Correlations of Calcium Content of 'Baldwin' Apples with Leaf Calcium, Tree Yield, and Occurrences of Physiological Disorders and Decay[1]

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Abstract. Calcium (Ca) level of leaves sampled in mid- or late summer was closely related to peel Ca levels of mature apples (*Malus pumila* Mill. cv. Baldwin). Ca content of fruit was directly related to fruit yield of the tree, cycling with biennial bearing. In 1971 bitter pit incidence could be predicted from either leaf or peel Ca; internal breakdown and decay were less predictable. In 1972 leaf Ca and peel Ca averaged, respectively, 27 and 17% higher than in 1971, accompanying increased yield. Little bitter pit, internal breakdown, or decay occurred, even at Ca levels correlated with high incidence rates the previous year. We concluded that Ca must be only 1 among several factors regulating these occurrences.

Although Ca deficiency is well known to result in abnormalities in apples (2, 3, 4, 5, 6, 7), Ca levels have seldom been correlated with the susceptibility of specific samples to these abnormalities. Such correlations could help determine the relative importance of Ca in development of the abnormalities, and could lead to predictive indices if Ca is the key factor in their development. In a recent study (1), we found close relationships between peel Ca content and postharvest defects of 'Baldwin' apples.

To more clearly assess the relationships, correlations between Ca levels and defects are reported here. In addition, crop size has been noted as a cultural factor that contributes strongly to pitting and corking disorders in apples, with fruit from trees bearing a smaller crop of larger fruit being more affected by these low-Ca manifestations (3). In our study (1), crop size on trees varied greatly within and between seasons, due to the alternate-bearing habit of 'Baldwin' trees. The effect of yield on fruit Ca levels has been determined for these trees.

Materials and Methods

Fruit and leaf samples were taken from a block of 52 mature 'Baldwin' apple trees, known to have widely varying Ca levels, at the Horticultural Research Center, Belchertown, Mass. Terminal leaf samples were randomly taken from each tree in early June, late July, and late August, 1971, and in late July, 1972, and dried 120 hr at 70°C. At commercial harvest in 1971 and 1972, 1 box of apples (80-100 fruit) was picked at random from each tree. Incidence of bitter pit at harvest was recorded ("October pit"), pitted fruit were placed in a kraft paper bag in the box, and the samples were stored in 0°C air for 5 months. After transfer to 21° air for 5 days, incidences of bitter pit, internal breakdown, and decay were recorded. The difference between total bitter pit and "October pit" was termed "storage pit." From each box, 10 randomly selected apples were mechanically peeled and the peels were dried for 120 hr at 70°C. Both leaf and peel samples were wet ashed in boiling HNO_3-$HClO_4$ and Ca was determined using a Perkin-Elmer Atomic Absorption Spectrophotometer, Model 214. All Ca values are reported on a dry weight basis. It should be noted that while fruit Ca is usually determined on fruit flesh, we analyzed for peel Ca because peel is more uniform than flesh tissue, is easier to prepare for precise analysis, and is closely correlated with bitter pit incidence (2, 5). Kidson et al. (5) found that peel and flesh Ca levels were equally related to bitter pit.

Correlation analyses on 52 pairs of data from the 1971 tests were conducted according to the procedures of Steel and Torrie, pp. 161, 453 (8).

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Results and Discussion

Leaf Ca level increased as the season progressed, with mean leaf Ca values of 0.35% for June, 0.83% for July, and 0.99% for August samples. When these leaf Ca levels were compared with Ca levels of peel from mature apples, June leaf Ca bore little relationship with peel Ca (r=0.277), but highly significant relationships existed when leaves were sampled in late-July (r=0.743) or late August (r=0.755). Leaf Ca thus appeared to be potentially useful for predicting peel Ca levels of mature apples if the leaves were taken in late summer.

During and after storage of fruit in 1971, physiological disorders and decay developed extensively. Incidences of bitter pit, internal breakdown, and decay were strongly related to peel Ca levels of the fruit, even though we demonstrated that Ca level had no effect on fruit maturation or ripening (1). When mature peel and late summer leaf Ca levels were compared with the incidence of these disorders, highly significant negative correlations existed between either peel or leaf Ca and the incidence of bitter pit, internal breakdown, or decay (Table 1). Peel Ca was more closely related than leaf Ca to the storage problems.

Table 1. Correlation coefficients between peel and leaf Ca content and decay and other disorders of 'Baldwin' apples, 1971.

Dependent variable	Independent variable	
	Mature peel Ca	July leaf Ca
"October pit"	-0.647**	-0.695**
"Storage pit"	-0.785**	-0.700**
Total bitter pit	-0.835**	-0.756**
Internal breakdown	-0.622**	-0.494**
Decay	-0.754**	-0.610**

**Indicates highly significant correlation.

From the correlation analyses, the slope values were assumed to represent linear relationships between both leaf Ca and peel Ca and each of the disorders and decay. These slope values were then used to predict the incidence ranges for the disorders and the decay within groups of samples using the leaf or peel Ca ranges within those groups. These predicted ranges were then compared with the observed ranges (Table 2). "October pit", "storage pit" and total bitter pit occurred at close to the predicted incidence ranges, implying that a linear relationship between leaf and peel Ca levels and bitter pit incidence did indeed exist over the range involved (350 to 920 ppm peel Ca). Internal breakdown and decay occurred more extensively than predicted, since both disorders were influenced only by peel Ca levels below 700 ppm (1) and the assumption of linearity was not valid. Peel Ca was only slightly better than leaf Ca as a predictive index (Table 2).

To confirm these findings, fruit samples were taken in 1972 from the same trees. However, following storage in 1972 the

Table 2. Ranges of incidence of 'Baldwin' apple disorders and decay, as predicted from ranges of mature peel and July leaf Ca levels and as observed following storage, 1971.

Disorder	Calculated range[z] based on Ppm leaf Ca	Ppm peel Ca	Observed range
"October pit"	0-22 %	0- 23 %	0- 43 %
"Storage pit"	11-77 %	11- 82 %	5- 84 %
Total bitter pit	9-99 %	9-100 %	5-100 %
Internal breakdown	0-12 %	0- 14 %	0- 34 %
Decay	0-38 %	0- 44 %	0- 66 %

[z]Calculated ranges were the product of linear regression of disorder on either ppm peel or ppm leaf Ca and the difference between mean and observed range of peel or leaf Ca.

fruits were essentially free of bitter pit and internal breakdown except for 3 samples below 500 ppm peel Ca (1). Hence, regression analyses would have been meaningless. It was clear, nevertheless, that the predictive index developed in 1971 was not applicable to 1972, since Ca levels that were associated with major deterioration in 1971 (e.g., 600-700 ppm peel Ca) (1) were related to only insignificant deterioration in 1972.

In 1972 Ca levels of leaves and fruit peels averaged, respectively, 27% and 17% higher than in 1971. This increase was not uniform, however; many trees with low Ca fruit in 1971 increased over 50% in peel Ca in 1972, and some trees with high peel Ca in 1971 fell nearly 50% in peel Ca in 1972. It was evident that the preceding year's Ca level of a tree was not a valid index for predicting the current year's Ca level of that tree (Table 3). Peel Ca was particularly subject to flux.

Since 'Baldwin trees are biennial in bearing habit, the relationship between yield and peel Ca was examined. In 1971, the low peel-Ca fruits were from the low yielding trees and the high peel-Ca fruits were from the high yielding trees (Table 4). However, due to alternate bearing the relative yields of these groups of trees in 1972 were generally the reverse of 1971. Accompanying this yield reversal was a dramatic and parallel shift in Ca levels. Of the 52 trees, 26 went from low yield, low peel-Ca status in 1971, to high yield, high peel-Ca status in 1972, while 18 trees exhibited the reverse pattern. When 1972 Ca levels were compared with yield for the 52 trees (Table 4), a yield-to-peel Ca relationship nearly identical to that in 1971 existed. Correlation coefficients between yield and peel Ca were r=0.0669** and 0.533** in 1971 and 1972, respectively, further illustrating that crop size had a major effect on Ca level of the fruit. Linear regressions showed peel Ca increases of 11 ppm in 1971 and 8 ppm in 1972 for each 1 box increase in yield of fruit per tree.

Garman and Mathis (4) previously reported that Ca content of 'Baldwin' apples was related to crop size. They found that fruit Ca was 457 and 313 ppm in August, and 459 and 214 ppm in October, in fruit from trees with large and small crops, respectively. Whether Ca level affected yield or yield affected Ca level can not be ascertained from 1 season's findings (4), but since in our study the individual trees showed biennial cycling of both yield and Ca level, crop size appears to be the determining factor in this relationship. It may be that with a small crop of fruit, the resultant rapid vegetative growth utilizes the available Ca at the expense of the developing fruits.

Despite the average increase of 17% in peel Ca in 1972, there were a number of trees that bore fruit with less than 700 ppm peel Ca (Table 4). From the results of 1971 these fruits would be expected to develop high incidences of bitter pit, internal breakdown, and decay if Ca level is a controlling factor in postharvest behavior of 'Baldwin' apples. This was not the case. Only when peel Ca was below 500 ppm were bitter pit and decay substantial (although these disorders were far below 1971 levels), and bitter pit was virtually absent in fruits with more than 500 ppm peel Ca (1). Furthermore, internal breakdown did not occur regardless of Ca level. Thus, it is evident that factors other than Ca level regulate the occurrences of these physiological and pathological problems. Perhaps low Ca imparts susceptibility, but other factor(s) trigger their development.

The marked deviation between years in incidence rates of disorders and decay at specific Ca levels suggests that simple predictive indices for these problems entirely based on either leaf or peel Ca levels would not be reliable. This deviation may have resulted from 1972 being an unusually cool, moist growing season. Moisture stress has been indicated as an important factor in bitter pit development (3), and may indeed be a key factor.

Table 3. Mature peel and July leaf Ca levels in groups of 'Baldwin' apple trees in 2 successive years.

Number of trees	Ppm Ca, 1971 Range, peel	Mean, peel	Mean, leaf	Ppm Ca, 1972 Range, peel	Mean, peel	Mean, leaf
11	350-500	415	6,601	676-1007	758	9,621
10	501-600	559	7,186	757- 863	807	8,912
7	601-700	649	8,220	669- 900	792	9,843
15	701-800	754	9,128	457-1082	697	11,159
9	801-920	853	10,131	463-1057	740	11,727
Mean		657	8,330		772	10,560

Table 4. Relationship between mature peel Ca content of 'Baldwin' apples and fruit yield per tree in 2 successive years.

1971 Number of trees	Range, peel Ca	Mean yield/ tree	1972 Number of trees	Range, peel Ca	Mean yield/ tree
	(ppm)	(bu. boxes)		(ppm)	(bu. boxes)
11	350-500	5.6	3	450- 500	3.4
10	501-600	12.1	4	501- 600	8.1
7	601-700	14.1	7	601- 700	14.5
15	701-800	23.4	16	701- 800	20.5
9	801-920	19.2	15	801- 900	21.9
			7	901-1080	21.7

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