidity after storage also may assist in developing marketing strategies. Perfect categorization is not required. If the industry could segregate a large percentage of potentially low and high quality fruit such that each category of fruit is appropriately marketed or stored, profit may be enhanced.

Sharples (9) has presented fruit mineral standards for 'Cox's Orange Pippin' apples, suggesting that the performance of fruit in storage can be predicted from fruit analysis immediately before harvest. An earlier analysis might allow altering cultural practices. Our goal was to relate seasonal analyses of both fruit and leaf tissues to various quality factors at harvest and after storage.

Materials and Methods

Data were obtained from an 8-year-old high-density 'Starkspur Golden Delicious' orchard near Corvallis, Oregon, where the response of 6 rootstocks to K and N treatments was evaluated. Details of the orchard design, cultural practices, and experimental results are described elsewhere (3). Since rootstock fertilizer interactions were not significant, data were pooled to provide a general application. In pooling the data, a wide range of leaf and fruit mineral concentrations with associated quality parameters was obtained. Leaf N values varied only slightly, but other mineral concentrations in leaves had coefficients of variation about half of that encountered in statewide surveys (Oregon State Univ. Plant Anal. Lab., unpublished data). Fruit mineral variability was similar to that observed in commercial apple orchard surveys (12). There were 96 study plots in 1980 and 72 in 1981. Each plot consisted of 4 trees.

Leaves were sampled in late August of 1980 and in late July, August, and September of 1981. At each sampling, composite samples of 40 leaves from each plot (10 leaves/tree) were collected from the midshoot of the current season's growth. Leaves were washed, dried in a 70°C forced-air oven to a constant weight, and ground to pass a 20 mesh screen. Fruit were sampled once a month from late May through mid-October in 1980 and from late July through mid-October in 1981. After the initial analysis of a composite sample of 32 fruit/plot in May 1980, a random 8-fruit/plot composite sample appeared satisfactory and was used thereafter. Fruit were washed, cored, sliced, freeze dried, and ground to a similar size. Leaf and fruit were analyzed for N by micro-Kjeldahl (8) and by spark emission for K, P, Ca, Mg, Mn, Fe, Cu, B, Zn, and Al (2).

Fruit for quality determination were sampled at commercial harvest time (15 Oct. 1980 and 10 Oct. 1981). Fruit from each plot were evaluated for quality both at harvest and after 6 months of 0°C storage. Each time, a random 6 fruit/plot composite sample was evaluated. Soluble solids percentage was measured by a hand refractometer, firmness by a penetrometer, and color by a color chart progressively ranging from 1 (yellow) to 5 (dark green). Titratable acidity was determined by titration of extracted juice with 0.1 N NaOH. The percentage of fruit with bitterpit after storage was determined for each plot.

Fruit mineral status was calculated on dry weight, fresh weight, and per-fruit bases. Correlations between fruit mineral status and yield or quality parameters for all 3 types of expression were obtained. Correlations were weaker for fresh weight or per-fruit approaches. Therefore, a dry weight basis was used to express mineral status of both leaves and fruit.

A forward stepwise multiple regression analysis on linearized variables (reciprocal when required) was used. Coefficients of determination (R^2) for each quality factor as a dependent variable were obtained. Yield and fruit weight were included as independent variables to clarify interrelationships between yield,

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[1]P

fruit size, mineral composition, and quality. Since fruit weight was much more important than yield as an independent factor, fruit weight was selected for use in final equation development. Dependent variables were regressed with leaf minerals and fruit weight, fruit minerals and fruit weight, and combined leaf and fruit minerals and fruit weight for each sampling period.

Regression equations using the 4 most important independent variables were used to calculate predicted values for each observation. The percentage of successful placement of fruit in high (upper 25%) and low (lower 25%) categories for each of the dependent quality variables was assessed. Similarly, the percentage of fruit that was severely misplaced (high observation placed in low category and vice versa) was determined.

A forward stepwise discriminate analysis also was used to place fruit in high and low categories for each dependent variable based on similar combinations of independent variables. Regression equations and discriminate functions developed for each individual year were used to make predictions for the other.

Results

Fruit weight was more strongly related to dependent variables than yield, and adding both to regression equations added little. Fruit weight almost always appeared before yield in stepwise multiple regression equations. Although mineral composition is clearly a function of yield, yield and fruit weight were less important (appeared later in equations) than mineral content with regard to soluble solids, titratable acidity and ground color. Yield or weight was a dominant factor with regard to firmness.

R^2 values for seasonal samplings are presented for harvest and storage parameters in Fig. 1 and 2. Although independent variables and the steps in which they appeared in regression equations varied slightly with sample time, equations were similar enough to summarize. Equations for at-harvest and post-storage relationships were similar, and therefore they have been combined for summarization. The independent variables most often occurring in regression equations, and whether they were negatively or positively associated with the dependent variables, appear in Table 1. Although R^2 values were sometimes low, regression equations could successfully place fruit in high or low categories for most quality parameters (Table 2). Relationships for specific parameters in each year are discussed below.

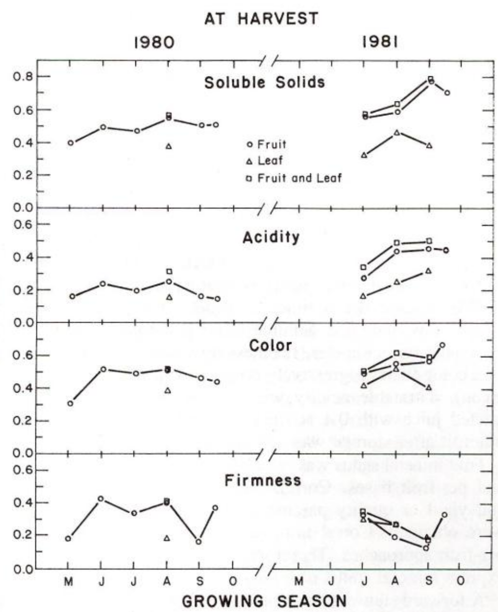

Fig. 1. Seasonal R^2 of various quality factors of 'Starkspur Golden Delicious' apple at the time of harvest as functions of fruit minerals and weight; leaf minerals and fruit weight; and both fruit and leaf minerals and fruit weight in 1980 and 1981.

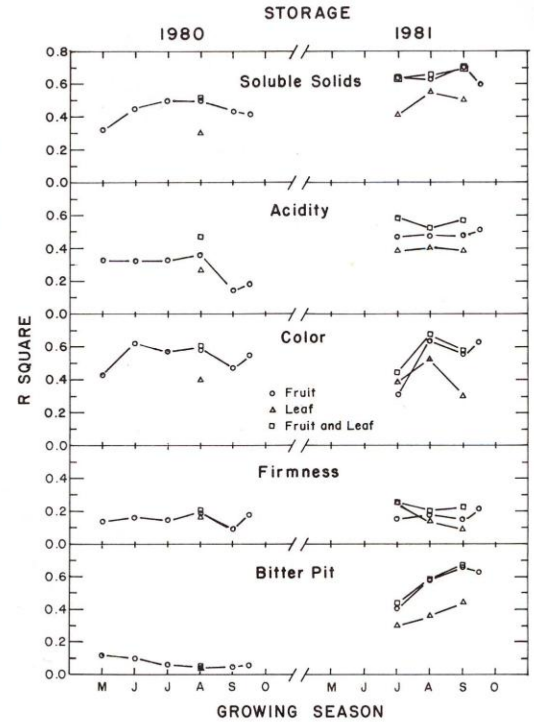

Fig. 2. Seasonal R^2 of various quality factors of 'Starkspur Golden Delicious' apple after 6 months of 0°C storage as functions of fruit minerals and weight, leaf minerals and fruit weight, and both fruit and leaf minerals and fruit weight in 1980 and 1981.

Soluble solids. Fruit analysis was better than leaf analysis for predicting soluble solids at harvest and after storage. Leaf analysis did not add strength to the prediction equations (Fig. 1 and 2). Fruit N, Ca, and P consistently associated negatively with fruit soluble solids in the first 3 steps in multiple regressions (Table 1). Although this is likely related to yield differences, yield or fruit weight was less important. Soluble solid predictions as early as June and July were as strong as the predictions made in September and even stronger than those made in October (Table 2).

Titratable acidity. Fruit titratable acidity was predicted better by the uses of combined fruit and leaf minerals in the prediction equations of both years (Fig. 1 and 2). Accuracy of predictions in July through September were similar (Table 2). Fruit Ca and

Table 1. Frequently appearing independent variables with their signs of associations (positive or negative) in the first 4 steps of forward stepwise multiple regressions for various apple quality factors (dependent variables) at harvest and after 6 months storage in 1980 and 1981.

Quality factor	Year	Tissue used: Fruit	Leaf	Leaf and fruit[z]
Soluble solids	1980	N(−),Ca(−),P(−),Wt[y](+)	Ca(−),K(+),Wt(+),B(+)	FN(−),FCa(−),FP(−),FB(+)
	1981	N(−),Ca(−),P(−),B(+)	Fe(+),Ca(−),N(−),Wt(+)	FP(−),FCa(−),FN(−),FB(+)
Acid	1980	Ca(−),Mg(−),N(−),Wt(+)	Wt(+),Fe(−),N(−),Cu(+)	FCa(−),LCu(+),LFe(−),FMg(+)
	1981	Ca(−),Cu(+),Mg(−),N(−)	Wt(+),Fe(+),Cu(+),K(+)	FCa(−),LCu(+),LFe(+),LB(−)
Skin green color	1980	N(+),Ca(+),Mg(+),Cu(+)	Ca(+),K(−),Cu(+),Mg(−)	FN(+),FCa(+),FFe(−),LK(+)
	1981	N(+),Ca(+),B(−),Cu(+)	N(+),Ca(+),Cu(+),Mg(−)	FN(+),FCa(+),FB(−),LN(+)
Firmness	1980	Wt(−),B(+),N(−),Ca(+)	Wt(−),Ca(−),P(−),B(+)	Wt(−),FN(−),FCa(+),LCa(−)
	1981	Wt(−),Ca(+),B(+),P(+)	Wt(−),N(+),Ca(−),P(+)	Wt(−),LMg(−),LCa(−),FCu(+)

[z]F = Fruit mineral. L = Leaf mineral.
[y]Wt = Fruit weight.

Table 2. Percentage of correct (Co) and severely misplaced (SM) categorizations for various quality factors after storage using preharvest variables and forward stepwise multiple regression equations for 1980 and 1981.

		Soluble solids				Titratable acidity				Skin color				Firmness			
		1980		1981		1980		1981		1980		1981		1980		1981	
Month	Tissue used	CO	SM	CO	SM	CO	SM	CO	SM	CO	SM	CO	SM	CO	SM	CO	SM
May	Fruit	65	9	---	---	55	8	---	---	77	8	---	---	42	20	---	---
June	Fruit	70	0	---	---	59	8	---	---	93	3	---	---	51	15	---	---
July	Fruit	62	4	75	0	64	9	64	10	81	4	53	9	47	13	40	13
	Leaf	---	---	49	3	---	---	57	6	---	---	51	8	---	---	65	11
	Fr & Lf	---	---	69	3	---	---	70	3	---	---	57	0	---	---	65	11
August	Fruit	66	3	69	0	46	6	59	0	92	0	74	0	49	8	38	23
	Leaf	44	5	61	0	57	17	55	0	78	10	59	0	46	11	44	12
	Fr & Lf	63	0	68	0	59	8	62	0	89	2	61	3	47	10	48	12
Sept.	Fruit	62	5	71	0	42	8	61	6	86	10	64	9	41	17	50	5
	Leaf	---	---	56	3	---	---	56	3	---	---	51	13	---	---	34	15
	Fr & Lf	---	---	79	3	---	---	72	0	---	---	59	5	---	---	55	3
Oct.	Fruit	68	2	63	0	47	12	66	0	90	0	67	0	59	8	45	11

leaf Cu were important variables both at harvest and after storage (Table 1).

Skin ground color. Fruit green color positively correlated with fruit N and Ca (Table 1). Fruit minerals were better indicators of fruit color than leaf minerals, and uses of combined leaf and fruit minerals did not improve the color prediction equations (Fig. 1 and 2). Overall, August sampling showed stronger relationships or predictions, although earlier samples also were accurate (Fig. 1 and 2 and Table 2).

Firmness. Firmness equations had low R^2 values, and predictions generally were weak (Fig. 1 and 2 and Table 2). Fruit size was negatively associated and fruit Ca positively associated with firmness in both years (Table 1).

Bitterpit. The incidence of bitterpit in 'Starkspur Golden Delicious' generally was low; thus, R^2 values usually were low, and predictions were weak for both years (data not shown). However, fruit Ca was consistently negatively associated with bitterpit.

Although within-year predictions are satisfactory (Table 2), regression equations derived from different years produced drastically different predictions. Over and underestimates were common in between-year predictions, especially for fruit based equations. For example, predictions using August of 1981 fruit data with August of 1980 equations, underestimated ground color by 95%. A 39% overestimate of soluble solids also was obtained. Although predicted values were not accurate between years, high and low plots were placed in a reasonable relative order. Between year predictions (Table 3) were not as good as within-year predictions (Table 2), but some between-year predictions were strong. The 1980 equations were more predictive than those of 1981 (Table 3). Predictions for firmness were weak, regardless of equation used. The stepwise discriminate analyses produced classifications similar to those obtained with regression equations within a given year, but were not suitable between years (data not shown). Discriminate functions from 1980 placed most of the observations in the high soluble solids category when used with Aug. 1981 data. Other parameters also were miscategorized.

Discussion

Quality parameters were associated with preharvest fruit and leaf mineral analyses, and although categorizations were not perfect, there can be some economic benefit from mediocre predictions. For example, a 50% correct and 12.5% severely misplaced categorization may not appear spectacular, but represents a group that contains twice as many high category fruit and half as many low category fruit than in a random selection (25% of total). One would expect about one-fourth of the fruit in a random sample to be in either the high (upper 25%) or low (lower 25%) category. The relative categorization scheme we

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	1981	Ca(−),Cu(+),Mg(−),N(−)	Wt(+),Fe(+),Cu(+),K(+)	FCa(−),LCu(+),LFe(+),LB(−)
Skin green color	1980	N(+),Ca(+),Mg(+),Cu(+)	Ca(+),K(−),Cu(+),Mg(−)	FN(+),FCa(+),FFe(−),LK(+)
	1981	N(+),Ca(+),B(−),Cu(+)	N(+),Ca(+),Cu(+),Mg(−)	FN(+),FCa(+),FB(−),LN(+)
Firmness	1980	Wt(−),B(+),N(−),Ca(+)	Wt(−),Ca(−),P(−),B(+)	Wt(−),FN(−),FCa(+),LCa(−)
	1981	Wt(−),Ca(+),B(+),P(+)	Wt(−),N(+),Ca(−),P(+)	Wt(−),LMg(−),LCa(−),FCu(+)

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		Soluble solids				Titratable acidity				Skin color				Firmness			
		1980		1981		1980		1981		1980		1981		1980		1981	
Month	Tissue used	CO	SM	CO	SM	CO	SM	CO	SM	CO	SM	CO	SM	CO	SM	CO	SM
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Table 3. Percentage of correct (Co) and severely misplaced (SM) categorizations for various quality factors after storage using August variables and multiple regressions models from one year on data from another.

Between years	Tissue used	Type of prediction	Soluble solids	Titratable acid	Color	Firmness
1980 predictions by 1981 equations	Fruit	Co	40	36	54	36
		SM	6	16	8	7
	Leaf	Co	30	38	49	15
		SM	10	12	11	26
	Fruit and Leaf	CO	44	39	42	36
		SM	10	28	17	13
1981 predictions by 1980 equations	Fruit	Co	60	51	57	44
		SM	0	4	2	15
	Leaf	Co	46	32	42	38
		SM	5	12	4	22
	Fruit and Leaf	Co	58	51	60	25
		SM	0	4	9	7

implemented (upper 25% and lower 25% categories) makes seasonal predictive differences less severe because, although predicted values were not accurate between years, high and low plots were placed in a reasonable relative order.

Independent variables sometimes were associated with each other. Fruit size and Ca obviously are related to each other, in that small fruit generally have high percentage Ca (3). Nitrogen relationships with soluble solids and skin color are consistent with the concept that excess application of N fertilizer will reduce these quality components and is in agreement with the report by Bramlage et al. (1). Leaf and fruit minerals alone may not adequately predict firmness. Including size is essential, and minerals may be of minor importance in firmness. Low incidence of bitterpit and weak predictions of this disorder could be because the fruit generally had more than 5 mg Ca/100 g freshweight at harvest (3) which is considered the threshold for bitterpit in 'Golden Delicious' apple (10).

Predictions of several quality variables by June or July mineral analyses are as strong as or even stronger than predictions by October minerals (Table 2). August analyses, however, would provide accurate predictions for most parameters with a single sampling. Sampling in August also allows sufficient laboratory time for analysis and recommendations. Recommendations could include altered cultural practices such as summer pruning (7, 10), marketing suggestions, and or postharvest fruit treatments to lessen the economic effect of potential storage disorders. Fruit mineral variation between years was the major cause of prediction differences. Although average leaf concentrations were relatively constant between years, fruit concentrations varied (3). Average August fruit concentrations for N, Ca, Mg, Cu, and B changed 58%, 21%, 85%, 66%, and 5%, respectively (3). 'Starkspur Golden Delicious' variety has a strong tendency for biennial bearing. Although thinning minimized differences between final yield, fruit set, or weather differences could have an effect on leaf-fruit relationships and final mineral compositions. Year-to-year variations in fruit mineral concentrations have been a major problem in bitterpit studies (11). Even though some correlations involving fruit minerals are consistent between years, management decisions could not be made from independent critical fruit mineral concentrations. Leaf analyses may provide critical values with improved stability between years but with reduced predictive value.

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