Sterol-Inhibiting Fungicides for Control of Certain Diseases of Apple in the Cumberland-Shenandoah Region

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ABSTRACT

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Certain sterol-inhibiting fungicides were field-tested against apple scab, rusts, and several summer diseases of apple in Pennsylvania and Virginia. Most of these compounds provided outstanding control of scab and rusts, weak control of summer diseases, and allowed adequate fruit finish. Exceptions were poorer rust control by prochloraz, better control of sooty blotch by bitertanol, and a consistent russeting of Golden Delicious fruit by fenapanil.

The Cumberland-Shenandoah Valley region of the eastern United States includes the major apple production counties of southern Pennsylvania, Maryland, West Virginia, and northern Virginia. Production practices and problems across the region are relatively uniform with regard to cultivar selection, orchard design, intended market, methods of pesticide application, and diseases.

Field-testing of experimental and standard fungicides for control of the common fungal diseases of apple in this region was conducted at the Virginia Polytechnic Institute and State University Fruit Research Laboratory, Winchester, and the Pennsylvania State University Fruit Research Laboratory, Biglerville, located 160 km apart. Standardization of many of the test methods at these locations has allowed us to compare the efficacy and phytotoxicity of tested materials under different weather conditions in a given year. In this paper, we report on evaluations of the effectiveness of experimental, sterol-inhibiting fungicides tested for the control of apple scab caused by *Venturia inaequalis* (Cke.) Wint., cedar-apple rust

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Table 1. Control of scab, cedar-apple rust, sooty blotch, and fruit rots by triarimol and standard fungicides

Treatment	Active ingredient (mg/L)	Leaves with scab (%)[t]	Cedar-apple rust (lesions per 80 leaves)[u]	Disease incidence (%)[v]	
				Sooty blotch	Fruit rots[w]
Triarimol 4.5%EC	40	1 ab[x]	0 a	27 b	15 c
Benomyl 50W	225	1 a	185 bc	0 a	2 a
Dikar 76.7W (mancozeb 72%)	(1,728)[y]	3 ab	111 b	0 a	2 ab
Captan 50W/ folpet 50W[z]	1,200/ 1,200/	1 ab	187 bc	0 a	4 ab
No fungicide	...	23 c	251 c	99 c	99 d

[t] Stayman cultivar. Data are from counts of leaves infected on 16 terminal shoots per tree on each of four replicate trees on 5 August 1969.
[u] Counts of five most severely infected Rome Beauty leaves on 16 shoots per tree on each of four replicate trees on 22 July 1969.
[v] Averages of four replicates, 100 Golden Delicious fruits per replicate, on 8 October 1969.
[w] Mixture of *Glomerella cingulata, Physalospora obtusa*, and *Botryosphaeria dothidea*.
[x] Mean separation by Duncan's multiple range test, 5% level.
[y] Active concentration of mancozeb; mixture also contained dinocap at 4.7%.
[z] Captan applied in all sprays through sixth cover. Folpet applied in seventh and eighth covers.

caused by *Gymnosporangium juniperi-virginianae* Schw., and "summer" diseases at these two locations.

MATERIALS AND METHODS

The following experimental materials were field-tested for effectiveness in controlling one or more of the major fungal apple diseases: bitertanol, CGA 64251 (1-[[2-(2,4-dichlorophenyl)-4-ethyl-1,3-dioxolan-2-yl]methyl]-1*H*-1, 2,4-triazole), fenapanil, fenarimol, fluotrimazole, prochloraz, triadimefon, triarimol, and triforine. Other materials in the test included AL-411F (mixture of surfactant and phytobland spray oil; Mobay Chemical Corp., Kansas City, MO 64120), benomyl, captan, Dikar (a mixture of 72% mancozeb and 4.7% dinocap; Rohm and Haas Co., Philadelphia, PA 19105), dinocap, DPX-115B (a mixture containing 10% benomyl and 50% captan; E. I. du Pont de Nemours & Co., Wilmington, DE 19898), folpet, mancozeb, pyrazophos, and thiram. Formulations of the materials appear in Tables 1–8.

Unless otherwise specified, treatments were applied to mature, well-pruned, semidwarf Rome Beauty, Golden Delicious, or Jonathan apple trees in a randomized block design of four to six single-tree replications. Typically, dilute treatments were applied to the point of runoff with a single-nozzle handgun and a high-pressure sprayer at 7- to 10-day intervals from early season to petal fall and at 2-wk intervals throughout the cover spray period. Some tests involved other methods and schedules of application as described. Three to five mature cedar galls suspended above each test tree before bloom provided cedar-apple rust inoculum. Other diseases developed from natural inoculum except as noted for some apple scab tests.

Generally, foliar disease was evaluated in early July, and fruit disease incidence was evaluated at harvest (mid-September for Jonathan, late September or early October for Golden Delicious, mid-October for Rome Beauty). Commercial insecticides, bactericides, and growth regulators were applied to the entire test blocks as needed. Additional information about dates of application, growth stages, and other materials applied is provided in the references cited for the experiments reported in the following tables: Table 1 (2), Table 2 (11), Table 3 (21), Table 5 (12), Table 6 (10), Table 7 (19), Table 8 (4).

Table 2. Control of scab and cedar-apple rust on Rome Beauty apples by prochloraz, CGA 64251, triforine, and fenapanil

Treatment	Active ingredient (mg/L)	Scab (%)		Cedar-apple rust (%)	
		Leaves[x]	Fruit[y]	Leaves[x]	Fruit[y]
Prochloraz 25W	188	0.4 ab[z]	0.2 ab	18 b	6 b
Prochloraz 40EC	360	0.0 a	0.0 a	16 b	7 b
CGA 64251 10W	19	0.0 a	0.5 ab	0 a	0 a
Triforine 18.2EC	186	1.5 ab	0.0 a	3 a	0 a
Fenapanil 2E + dinocap 48EC	300 + 72	1.8 bc	2.3 b	0 a	0 a
Dikar 76.7W (mancozeb 72%)	(1,728)	4.6 c	1.7 b	2 a	2 a
No fungicide	···	51.6 d	77.3 c	24 b	19 c

[x]Overwintering scab inoculum was supplemented by atomizing suspensions containing 2.5×10^5 conidia per milliliter onto all test trees 19 April and 4, 15, and 24 May. Data are from counts of all leaves on 10 terminal shoots per single-tree replicate on 26 July 1978.
[y]Harvest counts of 100 fruits per replicate.
[z]Mean separation by Duncan's multiple range test, 5% level.

Table 3. Control of scab and cedar-apple rust on Rome Beauty apples by bitertanol and fenapanil

Treatment	Active ingredient (mg/L)	Infected with scab (%)		Leaves infected with rust (%)[x]
		Leaves[x]	Fruit[y]	
Bitertanol 50W	150	9 a[z]	11 ab	0 a
Bitertanol 50W	75	22 b	33 abc	0 a
Fenapanil 2L	600	10 a	45 c	0 a
DPX-115B 60W (captan 50%) (benomyl 10%)	(1,200) (240)	11 ab	9 a	6 b
Dikar 76.7W (mancozeb 72%)	(1,728)	45 c	22 abc	8 bc
No fungicide	···	65 d	100 d	23 cd

[x]Data are from counts of all leaves on 10 terminal shoots from each of six single-tree replicates on 12 July 1979.
[y]Average of six replicates, 25 fruits per replicate, after 2-wk storage at 2 C.
[z]Mean separation by Duncan's multiple range test, 5% level.

RESULTS AND DISCUSSION

Control of apple scab. Triarimol was the first sterol-inhibiting fungicide tested on apples in the Cumberland-Shenandoah Valley region (Table 1). Scab was controlled at fungicide applications of 40 μg a.i./ml. Prochloraz, CGA 64251, triforine, and bitertanol all gave better control of scab on leaves and fruit than the Dikar standard (Tables 2–4). In one test, fenapanil (300 μg a.i./ml) and Dikar were equivalent for leaf and fruit scab control (Table 2); in another test, fenapanil (600 μg a.i./ml) was superior on leaf scab but equal to Dikar for fruit scab control (Table 3). Triadimefon was inferior to bitertanol at equivalent rates (Table 4).

Against apple scab, these fungicides exhibited several ranges of activity. Triarimol, fenarimol, and CGA 64251 gave good control at rates of 40 μg a.i./ml or less. Triforine, bitertanol, and prochloraz effectively controlled scab at 150–300 μg a.i./ml. Fenapanil was equally effective only at 300–600 μg a.i./ml or more in these tests. Triadimefon gave less scab control than bitertanol at 75 μg a.i./ml (Table 4) but was adequate in another test at 300 μg a.i./ml (8).

CGA 64251, fenapanil, and bitertanol were compared with benomyl for their ability to suppress sporulation of established scab lesions (Table 5). Fenapanil (600 μg a.i./ml) and bitertanol (300 μg a.i./ml) provided a slight reduction of sporulation but appeared to be somewhat less effective than benomyl (225 μg a.i./ml). The test was not highly conclusive because sporulation by untreated lesions also decreased greatly during the evaluation period.

Table 4. Control of foliar scab and cedar-apple rust on Rome Beauty by bitertanol and triadimefon

Treatment	Active ingredient (mg/L)	Leaves infected (%)[y]	
		Scab	Rust
Triadimefon 50W	75	13 c[z]	1 a
Bitertanol 2.5E	150	0 a	0 a
Bitertanol 2.5E	75	1 ab	0 a
Bitertanol 50W	150	0 a	0 a
Bitertanol 50W	75	1 ab	0 a
Dikar 76.7W (mancozeb 72%)	(1,728)	5 b	7 b
No fungicide	···	26 d	21 c

[y]Data are from counts of all leaves on 10 terminal shoots from each of five single-tree replicates on 3 July 1980.
[z]Mean separation by Duncan's multiple range test, 5% level.

Control of cedar-apple rust. All the sterol-inhibiting fungicides tested, except prochloraz, were highly effective against cedar-apple rust when compared with commercial standards (Tables 1–4, 6, and 7). Rust control data were acquired in tests of fungicides for broad-spectrum disease control. Rates selected for scab and mildew control generally exceeded those necessary to distinguish the relative rust activity of highly effective com-

Table 5. Suppression of *Venturia inaequalis* sporulation by CGA 64251, fenapanil, bitertanol, and benomyl applied to established scab lesions on Rome Beauty apple foliage

Treatment[x]	Active ingredient (mg/L)	Thousands of conidia per cm^2 of lesion area[y]		
		11 July	24 July	14 August
CGA 64251 10W	19	91.9 c[z]	35.4 b	2.7 bc
Fenapanil 2E	600	30.1 ab	13.2 ab	1.3 ab
Bitertanol 1.67 E +	313 +			
AL 411 F	0.6 ml	38.9 bc	22.1 ab	0.6 ab
Benomyl 50W	225	20.9 a	9.2 a	0.5 a
No fungicide	...	72.5 c	29.6 ab	5.6 c

[x]Trees were treated on 16 and 28 June and on 12 July 1978.
[y]Hemacytometer counts of composite spore samples of a single lesion from each of 10 leaves per single-tree replicate; four replicates.
[z]Mean separation by Duncan's multiple range test, 5% level.

Table 6. Control of cedar-apple rust on Rome Beauty apples by fenarimol, prochloraz, and CGA 64251

Treatment	Active ingredient (mg/L)	Leaves infected (%)[y]
Fenarimol 1EC	38	0.0 a[z]
CGA 64251 21.5W	8	0.1 a
Prochloraz 25W	380	17.1 b
Prochloraz 25W	190	19.1 b
Mancozeb 80W +	720 +	0.5 a
benomyl 50W +	80 +	
pyrazophos 30%EC	48	
No fungicide	...	23.1 b

[y]Data are from counts of all leaves on 15 terminal shoots from each of six single-tree replicates on 16 July 1977.
[z]Mean separation by Duncan's multiple range test, 5% level.

Table 7. Control of cedar-apple rust on Rome Beauty apple foliage and sooty blotch on Golden Delicious apple fruit by fenapanil, bitertanol, triforine, and CGA 64251

Treatment	Active ingredient (mg/L)	Leaves infected with rust (%)[x]	Sooty blotch (%)[y]
Fenapanil 2E	600	1.8 abc[z]	15 abc
Fenapanil 2E +	300 +	2.4 bc	36 de
dinocap	57		
Bitertanol 25W	300	0.2 a	1 a
CGA 64251 10W	19	1.1 ab	21 bcde
Triforine 18.2EC	186	0.5 ab	15 abcd
Dikar 76.7W			
(mancozeb 72%)	(1,728)	3.1 c	3 ab
No fungicide	...	5.4 d	99 f

[x]Data are from counts of all the leaves on 10 terminal shoots from each of six single-tree replicates on 7 August 1978.
[y]Harvest evaluation of 25 fruits from each of four replicates.
[z]Mean separation by Duncan's multiple range test, 5% level.

Table 8. Effect of preharvest application interval of triarimol on control of sooty blotch, fly speck, and fruit rots on Golden Delicious apples

Treatment[w]	Active ingredient (mg/L)	Days from last spray to harvest[x]	Disease incidence (%)[y]		
			Sooty blotch	Fly speck	Fruit rots
Triarimol 25W	75	45	49 cd[z]	56 c	20 c
Triarimol 25W	75	30	11 b	24 b	5 ab
Triarimol 25W	75	15	8 ab	9 ab	2 a
Folpet 50W	1,200	45	1 a	1 a	1 a
No fungicide	...	...	100 d	89 d	100 d

[w]All trees except those receiving no fungicide were treated with a standard commercial program before the fifth cover spray.
[x]The 45-day treatments received 5th–8th cover sprays; 30-day treatments received 5th–9th covers; 15-day treatments received 5th–10th covers.
[y]Counts of 100 fruits from each of four single-tree replicates at harvest on 8 October 1971.
[z]Mean separation by Duncan's multiple range test, 5% level.

pounds. A single comparison of fluotrimazole and triadimefon demonstrated equal or better effectiveness by triadimefon at 25% of the rate of fluotrimazole (5). In one test, fenapanil was less effective than bitertanol at 300 μg a.i./ml (Table 7). Although the severity of the rust tests was increased by placement of cedar-gall inoculum directly over the test trees, several of these materials completely controlled rust in some tests; comparative data on the minimum effective rates are lacking.

Control of summer diseases. Although some effects on summer diseases were evident, many of the sterol-inhibiting fungicides provided relatively poor control of summer diseases when compared with standard commercial fungicides (Tables 1, 7, and 8). Triarimol did not satisfactorily control sooty blotch caused by *Gloeodes pomigena* (Schw.) Colby and a mixture of fruit rots caused by *Physalospora obtusa* (Schw.) Cke., *Botryosphaeria dothidea* (Moug. ex Fr.) Ces. & de Not. (= *B. ribis* Gross. & Dugg.), and *Glomerella cingulata* (Stonem.) Spauld. & Schrenk when compared with benomyl, mancozeb, and captan (Table 1). In a test designed to examine the late-season residual activity of triarimol, progressively poorer control resulted as the interval from the last application to harvest was extended from 15 and 30 days to 45 days (Table 8). Under high disease pressure (Table 7), bitertanol (300 μg a.i./ml) gave exceptional sooty blotch control followed by triforine (186 μg a.i./ml), fenapanil (600 μg a.i./ml), and CGA 64251 (19 μg a.i./ml). Similar results were obtained in another test involving bitertanol, fenapanil, and CGA 64251.

Variable control of summer diseases by individual compounds in the group was probably related to favorable weather conditions at the test site at a critical time for disease development, permitting a high incidence on untreated trees but becoming unfavorable for disease development just as the weaker treatments began to break down. Inconsistent or relatively weak control by sterol inhibitors has been commonly observed on other summer diseases, including Brooks or Phoma fruit spot caused by *Mycosphaerella pomi* (Pass.) Lindau, fly speck caused by *Zygophiala jamaicensis* Mason, and various fruit rots (3–7, 9,20,21).

Effects on fruit finish. With the exception of fenapanil, finish of fruit treated with sterol inhibitors has been nearly normal compared with fruit from untreated trees. Occasionally a mild opalescence or russeting has been noted. Fenapanil, however, contributed to russeting of Golden Delicious in four consecutive years (9,19,21,22). In 1977, a rather dry year, russeting on fruit appeared almost entirely in a peculiar, circular pattern 1–2 cm in diameter. Increased opalescence and lenticel enlargement were also observed on Delicious fruit treated with fenapanil. No effect was noted on the finish of Rome Beauty. In these tests the finish of fruit was unaffected by fenarimol, triadimefon, bitertanol, triforine, or CGA 64251. Deleterious finish effects of fenapanil have also been observed in the Hudson Valley (16) and North Carolina (17).

Many of the sterol-inhibiting fungicides demonstrate activity suitable to control programs for the major early-season fungal diseases of apple in the

Cumberland-Shenandoah Valley. This useful spectrum of activity includes the rusts and scab, as reported here, and powdery mildew (13,14). The demonstrated postinfection activity of this group of compounds, particularly on rusts (15,16,18), would rank them high on a list of components of the fungicide arsenal.

Maximum usefulness of sterol inhibitors in apple spray programs of the region would be from pink to second cover on cultivars susceptible to scab, rust, and powdery mildew. Applications of sterol inhibitors earlier than pink and later than second cover might be warranted by unusually heavy disease potential by one or more of these diseases. During the period from pink to second cover, prochloraz would have to be supplemented with another material for rust control, and triadimefon would have to be supplemented for adequate scab control.

As indicated here and in tests conducted under heavy summer disease pressure in North Carolina and South Carolina (1,17,23), most of these compounds at present usage rates would have to be supplemented with materials having longer residual activity—such as mancozeb, zineb, captan, or folpet—for reliable summer disease control. Bitertanol, however, has shown residual activity for control of sooty blotch and fly speck under strong test conditions. Further testing of this compound under severe summer disease conditions is desirable.

Use of sterol-inhibiting fungicides should be valuable in combating strains of *V. inaequalis* resistant to benomyl or dodine. Potential for development of apple scab strains resistant to sterol inhibitors may not be as great as in northern apple growing regions because of the need for supplemental summer disease control during the cover period. Rust strains resistant to sterol inhibitors may develop, but the alternate host, 2-yr disease cycle, abundance of wild type inoculum, and continued usage of mancozeb and zineb for summer disease control during the period when the rust fungi are sporulating on apple should be important factors limiting the buildup of strains of rust fungi resistant to sterol inhibitors.

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