Senescent Breakdown of 'Jonathan' Apples in Relation to the Water-soluble Calcium Content of the Fruit Pulp before and after Storage

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Abstract. In 'Jonathan' apples grown in Israel, the incidence of senescent breakdown after 5 months of storage at 0°C was not correlated with total or water-soluble Ca content at harvest. Likewise, no other assayed component of the water-soluble or total mineral content (P, Mg, K) of the fruit pulp at harvest correlated with the disorder after storage. After storage, a general decrease in the solubility of Ca was observed. However, this decrease was not uniform in all fruit and, as a result, the correlation between water-soluble and total Ca content, which was high at harvest, diminished after storage. Water-extractable Ca from stored fruit was negatively correlated and water-soluble K/Ca was positively correlated with the incidence of senescent breakdown, whereas total Ca was not correlated.

Low Ca concentrations in apple at harvest have often been associated with fruit susceptibility to senescent breakdown, a disorder that may develop during cold storage (Dewey et al., 1981; Fukuda, 1972; van Goor, 1971; Ratkowsky and Martin, 1974). However, fruit with low Ca concentrations do not always show breakdown (Perring and Preston, 1974), and breakdown has sometimes been reported in fruit with high Ca levels (Perring and Plocharski, 1975a). In such instances, low P appeared to be involved in the development of the disorder (Perring and Plocharski, 1975a). In previous experiments we observed that occurrence of senescent breakdown did not correlate with Ca or P levels in the fruit at harvest and the disorder was even aggravated by application of calcium phosphate (unpublished results). One possible explanation for this apparent inconsistency with regard to Ca is that the physiological disorder is related only to a certain fraction of the cell Ca, which is not always directly correlated with total content. This possibility was suggested previously in relation to bitter pit, another storage disorder (van Lune

and van Goor, 1979). However, it still remains to be determined which Ca fraction might correlate satisfactorily with senescent breakdown. Fruit from trees sprayed with $\text{Ca}(\text{NO}_3)_2$, which can reduce the occurrence of senescent breakdown, contained a higher proportion of water-soluble Ca than those from nonsprayed trees (Perring and Preston, 1974). Furthermore, the distribution of total Ca within the apple fruit changes during storage (Bramlage et al., 1979; Rigney and Wills, 1981), reflecting a change in Ca solubility since, most likely, the water-soluble form would be mobile in the fruit tissue. Consequently, the physiological disorder might be better correlated with the level of water-soluble Ca at harvest or with the changing pattern of Ca solubility within the fruit during storage, than with total Ca.

In the present study we examined the correlation between the incidence of senescent breakdown and water-soluble and total Ca contents in the pulp of 'Jonathan' apple fruit before and after storage.

Since other apple storage disorders have been correlated with the ratios of Ca content to Mg and K (Bünemann and Lüdders, 1975; Li et al., 1985), we also tested such ratios with regard to their total and water-soluble levels.

Materials and Methods

In experiments conducted in 1984 and 1985, 'Jonathan' apples were picked at the beginning and at the peak of the com-

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Fig. 1. Senescent breakdown after 5 months of storage at OC and 7 days at 20C in relation to total (A) and water-soluble (B) Ca content determined at harvest. (Data for two harvest dates in 2 consecutive years.)

mercial harvest season (6 to 11 days between picking dates) from six orchards that had shown varying degrees of susceptibility to senescent breakdown in previous years. In each orchard 70 uniform fruit 65 to 70 mm in diameter were picked from five (1984) or seven (1985) randomly selected trees at each harvest date. Total and water-soluble contents of Ca, Mg, K, and P were determined in a composite sample of 10 fruit per tree, chosen at random both prior to and after storage, as previously described (Saks et al., 1988). The remaining fruit were stored in air at OC for 5 months, followed by 7 days at 20C, and senescent breakdown was determined visually in the halved apples.

Results and Discussion

The level of total Ca content in fruit from different orchards was always higher in our study than levels reported by others in fruit showing susceptibility to senescent breakdown (e.g., 1.05 to 2.21 mg/100 g fresh weight) (Bramlage et al., 1979). Yet, the disorder developed in both years, in the early as well as late-harvested fruit, reaching a maximum of 93% disordered fruit (Fig. 1A). Moreover, the total Ca content at harvest did not correlate with the subsequent incidence of senescent breakdown in the stored fruit (Fig. 1A). The above results agree with our previous observations (Saks et al., 1988) but not with those published by others (Dewey et al., 1981; Fukuda, 1972; van Goor, 1971; Ratkowsky et al., 1974). It seems that a simple, single factor correlation between the total Ca level at harvest and the occurrence of senescent breakdown after storage might not be strong enough in 'Jonathan' apples grown in Israel to produce a prediction formula for the disorder based on total Ca content in the fruit pulp at harvest (Bramlage et al., 1979; Sharples, 1980). Bramlage et al. (1979) and Steer (1977) have pointed

out that prediction of senescent breakdown from total Ca content in fruit pulp is not universally applicable.

In a similar analysis, the disorder also did not correlate with the total P, Mg, and K contents of the fruit pulp at harvest (data not shown). Neither did various relationships between Ca and other minerals, determined at or before harvest, correlate with the disorder detected in the stored fruit.

The level of water-soluble Ca in the fruit pulp, which amounted to 55% to 60% of the total Ca content, was consistent in the various orchards at both harvest dates in both years but did not correlate with disorder incidence (Fig. 1B). This result was to be expected, as soluble Ca at harvest was consistently correlated with the total Ca content ($P \leq 0.001$) (Table 1).

The total contents of Ca, Mg, and K in the pulp tissue of 'Jonathan' apples were constant during storage and subsequent shelf-life (Table 2). [The entire pulp was sampled for analysis, and therefore the possible changes resulting from mineral migration (Bramlage et al., 1985) were not reflected.] Thus, no correlations were found between the disorder and characteristics

Table 1. Correlation coefficients between water-soluble and total Ca⁺⁺ in the pulp of 'Jonathan' apples before and after storage.

Harvest	Before storage	After storage ^z
	1984	
Early	0.922***	0.614***
Late	0.936***	0.278 ^{NS}
	1985	
Early	0.780***	0.525**
Late	0.762***	0.430**

^zFive months of storage at OC followed by 7 days of shelf life at 20C.

^{NS}***Nonsignificant or significant at $P \leq 0.01$ or 0.001, respectively.

Table 2. Mineral content in the pulp of 'Jonathan' apples at harvest and after 5 months of storage at 0C and 7 days at 20C.

		Year			
		1984		1985	
		Harvest			
Mineral	Fraction	1st	2nd	1st	2nd
At harvest					
		mg/100 g fresh wt ($\pm$ SD)			
Ca	Soluble	2.9 $\pm$ 0.6	2.4 $\pm$ 0.5	2.0 $\pm$ 0.3	1.9 $\pm$ 0.3
	Total	4.5 $\pm$ 0.7	4.2 $\pm$ 0.6	3.4 $\pm$ 0.5	3.3 $\pm$ 0.5
Mg	Soluble	3.6 $\pm$ 0.6	3.4 $\pm$ 0.7	3.0 $\pm$ 0.5	2.5 $\pm$ 0.7
	Total	4.4 $\pm$ 0.6	4.3 $\pm$ 0.7	3.8 $\pm$ 0.7	4.2 $\pm$ 0.6
K	Soluble	104 $\pm$ 18.9	103 $\pm$ 24.1	76.8 $\pm$ 12.7	85.2 $\pm$ 20.3
	Total	107 $\pm$ 19.7	107 $\pm$ 24.9	82.0 $\pm$ 14.0	93.8 $\pm$ 16.2
After storage					
Ca	Soluble	1.5 $\pm$ 0.6	1.4 $\pm$ 0.5	1.3 $\pm$ 0.5	1.4 $\pm$ 0.5
	Total	4.2 $\pm$ 0.6	4.2 $\pm$ 0.9	4.5 $\pm$ 0.6	4.1 $\pm$ 0.5
Mg	Soluble	2.7 $\pm$ 0.7	2.7 $\pm$ 0.6	2.7 $\pm$ 0.6	2.5 $\pm$ 0.5
	Total	4.2 $\pm$ 0.7	3.9 $\pm$ 0.7	4.2 $\pm$ 0.8	4.1 $\pm$ 0.6
K	Soluble	86.3 $\pm$ 19.7	93.8 $\pm$ 16.6	86.5 $\pm$ 15.4	87.1 $\pm$ 15.0
	Total	92.8 $\pm$ 20.0	99.7 $\pm$ 16.8	92.7 $\pm$ 16.3	93.4 $\pm$ 15.0
	n	30	30	42	42

relating to the total contents of any of these minerals. However, volubility of Ca during storage decreased differentially, irrespective of the initial level at harvest. The ratio of SD values to water-soluble Ca values after storage increased by ≈55% in comparison with that at harvest (e.g., ± 0.6/1.5 vs. ± 0.6/2.9 in 1984). The differences between the SD values relative to the values for total and soluble Ca (Table 2) suggested that soluble Ca after storage might be a sensitive criterion in relation to disorder development. This relationship was also apparent in the correlation coefficients between total and water-soluble Ca, which diminished after storage in all four tested cases (Table 1). A decrease in water-soluble Ca during storage was reported for 'Cox's Orange Pippin' apples (Perring and Plocharski, 1975a). Also, Li et al. (1985) reported that the correlation between apple juice and total Ca content in apple flesh was good in mature but poor in overmature fruit. Water-soluble Ca after storage correlated negatively with senescent breakdown in both seasons (Table 3). Other correlations with soluble mineral content were either less significant or inconsistent. The solubilities of Mg and K did not follow the same pattern as that of Ca during the storage period. Magnesium solubility slightly decreased but that of K did not change. In both cases, the total content of each mineral remained highly correlated with the soluble fraction, but there was no correlation with the disorder. The values for the ratio of soluble K/Ca were correlated significantly with the disorder, but this was only as a result of the change in Ca.

Calcium appears to be a factor involved in the development of senescent breakdown, even in cases where the disorder may not be predictable on the basis of total Ca content at harvest. The involvement is expressed as a change in Ca solubility. Decrease in Ca solubility may precede senescent breakdown development because, in nonaffected fruit after storage, soluble Ca had decreased from the initial average level of 55% to ≈40%, whereas in the severely disordered fruit it had declined to 22%. Water-soluble Ca could be a more meaningful index than the total content for measuring changes that reflect Ca involvement in the development of the disorder. A water-soluble content of ≈40% of the total might be used as the criterion to indicate the

Table 3. Correlations between the water soluble or total mineral content in the fruit pulp after storage and the incidence of senescent breakdown (SB) in stored 'Jonathan' apples.

Fraction	1984	1985	
	2nd harvest	1st harvest	2nd harvest
<i>Ca</i>			
Soluble	-0.492***	-0.625***	-0.660***
Total	NS	-0.321*	NS
<i>Mg</i>			
Soluble	NS	-0.631***	-0.449**
Total	NS	-0.363**	NS
<i>K</i>			
Soluble	NS	-0.436**	-0.315*
Total	NS	-0.387**	NS
<i>Mg-Ca</i>			
Soluble	NS	NS	NS
Total	NS	NS	NS
<i>Ca/Mg</i>			
Soluble	NS	NS	-0.399**
Total	NS	NS	NS
<i>K/Ca</i>			
Soluble	0.555***	NS	0.510***
Total	NS	0.311*	NS
% SB ± SD	16.9 ± 14.4	16.7 ± 12.3	29.2 ± 14.5
df	28	40	40

*Regular air storage for 5 months at 0C followed by 7 days of shelf life at 20C.

NS,*,**,*Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

termination of storage before the onset of senescent breakdown. (This value might differ for cultivars other than 'Jonathan', and in diverse locations.) A similar concept has been suggested by Perring for bitter pit prediction in the 'Cox's Orange Pippin' apple (Perring and Plocharski, 1975 b).

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