Suppression of Cedar Apple Rust Pycnia on Apple Leaves Following Postinfection Applications of Fenarimol and Triforine

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ABSTRACT

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The experimental fungicides fenarimol and triforine were compared with mancozeb to determine control of cedar apple rust (caused by *Gynmosporangium juniperi-virginianae*) following postinfection applications to apple under both greenhouse and orchard conditions. Fenarimol and triforine inhibited normal development of pycnia and only small flecks developed. In the greenhouse, fenarimol at 20, 40, and 60 μg/ml provided 98% control when applied 3 days after inoculation; triforine at 120, 240, and 360 μg/ml provided 89–98% control 1 day after inoculation with 59–94% and 68–83% control after 2 and 3 days, respectively. In the orchard, fenarimol at 20 and 40 μg/ml suppressed pycnial formation 96–99% and 97–100%, respectively, when applied 5 or 7 days after commencement of infection periods. Triforine at 240 μg/ml suppressed pycnial formation by 80–83% with sprays within 2 days after infection in the orchard, but control decreased to 71 and 79% at 3 or 5 days. Inadequate control was obtained with postinfection applications of mancozeb, a commonly used rust fungicide, in either greenhouse or orchard.

Additional key words: Malus pumila.

The efficacy of a fungicide usually is determined by examining its ability to prevent infection when the fungicide is present on the plant before or during onset of infection. Some fungicides, however, prevent disease development if they are applied after infection and are said to have "kickback," "eradicative," or "curative" properties (2,11).

Fungicides used commercially to control cedar apple rust which is incited by *Gymnosporangium juniperi-virginianae* Schw. have not provided control when applied after onset of infection and are classified solely as protectants. However, Szkolnik (8,10) demonstrated control of cedar apple rust following postinfection applications of *N,N'*-(1,4-piperazinediylbis [2,2,2-trichloroethylidene])bis(formamide) (triforine) under greenhouse conditions. Pearson and Szkolnik (5) also reported briefly on postinfection control obtained with applications of triforine and α-(2-chlorophenyl)-α-(4-chlorophenyl)-5-pyrimidinemethanol (fenarimol) under greenhouse and orchard conditions. This paper elaborates on these preliminary reports.

MATERIALS AND METHODS

Greenhouse studies.—Single-shooted Rome Beauty apple (*Malus pumila* Mill.) trees were treated in the following sequence: (i) leaves were inoculated with a suspension of basidiospores of *G. juniperi-virginianae* (70,000/ml), (ii) trees were placed in a mist chamber (18 C and 100% RH), (iii) dilute fungicides were applied at different intervals after inoculation, and (iv) trees were incubated in a greenhouse. Details of the technique have been published (10).

Data were recorded as number of pycnial lesions per leaf. Lesions counts then were converted to a percent disease control rating. Values in each experiment were based on average ratings of three leaves on each of three trees per treatment. Experiments were repeated a minimum of five times.

Field studies.—Infection periods for cedar apple rust were identified by comparing the temperature and the duration of rain-initiated leaf wetness with required values determined previously in laboratory studies (R. C. Pearson, *unpublished*).

Golden Delicious apple trees were sprayed to runoff by handgun at 550 psi (38.5 kg/cm^2). Treatments were applied to half-tree plots and the unsprayed half-tree was used as a buffer between treatments. Tags were tied on the youngest unfolded leaf after each fungicide application to identify sprayed leaves and date of application. Two types of data were recorded as Barratt-Horsfall ratings (6) of leaf area covered by lesions: (i) total lesions including normal lesions with pycnia and chlorotic or necrotic flecks without pycnia and (ii) normal lesions with pycnia. Barratt-Horsfall ratings were converted to percent leaf area affected with Elanco conversion tables (6). Data were taken on all sprayed leaves on a minimum of 20 clusters or terminals per replicate. Treatments in all field plots were replicated five times in a randomized complete block design.

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RESULTS

Greenhouse studies.—Fenarimol, mancozeb, and triforine were applied 1, 2, or 3 days after inoculation. Fenarimol, at rates of 20–60 μg/ml, gave 98% control when applied as long as 3 days after inoculation (Table 1). Triforine gave more than 98% control when applied 1 day after inoculation at 240 and 360 μg/ml but not at 120 μg/ml. Triforine used at 360 μg/ml still provided 94% control when applied 2 days after inoculation. Mancozeb showed no postinfection control.

Field studies, 1975.—Fenarimol (Eli Lilly EL 222 12.5-EC) 40 μg/ml active ingredient (AI), triforine (Celamerck CME 74770 20EC) 240 μg/ml AI, and mancozeb (Rohm & Haas Dithane M-45 80W) 9,920 μg/ml AI were compared for postinfection control. Nine cedar apple rust infection periods were recorded in relation to stage of flower development (1): 24–25 April (centimeter green), 1–2 May (early tight cluster and three terminal leaves), 4–5 May, 6–7 May (tight cluster and three to five terminal leaves), 11–13 May (pink and seven to nine terminal leaves), 16 May (bloom), 22–23 May, 30–31 May, and 4 June 1975.

In one trial, sprays were applied on 14 May (3 days after start of rain) and on 9 June (4 days after the start of a rain) (Table 2). In another trial, sprays were applied only once at 1, 2, 3, or 5 days after the beginning of a wet period commencing 30 May (Table 3).

Lesions that developed on untreated leaves or those treated with mancozeb produced both pycnia and aecia (normal lesions), whereas those treated with fenarimol or triforine produced small chlorotic or necrotic flecks

TABLE 1. Control of cedar apple rust (caused by *Gymnosporangium juniperi-virginianae*) on apple by postinfection application of fungicides in the greenhouse

Treatment	Dosage (active ingredient) (μg/ml)	Disease control rating[a]		
		1 day[b]	2 days	3 days
Untreated check		10[c]	10	10
Mancozeb 80W	1,440	9	10	8
Fenarimol (EL 222) 12.5EC	20	tr	tr	1
	40	0	0	tr
	60	0	0	1
Triforine (CA 70203) 20EC	120	3	7	6
	240	1	5	5
	360	1	2	4
LSD ($P \leq 0.01$)		1.40	1.35	3.08

[a]Minimum disease control for rating 0, 1, 2, etc. to 10 is 100, 98, 94, 89, 83, 76, 68, 59, 47, 29, and 0%, respectively. tr = trace; more than 99.5% control.

[b]Days refer to interval between inoculation and application of fungicide.

[c]Figures for 1, 2, and 3 day intervals are based on the average of nine, eight, and five experiments, respectively. Values in each experiment were based on average ratings of three leaves on each of three trees per treatment.

TABLE 2. Suppression of pycnia of cedar apple rust (caused by *Gymnosporangium juniperi-virginianae*) on apple by postinfection application of fungicides under orchard conditions in 1975

Treatment	Dosage (active ingredient) (μg/ml)	Leaf area infected[a] after spraying:					
		Cluster leaves 14 May (pink)[b]		Terminal leaves			
				14 May (pink)[b]		14 May[b] and 9 June[c]	
		Total[d] (%)	Normal[e] (%)	Total (%)	Normal (%)	Total (%)	Normal (%)
Mancozeb 80W	1,920	35.3 A	34.9 B	26.9 B	26.9 B	9.3 A	9.3 C
Fenarimol 12.5EC	40	18.2 A	0.0 A	12.3 A	0.5 A	13.2 A	0.7 A
Triforine 20EC	240	16.1 A	0.2 A	13.6 A	1.2 A	11.2 A	4.0 B
Untreated	...	27.4 A	27.4 B	21.8 B	21.8 B	21.2 B	21.2 D

[a]Percent leaf area infected determined by Barratt-Horsfall ratings of all leaves exposed to the fungicide treatment (20 clusters or terminals per replication). Cluster leaf data recorded 11 and 19 June; terminal leaf data recorded 29–31 July 1975. Values followed by same letter did not differ significantly ($P \leq 0.05$) according to Duncan's multiple range test on arcsin-transformed data.

[b]Fungicide applied 3 days after start of rain on 11 May.

[c]Fungicide applied 4 days after start of rain on 5 June.

[d]Percent leaf area covered with normal pycnial lesions and abnormal lesions (flecks without pycnia).

[e]Percent leaf area covered with normal pycnial lesions that subsequently gave rise to aecia.

(0.5–1.0 mm) and aecia did not develop (abnormal lesions). Based on suppression of normal lesion development, fenarimol and triforine provided excellent postinfection control of cedar apple rust when applied within 3 or 4 days after the beginning of a rain (Table 2). When only one spray was applied during the season, mancozeb provided no control. However, terminal leaves sprayed with mancozeb 14 May and again 9 June significantly reduced both total lesions and normal lesions. Perhaps fungicide residue from the 14 May application was redistributed to unsprayed leaves that emerged after 14 May but before 9 June.

Results of a second trial revealed significant and equal reduction of total lesion development of cedar apple rust following single applications of fenarimol and triforine 1–5 days after the start of a rainy period (Table 3). Based on normal lesion development, however, fenarimol and triforine applied 3 days after infection gave 91 and 71% control, respectively.

Field studies, 1976.—Fenarimol 12.5EC at 20 and 40 μg/ml AI was compared to mancozeb (DuPont Manzate 200 80W) at 1,400 μg/ml AI. Five infection periods were recorded: 24–26 April (pink), 1–2 May (bloom), 7 May (petal fall), 11–12 May (12–14 terminal leaves), and 16–17 May (13–16 terminal leaves).

Treatments were applied 3, 5, or 7 days after a long wet period between 24 and 26 April. The mean temperature during this 48-hr rainy period was 6 C, which was too cold for basidiospore formation (4) and therefore precluded infection. These applications did provide protection for the infection periods of 1–2 and 7 May (Table 4). Even though all treatments were applied before the infection periods, subsequent normal lesion development was less than total lesion development in both rates of fenarimol. Normal lesion development in most fungicide treatments ranged from 0.4 to 1.9% leaf area infected, and only the 20 μg/ml rate of fenarimol applied on 27 April resulted in significantly less ($P \leq 0.05$) protection. Nevertheless, the leaf area infected in this treatment was significantly smaller ($P \leq 0.05$) than the leaf area infected on untreated leaves.

In another trial, treatments were applied 6 or 8 May, 5 and 7 days, respectively, after the beginning of rain. Additionally, these treatments were 1 day before or 1 day after the 7 May infection period. All treatments except mancozeb provided 98–100% suppression of normal cedar apple rust lesions on cluster leaves (Table 4). Fenarimol at 20 and 40 μg/ml also provided 96% suppression of normal cedar apple rust lesions on terminal leaves. Mancozeb-treated terminal leaves contained significantly more ($P \leq 0.05$) normal lesions than fenarimol-treated leaves but bore significantly fewer ($P \leq 0.05$) lesions than nonsprayed terminal leaves. The infection periods of 11–12 May and 16–17 May that followed the above applications did not result in infection of previously sprayed leaves, indicating protection for at least 8–10 days.

Although no quantitative data are available, by mid-August considerable defoliation by cedar apple rust was observed on the untreated trees and on the untreated half of fungicide-treated trees.

DISCUSSION

Previous greenhouse studies have shown that fenarimol and triforine are capable of postinfection control of apple scab (*Venturia inaequalis*) (8,12), cherry leaf spot (*Coccomyces hiemalis*) (8,12), and peach brown rot (*Monilinia fructicola*) (13). Spotts (7) showed that

TABLE 3. Suppression of pycnia of cedar apple rust (caused by *Gymnosporangium juniperi-virginianae*) on apple after a single postinfection application of fungicide under orchard conditions in 1975

Treatment	Dosage (active ingredient) (μg/ml)	Spray date	Application time after start of rain on: 30 May (days)	Application time after start of rain on: 1 June (days)	Leaf area infected[a] Total lesions[b] (%)	Leaf area infected[a] Normal lesions[c] (%)
Mancozeb 80W	1,920	31 May	1	...	18.4 C	18.4 C
		1 June	2	0.5	19.8 C	19.8 C
		2 June	3	2	17.6 BC	17.6 C
		4 June	5	3	21.7 C	21.7 C
Fenarimol 12.5EC	40	31 May	1	...	9.8 A	1.6 A
		1 June	2	0.5	9.2 A	2.4 AB
		2 June	3	2	10.2 A	1.9 A
		4 June	5	3	8.8 A	1.9 A
Triforine 20EC	240	31 May	1	...	7.1 A	3.6 AB
		1 June	2	0.5	8.6 A	4.3 AB
		2 June	3	2	11.5 AB	6.2 B
		4 June	5	3	8.9 A	4.4 AB
Untreated					21.2 C	21.2 C

[a]Percent leaf area infected determined by Barratt-Horsfall ratings of all terminal leaves exposed to the fungicide treatment (20 terminals per replication). Data recorded 29–31 June 1975. Values followed by same letter did not differ significantly ($P \leq 0.05$) according to Duncan's multiple range test on arcsin-transformed data.

[b]Percent leaf area covered with normal pycnial lesions and abnormal lesions (flecks without pycnia).

[c]Percent leaf area covered with normal pycnial lesions that subsequently gave rise to aecia.

fenarimol also has eradicative properties against grape black rot (*Guignardia bidwellii*). In the tests reported here with cedar apple rust, fenarimol at 20 μg/ml provided 98% control when applied as long as 3 days postinfection in the greenhouse and more than 95% control when applied 5 to 7 days postinfection in the orchard. Triforine at 240 μg/ml provided 98% control at 1 day postinfection in the greenhouse and dropped to 76% control at 2 and 3 days, whereas the same rate of triforine under orchard conditions provided 79% control as long as 5 days postinfection. More favorable conditions for infection in the greenhouse probably accounted for the weaker postinfection control in greenhouse experiments.

The flecks that developed when postinfection treatments with fenarimol were applied before symptom expression are equivalent to "presymptom" control described for dodine and benomyl on apple scab (11) and triforine on cedar apple rust (10) and cherry leaf spot (9). Symptoms that developed after preinfection applications of fenarimol were similar to those that developed after postinfection applications (Table 4). More total lesions developed on trees receiving preinfection applications of fenarimol than on those treated with mancozeb, but the same number of pycnial lesions developed after both treatments. Apparently, the fungus is most affected by fenarimol after infection develops but before lesions are visible, hence the occurrence of flecks. The chance of total prevention of symptom expression is better, however, if sprays are applied soon after infection occurs.

The occurrence of nonsporulating flecks in place of pycnial lesions is a form of control because the absence of pycnia precludes the formation of aecia (3), which cause more leaf damage. Thus, the life cycle is broken by preventing infection of *Juniperus virginiana,* the alternate host. The occurrence of small flecks instead of pyncial and aecial lesions and the reduction in defoliation may contribute to control by keeping leaves more functional than diseased leaves with full symptom expression.

Fungicides with postinfection control capabilities should be valuable tools in controlling cedar apple rust. Previously, when weather conditions prevented adequate coverage with protectant fungicides prior to an infection period, disease was likely to develop. Less frequent postinfection application of fungicides would reduce the cost of disease control in an economically and environmentally sound manner.

TABLE 4. Suppression of pycnia of cedar apple rust (caused by *Gymnosporangium juniperi-virginianae*) on apple following preinfection or postinfection treatment with fungicides under orchard conditions in 1976

Treatment	Dosage (active ingredient) (μg/ml)	Spray date	Application time in relation to start of rain period of:		Leaf area infected[a]			
					Cluster leaves		Terminal leaves	
			1–2 May (days)	7 May (days)	Total lesions[b] (%)	Normal lesions[c] (%)	Total lesions (%)	Normal lesions (%)
Preinfection treatments:								
Fenarimol 12.5EC	20	27 April	4 before	10 before	...[d]	...	7.3 D	6.3 B
		29 April	2 before	8 before	...	...	3.7 BC	1.5 A
		1 May	0 before	6 before	...	...	4.7 CD	1.4 A
Fenarimol 12.5EC	40	27 April	4 before	10 before	...	...	2.9 ABC	1.9 A
		29 April	2 before	8 before	...	...	1.7 AB	0.5 A
		1 May	0 before	6 before	...	...	3.2 ABC	0.4 A
Mancozeb 80W	1,440	27 April	4 before	10 before	...	...	1.4 AB	1.4 A
		29 April	2 before	8 before	...	...	1.1 A	1.1 A
		1 May	0 before	6 before	...	...	1.1 A	0.9 A
Untreated					...	...	24.2 E	24.2 C
Postinfection treatments:								
Fenarimol 12.5EC	20	6 May	5 after	1 before	0.3 A	0.1 A	7.9 A	1.2 A
		8 May	7 after	1 after	1.5 A	0.4 A	7.7 A	1.1 A
Fenarimol 12.5EC	40	6 May	5 after	1 before	1.0 A	0.0 A	10.1 AB	0.6 A
		8 May	7 after	1 after	1.3 A	0.2 A	12.5 AB	0.9 A
Mancozeb 80W	1,440	6 May	5 after	1 before	15.8 B	16.1 B	12.8 AB	12.4 B
		8 May	7 after	1 after	16.8 B	16.8 B	16.0 B	14.4 B
Untreated					16.1 B	16.1 B	26.8 C	26.7 C

[a]Values based on Barratt-Horsfall ratings of leaves exposed to the fungicide treatment (20 terminals or clusters per replication). All data recorded 2–6 July 1976. Values followed by same letter did not differ significantly ($P \leq 0.05$) according to Duncan's multiple range test on arcsin-transformed data.

[b]Percent leaf area covered with normal pycnial lesions and abnormal lesions (flecks without pycnia).

[c]Percent leaf area covered with normal pycnial lesions that subsequently gave rise to aecia.

[d]No data recorded for cluster leaves in preinfection treatments.

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