Relationships of Calcium Content to Respiration and Postharvest Condition of Apples[1]

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Abstract. Postclimacteric respiration of apples (*Malus pumila* Mill. cv. Baldwin) decreased as peel Ca level increased from 400 to 1300 ppm. The respiratory climacteric occurred simultaneously in fruit of all Ca levels, indicating that maturation was unaffected by these Ca levels. Occurrence of bitter pit was inversely related to Ca levels. Scald, internal breakdown, and decay were more prevalent when peel Ca was below 700 ppm. Fruits were firmer after 5 months storage in 0°C air if Ca was below 700 ppm, although they were larger, yellower, and more susceptible to decay and other disorders than higher Ca fruit.

Ca level is related to the incidence of cork spot and bitter pit of apple (5). Negative correlation between peel Ca content and occurrence of bitter pit in 'Baldwin' apples has been demonstrated and it was concluded that 'Baldwin' apples with less than 0.07% (700 ppm) peel Ca should not be stored (4). In recent work it has become increasingly clear that postharvest effects of Ca extend beyond the relationships to cork spot and bitter pit. Occurrence of internal breakdown has been correlated with low Ca content of apples (9), and both preharvest sprays (9) and postharvest dips (2) with Ca have reduced its incidence. Furthermore, Faust and Shear (6) found that apple tissue very low in Ca respired CO_2 at an accelerated rate; Wang and Mellenthin (14) found that pears affected with cork spot, which is related to low Ca (10), respired more rapidly than sound fruit. Faust and Shear (6) suggested a fundamental role for Ca in controlling respiration and if this is correct, regulation of many physiological disorders might be integrally involved.

A serious problem in studying correlative effects of Ca on apples is the difficulty of establishing a wide range of Ca levels in bearing trees, since applied Ca is absorbed and translocated only slightly (5). At our Horticultural Research Center, Belchertown, Mass., a block of mature 'Baldwin' apple trees was found to have unusually low Ca levels. A series of treatments have been employed to raise these levels, and markedly different Ca levels now exist among the trees. Thus, large quantities of fruit comparable except for Ca level were available, and these were used to determine the simultaneous effects of Ca levels on respiration rate, occurrence of the respiratory climacteric, and postharvest behavior of apples.

Materials and Methods

Two sets of fruit samples were taken in October, 1971. The first set, taken for respiratory analysis, consisted of 10 fruits per tree taken from 8 and 10 trees having relatively high and low leaf Ca, respectively. The samples were taken prior to commercial harvest, stored at 0°C and 90-95% relative humidity for 3 months, and assessed for whole fruit CO_2 evolution by differential CO_2 analysis of effluent air using a MSA Model 200 infra-red gas analyzer. Fruits were sealed in a 9-liter desiccator at 21°C and a continuous flow of air (10 liters/min) was monitored daily for 9 days. At the end of the experiment, the apples were mechanically peeled, the peels were dried for 120 hr at 70°C, then wet-ashed in boiling HNO_3-$HClO_4$. Ca was determined using a Perkin-Elmer Atomic Absorption Spectrophotometer, Model 214, and is reported on a dry-weight basis.

The second set of samples was taken to assess storage life. At commercial harvest, 1 bu of apples per tree was taken from each of 52 trees and stored at 0°C, 90-95% relative humidity for 5 months. The fruits were transferred to room temp (approx 21°C); they were examined by 1 judge after 1 day for bitter pit, and after 7 days for scald, internal breakdown, and decay. Ten fruits from each sample were peeled and the peels were analyzed for Ca as above.

In October, 1972, 3 sets of samples were taken. Prior to commercial harvest, 10 fruits per tree were taken from 12 trees representing a wide range of Ca levels. These samples were immediately assessed for CO_2 evolution during 16 days at 21°, and their peel Ca was determined. At commercial harvest, 10-fruit samples were taken from 20 trees of varying Ca levels and assessed as above. In addition, at commercial harvest 61 1-bu samples were taken and stored at 0°C and 90-95% R.H. for 5 months. Two days after transfer to room temp, 10 fruits per sample were measured with a Magness-Taylor pressure tester, peeled, and peel Ca was determined. After 9 days at room temp the remainder of each sample was assessed for scald, internal breakdown, bitter pit, and decay. Correlation co-efficients were determined by procedures of Steel and Torrie, pp. 161, 453 (13).

Results

Respiration. All fruit assessed for respiration in 1971 exhibited a postclimacteric pattern during 9 days at 21°, but wide differences in respiration rate were evident among samples (Fig. 1A). Since the pattern was similar for all samples, the mean of the 9 CO_2 determinations for each sample during this period was computed and compared with peel Ca content of the fruits in that sample. A highly significant negative correlation (r = -0.82) existed between peel Ca and respiration rate, the plot of which (Fig. 2A) is similar to that of Faust and Shear (6) for 'York Imperial' apples. An increase in peel Ca from 340 to 940 ppm was associated with a 34% reduction of postclimacteric CO_2 production.

These results were confirmed from 1972 samples, taken at commercial harvest, which exhibited a climacteric peak-postclimacteric drift during 14 days at 21° (Fig. 1B). The mean of the respiration determinations for each sample was computed, and these means were correlated with peel Ca levels of the samples. As in 1971, a highly significant negative correlation (r = -0.88) existed, and the plotted data compared well with those obtained the previous year. It should be noted that Ca levels were generally higher in 1972 than in 1971.

Data of Faust and Shear (6) were difficult to interpret because stage of fruit development was unknown. Our correlations were for fruit of defined stages of fruit development, and showed that Ca levels can markedly influence respiration rate of apples. Nevertheless, a critical question in assessing postharvest behavior of the fruit was whether or not these differences in Ca level were influencing time of fruit ripening. Samples taken in early October, 1972, were preclimacteric and exhibited typical respiratory climacteric patterns during 16 days at 21° (Fig. 3). Throughout the climacteric, the respiration rate was inversely related to Ca level.

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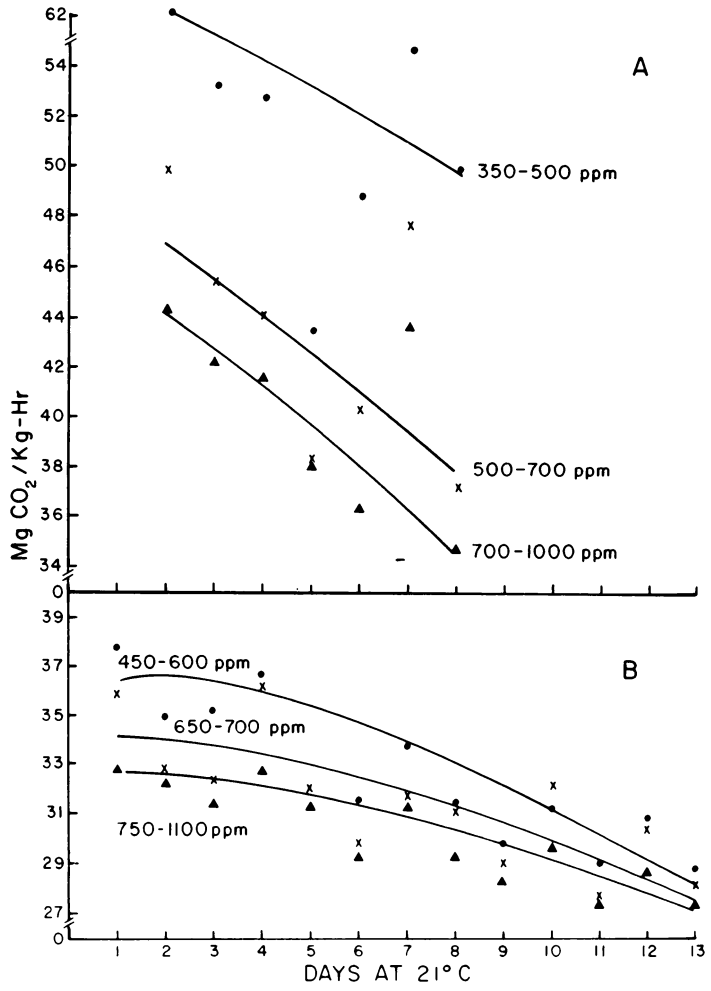

Fig. 1. Changes in respiration rate of 'Baldwin' apples of different Ca levels with time at 21°C. A. 1971-72. B. 1972-73. Symbols: ·, 350-500 and 450-600 ppm; x, 500-700 and 650-700 ppm; ▲ 700-1000 and 750-1100 ppm.

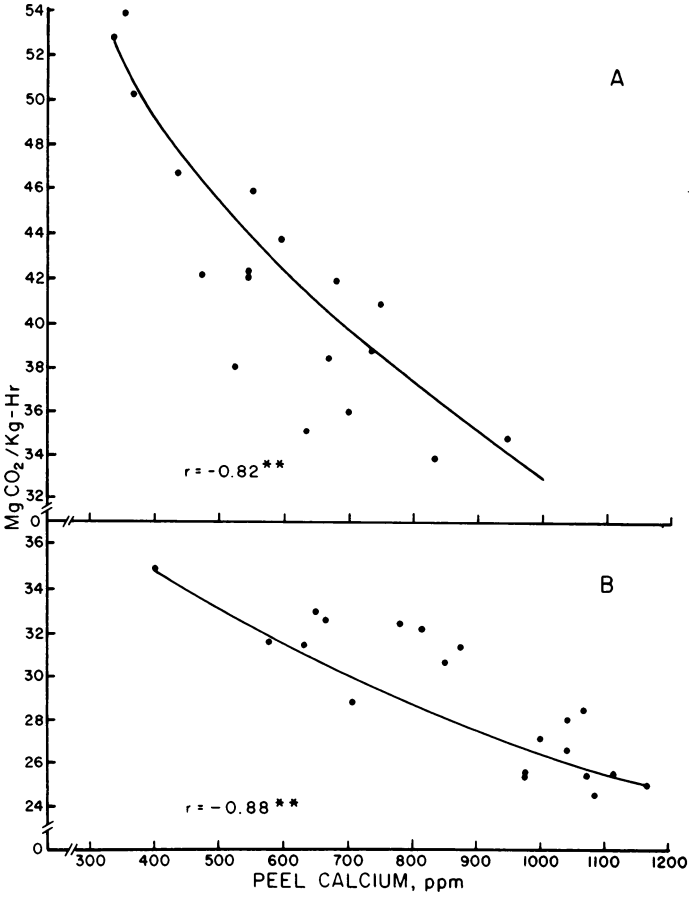

Fig. 2. Relationship of average respiration rate at 21°C to peel Ca content of 10-fruit samples of 'Baldwin' apples. A. 1971-72, avg. of 9 days. B. 1972-73, avg. of 13 days.

Differences in Ca level clearly did not affect time of occurrence of the climacteric, hence we concluded that Ca differences existing among these fruits did not influence their rate of maturation or ripening.

Postharvest condition. A relationship between Ca content and postharvest behavior of the fruit was evident after 5 months storage in 0° air in 1971-72 (Table 1). Bitter pit was reduced significantly by each 100 ppm increment increase of Ca. Internal breakdown was reduced by each increment up to 700 ppm, and decay by each increment to 800 ppm. Incidence of scald was not related to Ca level in 1971-72, however. Respiration, bitter pit, internal breakdown, and decay were all significantly and negatively correlated with fruit peel Ca (r = -0.820, -0.861, -0.776, and -0.622, respectively) among 18 pairs of observations. Low-Ca fruits were yellower than relatively higher Ca fruits, as observed by Shear (12).

In 1972-73, deterioration following storage was substantially less than in the preceding year (Table 2). Bitter pit was negligible except in the extremely low Ca fruit, and internal breakdown was virtually absent and is not reported. Decay was also minor except in the extremely low Ca fruit. Scald occurred less than in 1971-72, but it was significantly associated with Ca level, being more prevalent on fruits with less than 700 ppm Ca. This difference may have been masked in 1971-72 by the prominence of other defects (Table 1).

Additional relationships of low Ca to fruit condition were noted in 1972-73. Fruits with less than 700 ppm Ca were 3/4 to 1 kg (1½ to 2½ lb) firmer than ones with more than 700 ppm Ca (Table 2). This was surprising because these low Ca fruits were substantially larger and yellower than the higher Ca fruits. It was also noted that fruits with less than 700 ppm Ca were considerably less waxy than the higher Ca fruits.

Discussion

Our results confirm that Ca level influences respiration rate

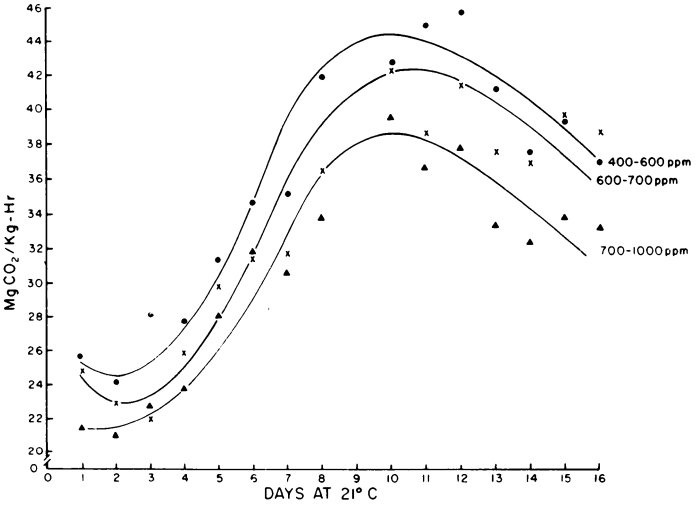

Fig. 3. Respiratory climacteric of 'Baldwin' apples of various peel Ca contents, 1972-73. Symbols: ·, 400-600 ppm; x, 600-700 ppm; ▲, 700-1000 ppm.

Table 1. Relationships between peel Ca content and mean incidence of 4 physiological disorders of 'Baldwin' apples after 5 months air storage at 0°C, 1971-72, with standard deviations of the means.

Peel Ca (ppm)	No. of samples	Bitter pit (%)	Scald (%)	Internal breakdown (%)	Decay (%)
350-500	11	89 ± 3	49 ± 7	16 ± 3	39 ± 5
501-600	10	75 ± 5	58 ± 6	5 ± 1	26 ± 5
601-700	7	57 ± 10	49 ± 3	2 ± 1	14 ± 3
701-800	15	33 ± 4	59 ± 5	1 ± 1	7 ± 1
801-920	9	22 ± 5	52 ± 7	1 ± 1	5 ± 2

Table 2. Relationships between peel Ca content and mean condition of 'Baldwin' apples after 5 months air storage at 0°C, 1972-73, with standard deviations of the means.

Peel Ca (ppm)	No. of samples	Firmness (kg)[z]	Scald (%)	Bitter pit (%)	Decay (%)
450- 500	3	6.12(13.6) ±.13	32±11	7 ± 4	12±6
501- 600	4	5.94(13.2) ±.33	28± 9	1 ± 0	3±2
601- 700	8	5.76(12.8) ±.20	37± 7	1 ± 0	1±0
701- 800	19	5.04(11.2) ±.05	16± 4	1 ± 0	4±1
801- 900	16	4.95(11.0) ±.05	10± 3	0 ± 0	3±1
901-1000	4	5.00(11.1) ±.06	9± 3	0 ± 0	2±1
1001-1400	7	5.00(11.1) ±.01	8± 3	0 ± 0	1±0

[z]Numbers in parentheses are values in lbs pressure.

of apples, and show that this effect is not due to different rates of fruit maturation or ripening. In fact, the uniformity of the respiratory difference at all stages is striking. This difference in respiration could arise directly from a Ca effect on mitochondria, or indirectly from cytological changes that modify mitochondrial activity. Ca has been shown to influence plant mitochondrial metabolism *in vitro,* but the effect is generally stimulatory (7). Since Ca, even at the lowest levels, was present in more than catalytic quantities, its known activity as an enzymatic cofactor (8) would not seem to be a factor contributing to the differences in respiration. Ca is believed to enhance membrane stability (8), and it is perhaps most reasonable to speculate that with suboptimal Ca, more rapid penetration of mitochondrial membranes by metabolites leads to accelerated decarboxylation rates.

Every parameter of postharvest condition examined in our study varied with Ca level. Thus, a general effect of Ca on postharvest behavior of fruit is suggested with a strong indication that more rapid senescence occurred when Ca was low. This evidently was not due to earlier maturation; the respiratory climacteric occurred simultaneously at all Ca levels, and scald, which is lessened by advanced maturity (11), was equal or greater at low compared with high Ca. Since cellular disorganization normally accompanies fruit ripening (1), membrane instability due to low Ca might hasten senescent deterioration after harvest. However, the possibility that deterioration is promoted by rapid accumulation of respiratory metabolites cannot be dismissed. Bangerth, et al. (2) found that infusion of Ca into apples reduced both respiration and occurrence of internal breakdown.

Our results suggest that 700 ppm peel Ca may be a critical level in postharvest behavior of 'Baldwin' apples. Internal breakdown, decay, and scald were significantly greater below 700 ppm and firmness was substantially greater below 700 ppm. Only bitter pit seemed to be proportionally related to Ca level across the range of Ca concentrations. The earlier suggestion, that 'Baldwin' apples below 700 ppm peel Ca should not be stored (4), is supported by these findings.

The greater firmness of low Ca fruit was not consistent with the general expression of advanced senescence of these fruit. It was particularly surprising since the low Ca fruits tended to be larger than the high Ca ones. Faust and Shear (6) found that low Ca apples yielded increased amounts of an ethanol-insoluble residue presumed to be cellulose. The greater firmness may thus be a reflection of a modified cell wall structure, and the suggestion that pressure tests are not reliable indices of fruit condition when Ca is low (6) seems appropriate.

The observation in 1972-73 that low Ca fruits were generally larger than higher Ca fruits prompted an examination of yield data from this block of trees. The findings, reported separately (3), showed that the very low Ca trees were those with light crops and large fruit. Hence, the effects of Ca on postharvest behavior reported here were perhaps confounded with effects of crop size. Nevertheless, since maturity did not differ and larger fruit were not softer, we believe that the differences we report are primarily the direct result of nutritional status of the fruit, although crop size may be a major factor inducing the nutritional differences.

Bitter pit, scald, internal breakdown, and decay were most abundant in fruits very low in Ca. Ca level thus appears to be a major contributing factor to these forms of deterioration. However, the substantially different incidence rates of these disorders and decay during the 2 storage seasons within samples of equivalent Ca levels implies that Ca level was not the sole or even prime factor in regulating postharvest behavior of these fruit. A fuller evaluation of the correlations between Ca levels and postharvest behavior of these fruits (3) supports this view.

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