Prohexadione-Ca (Apogee®): Growth Regulation and Reduced Fire Blight Incidence in Pear

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Abstract. Prohexadione-Ca (Apogee®) was tested as a growth retardant and fire-blight control agent in the pear (*Pyrus communis* L. cv. Abbé Fétel) on both bearing trees in the orchard and on 1-year-old scions under greenhouse conditions. Four sprays of 50 and 100 mg·L⁻¹ of the chemical were applied to trees in the orchard at 2-week intervals starting at petal fall, when terminal growth was 4 cm (mid-April). Scions received a single application (250 mg·L⁻¹) and were transferred 2 weeks later to a greenhouse where the shoots were inoculated with a local, virulent strain of *Erwinia amylovora* (Burrill) Winslow et al. In the orchard, the higher prohexadione-Ca concentration was more effective in reducing shoot growth, enhancing fruit weight and controlling fire blight incidence and severity. Similar effects on growth parameters and disease progression were observed under greenhouse conditions. Chemical name used: calcium 3-oxido-4-propionyl-5-oxo-3-cyclohexene carboxylate (prohexadione-Ca)

Prohexadione-Ca, an acylcyclohexadione, is a new plant growth retardant jointly developed by BASF (Limburgerhof, Germany) and Kumiai Chemical Industry (Tokyo). It was first used on rice and small grains in Japan and France and will be introduced for use on apple (*Malus domestica* Borkh.) in the United States and several European countries. It reduces shoot growth by inhibiting late stages of gibberellin (GA) biosynthesis, e.g., hydroxylation of GA₂₀ to GA₁ (Bomben et al., 1998; Brown et al., 1997; Byers and Yoder, 1999; Evans et al., 1997, 1999; Griggs et al., 1991; Owens and Stover, 1999; Rademacher, 1993; Rademacher et al., 1992; Unrath, 1999). Research carried out mainly on apple (Rademacher et al., 1998; Römmelt et al., 1999; Winkler, 1997; Yoder et al., 1999) suggested that prohexadione-Ca may induce resistance to fire blight infections (caused by *Erwinia amylovora*) by altering flavonoid metabolism.

The compound has recently been studied for potential application, as well as for a better understanding of its mechanism of action (Brown et al., 1997; Rademacher, 1993; Rademacher et al., 1992, 1998). It is easily

absorbed by leaves and is translocated acropetally, but basipetal movement is limited; it has also been designated as a “reduced-risk” chemical (Evans et al., 1997; Winkler, 1997). The aim of the present study was to assess the action of prohexadione-Ca as a growth retardant and fire-blight control agent, given that excessive shoot growth in pear is no longer efficiently controlled by cycocel (CCC : 2-chloroethyl-trimethyl ammonium chloride) and that an extensive outbreak of fire blight in the most important Italian pear-growing areas is a real threat.

Materials and Methods

The trials were carried out in the field and greenhouse in 1998 on the pear cv. Abbé Fétel grafted on quince BA29 rootstock.

Orchard experiment. The site was a 10-year-old pear orchard with a planting density of 2250 trees/ha (3.7 × 1.2 m spacing; average tree height was 3.8 m) trained as pal-spindle, located in the Ferrara district, northeastern Italy, where severe outbreaks of fire blight occurred in 1997. The test trees were of uniform trunk cross-sectional area (TCSA) and bloom density. Prohexadione-Ca (trade name Apogee®, testing code BAS 125 11 W), a wettable powder containing 27.5% active ingredient, was applied as a spray at 50 and 100 mg·L⁻¹ four times during the vegetative growth period beginning in mid-April, when shoots were 4 cm long; the other three sprays were applied 27 Apr., 5 May, and 6 June. Additional trees remained as untreated controls. A randomized complete-block design was used with four blocks. Each treatment was

applied to 10 trees in each block. An orchard sprayer delivered a water volume of 1000 L·ha⁻¹, which resulted in uniform coverage of tree canopies.

Data recorded. Shoot length was determined on 80 terminal shoots per treatment (two randomly selected shoots per tree). Number of blossoms per tree was determined on two trees per replication per treatment (a total of eight trees per treatment). Fruit set was expressed both as the number of fruit per cm² trunk cross-sectional area (TCSA) and as number of fruits as a percentage of the number of flowers per tree. Yield per tree and average fruit weight were recorded at harvest. Total yield was determined by weighing all fruits on each tree (40 per treatment). Average fruit weight of the treated and control fruits was determined by sampling and individually weighing 350–400 fruits randomly chosen from all trees per treatment. Effects on fire blight incidence (total number of infected organs per tree) were assessed on flowers (first and second bloom), on shoots, on fruits and on twigs during the vegetative period. Data were expressed as percentage of control (nontreated trees = 100%). Disease severity on shoots was determined by measuring the length of the necrotic lesion and expressing it as a percentage of the current season's shoot growth.

Greenhouse experiments. Each of the 20 ‘Abbé Fétel’ scions grafted to quince BA29 rootstock was kept outside in a 30-L pot and pruned in winter to provide five uniform shoots per scion. On 21 May, when shoots were ≈30 cm long, prohexadione-Ca (250 mg·L⁻¹) was applied to 10 scions. Two weeks thereafter, the scions were transferred to a greenhouse [25 °C, 75% relative humidity (RH)] and each shoot was inoculated with an aqueous suspension of *Erwinia amylovora* strain SFR 1077/7, containing ≈10⁸ cells/mL. For inoculation, the apical portions of the two youngest leaves on each shoot were cut with scissors dipped in the bacterial suspension. Shoot growth and disease progression were determined weekly up to early July, when terminal growth of the control trees was ≈50 cm. Experiments were carried out on scions twice in the same season, but only one data set is reported.

Results

Orchard experiment. The average TCSA values and blossom cluster density were uniform among treatments. Application of prohexadione-Ca did not affect fruit set or yield per tree, but significantly increased fruit weight (Table 1). The higher concentration of prohexadione-Ca inhibited shoot growth; this was evident by early June. However, the lower rate had no effect on growth (Table 1; Fig. 1). Prohexadione-Ca neither had phytotoxic effects nor caused any damage to fruits or foliage at the concentrations and times of application tested.

Fire blight infections did not occur during primary bloom. Data were collected the first 10 days of July, when symptoms were evident on all other types of plant organs. In all cases, prohexadione-Ca application re-

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duced relative disease incidence in proportion to concentration applied. Secondary blossoms were the organs with the greatest infection rate, and the highest concentration of the chemical was most effective in reducing relative disease incidence (16.2% of controls) (Table 2). Prohexadione-Ca application significantly reduced the length of the necrotic lesions on shoots as well as disease severity (Table 3).

Greenhouse experiment. In controlled conditions, all prohexadione-Ca treatments reduced shoot growth by an average of 20% (data not shown), as well as the length of necrotic lesions (Table 4). Experimental in-

oculation with *Erwinia amylovora* did not affect final shoot length.

Discussion

Prohexadione-Ca applications reduced shoot growth of bearing trees in the orchard and of nonbearing scions under greenhouse conditions. In the orchard, the lower concentration ($50 \text{ mg} \cdot \text{L}^{-1} \times \text{four application dates}$) did not significantly affect shoot growth, but the higher concentration ($100 \text{ mg} \cdot \text{L}^{-1} \times \text{four application dates}$) did; this was detectable ≈ 3 weeks after the first application. Although yield was not affected, fruits of the trees sprayed with

prohexadione-Ca were larger than control fruit. This effect is in agreement with the results reported for 'Golden Delicious' apple (Bomben and Vizzotto, 2000), although Greene (1999) reported either no effect or a reduction in size of 'McIntosh' apple following prohexadione-Ca application. However, growth retardants reduce competition between vegetative and reproductive sinks, leading to increased fruit weight (Costa et al., 1986; Ramina et al., 1981). Treated leaves of 'Abbé Fétel' pear were greener, contained more chlorophyll, and had higher photosynthetic efficiency than did control leaves (Bregoli and Sabatini, 2000), which could increase fruit quality and size. Prohexadione-Ca also reduced host susceptibility to fire blight on 'Abbé Fétel' pear, thereby confirming the results, mainly in apple trees, reported to date (Fernando and Jones, 1999; Jones et al., 1999; Momol et al., 1999; Rademacher et al., 1998; Römmelt et al., 1999; Winkler, 1997; Yoder et al., 1999).

The orchard application rate ($100 \text{ mg} \cdot \text{L}^{-1} \times \text{four application dates}$) was clearly the most effective in reducing peak disease incidence and severity. Under greenhouse conditions, a single application of prohexadione-Ca ($250 \text{ mg} \cdot \text{L}^{-1}$) 2 weeks before experimental inoculation with *Erwinia amylovora* reduced lesion progression on shoots. As posited in other systems including apple scab caused by *Venturia inaequalis* (Cooke) Wint. and mildew caused by *Podosphaera leucotricha* (Ell. & Ev.) Salm. (Winkler, 1997), the reduction in susceptibility to fire blight may be indirectly linked to shoot lignification and to the creation of a micro-environment that is not conducive to the spread of the infection (e.g., reduced vegetative growth, improved air cir-

Fig. 1. Cumulative shoot length of 'Abbé Fétel' pear as affected by prohexadione-Ca application. Arrows indicate application dates. Each concentration of prohexadione-Ca was applied four times. Vertical bars represent least significant differences at $P \leq 0.05$.

Table 1. Effect of prohexadione-Ca application on vegetative and reproductive responses of 'Abbé Fétel' pear.

Prohexadione-Ca ($\text{mg} \cdot \text{L}^{-1}$)	TCSA (cm^2)	Blossom no./ cm^2 TCSA	Fruit set (fruits/ cm^2 TCSA)	(%)	Yield/tree (kg)	Avg fruit wt (g)	Final shoot length (cm)
0 (control)	42.3 a ^z	5.5 a	0.60 a	2.27 a	8.0 a	317 a	113 a
50 ^y	40.7 a	5.1 a	0.58 a	2.37 a	7.9 a	338 b	108 a
100 ^y	42.6 a	5.0 a	0.59 a	2.33 a	8.5 a	342 b	84 b

^aMean separation within columns by Duncan's multiple range test, $P \leq 0.05$.

^yFour applications.

Table 2. Disease incidence (number of infected organs per pear tree) and percentage of disease control as affected by prohexadione-Ca application.

Prohexadione-Ca ($\text{mg} \cdot \text{L}^{-1}$)	Secondary blossoms		Shoots		Fruits		Twigs		Total infections	
	No.	% of control	No.	% of control	No.	% of control	No.	% of control	No.	% of control
0 (control)	6.44 a ^z	100	4.73 a	100	0.34 a	100	2.68 a	100	14.19 a	100
50 ^y	2.55 b	39.6	3.02 b	63.8	0.22 ab	64.7	2.02 a	75.4	7.82 b	55.1
100 ^y	1.07 c	16.6	1.62 c	34.2	0.05 b	14.7	1.02 b	38.1	3.77 c	26.6

^aMean separation within columns by Duncan's multiple range test, $P \leq 0.05$.

Table 3. Fireblight, shoot infection, and disease severity of 'Abbé Fétel' pear as related to prohexadione-Ca application.

Prohexadione-Ca ($\text{mg} \cdot \text{L}^{-1}$)	Canker length (cm)	Severity (%)
0 (control)	36.0 a ^z	77.6 a
50 ^y	24.8 b	64.2 b
100 ^y	21.9 b	64.6 b

^aMean separation within columns by Duncan's multiple range test, $P \leq 0.05$.

^yFour applications

Table 4. Effect of prior treatment with prohexadione-Ca $250 \text{ mg} \cdot \text{L}^{-1}$ on incidence and severity of fire blight infections on 'Abbé Fétel' pear shoots inoculated with *Erwinia amylovora*

Treatment	Incidence (%)	Severity (%)	Lesion extension (cm)
Control	70.0 a ^z	21.8 a	12.1 a
Prohexadione-Ca	57.9 a	15.1 a	6.5 b

^aMean separation within columns by Duncan's multiple range test, $P \leq 0.05$.

cultation and light penetration, reduced relative humidity). However, prohexadione-Ca-induced resistance to apple scab and fire blight is linked to altered flavonoid metabolism; the chemical inhibits a specific enzyme (flavanone 3-hydroxylase) controlling the conversion of eriodictyol to dihydroquercetin and quercetin (Römmelt et al., 1999). Consequently specific phenolic metabolites (flavan-3-ols) accumulate that may increase resistance to fire blight (Rademacher et al., 1998; Römmelt et al., 1999). Specific research is currently under way to study this defense mechanism in pear.

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