Apple Powdery Mildew and Scab Control Studies in the Pacific Northwest

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ABSTRACT

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The sterol-inhibiting fungicides bitertanol, triadimefon, fenapanil, and CGA 64251 were all effective in the control of apple mildew and scab. Factors influencing the occurrence of these diseases in the major fruit-growing areas of the Pacific Northwest are discussed.

The climatic variation in the major apple and pear districts in the Pacific Northwest probably approaches the variations under which these crops are grown worldwide. The vast majority of commercial production, however, is limited to the arid and semiarid regions of the area. Apple powdery mildew is found throughout the area, but scab is limited in many districts by the lack of rainfall. Fungicide testing programs on apple and pear for the control of powdery mildew caused by *Podosphaera leucotricha* (Ell. & Everh.) Salm. are carried out at the Tree Fruit Research Center, Wenatchee, WA, the Mid-Columbia Experiment Station in Hood River, OR, and at Oregon State University, Corvallis. At the last two locations, fungicides are also tested for the control of apple and pear scab caused by *Venturia inaequalis* (Cke.) Wint. and *V. pirina* Aderh., respectively.

MATERIALS AND METHODS

Test procedures and methods of

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Table 1. Incidence and control of powdery mildew on apple terminals in Wenatchee, WA, 1975–1980

Fungicide	Rate/L	Terminal mildew rating[x] 1975	1976	1977	1978	1979	1980
None	0	84.1 a[y]	74.0 a	76.2 a	73.6 a	54.4 a	56.2 a
Dinocap 19.5 WP + B1956	0.89 g 0.47 ml	45.4 b	25.7 b	17.6 b	25.5 b	16.4 b	11.5 b
Triadimefon 25 WP	1.20 g	4.4 c	...[z]	...	...	...	...
Triadimefon 50 WP	0.075 g	...	...	...	...	...	4.3 bc
Triadimefon 50 WP	0.15 g	...	7.1 c	2.4 c	2.7 e	6.7 c	2.0 c
Triadimefon 50 WP	0.30 g	...	2.6 c	2.3 c	1.5 e	4.3 c	1.0 c
CGA 64251 10 WP	0.26 g	...	...	...	10.4 c	5.5 c	2.6 c
CGA 64251 10 WP	0.38 g	...	...	...	8.2 cd	6.1 c	1.4 c

[x] Based on observations made 10 days after the last spray. The rating is calculated as prevalence (percentage of terminals infected) × severity (estimated area of leaves covered with mildew, on a scale of 0.10–1.0).

[y] Numbers followed by the same letter within columns are not significantly different ($P = 0.05$) according to Duncan's new multiple range test.

[z] ... = Not tested.

evaluation used in these studies varied with location. Apple powdery mildew studies carried out at Wenatchee used Black Jonathan as a host plant. Spray materials were applied by handgun to runoff at 400 psi (28 kg/cm^2). The first sprays were applied each year at the 1-cm stage of green tip, at which time mildew is frequently evident on the leaves. Subsequent sprays were applied on about an 11-day schedule except during the blossom period. The last sprays were applied about 1 June each year, resulting in a total of four to five applications. Rates and formulations of fungicides included in the tests are listed in Table 1. The single-tree treatments were replicated five times.

Data on fungicide efficacy were gathered 10 days after each spray application. Evaluation was based on prevalence multiplied by severity. Prevalence was determined by calculating the percentage of terminals infected at eye level. Severity was based on subjective evaluation of the infected leaf area on the infected terminals on which mildew was sporulating. A scale of 0.1–1.0 was used for this evaluation, with % 0.1 = 10% and 1.0 = 100% of the leaf area infected. At harvest, the percentage of the fruit with mildew russet was also determined by visual inspection of at least 100 randomly sampled apples per replicate.

Orchard studies were conducted in Hood River, OR, during 1979 and 1980. Temperature and relative humidity in the orchard were monitored with a 7-day recording hygrothermograph, rainfall with a recording tipping bucket rain gauge, and leaf wetness with a DeWit leaf wetness recorder (M. DeWit, Hengelo, Holland). *V. inaequalis* ascospores and *P. leucotricha* conidia were monitored with a Burkard volumetric spore trap (Burkard Manufacturing Co., Ltd., Rickmansworth, Hertfordshire, England).

Fungicide treatments were applied to randomized, single-tree plots (two to four replicates) of mature Golden Delicious and Rome Beauty on MM 106 rootstock. Trees were sprayed to runoff at 300 psi (21 kg/cm^2) with a handgun at the 1-cm green tip stage, pink, petal fall, and first cover. Several insecticides, including endosulfan, cyhexatin, prolate, dimethoate, and Diazinon were mixed in the tank with fungicides as needed. Leaf scab and mildew were counted on the 10 oldest (1979) or 10 terminal (1980) leaves of 10 shoots per tree. All terminals with primary mildew were counted on half of each tree. Fruit scab counts were made on 25 (1979) or 50 (1980) fruits per tree.

To study the effect of sterol-inhibiting fungicides on *V. inaequalis* development in infected leaves, we collected scab-infected Delicious leaves on 26 December 1979 and dipped them in bitertanol at 0.6 g/L, triadimefon at 0.3 g/L, or water. Leaves were air-dried, then placed under a wire screen in the orchard. Ascospore maturation was determined from 25 March to 13 May 1980 by the method of Szkolnik (7).

At Corvallis, apple scab and powdery mildew studies were carried out on single-tree plots of mature Jonathan, Delicious, and Rome Beauty (four replicates). Trees were sprayed to runoff at 400 psi (28 kg/cm^2) with a handgun at prepink, pink, petal fall, and first and second cover.

Table 2. Incidence and control of powdery mildew russet on apple fruit in Wenatchee, WA, 1975–1980

Fungicide	Rate/L	Mildew russet[x] 1975	1976	1977	1978	1979
None		47.2 a[y]	38.0 a	61.0 a	53.9 a	4.6 a
Dinocap 19.5 WP + B1956	0.89 g 0.47 ml	23.4 b	8.6 b	21.9 b	7.7 bc	1.4 a
Triadimefon 25 WP	1.20 g	1.4 c	...[z]	...	...	...
Triadimefon 50 WP	0.15 g	...	4.0 c	9.7 c	7.4 bc	0.2 a
Triadimefon 50 WP	0.30 g	...	0.6 d	6.0 c	11.3 bc	0.4 a
CGA 64251 10 WP	0.26 g	...	...	...	6.5 bc	1.1 a
CGA 64251 10 WP	0.38 g	...	...	...	4.5 c	0.2 a

[x] Fruit was considered to have mildew russet when a distinct net pattern was noted on the cheek of the fruit. Russet too small to downgrade fruit commercially was included in the counts.
[y] Numbers followed by the same letter within columns are not significantly different ($P = 0.05$) according to Duncan's new multiple range test.
[z] ... = Not tested.

Table 3. Effect of sterol-inhibiting fungicides on apple scab and powdery mildew, Hood River, OR, 1979

Fungicide and rate/L[v]	Leaf scab (%) Gold. Del.[w]	Rome[x]	Fruit scab (%) Gold. Del.	Rome	Powdery mildew (%) Gold. Del.	Rome
Bitertanol 50 WP, 0.63 g	0 a[y]	0 a	1 ab	1 a	1 ab	3 a
Triadimefon 50 WP, 0.3 g, + Dodine 65 WP, 0.45 g	0 a		0 a	0 a	0 a	0 a
Triadimefon 50 WP, 0.15 g, + Dodine 65 WP, 0.45 g	...[z]	0 a	...	1 a	...	0 a
Dodine 65 WP, 0.89 g, + Dinocap 19.5 WP, 0.89 g	0 a	0 a	0 a	0 a	3 ab	3 a
Fenapanil 2 LC, 2.5 ml	0 a	0 a	0 a	1 a	3 ab	1 a
Fenapanil 25 WP, 2.4 g	1 a	1 a	0 a	1 a	2 ab	3 a
None (insecticides only)	11 b	9 b	5 b	7 b	5 b	8 b

[v] Fungicides were applied on 16 April (1-cm green), 3 May (early bloom), 14 May (petal fall), and 30 May 1979.
[w] Golden Delicious.
[x] Rome Beauty.
[y] Numbers followed by the same letter within columns are not significantly different ($P = 0.05$) according to Duncan's new multiple range test.
[z] ... = Not tested.

Table 4. Effect of sterol-inhibiting fungicides on apple scab and powdery mildew, Hood River, OR, 1980

Fungicide and rate/L[w]	Leaf scab (%) Gold. Del.[x]	Rome[y]	Fruit scab (%) Gold. Del.	Rome	Powdery mildew (%) Gold. Del.	Rome
Bitertanol 300 EC, 0.31 ml	1 a[z]	0 a	1 a	0 a	18 abc	27 cd
Bitertanol 300 EC, 0.63 ml	1 a	0 a	0 a	0 a	12 ab	8 ab
Bitertanol 50 WP, 0.3 g	2 a	0 a	1 a	1 a	30 cde	22 bcd
Bitertanol 50 WP, 0.6 g	0 a	0 a	1 a	0 a	25 bcd	23 bcd
Triadimefon 50 WP, 0.075 g + Dodine 65 WP, 0.45 g	0 a	0 a	1 a	1 a	7 a	8 ab
Triadimefon 50 WP, 0.15 g + Dodine 65 WP, 0.45 g	0 a	0 a	0 a	0 a	7 a	4 a
CGA 64251 10 WP, 0.19 g	0 a	0 a	0 a	0 a	14 ab	3 a
Dodine 65 WP, 0.89 g, + Dinocap 4 LC, 0.39 ml	0 a	0 a	0 a	0 a	15 ab	14 abcd
None (insecticides only)	17 b	3 b	21 b	8 b	41 e	29 d

[w] Fungicides were applied on 8 April (1 cm green), 22 April (pink), 7 May (petal fall), and 30 May 1980. Disease evaluations were made on 1 July.
[x] Golden Delicious.
[y] Rome Beauty.
[z] Numbers followed by the same letter within columns are not significantly different at $P = 0.05$ according to Duncan's new multiple range test.

The insecticides azinphos-methyl and cyhexatin were applied separately as needed.

Powdery mildew control was evaluated on 100 terminals per tree and leaf scab on 100 leaves per tree. Terminals and leaves were assessed as diseased or healthy on 20–25 June 1979. Scab was evaluated on approximately 40 kg of fruit per replicate on 28 September (Delicious) or 9 October (Rome Beauty).

RESULTS

Washington. Several nonregistered fungicides tested at Wenatchee from 1975 to 1980 have equaled or exceeded the standard dinocap treatment for control of powdery mildew on apple. Many of the test data on these fungicides have been published (2–5). Tables 1 and 2 summarize the results obtained during this period with two of the most efficacious fungicides.

In every test and at most rates tested, triadimefon applications resulted in significantly less terminal mildew than that which occurred with the standard dinocap treatment. The only exception to this generalization was in the 1980 test, when there was no difference between triadimefon at 0.075 g/L and the standard dinocap treatment. At the range of rates tested, increased concentrations of triadimefon had no significant effect on the level of powdery mildew control.

At both rates (0.26 and 0.38 g/L), CGA 64251 (1-[[2-(2,4-dichlorophenyl)-4-ethyl-1,3-dioxolan-2-yl]methyl]-1*H*-1,2,4-triazole) exceeded the standard dinocap treatment for control of terminal mildew. In two of the three tests where triadimefon and CGA 64251 were compared, no significant differences were noted between the two fungicides. In the 1978 comparison, however, triadimefon was more effective than CGA 64251 at the rates tested.

A small amount of fruit russet occurred in 1979; this probably accounts for the lack of significant difference between treatments. In 1978 tests, there were no differences between the dinocap, CGA 64251, and triadimefon treatments. In other test years, fungicide application reduced the amount of fruit russet. In 1975 through 1977, fruits receiving triadimefon treatments had significantly less russet than those sprayed with dinocap.

Oregon (Hood River). From April through June, total rainfall and average temperatures were 5.5 cm and 13.3 C during 1979 and 12.6 cm and 12.8 C during 1980. During this time, six and eight primary scab infection periods were recorded in 1979 and 1980, respectively.

Of the total *V. inaequalis* ascospore catch, 92 and 89% occurred between green tip and pink in 1979 and 1980, respectively. Maximum daily *P. leucotricha* conidia concentrations through petal fall were 5 and 15 conidia per cubic meter of air during 1979 and 1980, respectively. A large increase in airborne conidia occurred after 26 May 1980, but a similar increase was not observed in 1979 until after 20 June. Average daily concentrations of *P. leucotricha* conidia were 2.7 and 8.2/m^3 in May and June 1979, respectively, and 6.5 and 42.8/m^3 in May and June 1980, respectively.

Disease pressure was light in 1979 (6) and moderate in 1980. Under these conditions, bitertanol, triadimefon + dodine, fenapanil, CGA 64251, and dodine + dinocap gave excellent control of leaf and fruit scab when applied four times from the 1-cm green tip stage through petal fall (Tables 3 and 4). Mildew infection was light in 1979, and bitertanol, triadimefon, fenapanil, and dinocap + dodine gave acceptable control (Table 3). In 1980, bitertanol EC, triadimefon, CGA 64251, and dinocap + dodine controlled foliar mildew (Table 4). Bitertanol EC appeared more effective than the WP formulation, which was not very effective in mildew control. Triadimefon at 0.075 g/L and CGA 64251 at 0.19 g/L gave good mildew control.

Primary mildew was present in all trees in the study. None of the fungicides applied in 1979 completely prevented terminal bud infection, and none applied in 1980 completely eradicated existing infections.

Ascospores in leaves dipped in triadimefon appeared to mature more quickly than water controls (Table 5). Although ascospore discharge was less than the controls at tight cluster and early petal fall, there was no difference in the percentage of empty asci between triadimefon and water treatments at late petal fall. Asci in leaves dipped in bitertanol consistently discharged ascospores more completely than controls (Table 5). Neither bitertanol nor triademefon prevented development of *V. inaequalis* in overwintered leaves.

Table 5. Effect of sterol-inhibiting fungicides on *Venturia inaequalis* ascospore maturity[y]

Level of maturity / Treatment	Percentage of asci at level			
	25 March[z]	14 April	6 May	13 May
Spores being formed				
Triadimefon	8	1	0	0
Bitertanol	16	3	0	0
Water	16	4	0	0
Spores formed, not colored				
Triadimefon	8	16	8	1
Bitertanol	12	16	0	0
Water	24	23	0	1
Spores colored, mature				
Triadimefon	72	73	79	42
Bitertanol	32	34	17	0
Water	36	62	32	45
Ascus empty, spores discharged				
Triadimefon	0	4	13	57
Bitertanol	0	37	83	100
Water	0	6	66	54

[y] Infected Delicious leaves dipped in bitertanol 50 WP at 0.6 g/L, triadimefon 50 WP at 0.3 g/L, or water on 26 December 1979 and overwintered on the orchard floor. Values represent the percentage of asci at each level of maturity. Data on undifferentiated spores are not included.
[z] Growth stage on 25 March, green tip; 14 April, tight cluster; 6 May, early petal fall; and 13 May 1980, late petal fall.

Table 6. Effect of sterol-inhibiting fungicides on apple scab and powdery mildew, Corvallis, OR, 1979

Fungicide and rate/L[v]	Leaf scab (%)	Fruit scab (%)		Powdery mildew (%)	
	Del.[w]	Del.	Rome[x]	Jon.[y]	Rome
Bitertanol 50 WP, 0.6 g	2	11	4	...	3
Triadimefon 50 WP, 0.3 g	...[z]	...	...	11	5
Dodine 65 WP, 0.89 g, + Dinocap 19.5 WP, 0.89 g	1	1	...	...	...
	...	...	3	16	6
None	58	99	64	48	28

[v] Fungicides were applied on Jonathan and Delicious on 13 April (prepink), 19 April (pink), 1 May (petal fall), 14 May, and 4 June. They were applied on Rome Beauty on 13 April (prepink), 23 April (pink), 10 May (petal fall), and 4 and 19 June 1979.
[w] Delicious.
[x] Rome Beauty.
[y] Jonathan.
[z] ... = Not tested.

Oregon (Corvallis). Under conditions highly favorable for disease, bitertanol and dodine gave good leaf and fruit scab control, with dodine performing slightly better than bitertanol (Table 6). Control of powdery mildew was best with bitertanol and triadimefon, both performing better than the dinocap standard (Table 6).

DISCUSSION

Triadimefon and CGA 64251 suppressed the development of apple powdery mildew at all locations. Fenapanil was also included in most of the tests at Wenatchee, and results obtained with fenapanil were comparable to those obtained with triadimefon and CGA 64251.

Powdery mildew is a perennial problem on susceptible varieties of apples and pears in the Pacific Northwest. However, as winter temperatures drop below −15 C, terminals infected with the mildew fungus are progressively killed (1). Thus, after severe winters, overwintering populations are greatly reduced. The low russet counts recorded for the check treatment at Wenatchee in 1979 (Table 2) are the result of low temperatures during the previous winter. In studies at Hood River, triadimefon, bitertanol, and CGA 64251 did not eliminate primary mildew, perhaps because applications were not continued through June and July when bud infection probably occurred.

The economic importance of apple powdery mildew in the Pacific Northwest has decreased since the late 1940s because of the increased Delicious acreage. Under high infection pressure, terminal infection is occasionally noted on Delicious, but mildew fruit russet seldom, if ever, occurs. Fruit russet and terminal infection are commonly noted on Golden Delicious. Mildew is only an occasional problem on Winesap, but it is frequently a major problem on Rome Beauty, Newtown, and Jonathan, which tend to serve as infection reservoirs for the other cultivars. Apple mildew may increase in the Pacific Northwest as plantings of the Granny Smith cultivar increase.

The grower's prime concern with apple mildew is the control of fruit russet on both apples and pears. Many apple growers successfully use a two-spray program (pink and petal fall) to control this phase of the disease. Both Anjou and Bartlett pears are susceptible to mildew russet, with the most damage occurring on the former. Terminal infection on pears is rare, and a two-spray program is recommended. The first of these sprays is applied when the fingers of the blossoms in the clusters separate and the second at petal fall. Oxythioquinox is frequently used as a dual-purpose spray at finger separation, controlling both powdery mildew and pear psylla (*Psylla pyricola* Foerster).

At least four different apple scab disease situations are present in eastern Washington: (i) Scab occurs frequently, and prebloom sprays are generally applied for control (Spokane); (ii) scab occurs frequently, and prebloom sprays should be applied for control but often are not (the upper Okanogan Valley); (iii) scab is infrequent, and general spray programs are not justified (the upper Wenatchee Valley); and (iv) scab causes economic loss only under special conditions (bulk of eastern Washington). Although we have no experimental data, some general observations on these special conditions can be noted. Irrigation above the tree is always associated with the scab problem. In most cases, this type of irrigation had been used for frost protection during the year when scab was first noted. In addition, apple boxes or picking bins containing scab-infected leaves have frequently been brought into the orchard from areas where scab is a problem.

Most of the commercial apple and pear growing areas in Oregon require prebloom fungicide application for scab control. In Oregon, scab control with bitertanol was excellent under conditions of light to moderate infection pressure (Hood River) and acceptable under severe disease conditions (Corvallis), where the standard dodine program appeared more effective. Scab control with CGA 64251 was excellent. Although bitertanol and triadimefon, when applied after leaf drop, did not inhibit *V. inaequalis* development in infected leaves, earlier application should be investigated.

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