Suppression of Apple Bloom by Fungicides That Inhibit Sterol Synthesis

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ABSTRACT

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The proportion of spurs blooming on Redspur Delicious apples in 1983 was significantly lower after season-long applications in 1982 of bitertanol and etaconazole (fungicides that inhibit biosynthesis of ergosterols) and some fenarimol-captan treatments than with benomyl and carbamate fungicides. Return bloom in 1984 was significantly less after season-long applications of bitertanol or etaconazole than after benomyl, suggesting detrimental effects to apple buds by the former fungicides. Return bloom in 1984 from trees not sprayed during 1983 was positively correlated with leaf numbers at harvest in 1983. Trees partly defoliated by scab caused by *Venturia inaequalis* showed less return bloom in 1984.

Return bloom, a reflection of an apple tree's vigor during the previous year, can be influenced by disease, detrimental pesticides, crop load, nutrition, thinning, and hormone sprays (2,4,6). The quantity and quality of the ensuing crop may also be influenced by the tree's vigor.

Szkolnik (5) observed a plant growth regulator (PGR)-like response when multiple applications of the ergosterol biosynthesis inhibitor (EBI) fungicide etaconazole were made to apple seedlings; no PGR-like response occurred with other fungicides or when only a single application of etaconazole was made. Kelley and Jones (3) also reported PGR-like effects on apple trees sprayed with etaconazole. Plants were shorter, lateral shoot elongation was retarded, and leaves were smaller, thicker, less flexible, puckered, and darker green on trees receiving EBI fungicides (5) than on unsprayed trees (3). Kelley and Jones (3) also reported that apple leaves from trees sprayed with etaconazole had three to five layers of palisade cells, whereas those from unsprayed trees had only two to three layers. The growth-retarding effects of bitertanol applied on a 7- or 14-day schedule were slight.

During 1983, apple bloom at the North Alabama Horticulture Substation, Cullman, differed among plots sprayed with fungicides during 1982. Some trees sprayed with EBI fungicides did not have appreciably more blossoms than unsprayed check trees. This indicated the possibility of long-term inhibitory effects by some fungicides. Subsequently, these investigations were made to evaluate selected fungicides for control of scab (caused by *Venturia inaequalis* (Cke.) Wint.) and their subsequent effects on return bloom of Delicious apple.

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MATERIALS AND METHODS

Fungicides. Materials evaluated alone or in combination for control of apple diseases were benomyl (Benlate 50W), bitertanol (Baycor 50W), captafol (Difolatan 4F), captan (Captan 50W), etaconazole (CGA-64251), fenarimol (EL-222), mancozeb (Manzate 200 80W), maneb + zinc (Dithane FZ), and triadimefon (Bayleton 50W) (Tables 1 and 2).

Disease control. The study was conducted at the North Alabama Horticulture Substation, Cullman, on Redspur Delicious and Sharp Red Delicious planted in 1977 and grown on trellises or as free-standing trees. Smoothee Golden Delicious and Winter Banana were the pollinator cultivars used in each orchard. The pollinators were alternated in the row in three-tree blocks so that each Delicious tree in the orchard was within two trees of two different pollinators. Trellised trees were grown as a horizontal palmette system on a four-wire trellis with the wires spaced 46 cm apart. The trees were grown on M26 dwarfing rootstock and spaced 2.4 × 5.5 m apart. Free-standing trees were trained to a modified central leader and grown on M106 semidwarfing rootstock spaced 6.1 × 6.1 m apart. Each rootstock was grown in a separate block. The fruit on all trees were uniformly thinned each year to a commercially acceptable fruit set to alleviate any alternate bearing affects resulting from heavy crop load.

Treatments were applied to three-tree plots replicated four times in a randomized complete block design. The fungicides were applied to runoff as dilute sprays with a single-nozzle handgun at 4,482 kPa (650 psi). As part of season-long disease control evaluation programs, the fungicides were applied at 7- to 10-day intervals from early season to first cover and then at 10- to 14-day intervals throughout the cover spray period. Commercial insecticides and bactericides were applied to the entire test orchard as needed. Monthly rainfall totals for March through August were 5.6, 27.7, 5.5, 11.7, 6.9, and 2.2 cm in 1982 and 12.1, 20.1, 17.7, 11.6, 1.1, and 11.9 cm in 1983.

Table 1. Effects of selected fungicides on apple scab incidence in 1982 and return bloom of Redspur Delicious apple trees in 1983

Fungicide[w]	Rate (mg a.i./L)	Scab incidence[x] (%) (1982)	Bloom[y] (%) (1983)
Benomyl 50W + mancozeb 80W	74 719	0.00 a[z]	71.4 a
Captafol 4F (silver tip), captan 50W (cover)	1,797 1,198	1.00 a	71.1 a
Etaconazole 10W	19	0.75 a	52.9 b
Fenarimol 1E (bloom only), captan 50W (cover)	56 1,198	0.62 a	57.5 b
Bitertanol 50W + triadimefon 50W	149 37	0.25 a	36.1 c
Fenarimol 1E (full season) + captan 50W	56 1,198	0.50 a	62.7 ab
No fungicide (control)	...	98.00 b	14.4 d

[w] Treatments applied by handgun at 4,482 kPa (650 psi) to runoff.
[x] Percentage of fruit with lesions caused by *Venturia inaequalis*.
[y] Percentage of spurs blooming on 60 cm of apple branch, two branches per tree.
[z] Means in the same column followed by the same letter do not differ significantly according to Duncan's multiple range test ($P = 0.01$).

Table 2. Effects of fungicides applied in 1983 on numbers of leaves, scab index, incidence of fruit scab, and weights of Redspur Delicious apples

Fungicide[t]	Rate (mg a.i./L)	No. of leaves[u]		Scab index[v]		Fruit scab incidence[w] (%)		Apple weight[x] (kg)	
		Maneb + zinc 37F[y]		Maneb + zinc 37F		Maneb + zinc 37F		Maneb + zinc 37F	
		Added	Not added	Added	Not added	Added	Not added	Added	Not added
Benomyl 50W	74	126.4 a[z]	···	0.23	···	4.5 a	···	8.98 a	···
Bitertanol 50W	149	128.5 aA	122.0 aA	0.01	0.13	7.0 abA	10.8 aA	8.89 aA	8.30 aB
Etaconazole 10W	26	123.4 aA	118.2 aA	0.17	0.75	18.5 bA	29.0 bA	8.16 bA	7.71 bA
Control	0	110.1 aA	34.0 bB	0.76	4.00	49.3 cA	93.8 cB	7.34 cA	5.35 cB

[t] Treatments applied by handgun at 4,482 kPa (650 psi) to runoff.
[u] Number of leaves collected from 20 fruit spurs per plot on 18 August 1983.
[v] Calculated by multiplying the percentage of diseased leaves in a disease severity class by the class number. Class 1 = no scab, class 2 = 1–5 scab lesions per leaf, class 3 = 6–10 scab lesions per leaf, and class 4 = 10+ scab lesions per leaf.
[w] Percentage of fruit with lesions caused by *Venturia inaequalis*.
[x] Weight of 50 apples per plot at harvest on 22–23 August 1983.
[y] Applied at 354 mg a.i./L.
[z] Means followed by the same lowercase letters in columns and means followed by the same capital letters in rows do not differ significantly according to Duncan's multiple range test ($P = 0.05$).

Before apple harvest on 18 August 1983, leaves were collected from 20 fruit spurs per plot and counted as a measure of defoliation by scab. Also, leaves showing scab lesions were counted and disease severity was rated: class 1 = no scab, class 2 = 1–5 scab lesions per leaf, class 3 = 6–10 scab lesions per leaf, and class 4 = 10+ scab lesions per leaf. A scab index was calculated for each treatment by multiplying the percentage of diseased leaves in a class by the class number. Replicates were summed and the total divided by the product of the replicates. Fifty apple fruits were selected at random from the trees in each replicate and examined for incidence of scab on 16 August 1982 and 22 and 23 August 1983. The weight of 50 fruits per plot was recorded in 1983. Evaluations made on Sharp Red Delicious trees in trellised and free-standing orchards gave results that were similar to those for Redspur Delicious; therefore, data are presented only for the latter.

Statistical analysis. Data for 1982 were analyzed for fungicide effects in a randomized complete block design. Data for 1983 and 1984 were analyzed as a factorial arrangement of fungicide with or without maneb + zinc in a randomized complete block design. Data for trellised and free-standing trees were combined when there were no interactions between tree type and treatments.

Bloom the following year. Fruit spurs with and without blossom clusters were counted at full bloom from a 60-cm section of branch trained on the second wire of trellised trees and located 1 m above the soil. Spur counts were made on two branches on opposite sides of the trunk of the middle tree in the three-tree plot. Counts were made on free-standing trees by a similar procedure for branches 1–1.5 m above the soil. The percentage of spurs with blossoms was recorded on 15 April 1983 and on 9 April 1984. The bloom results for Sharp Red Delicious were similar to those for Redspur Delicious; therefore, data are presented only for Redspur Delicious.

Table 3. Effects of fungicides applied in 1983 on return bloom[x] of Redspur Delicious in 1984

Fungicide	Rate (mg a.i./L)	Maneb + zinc 37F[y]		Mean
		Added	Not added	
Benomyl 50W	74	89.7	···	89.7 a[z]
Bitertanol 50W	149	72.4	57.5	64.9 b
Etaconazole 10W	26	61.8	63.8	62.8 b
Control	0	49.4	31.0	40.2 c
Mean		68.3 a	50.7 b	

[x] Percentage of spurs blooming on 60 cm of apple branch, two branches per tree.
[y] Applied at 354 mg a.i./L.
[z] Means in rows or columns followed by the same letter do not differ significantly according to Duncan's multiple range test ($P = 0.05$).

RESULTS

Disease control. No phytotoxicity or PGR-like responses were evident on apple foliage during 1982 or 1983.

Because data for disease control in 1982 and return bloom in 1983 for the trellised and free-standing tree orchards showed no significant interactions, data for cultural practices were combined (Table 1). All fungicides used singly or in combination controlled scab equally. No significant differences occurred among fungicide treatments, but all treatments were significantly different from the untreated controls. At harvest, leaves on fungicide-sprayed trees appeared healthy, but unsprayed check trees were severely diseased and 75% defoliated.

During 1983, leaf numbers before harvest were significantly higher in fungicide-sprayed plots than in unsprayed controls (Table 2). The scab indices for the controls showed the high incidence of scab that occurred in the orchard when it was not controlled by fungicides. Bitertanol + maneb + zinc gave the lowest scab index.

Control of scab on fruit with benomyl + maneb + zinc treatments was significantly better than with etaconazole or maneb + zinc used alone (Table 2). Control of scab with bitertanol was significantly better than with etaconazole.

The weight of 50 apples per fungicide-treated plot was significantly greater than from untreated control trees. Benomyl + maneb + zinc yielded the greatest fruit weights followed by bitertanol and the other fungicides tested singly or in combination (Table 2).

Bloom the following year. In 1983, the percentage of spurs with blossoms was highest on trees treated with benomyl + mancozeb during 1982. The percentage of spurs blooming was almost the same for captafol, followed by captan and fenarimol + captan (Table 1). Treatments that included EBI materials resulted in significantly fewer blossoms than the benomyl + maneb + zinc treatment.

Because leaf and fruit scab data in 1983 and return bloom data in 1984 were similar for the trellis and free-standing tree orchard, only the means for the orchard types are presented. The percentage of spurs blooming in 1984 was greatest on trees treated with benomyl + maneb + zinc in 1983 (Table 3). The only fungicide treatment in 1983 that did not result in significantly more bloom in 1984 than the control was maneb + zinc.

Return bloom in 1984 was significantly and positively correlated with apple fruit weight and number of leaves on trees before harvest in 1983 and negatively correlated with incidence of fruit scab in 1983 (Table 4).

DISCUSSION

For flower buds to form, apple trees must have healthy leaf area exceeding that necessary for fruit and tree growth (2). Flower bud formation may be reduced by defoliation from scab or spray

Table 4. Correlation coefficients between return bloom in 1984 and numbers of leaves before harvest, incidence of fruit scab, and weights of Redspur Delicious apples treated with fungicides in 1983

	Bloom (%)	No. of leaves	Fruit scab (%)	Apple weight
Bloom (%)	...	0.44*[a]	−0.58**	0.64**
No. of leaves	...	...	−0.79**	0.72**
Fruit scab (%)	...	...	...	−0.84**
Apple weight	...	...	...	...

[a] * = Correlation significant at $P \leq 0.02$ and ** = correlation significant at $P \leq 0.001$.

injury if this occurs early in the growing season (4). In our tests, trees left unsprayed as controls had lost a significant number of leaves by mid-August just before apple harvest. These trees bloomed poorly the following year. The correlations between scab on fruit or number of leaves remaining on trees before apple harvest and low return bloom indicated that the trees were debilitated by scab.

Donoho (1) reported no significant influence on amount of return bloom the year after application of the fungicides captan, dichlone, dodine, glyodin, or phenyl mercury acetate. He considered these results surprising, since many of the treatments had substantially reduced fruit set and yields the previous year. In our evaluations, season-long applications of EBI fungicides suppressed return bloom despite effective control of scab as demonstrated by number of leaves before harvest, incidence of fruit scab, and weights of fruits.

At the rate tested on apples, etaconazole was apparently nontoxic; however, at higher rates of application, phytotoxic responses may occur. On pecan trees, dark green, stunted, puckered leaves and stunted nuts were observed after applications of propiconazole at two and one-half times the suggested rate (A. J. Latham, *unpublished*). Propiconazole and etaconazole are chemically similar in structure, differing only in a propyl substituent in propiconazole where etaconazole has an ethyl group.

The absence of PGR-like effects such as abnormally dark, small, or puckered leaves suggested no adverse effects in our tests by the EBI fungicides tested. The adverse growth responses reported by Szkolnik (5) with etaconazole were on seedling trees, which may have been more sensitive than the 6-yr-old trees in our orchard. Numbers of leaves from trees treated with bitertanol were similar statistically to those from trees treated with benomyl + maneb + zinc, and their scab indices were among the lowest in these tests. However, return bloom percentages were significantly lower than those of trees treated with benomyl + maneb + zinc. Therefore, it appears that scab was not the only factor that caused the reduction in bloom percentages. The season-long application of bitertanol may have had a cumulative effect that was detrimental to apple bud formation and subsequent return bloom. Likewise, the low return bloom in trees treated with etaconazole may have been due to season-long applications of this EBI fungicide.

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