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Bitter Pit Control by Sprays and Vacuum Infiltration of Calcium in 'Cox's Orange Pippin' Apples

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Abstract. **The incidence of external and internal bitter pit in 'Cox's Orange Pippin' apple *(Malus domestics* Borkh.) fruit sprayed with normal therapeutic sprays either with or without Ca salts at 2-week intervals during the growing season was determined after 6 weeks of storage over 7 consecutive years. Following harvest, fruit was either vacuum-infiltrated with $CaCl_2$ or received no further treatment. Although there was a tendency for fruit that had been sprayed and vacuum-infiltrated with Ca to exhibit the greatest degree of bitter pit control, this treatment was not significantly superior to Ca sprays alone. Vacuum infiltration alone reduced the disorder to a lesser extent than Ca sprays and was more effective in reducing external than internal bitter bit. The results suggest that Ca applications over the growing season are superior to postharvest vacuum-infiltration with Ca in the prevention of bitter pit.**

Increasing fruit Ca content with preharvest and postharvest Ca treatments is a successful way of reducing the incidence of bitter pit in apples (Ferguson and Watkins, 1989; Perring, 1986). In experimental trials with preharvest Ca sprays, incidence of bitter pit has been significantly reduced, although rarely eliminated (Turner et al., 1977; Watkins et al., 1989). Although Ca sprays are mandatory for 'Cox's Orange Pippin' apples destined for export from New Zealand, in practice, variable and commercially unacceptable levels of bitter pit still occur. In an attempt to reduce the disorder and improve fruit quality, the New Zealand apple industry introduced a vacuum-infiltration treatment (Scott and Wills, 1977, 1979) in 1978 for postharvest application of $CaCl_2$ to 'Cox's Orange Pippin' apples. Infiltration of Ca into fruit allowed the rinsing of fruit with water after treatment without removing beneficial Ca from fruit tissues, thereby reducing the risk of Ca burn to fruit as well as damage to grading equipment.

Control of bitter pit by infiltration was improved compared with that obtained by Ca dips, and it was claimed that the relatively high degree of bitter pit control obtained with vacuum infiltration may make spraying the trees with Ca during the growing season unnecessary (Scott and Wills, 1979). However, industry observations suggested that bitter pit control using the vacuum-infiltration technique alone was not adequate and that a declining use of Ca sprays by growers was associated with a higher incidence of bitter pit even in vacuum-infiltrated fruit. Subsequent research with vacuum infiltration confirmed that high levels of bitter pit could occur in infiltrated fruit (Hewett and Thompson, 1989a).

Our objective was to compare bitter pit levels in unsprayed and Ca-sprayed fruit with or without postharvest Ca infiltration using a commercial vacuum plant.

Each year from 1979 to 1985, 'Cox's Orange Pippin' were harvested in mid-February (first week of commercial harvest) from mature trees grown at the DSIR Research Orchard, Appleby, Nelson, New Zealand. Treatments were applied randomly across a

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Table 1. External and internal bitter pit in unsprayed and Ca-sprayed 'Cox's Orange Pippin' apple fruit that were either not treated further or vacuum-infiltrated with $CaCl_2$ following harvest and then stored for 6 weeks at 1C and 1 week at ambient temperatures before assessment.[z]

Year	Preharvest Ca spray	External bitter pit (%)		Internal bitter pit (%)	
		No vacuum	Vacuum	No vacuum	Vacuum
1979	No	41.6 a	19.8 b	46.7 a	34.2 a
	Yes	3.1 c	0.9 c	3.8 b	1.9 b
1980	No	19.2 a	1.9 b	29.4 a	16.2 b
	Yes	4.6 b	2.7 b	6.3 c	5.9 c
1981	No	27.5 a	0.9 b	40.7 a	15.2 b
	Yes	1.5 b	0.8 b	5.9 c	4.4 c
1982	No	25.8 a	8.0 b	31.4 a	10.1 b
	Yes	4.4 b	0.0 c	7.1 b	1.5 c
1983	No	29.3 a	16.0 b	46.4 a	37.8 a
	Yes	4.7 c	6.1 c	10.2 b	12.3 b
1984	No	37.0 a	3.6 b	41.7 a	8.4 b
	Yes	4.6 b	2.4 b	5.9 b	4.2 b
1985	No	4.7 a	3.5 a	6.5 a	3.7 a
	Yes	1.4 a	3.7 a	1.8 a	3.9 a
Mean	No	26.5 a	7.6 b	34.7 a	18.3 b
	Yes	3.4 b	2.1 bc	5.7 c	4.7 c

'For either external external bitter pit, mean separation between and within columns at $P = 0.05$ for each year and the overall mean. Analysis performed on transformed data; backtransformed data are presented.

Table 2. Calcium levels in unsprayed or Ca-sprayed 'Cox's Orange Pippin' apples that were not treated further or were vacuum-infiltrated with $CaCl_2$ following harvest and then stored for 6 weeks at 1C.

Year	Preharvest Ca spray	Ca concn ($mg \cdot 100\ g^{-1}$ fresh wt)	
		No vacuum	Vacuum
1979	No	1.41	2.17
	Yes	2.02	3.32
1985	No	1.65	2.54
	Yes	2.40	3.49
Mean	No	1.53	2.36
	Yes	2.21	3.41

single block of trees receiving 0.6% $Ca(NO_3)_2$ (w/v) plus 0.01% Agral (v/v) at 2-week intervals (up to seven times) during the growing season. Immediately after harvest, field bins of unsprayed and Ca-sprayed fruit remained either untreated or were treated in a commercial vacuum-infiltration plant with 2.5% $CaCl_2$(w/v) for 2 min and then rinsed with water.

Within 36 h of harvest, fruit were graded to two weight groups, 134 or 148 g (size counts 138 and 125, respectively), and packed into New Zealand Apple and Pear Marketing Board export cartons. Four to six replicate cartons for each treatment were stored at lC for 6 weeks before removal to ambient temperatures (12 to 18C) for 7 days before assessment of external and internal disorders (Hewett and Thompson, 1989a). Calcium concentrations in cortical plugs of duplicate samples of 20 fruit from each treatment were determined after the 6-week storage period in 1979 and 1985 using the procedures of Turner et al. (1977).

Data analysis was performed using a Genstat 5 statistical package and analysis of variance was carried out after angular transformation. F ratios were obtained for determining probability levels and standard errors of the difference of the means for comparison of means.

Bitter pit development, as indicated by the frequency of the disorder in unsprayed, nonvacuum-infiltrated fruit, varied over the 7 years of this trial. Overall, external and internal bitter pit levels in this fruit were 26.5% (range 4.7% to 41.6%) and 34.7% (6.5% to 46.7%), respectively (Table 1).

Significant ($P = 0.05$) effects of either sprays or vacuum infiltration of Ca on bitter pit levels were found in all years, except 1985, when the incidence of bitter pit in all fruit was low (Table 1). Vacuum infiltration with Ca reduced the incidence of external bitter pit in unsprayed fruit in all years, except 1985. However, while internal bitter pit was reduced by vacuum infiltration, the reduction was not significant in 1979, 1983, and 1985, indicating that efficacy of the treatment could be variable. On average, vacuum infiltration of unsprayed fruit reduced external and internal bitter pit by 71% and 47%, respectively. In contrast, Ca sprays reduced both external and internal bitter pit by 87% and 84%, respectively. Vacuum infiltration reduced external and internal bitter pit in sprayed fruit overall by only 38% and 18%, respectively, and except in 1982, the effect was not significant. A preharvest Ca spray program reduced external and internal bitter pit more effectively than vacuum infiltration of unsprayed fruit in 2 and 4 years out of 7, respectively.

Thus, comparison of bitter pit levels in fruit from a preharvest Ca spray with fruit from a postharvest vacuum infiltration treatment indicated that, in general, superior control of this disorder, especially internal bitter pit, was achieved by Ca sprays. Reduction in incidence of external bitter pit levels in sprayed fruit resulted in all fruit falling within the maximum commercial tolerance of 5% incidence of the disorder. Comparable reductions in bitter pit incidence as a result of Ca sprays has been shown in other studies (Reid et al., 1978; Turner et al., 1977; Watkins et al., 1989). In commercial practice, however, control of bitter pit is often less successful than can be shown experimentally, possibly due to incomplete coverage by the Ca sprays, as well as a range of orchard factors that aggravate the disorder (Ferguson and Watkins, 1989).

Although infiltration of Ca reduced bitter pit incidence in unsprayed fruit, internal bitter pit was reduced to a lesser extent than external bitter pit. A differential effect of vacuum infiltration on external and internal bitter pit is presumably related to the time required for Ca to move from the skin into the fruit and through cortical tissue to potential lesion sites (Ferguson and Watkins, 1989). In an earlier study, the total number of pits located deeper than 5 mm into the flesh was similar in untreated and vacuum-infiltrated fruit, even though total bitter pit incidence was highest in untreated fruit (Ferguson and Watkins, 1983).

A differential effect on external and internal bitter pit reduction by vacuum infiltration was also observed in sprayed fruit, but the reduction of bitter pit by the treatment was much lower than that obtained with unsprayed fruit. Overall, levels of bitter pit in sprayed fruit were markedly lower than in unsprayed fruit. The limited ability to further reduce these levels with vacuum infiltration indicates the presence of a certain proportion of fruit that is highly predisposed to bitter pit which no treatment can easily ameliorate.

Calcium concentrations in fruit from each treatment were similar in both 1979 and 1985 (Table 2). Spraying with Ca regularly throughout the season increased the mean fruit Ca concentration by 44%, compared with unsprayed fruit. Postharvest vacuum infiltration increased Ca concentrations by 54%, regardless of whether fruit had been sprayed or not. Vacuum infiltration of sprayed fruit resulted in the highest fruit Ca levels—123% more than unsprayed, nonvacuum-infiltrated fruit. Our data on Ca concentrations in fruit from the four treatments are limited, but confirm a preliminary study (Reid et al., 1978) that showed that the highest Ca concentrations were found in the sprayed, vacuum-infiltrated fruit. Reid et al. (1978) found higher Ca concentrations in sprayed fruit than in unsprayed, vacuum-infiltrated fruit, whereas there was little difference in concentrations between the two treatments in our study. If anything, vacuum-infiltrated fruit had marginally higher Ca levels than sprayed fruit. A combined treatment of vacuum infiltration and sprayed fruit resulted in the highest Ca level of all treatments.

In this work, there was no clear relationship between Ca concentrations in fruit after treatment and incidence of bitter pit. However, it may not be actual measured values after 6 weeks of storage that are critical. Our methods for Ca analysis involve the use of equatorial cortical plugs from just under the skin (Turner et al., 1977). Although this represents a measurement of Ca concentration in a zone where concentrations are lower, the distribution of the applied Ca is unknown. While Ca sprays do not eliminate bitter pit, their application during the growing season is likely to ensure a better Ca balance in the whole fruit and, thus, result in better disorder control than that attainable by postharvest treatment, notwithstanding the apparently slightly higher Ca concentrations measured in such fruit compared with sprayed fruit.

Although there were no reports of fruit rotting associated with vacuum infiltration in the studies of Scott and Wills (1979), an increased incidence of rot in treated fruit was noted by Reid et al. (1978). In our experiments, a significantly *(P* < 0.001) higher incidence of rot was found in vacuum-infiltration treatments (3.7%) than in nonvacuum-infiltration treatments (1.8%). However, the relatively small increase in rotting found in our and other experiments using a commercial vacuum-infiltration treatment plant (Hewett and Thompson, 1989b; Reid et al., 1978); suggests that a commercially serious risk of increased fruit rotting is not likely with this treatment. Both vacuum and pressure infiltration of fruit with conidial suspensions of *Penicillium expansum* increased decay levels in several apple cultivars (Conway and Sams, 1983; Scholberg et al., 1989), but infiltration of $CaC1_2$ to the fruit either before inoculation (Conway and Sams, 1983) or with the conidial suspensions (Scholberg et al., 1989) reduced the extent of the decay. An increased risk of decay associated with infiltration of inoculum into fruit lenticels and cracks in the fruit surface appears to be reduced by beneficial effects of Ca.

Our results indicate that correct preharvest Ca spray application is a primary means of decreasing the incidence of bitter pit in ‘Cox’s Orange Pippin’ apple fruit and is superior to a postharvest treatment with Ca. It is interesting to note that since the New Zealand industry required minimum Ca concentration in apples for export, there has been an overall increase in Ca levels in fruit in all districts. This increase has resulted in a lowered risk of bitter pit, which when combined with widespread use of postharvest Ca drenches, has markedly reduced the historical problem of this disorder in ‘Cox’s Orange Pippin’.

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