Controlling Bitter Pit in 'Honeycrisp' Apples

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SUMMARY. Control of bitter pit in 'Honeycrisp' apples (*Malus* × *domestica*) from trees treated during the growing season with foliar sprays of trifloxystrobin fungicide and calcium was evaluated in four replicated trials over 2 years. All trials were in commercial orchards of 'Honeycrisp' trees that were 3 to 6 years old. The effectiveness of combining boron with foliar applications of calcium chloride ($CaCl_2$) was evaluated in two trials, and effectiveness of harpin protein, used either alone or in alternating sprays with $CaCl_2$ was assessed in one trial. Trifloxystrobin applied twice during the 30 days before harvest reduced bitter pit incidence at harvest in one of the four trials, but the reduction was transitory, no longer being evident when fruit were re-evaluated after 63 days of cold storage. Harpin protein did not affect disorder incidence. Calcium sprays failed to control bitter pit in treatments where the total elemental calcium applied was less than 2.7 lb/acre (3.03 $kg \cdot ha^{-1}$) per year for tree canopies that were sprayed to drip using 100 gal/acre (935.4 $L \cdot ha^{-1}$) of spray solution. In the two trials where some treatments involved application of at least 2.9 lb/acre (3.25 $kg \cdot ha^{-1}$) of elemental calcium per season, the incidence of fruit with bitter pit at harvest was reduced by 76% to 90%. Effectiveness of calcium sprays for bitter pit control was not enhanced by superimposing trifloxystrobin, boron, or harpin protein treatments. Flesh firmness at harvest was lower in calcium-treated than in non-treated fruit, and fruit maturity was more advanced on trees receiving boron sprays than on trees receiving no boron. In one trial, where the first calcium application was made approximately 2 weeks after petal fall and 4 days prior to a fruit thinning spray, crop load of trees that received calcium sprays, measured as number of fruit per cm² trunk cross-sectional area, was 38% greater than on trees that received no calcium sprays. $CaCl_2$ provided better control of bitter pit in 'Honeycrisp' than any of the other materials tested.

'Honeycrisp' is a relatively new apple cultivar that has a unique crisp juicy texture found in no other commercially available apple cultivar (Tong et al., 1999). The texture of 'Honeycrisp' has generated considerable interest among apple growers and consumers, and the cultivar is being planted throughout northern fruit producing regions in the United States. 'Honeycrisp' has excellent long-term storage characteristics. Apples held in regular air storage for 9 months still retained more crispness than most apples available in retail stores in May and June (Luby and Bedford, 1992).

In many young plantings, however, more than 50% of 'Honeycrisp' fruit develop bitter pit prior to harvest or during storage (Rosenberger et al., 2001). Bitter pit is common in young, lightly cropped trees of other apple cultivars, but in some 'Honeycrisp' plantings bitter pit is still causing significant losses after 4 or 5 years of regular cropping. Further expansion of 'Honeycrisp' plantings will be feasible only if growers can minimize losses to bitter pit.

Bitter pit is a physiological disorder associated with low calcium content in fruit. It is aggravated by excessive tree vigor and fruit size, low soil pH, boron deficiency, and environmental stress such as drought (Faust and Shear, 1968; Ferguson and Watkins, 1989). In other cultivars prone to this disorder, bitter pit can be reduced by applying calcium in foliar sprays during summer. However, effectiveness of spray regimes for controlling bitter pit has been highly variable and the sprays can be phytotoxic to apple foliage, especially when calcium is applied at high concentrations, high temperatures, or in combination with other pesticides (Ferguson and Watkins, 1989).

Several new chemistries that reportedly affect plant physiology and stress responses were recently registered for application to apples. Strobilurin fungicides affect many different aspects of plant metabolism, some of which contribute to increased "greening" and productivity of treated crops (Bartlett et al., 2002; Ypema and Gold, 1999). Kresoxim-methyl has been shown to cause a decrease in the level of 1-aminocyclopropane-1-carboxylic acid (ACC), ACC synthase activity, and ethylene production, and it may thereby slow chlorophyll degradation and delay senescence (Ypema and Gold, 1999). Another strobilurin fungicide, trifloxystrobin, reduced bitter pit incidence on apples in 2 years of trials at the Novartis Northeast Research Station in Hudson, N.Y. (M.A. Pastor-Corrales, personal communication). In those trials, trifloxystrobin applied in eight cover sprays in 1998 reduced the incidence of bitter pit in 'Idared,' 'Stayman,' and 'Delicious' by 91%, 95%, and 75%, respectively. In 1999, two applications of trifloxystrobin during August reduced bitter pit incidence on 'RedCort' fruit from 29% in control plots to 5% in treated plots.

Harpin protein induces systemic acquired resistance in plants (Dong et al., 1999). The harpin protein product label claims that this product can also enhance growth, fruit development and nutrient uptake in a wide range of plant species.

The objective of our experiments was to evaluate the effectiveness of foliar calcium sprays for controlling bitter pit on 'Honeycrisp' apples when calcium sprays are applied alone or in combination with foliar boron,

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trifloxystrobin, and harpin protein treatments.

Materials and methods

Field trials were conducted for two consecutive years in 'Honeycrisp' orchards in the Hudson Valley (southeastern New York state) and for 1 year in a western New York 'Honeycrisp' orchard near Lyndonville, Niagara County, N.Y. In the Hudson Valley, treatments in 2000 were applied to sixth-leaf trees on 'Malling 26' rootstock (Milton, Ulster Co., N.Y.) and to fifth-leaf trees on 'Malling 9' rootstock (Gardiner, Ulster Co., N.Y.). The same Milton orchard was used for the 2001 field trial. In 2001, treatments were also applied to third-leaf trees on 'Malling 9' rootstock near Lyndonville. In all trials, growers applied routine fungicide, insecticide, and nutritional programs without any strobilurin fungicide sprays or foliar calcium sprays.

A randomized block design was used for all of the trials. In the Hudson Valley, trees were placed into replicates based on blossom density assessed when trees were slightly past king bloom. Trees with similar blossom densities were used for comparisons within replicates because fruit load is known to influence susceptibility to bitter pit. Single-tree plots were used for experiments at Gardiner and Milton. Five-tree plots were used at Lyndonville. Treatments were replicated five times in all locations.

Treatments at Lyndonville were applied with a Solo 425 backpack sprayer (Solo Inc., Newport News, Va.) whereas a high-pressure pump and handgun were used to spray trees at Gardiner and Milton. In all locations, spray volume was determined by spraying trees until the spray solution began to drip from leaves. In all except the Gardiner orchard, fruit were harvested and evaluated to determine how field treatments affected fruit maturity, fruit mineral content and the incidence of externally-visible bitter pit at harvest and after cold storage. In the Gardiner trial, the only data collected was incidence of bitter pit at harvest.

Gardiner and Milton trials, 2000. A factorial design was used to evaluate trifloxystrobin-calcium interactions. Treatments included a control (no summer sprays of trifloxystrobin or calcium), trifloxystrobin fungicide (Flint 50WDG, Novartis, Inc., Greensboro, N.C.) at 1 oz/100 gal (75 mg·L^{-1}) of formulated product applied on 4 and 15 Aug., calcium applied on 3 and 17 July and 4 and 15 Aug., and a combination of the trifloxystrobin and calcium treatments. Calcium sprays consisted of NorCOP Calcium Mannitol Solution (Notrace, Ltd., Greeley, Colo.) applied at 1qt/100 gal (2.5 mL·L^{-1}), a rate that provided 0.29 lb/100 gal (347 mg·L^{-1}) of actual calcium in each application.

Harvest samples consisting of 50 randomly selected fruit per tree were collected on 5 Sept. 2000. At the Milton orchard, the fruit remaining on the tree after the harvest samples had been removed were counted to determine total crop load. Trunk diameters were measured at 12 inches (30.5 cm) above the soil line during late Oct. 2000 to allow calculation of fruit/cm^2 of trunk cross-sectional area (TCSA). The 50-fruit harvest samples were used to assess incidence and severity of externally-visible bitter pit immediately after harvest and again after 85 d cold storage at 34.5 °F (1.39 °C).

An additional 20-fruit subsample of mid-sized fruit was harvested from each tree for determination of fruit firmness and fruit mineral content. A Model EPT-1 Pressure Tester (Lake City Technical Products, Kelowna, B.C., Canada) fitted with an 11.1-mm-diameter probe was used to measure fruit firmness on opposite faces of each fruit. Tissue samples were collected from the same 20 fruit for mineral analyses. Tissue was collected by cutting a 0.25 inch (6.4 mm)-thick equatorial slice through the core of the apple, then removing two 0.31-inch- (8mm) diameter plugs from just beneath the skin on opposite sides of the slice and pooling the samples for all of the apples from the same tree (Turner et al., 1977). After drying, fruit tissues were wet-ashed and mineral concentrations were analyzed by using an inductively coupled argon plasma (ICP) atomic emission spectrometer in the ICP Nutrient Analysis Lab of the Department of Horticulture at Cornell University, Ithaca (Greweling, 1976).

Milton 2001. Trees in test plots were treated during summer with CorClear Calcium Chloride (97% $CaCl_2$; Sego International, Portland, Ore.) either alone or in combination with other products that might affect bitter pit development (Table 1). In addition to foliar $CaCl_2$ sprays, other products tested as foliar sprays included trifloxystrobin fungicide, sodium borate (Solubor, 20.5% boron from sodium borate; U.S. Borax, Valencia, Calif.) and harpin protein (Messenger, 3% harpin protein; Eden Bioscience, Bothell, Wash.). A factorial design was used to compare five treatments (control, trifloxystrobin, sodium borate, harpin protein, and a trifloxystrobin+sodium borate+harpin protein combination) applied either alone or in conjunction with the $CaCl_2$ spray schedule (Table 1). $CaCl_2$ was applied six times at bi-weekly inter-

Table 1. Treatments and dates they were applied to 'Honeycrisp' apple trees at the orchard in Milton, N.Y., in 2001.

Generic name	Trade name	Active ingredient (%)	Rate applied[z] (formulated product)	May			June		July			Aug		
				16	24	30	13	20	11	17	24	1	8	14
Calcium chloride[y]	CorClear	94-97	1 lb/100 gal	x		x		x						
			2 lb/100 gal							x		x		x
Trifloxystrobin	Flint 50WDG	50.0	1 oz/100 gal									x		x
Sodium borate	Solubor	20.5	1 lb/100 gal			x		x		x				
Harpin protein	Messenger	3.0	4.5 oz/100 gal		x		x		x		x		x	
Harpin protein	Messenger	3.0	4.5 oz/100 gal		x		x		x		x		x	
+ Sodium borate	Solubor	20.5	1 lb/100 gal			x		x		x				
+ Trifloxystrobin	Flint 50WDG	50.0	1 oz/100 gal									x		x

[z]1 lb/100 gal = 1.2 g·L^{-1}; 1 qt/100 gal = 2.5 mL·L^{-1}; 1 oz/100 gal = 75 mg·L^{-1}.
[y]The calcium chloride treatment was superimposed over half of all the plots in this trial using a factorial design that allowed evaluation of interactions between calcium chloride and other treatments. Calcium chloride sprays were tank mixed with other products applied on the same dates.

vals. Harpin protein was applied five times on alternate weeks to avoid any possibility that harpin protein would be inactivated by other products in a tank mix. Sodium borate was applied three times to the replicated plots. Trifloxystrobin was applied twice in August, about 28 and 14 d before harvest.

Trees in the test orchard reached petal fall on 12 May. The grower's spray program on this farm included sodium borate applied at 2.4 lb/acre (2.69 kg·ha^{-1}) on 2, 22, and 29 May and Epsom salts at 21 lb/acre (23.5 kg·ha^{-1}) on 29 May, 29 lb/acre (32.5 kg·ha^{-1}) on 6 and 26 June, and 14 lb/acre (15.7 kg·ha^{-1}) on 15 June and 9 July.

A random sample of 90 fruit was harvested from each tree on 29 Aug., and fruit remaining on the tree after sampling were counted. Mature fruit that dropped to the ground prior to 29 Aug. were also counted. Trunk diameters were measured at 12 inches above the soil line on 30 Oct. to allow calculation of fruit numbers per cm^2 TCSA.

Ten fruit were used to assess fruit firmness and starch content immediately after harvest. Starch hydrolysis was assessed on a scale of 1 (no hydrolyzed starch) to 8 (all starch hydrolyzed) using the Cornell generic starch index (Blanpied and Silsby, 1992). Eighty fruit were evaluated for bitter pit. The 80 fruit were then divided into two boxes of 40 fruit each. One box was dipped for 30 s in a solution containing CorClear Calcium Chloride (94 to 97% $CaCl_2$) at 2.5 lb/100 gal (3.0 g·L^{-1}). All fruit in this experiment were held at 69 °F (20.6 °C) until 31 Aug. when the $CaCl_2$ postharvest treatments were applied. Fruit were then moved to cold storage at 37 °F (2.8 °C). Fruit were assessed for incidence of bitter pit after 63 d of cold storage. At the time of the final rating on 1–2 Nov., each sample of fruit was weighed to determine mean fruit weight. A 15-fruit sub-sample was collected from each of the 100 experimental lots (20 field treatments × 5 replications × 2 $CaCl_2$ postharvest treatments) after fruit were removed from storage, and the sub-samples were analyzed for fruit mineral content at the Cornell ICP Nutrient Analysis Laboratory.

Lyndonville, 2001. Six different calcium formulations and trifloxystrobin fungicide were compared using the rates suggested by the product manufacturers (Table 2). Calcium treatments were applied to trees on 28 June, 14 and 20 July, and 3, 17, and 23 Aug. Trifloxystrobin was applied only on 17 and 23 Aug. All calcium treatments were applied with the adjuvant LI-700 (Loveland Industries, Greeley, Colo.) used at a rate of 16 fl oz/100 gal (1.25 mL·L^{-1}). Control trees were unsprayed except for the grower-applied standard pesticides. Mature fruit were harvested on 15 Sept. and were stored at 33 °F (0.6 °C) for 90 d. Fruit firmness and mineral content were determined as described previously.

Results

Year 2000 trials. Calcium treatments did not provide significant reductions in bitter pit in either of the trials conducted during the 2000 growing season. At Milton, the replicate involving trees with the heaviest crop averaged 6.83 fruit/cm^2 TCSA, and fruit from this replicate had relatively little bitter pit due to their smaller fruit size. With that replicate omitted in a subsequent analysis, the mean incidence of bitter pit at harvest was 47% lower for fruit treated with trifloxystrobin than for fruit receiving no trifloxystrobin (i.e., 11% vs. 20% of fruit with bitter pit, Table 3). However, the effect of trifloxystrobin on bitter pit disappeared during cold storage. Treated and non-treated fruit had similar levels of bitter pit (21% vs. 24%) after 85 d of cold storage (Table 3).

None of the treatments at Milton affected concentrations of calcium in fruit (P = 0.23). The calcium sprays used in Milton did not affect fruit firmness either at harvest (P = 0.19) or after 85 d of cold storage (P = 0.52).

At Gardiner, trees had a very light crop (mean of only 18.8 fruit per tree) and fruit were therefore evaluated only at harvest. Trees treated with trifloxystrobin had 27% less fruit with bitter pit than trees not receiving trifloxystrobin, but this difference was not significant (P = 0.23).

Milton, 2001. $CaCl_2$ applied six times during summer reduced the incidence of bitter pit by 76 and 47%

Table 2. Foliar treatments applied to 'Honeycrisp' apple trees at Lyndonville, N.Y., and effects of treatments on incidence of fruit with externally visible bitter pit as determined after cold storage.

Treatment	Manufacturer[z]	% Elemental calcium in the formulation	Application rate (formulated product/100 gal of spray)[y]	Total amount of elemental calcium applied (lb/acre)	Fruit with bitter pit after cold storage (%)[x]
Control	---	---	---	---	27 c[w]
DowFlake Process Grade Calcium Chloride	Dow Chemical	28	3 lb +6 lb[v]	6.8	3 a
Calcium Chloride 405 Concentrate	Cerexagri	12	1 qt + 2 qt[v]	2.9	2 a
Stop It Liquid Calcium Chloride	Pace International	12	1 qt + 2 qt[v]	2.9	4 a
Nortrace 10% Calcium	UAP-Nortrace	10	2 qt	3.5	6 a
Nortrace Norplex 6	UAP-Nortrace	6	2 qt	1.8	18 ab
Nortrace Norplex 6 plus Boron	UAP-Nortrace	6	2 qt	1.8	16 ab
Trifloxystrobin	Novartis	0	3 oz	---	19 bc

[z]Dow Chemical Co., Midland, Mich.; Cerexagri, King of Prussia, Pa.; Pace International LLC, Kirkland, Wash.; UAP-Nortrace Ltd., Ozark, Ala.; Novartis, Greensboro, N.C.
[y](1 lb/100 gal = 1.2 g·L^{-1}; 1 qt/100 gal = 2.5 mL·L^{-1}; 1 oz/100 gal = 75 mg·L^{-1}; 1 lb/acre = 1.2 kg·ha^{-1}).
[x]Bitter pit was rated after 90 d of cold storage followed by a 7-d shelf-life test at 68 °F (20.0 °C).
[w]Means followed by the same small letter are not significantly different as determined using Fishers protected least significant difference test (P = 0.05).
[v]Four applications at the first rate followed by two applications at the second rate.

Table 3. Incidence of bitter pit on 'Honeycrisp' apple fruit harvested in 2001 from the orchard in Milton, N.Y., as affected by application of trifloxystrobin and calcium chloride foliar sprays during summer.

Trifloxystrobin treatment[z]	Fruit with bitter pit at harvest (%)			Fruit with bitter pit after 85 d cold storage (%)		
	Calcium chloride ($CaCl_2$)		Grand means for effects of trifloxystrobin	Calcium chloride ($CaCl_2$)		Grand means for effects of trifloxystrobin
	None	Four applications[z]		None	Four applications[z]	
None	12	27	20	25	23	24[x]
Two applications	9	13	11*[y]	19	22	21
Grand means:						
Effects of $CaCl_2$	11	20		22[x]	23	

[z]Calcium chloride [NorCOP Calcium Mannitol Solution, 1 qt/100 gal (2.5 mL·L^{-1})] was applied on 3 and 17 July; 4 and 15 Aug., and provided elemental calcium at the rate of 0.29 lb/100 gal (347 mg·L^{-1} per application. Trifloxystrobin [Flint 50WDG, 1 oz/100 gal (1.2 g·L^{-1})] was applied 4 and 15 Aug.
[y]Means for effects of trifloxystrobin are significantly different. *P*-values for trifloxystrobin, calcium, and calcium × trifloxystrobin interaction were 0.05, 0.06, and 0.21, respectively, as determined using a two-way analysis.
[x]*P*-values for calcium sprays, trifloxystrobin spray, and calcium × trifloxystrobin interaction were 0.81, 0.51, and 0.38, respectively.

Table 4. Fruit maturity ratings and incidence of bitter pit in 'Honeycrisp' apple fruit harvested in 2001 from the orchard in Milton, N.Y., as affected by foliar treatments of calcium chloride ($CaCl_2$), trifloxystrobin, sodium borate, and harpin protein applied in various combinations.

Spray programs[z]	Maturity ratings at harvest		Fruit with bitter pit (%)	
	Starch index	Fruit firmness (lbf)[y]	At harvest 29 Aug.	After 63 d at 37 °F (2.8 °C)
No $CaCl_2$ sprays				
No subsidiary sprays	3.3 abc[x]	17.1 bc	9 bc[z]	80 c
Trifloxystrobin	2.9 ab	18.2 d	13 c	84 c
Sodium borate (SB)	3.7 bc	17.2 bcd	7 bc	61 b
Harpin protein (HP)	2.7 a	17.2 bcd	7 bc	86 c
Trifloxystrobin + SB +HP	3.9 c	17.6 cd	12 c	86 c
With $CaCl_2$ sprays				
No subsidiary sprays	3.1 ab	16.5 abc	<1 a	37 a
Trifloxystrobin	3.3 abc	15.6 a	1 a	41 a
Sodium borate	4.1 c	16.3 ab	3 ab	44 a
Harpin protein	2.8 a	16.3 abc	3 ab	43 a
Trifloxystrobin + SB +HP	3.7 bc	16.9 bc	4 ab	44 a
P values for $CaCl_2$ × subsidiary treatment interactions	0.733	0.034	0.337	0.006
Grand means for $CaCl_2$ effects				
No $CaCl_2$ treatments	3.3	17.4 b	9 b	79 b
With $CaCl_2$ treatments	3.4	16.3 a	2 a	42 a
P values for $CaCl_2$ treatment effects	0.720	<0.001	0.001	<0.001
Grand means for subsidiary treatments				
No subsidiary sprays	3.2 a	16.8	4	59 ab
Trifloxystrobin	3.1 a	16.9	7	63 b
Sodium borate	3.9 b	16.8	5	52 a
Harpin protein	2.8 a	16.8	5	65 b
Trifloxystrobin + SB +HP	3.8 b	17.1	8	65 b
P values for subsidiary treatments	0.001	0.817	0.354	0.024

[z]See Table 1 for details of rates and spray application dates.
[y]1 lbf = 4.45 N.
[x]Letter separations within columns for simple means or for grand means were determined using Fisher's protected least significant difference test ($P = 0.05$) applied to the results of two-way analyses wherein trees with or without calcium foliar sprays were subjected to five subsidiary treatments.

for ratings at harvest and after 63 d of storage, respectively. The mean incidence of fruit with bitter pit at harvest was 2.2% for trees sprayed with $CaCl_2$ compared with 9.2% for trees receiving no $CaCl_2$ sprays (Table 4). After storage, bitter pit was evident on 41.8% of fruit from trees sprayed with $CaCl_2$ compared with 79.4% for trees with no $CaCl_2$ sprays. Postharvest treatment with $CaCl_2$ did not affect development of bitter pit during storage (data not presented). Treatments involving trifloxystrobin, sodium borate, and harpin protein did not affect the incidence of bitter pit (Table 4).

Fruit from trees sprayed with $CaCl_2$ had less bitter pit on both evaluation dates. However, after 63 d of storage there was an interaction between the $CaCl_2$ and the supplemental treatments, primarily because sodium borate suppressed bitter pit slightly in trees that did not receive $CaCl_2$ sprays but had no effect on bitter pit in trees sprayed with $CaCl_2$ (Table 4). Thus, the effects of $CaCl_2$ and sodium borate were not additive.

Fruit from trees sprayed with $CaCl_2$ were softer at harvest than fruit

Table 5. Productivity, premature drop, fruit size and shoot growth from 'Honeycrisp' apple trees in 2001 in the orchard in Milton, N.Y., as affected by foliar treatments of calcium chloride ($CaCl_2$), trifloxystrobin, sodium borate, and harpin protein applied in various combinations.

Spray programs[y]	No. of fruit per cm^2 trunk cross-sectional area[z] Total crop	Harvested crop	Premature drop as a percent of total crop	Mean fruit wt (g)	Mean shoot growth (cm)
No $CaCl_2$ sprays					
No subsidiary sprays	3.6 abc[y]	3.2 abc	12.5 c	299 cd	32
Trifloxystrobin	2.1 a	1.9 a	7.7 abc	300 cd	27
Sodium borate (SB)	4.3 bcd	3.9 cde	7.9 abc	294 cd	22
Harpin protein (HP)	3.2 ab	2.9 abc	7.9 abc	313 d	30
Trifloxystrobin + SB +HP	2.4 a	2.2 ab	9.1 bc	322 d	30
With $CaCl_2$ sprays					
No subsidiary sprays	6.1 e	5.7 f	5.3 ab	240 a	27
Trifloxystrobin	5. 8 de	5.2 ef	8.8 abc	256 ab	27
Sodium borate	3. 9 abcd	3.6 bcde	6.5 abc	275 bc	27
Harpin protein	5.4 cde	4.9 def	7.6 abc	256 ab	29
Trifloxystrobin + SB +HP	3.7 abc	3.5 abcd	4.5 a	269 abc	29
P values for interaction between $CaCl_2$ and subsidiary treatments	0.039	0.040	0.153	0.408	0.505
Grand means for $CaCl_2$ treatment					
No $CaCl_2$ treatments	3.1 a	2.8 a	9.0 b	305 b	28
With $CaCl_2$ treatments	5.0 b	4.6 b	6.6 a	259 a	28
P values for $CaCl_2$ treatment effects	<0.001	<0.001	0.038	<0.001	0.825
Grand means for subsidiary treatments					
No subsidiary treatment	4.9	4.5	8.9	269	30
Trifloxystrobin	3.9	3.6	8.3	278	26
Sodium borate	4.1	3.8	7.2	284	25
Harpin protein	4.3	3.9	7.8	284	30
Trifloxystrobin + SB +HP	3.0	2.9	6.9	296	30
P values for subsidiary treatment effects	0.092	0.100	0.886	0.214	0.238
Block effects					
Block I (full bloom, large trees)	2.3 a	2.2 a	6.6	331 d	31 cd
Block IV (light bloom, large trees)	3.1 ab	2.8 ab	9.1	274 b	35 d
Block V (light bloom, small trees)	4.2 b	3.9 bc	8.8	247 a	25 ab
Block II (full bloom, medium trees)	4.4 b	4.1 c	6.5	301 c	28 bc
Block III (full bloom, small trees)	6.1 c	5.6 d	8.1	258 ab	20 a
P-values for block effects	<0.001	<0.001	0.427	<0.001	<0.001

[z]1 cm^2 = 0.155 $inch^2$; 1 g = 0.035 oz; 1 cm = 0.394 in.
[y]See Table 1 for details for rates and spray application dates.
[x]Letter separations within columns for simple means or for grand means were determined using Fisher's protected least significant difference test ($P = 0.05$) applied to the results of two-way analyses wherein trees with or without calcium foliar sprays were subjected to five subsidiary treatments. Each treatment combination was replicated five times.

from trees that received no $CaCl_2$ (Table 4). $CaCl_2$ did not affect the starch maturity index, but ethylene production by the fruit was not measured. Therefore, it is uncertain if differences in firmness are attributable to advanced maturity of fruit from trees sprayed with $CaCl_2$ as shown for other cultivars in New York (Watkins, 1997). Reduced fruit firmness in $CaCl_2$-treated trees is especially surprising because $CaCl_2$ treatment also resulted in increased fruit set and reduced fruit size (Table 5). Trifloxystrobin applied alone produced the firmest fruit whereas trifloxystrobin applied with $CaCl_2$ produced the softest fruit.

The mean fruit calcium content across all trees that received $CaCl_2$ sprays during summer was 18 ppm greater than for fruit from trees that did not receive calcium sprays during summer (Table 6). Where $CaCl_2$ sprays were not applied, fruit sprayed with trifloxystrobin or sodium borate alone had more calcium than control fruit whereas both treatments that included harpin protein had less calcium than control fruit. Where $CaCl_2$ was applied, the highest calcium concentration occurred in fruit sprayed with $CaCl_2$ alone and the lowest occurred where both trifloxystrobin and $CaCl_2$ were applied. Application of $CaCl_2$ also contributed to lowered concentrations of potassium and phosphorus in fruit along with increased concentrations of manganese.

Sodium borate treatments increased fruit boron concentrations (Table 6). When sodium borate was applied in combination with trifloxystrobin and harpin protein, fruit boron concentrations were higher than when sodium borate was applied alone. Treatment with sodium borate, either alone or in combination with trifloxystrobin and harpin protein, resulted in advanced fruit maturity as judged by the starch index (Table 4). However, sodium borate did not affect fruit firmness. Trifloxystrobin-treated fruit had higher boron concentrations than fruit treated with harpin protein alone but

Table 6. Mineral content of 'Honeycrisp' apple fruit harvested in 2001 from the orchard in Milton, N.Y., as affected by foliar treatments of calcium chloride ($CaCl_2$), trifloxystrobin, sodium borate, and harpin protein applied in various combinations.

	Fruit mineral content [ppm ($mg \cdot kg^{-1}$)]				
Spray programs	**Boron**	**Calcium**	**Potassium**	**Phosphorous**	**Manganese**
No $CaCl_2$ sprays					
No subsidiary sprays	14.8 cd	110 d	5730 cde	479 bc	1.82 bc
Trifloxystrobin	17.4 c	117 c	6540 a	581 a	1.84 bc
Sodium borate (SB)	24.1 b	123 c	6050 abc	461 bcd	1.97 abc
Harpin protein (HP)	12.2 de	104 e	5910 bc	434 cd	1.95 abc
Trifloxystrobin + SB +HP	25.1 b	103 e	6170 abc	524 ab	1.80 c
With $CaCl_2$ sprays					
No subsidiary sprays	12.6 de	136 a	5070 f	424 cd	2.04 abc
Trifloxystrobin	11.0 e	124 c	5280 ef	406 d	2.03 abc
Sodium borate	22.3 b	129 b	5870 bcd	473 bcd	2.06 ab
Harpin protein	12.4 de	130 b	5310 def	419 cd	1.95 abc
Trifloxystrobin + SB +HP	28.9 a	133 b	6340 ab	547 a	2.10 a
P values for interaction between $CaCl_2$ and subsidiary treatments	0.004	0.052	0.006	<0.001	0.456
Grand means for $CaCl_2$ treatments					
No $CaCl_2$ treatments	18.7 a	112 b	6070 a	494 a	1.88 b
With $CaCl_2$ treatments	17.1 a	130 a	5560 b	452 b	2.03 a
P-values for $CaCl_2$ treatment effects	0.139	<0.001	<0.001	0.003	0.005
Grand means for subsidiary treatments					
No subsidiary sprays	13.7 c	124 a	5400 c	452 bc	1.93
Trifloxystrobin	14.1 c	121 a	5880 ab	489 b	1.94
Sodium borate	23.2 b	126 a	5960 ab	467 bc	2.02
Harpin protein	12.3 c	117 a	5160 bc	427 c	1.95
Trifloxystrobin+ SB +HP	26.9 a	118 a	6250 a	535 a	1.94
P-values for subsidiary treatments	<0.001	0.376	<0.001	<0.001	0.881

[z]See Table 1 for details for rates and spray application dates.
[y]Letter separations within columns for simple means or for grand means were determined using Fisher's protected least significant difference test ($P = 0.05$) applied to the results of two-way analyses wherein trees with or without calcium foliar sprays were subjected to five subsidiary treatments. Each treatment combination was replicated five times.

not when summer sprays of $CaCl_2$ were added to the trifloxystrobin and harpin protein treatments (Table 6).

Trees treated with $CaCl_2$ had 4.6 harvestable fruit/cm² TCSA compared with only 2.8 for trees that did not receive $CaCl_2$ (Table 5). Sodium borate treatment produced the highest crop load among trees not sprayed with $CaCl_2$ and the second lowest crop load among trees that were sprayed with $CaCl_2$.

Differences in bloom density and trunk diameters were used to assign trees to replicates, and therefore replicates differed in crop load, fruit size, and terminal shoot length (Table 5). Replicates with the lightest crop generally produced the most shoot growth and the largest fruit. Although the inverse relationship between crop load and shoot growth was observed when replicates were compared, treatments did not affect shoot growth even though trees treated with $CaCl_2$ had a heavier crop load.

Lyndonville, 2001. Control of bitter pit was directly related to the amount of calcium applied during the season regardless of the formulation of calcium used. In four treatments where trees received at least 2.9 lb/acre of elemental calcium, bitter pit was reduced by 79 to 91% compared with control trees (i.e., bitter pit incidence was 3% to 6% in calcium-treated trees compared with 27% in control trees). Bitter pit was reduced by only 36 to 40% in two treatments where trees received only 1.8 lb/acre (2.02 $kg \cdot ha^{-1}$) of elemental calcium (Table 2). Trifloxystrobin did not control bitter pit in the Lyndonville trial.

In the three trials where fruit mineral content was analyzed, there was a significant linear relationship between mean calcium content in fruit from individual trees and the incidence of bitter pit in fruit from those same trees (Fig. 1). Calcium concentrations in fruit accounted for 35% to 48% of the variability in incidence of bitter pit after cold storage. Calcium concentrations in fruit fell within the same range for Lyndonville and Milton 2000, but were somewhat higher for fruit from Milton in 2001.

Discussion

The experimental design provided a severe test for controlling bitter pit because treatments were applied to young, lightly cropping trees. Also, fruit were harvested at the very earliest stages of acceptable fruit maturity because the random samples had to be harvested before the first color picking was done by the cooperating growers. The fruit used for bitter pit evaluations were randomly selected from throughout the tree canopy and were therefore even more immature than commercially harvested fruit where only highly colored fruit would be removed on the first harvest. Bitter pit is usually more severe on immature than on mature fruit (Ferguson and Watkins, 1989). Cooling of harvested fruit from the 2001 Milton trial was delayed 2 d while fruit were rated and the postharvest $CaCl_2$ treatment was

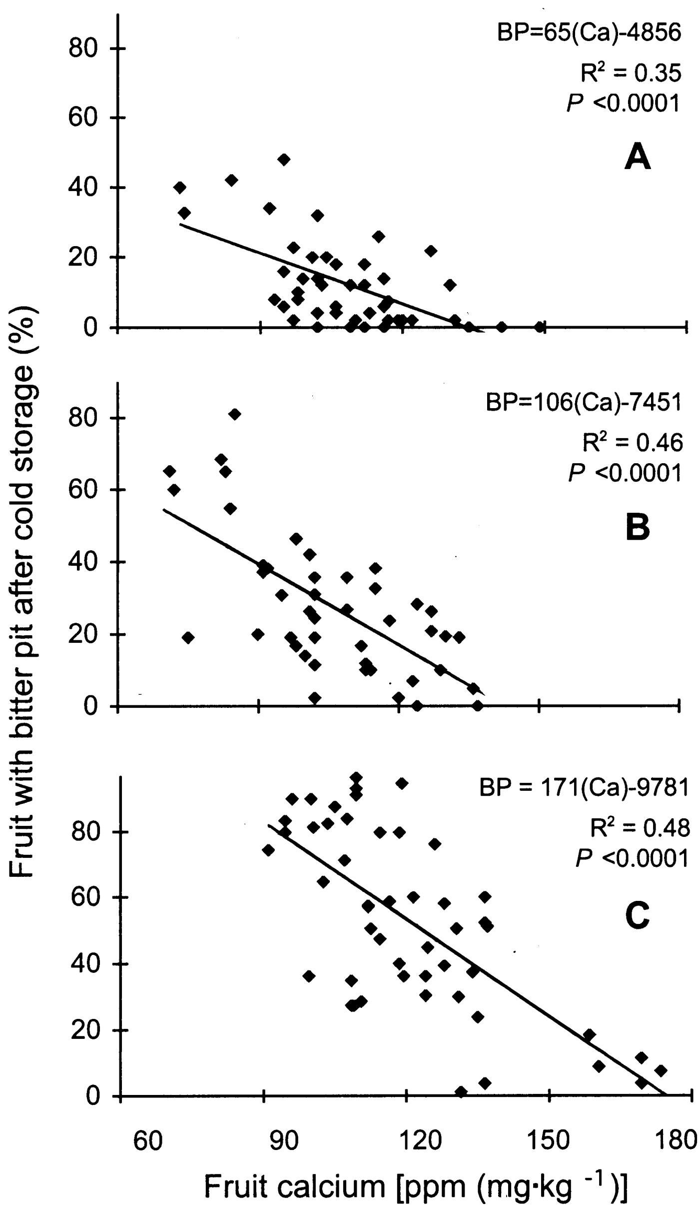

Fig. 1. Linear regressions showing effects of fruit calcium concentrations on incidence of bitter pit after cold storage for the experiments conducted at Lyndonville in 2001(A) and Milton in 2000 (B) and 2001 (C). Regression equations show predicted incidence of bitter pit (BP) based on concentrations of calcium (Ca), expressed as ppm (mg·kg^{-1}) in fruit tissue.

applied. Then fruit were then stored at 37 °F (2.8 °C) to avoid chilling injury (soft scald) that would have interfered with bitter pit evaluations. Delayed cooling and warmer storage temperatures both favor development of bitter pit in 'Honeycrisp' apples (Watkins et al., 2004).

$CaCl_2$ provided better control of bitter pit than any of the other materials evaluated in this study. In the Milton orchard, control was better in 2001 than in 2000 when less $CaCl_2$ was applied [3.2 vs. 1.2 lb/acre (3.59 vs. 1.35 kg·ha^{-1})] actual calcium for 2001 and 2000, respectively). Also, $CaCl_2$ was applied six times in 2001 compared with only four times in 2000, and the applications at Milton were initiated during May in 2001 compared with July in 2000. The total amount of elemental calcium that was applied at Milton and Gardiner in 2000 was too low to control bitter pit on young trees of a bitter-pit susceptible cultivar such as 'Honeycrisp.' Based on results from Lyndonville (Table 2), it appears that a seasonal total of at least 2.9 lb/acre of elemental calcium is required to suppress bitter pit on young 'Honeycrisp' trees with a canopy size that requires 100 gal/acre of spray for complete dilute spray coverage. In the Lyndonville trial, the maximum labeled rate was used for most of the calcium formulations tested, and a total of six applications were made. When product labels allow for applications of only small amounts of elemental calcium in each spray, application of 2.9 lb/acre of elemental calcium per season can be accomplished only by making more than six applications. Label limitations on rates per acre become even more problematic in orchards with larger trees that would require more than 100 gal/acre of dilute spray to achieve the same coverage tested in these experiments.

The $CaCl_2$ effect on crop load in this experiment made it impossible to determine how much of the $CaCl_2$-induced reduction in bitter pit observed in the Milton 2001 trial is attributable to increased uptake of calcium by the fruit and how much is attributable to reduced bitter pit susceptibility normally associated with smaller fruit. However, activity of $CaCl_2$ was not enhanced by combining $CaCl_2$ with trifloxystrobin, sodium borate, or harpin protein. Multiple applications of sodium borate in Milton in 2001 resulted in earlier ripening but did not enhance the control of bitter pit.

The finding that trifloxystrobin treatment reduced bitter pit at harvest at Milton in 2000 is consistent with data provided by Novartis researchers for experiments they conducted in 1998 and 1999 (M.A. Pastor-Corrales, personal communication). However, differences between trifloxystrobin-treated fruit and control fruit were significant in only one of the four trials reported here. In the trial where trifloxystrobin treatment significantly reduced the incidence of bitter pit at harvest, the effect of the trifloxystrobin treatment disappeared when fruit were re-evaluated after cold storage. The severity of the trial conditions may have decreased the likelihood of detecting bitter pit suppression from trifloxystrobin, sodium borate, and harpin protein, especially if those products are only weakly suppressive. Nevertheless, results clearly show that $CaCl_2$ will provide better control of bitter pit than any of the other materials and that activity of

$CaCl_2$ cannot be enhanced by adding the other products tested.

As a result of this research, 'Honeycrisp' producers will be advised to make at least six applications of $CaCl_2$ per season with the objective of applying a seasonal total of at least 3 lb/acre (3.4 $kg \cdot ha^{-1}$) of elemental calcium on 'Honeycrisp' trees that can be sprayed to drip with 100 gal/acre of spray solution. Rates of calcium may need to be increased proportionately for larger trees with canopies that require more than 100 gal/acre for complete coverage with a dilute spray.

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