Control of Powdery Mildew on Greenhouse-grown Roses by Volatilization of Fungicides

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ABSTRACT

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Rose powdery mildew was controlled in greenhouses by heating fungicides in shallow containers. Duration of heating and temperature requirements varied according to the physical and chemical properties of the fungicide. Treatments were applied at night to allow the greenhouse to be tightly sealed in order to maintain an effective dosage. Fenarimol and fenapanil effectively controlled rose powdery mildew and caused no phytotoxic effects. Volatilization of fungicides offers ease of application, uniform distribution, and reduced hazard to greenhouse personnel.

Control of powdery mildew diseases with volatile fungicides was introduced in 1852 by Bergman (2), who reduced the incidence of grape powdery mildew in a greenhouse by sprinkling sulfur on moist heating pipes. Although similar methods remain in use for control of rose powdery mildew, they are not widely practiced because efficacy and phytotoxicity are affected by ambient temperature. Yarwood (13) showed that inhibition of bean powdery mildew with sulfur vapors increased as ambient temperature increased between 7 and 43 C. There was a direct correlation between duration of exposure and inhibition of fungal development. Various other investigators have studied the mode of action of sulfur, and their results were reviewed by Horsfall (7).

Fumigation of greenhouse crops for insect control was widely practiced during the early part of this century, but few chemicals are presently registered for this purpose. Various fumigation techniques were reviewed by Hough and Mason (8). McKeen (9) reported powdery mildew control on greenhouse-grown cucumbers using a dinocap smoke generator, and Bent (1) demonstrated control of powdery mildews by vapor action of fungicides. Hislop (6) showed that susceptibility of fungi to vapor action was not limited to the Erysiphaceae. Spurr and Chancey (10) reported vapor phase activity of a new pyrimidine fungicide against bean powdery mildew. Szkolnik (11,12) controlled apple powdery mildew in the greenhouse by placing recently sprayed plants near unsprayed plants and by exposing plants to vapors emitted from cheesecloth soaked in fungicide.

None of the recent investigators suggested heating fungicides as an application method for control of powdery mildew diseases in the greenhouse. The purpose of the present study was to test the feasibility of that concept. Preliminary results were published previously (3–5).

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MATERIALS AND METHODS

All fungicides were volatilized by heating the chemical in shallow containers. The dosage was initially based on the amount of compound necessary to provide good coverage of the plants as a dilute spray and subsequently adjusted according to experimental results. The chemicals and formulations used were fenapanil (Sisthane, 25% emulsified concentrate—development discontinued by the manufacturer); fenarimol (Rubigan, 12% emulsified concentrate); parinol (Parnon, 4% liquid concentrate); and piperalin (Pipron, 82.4% liquid concentrate). Experiments were conducted in small research greenhouses and large commercial rose ranges.

Powdery mildew caused by *Sphaerotheca pannosa* (Wallr. ex Fr.) Lév. var. *rosae* Wor. was assessed by counting the number of colonies per stem or recording the number of flower stems infected with the fungus. The number of powdery mildew colonies per stem was recorded by randomly selecting 25 flowering stems and counting the colonies on each of the four terminal five-leaflet leaves. Results were subjected to an analysis of variance.

A bioassay technique, utilizing *S. pannosa* var. *rosae*, was used to determine the effects on growth and development of the fungus. Detached rose leaf disks were inoculated with conidia from vigorous powdery mildew colonies at various intervals before exposure to the fumigant. Leaf disks were either placed in the greenhouse immediately after inoculation or were incubated at 95% relative humidity (RH) for 6 hr prior to fumigation. The effects of the fumigant on hyphal growth and development were observed microscopically and recorded. Insect and mite control was achieved in all experiments by application of appropriate chemicals with conventional spray equipment.

Efficacy of volatilized fenapanil. Two series of treatments were applied in this experiment to determine the efficacy of fenapanil and the reinfection rate after volatilization of this fungicide. Treatments were applied 4 consecutive weeks followed by 4 wk without treatment, then resumed for an additional 4-wk period. Fifty plants each of cvs. Pink Parfait and Mary Devor were fumigated by heating 3.72 g (a.i.) of fenapanil to 150 C for 8 hr/treatment in a conventional glass greenhouse (9.14 × 7.39 m; 298 m^3) maintained at 18 C (± 4). The formulated fungicide (25 EC) was added directly to a shallow pan and heated each night for 1 wk. New fungicide was added each week for 4 successive weeks. The incidence of powdery mildew was assessed 2 wk after the last treatment of the first series by randomly selecting 25 flowering shoots as described previously. Powdery mildew incidence was reassessed 1 wk after the final treatment of the second series.

Effect of long-term fenarimol treatment. The purpose of this experiment was to observe effects of fenarimol volatilization on roses over an extended period. Flower production and powdery mildew incidence were recorded during 6 mo of fumigation with fenarimol. Rose cv. Mary Devor plants were pruned back to four or five vigorous canes and grown in a conven-

tional glasshouse (8.76 × 8.0 m; 240 m^3) until both the upper and the lower leaf surfaces were entirely covered with powdery mildew.

Twenty-six plants were randomly selected for treatment with a volatilized fungicide (group I), and an equal number remained untreated (group II) for 60 days in an isolated but identical glasshouse. The untreated plants were then moved to the treated area and remained there for the duration of the test. Plants in group I were treated 29 times (187 fumigation hours) beginning 11 December 1978, and those in group II were treated nine times (72 fumigation hours) beginning 28 March 1979. The final fenarimol treatment was applied on 26 April 1979. The maximum calculated dosage during a single exposure was 9.65 mg (a.i.)/m^3 assuming that all the fungicide was volatilized during the fumigation period.

The plants were grown in fiber pots (38 cm wide × 35 cm deep) in equal parts of sand, soil, and peat. The greenhouses were equipped with high-pressure sodium vapor lights that provided supplemental lighting (6–7 klux, 16 hr/day). Weekly fumigation during the first 30 days was achieved by heating 2.32 g (a.i.) of fenarimol to 136 C for 4 hr in a shallow container. During the succeeding 30 days, the fumigation period was varied (4–8 hr), and the effect of these treatments was observed on bioassay disks. During the remaining period, the treatment time was adjusted to a single 8-hr exposure, with no reheating of the fungicide. Flowers were cut periodically, and the number of infected and uninfected shoots was recorded. A flower shoot was rated infected if powdery mildew was visible to the unaided eye.

Comparison of volatilized fenapanil and fenarimol. The purpose of this experiment was to evaluate the efficacy of two fungicides applied by the volatilization technique in a commercial rose greenhouse. Rose cv. Forever Yours plants were grown in each of three separate polyethylene-covered (6-mil roof, 4-mil sides) structures (9.75 × 61 m; 1,888 m^3). Fenapanil and fenarimol were compared as fumigants at rates of 31 and 15 g (a.i.)/greenhouse per treatment, respectively, with a standard spray treatment that consisted of a mixture of parinol and piperalin at rates of 0.312 and 0.984 kg/ha, respectively. The fumigants were volatilized by heating to 150 C for 8 hr in two shallow containers centrally located in each greenhouse. The containers were reheated nightly and recharged weekly with new chemical for 4 wk. The incidence of powdery mildew on flowering shoots was assessed, as previously described, just prior to the first treatment and again 1 wk after the final treatment.

RESULTS

Efficacy of volatilized fenapanil. Powdery mildew was completely inhibited on two rose cultivars following two 4-wk series of fenapanil fumigation treatments (Table 1). The fungus recolonized Mary Devor more rapidly than Pink Parfait when treatment was discontinued during a 4-wk interval. The disease was controlled again during a second series of treatments. Fumigated rose leaves collected 4 hr after the final treatment in the first series and inoculated with unfumigated *S. pannosa* var. *rosae* conidia supported good hyphal growth, formation of secondary conidia, and only a small number (approximately 5%) of swollen hyphal tips. Exposure of rose leaf bioassay plates to fenapanil fumigation caused poor growth of the fungus, approximately 25% swollen hyphal tips, and no production of secondary conidia.

Table 1. Control of powdery mildew on Pink Parfait and Mary Devor roses in 1979 by volatilization of fenapanil[a]

Treatment date	Assessment date	Powdery mildew infection[b] (avg. no. of colonies/stem)	
		Mary Devor	Pink Parfait
Series I			
9 April	8 April	216	227
16 April			
23 April			
30 April	16 May	0	0
Series II			
4 June	5 June	116	2.6
11 June			
18 June			
25 June	5 July	0	0

[a] Fifteen milliliters of formulated fenapanil (25 EC) was heated to 150 C for 8 hr/night during the treatment period. New chemical was added weekly. The theoretical dosage was 12.48 mg/m^3.
[b] Twenty-five stems were selected at random, and the number of powdery mildew colonies on the first four five-leaflet leaves were counted.

Effects of long-term fenarimol treatment. Plants in both treatment groups were severely infected with powdery mildew when the first treatments were applied to group I plants on 11 December 1978. Those treated with fenarimol gradually recovered and were free of infection by 7 March 1979 (Table 2). Plants in the untreated group (II) continually produced infected foliage and flowers through March 1979. Group II plants improved quickly after they were moved to the fumigated greenhouse on 28 March 1979. The first uninfected flower was harvested from group II on 18 April 1979, and by mid-May most harvested flowers were free of the disease. Plants in group II gradually became reinfected after fumigation was discontinued on 26 April 1979, but those in group I continued to produce mildew-free flowers for the duration of the test period. Although flower quality was not specifically assessed, plants in group I consistently produced flowers of better

Table 2. Flower production and powdery mildew infection of Mary Devor roses fumigated with fenarimol at a theoretical dosage of 9.65 mg/m^3

Month	Group I[a]		Group II[c]	
	No. of flowers	Mildewed (%)[b]	No. of flowers	Mildewed (%)
Jan	231	94.4	213	100
Feb	249	54.2	166	100
Mar	111	7.2[d]	168	100
Apr	208	0.0	178	80.3
May	354	0.0	372	0.3
Jun	275	0.0	264	4.9
Total	1,428		1,366	
Mean no. per plant[e]	54.92		52.54	

[a] Fumigated 29 times between 11 December 1978 and 26 April 1979.
[b] Cut flowers with any visible powdery mildew were counted as infected.
[c] Fumigated nine times between 28 March 1979 and 26 April 1979.
[d] Last infected flower cut on 7 March 1979.
[e] Numbers based on 26 plants per group.

Table 3. Comparison of fenapanil and fenarimol fumigation with spray application of parinol-piperalin for control of powdery mildew on Forever Yours roses

Fungicide	Application method	Dosage (a.i.)	Powdery mildew infection (avg. no. of colonies/shoot)[a]	
			Pretreatment	Posttreatment
Fenapanil	Fumigation	31 mg/m^3	35.19	0.0
Fenarimol	Fumigation	15 mg/m^3	8.26	0.05
Parinol + piperalin	Spray	0.312 + 0.984 kg/ha	13.47	1.65
LSD (0.05)			8.58	0.425

[a] Powdery mildew colonies were counted on the first four five-leaflet leaves of flowering shoots just prior to treatment (13 March 1979) and again 1 wk after the final treatment (18 May 1979).

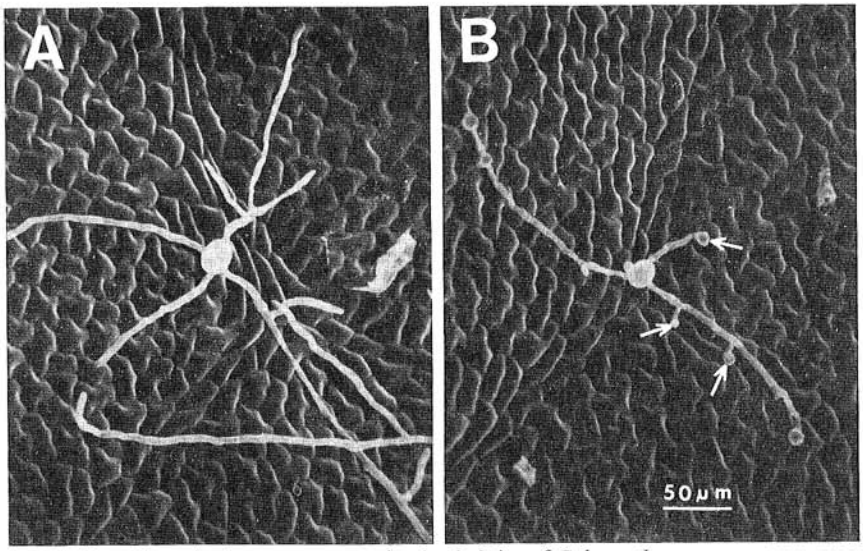

Fig. 1. Effect of nuarimol vapors on growing hyphal tips of *Sphaerotheca pannosa* var. *rosae*. Scanning electron micrographs show **(A)** normal germination and hyphal growth and **(B)** swollen hyphal tips (arrows) after 4 hr of exposure to nuarimol vapors.

quality than those fumigated a shorter period of time.

Comparison of volatilized fenapanil and fenarimol. Fumigation with fenapanil or fenarimol significantly reduced the incidence of powdery mildew on newly emerging rose leaves (Table 3). No new colonies formed on fenapanil-treated leaves, and only five colonies were observed on 100 randomly sampled fenarimol-treated leaves. These colonies were restricted to the two older leaves, suggesting that they were already present on young leaves of slow-growing shoots when the first treatments were applied. Microscopic examination revealed that the hyphae and spores were severely desiccated.

DISCUSSION

McKeen (9) successfully controlled cucumber powdery mildew with dinocap smoke, but his technique was quite different from the method described here. Smoke generators rely on distribution of pesticides on particulate matter; unlike the present method, however, the fungicide is subjected to elevated temperature for a relatively short period. Heating fungicides to the temperatures indicated in these experiments enhances gaseous evolution and maintains the concentration for sufficient duration to interact with the fungus. Optimum temperature for each fungicide depends on its inherent volatility. Although some fungicides volatilize at relatively low temperatures, others may require higher temperatures to maintain an effective dosage. This was demonstrated by the ineffectiveness of bupirimate at 105 C, whereas subsequent laboratory tests showed greatly enhanced disease control when the temperature was increased to 185 C (D. L. Coyier, *unpublished*).

Most fungicides that we tested caused swelling of actively growing hyphal tips (Fig. 1), and swollen tips were readily apparent within several hours of fumigation. Hyphal tips that were not in an active growth period remained morphologically unaffected. These observations suggest that vapors of certain fungicides interfere with fungal cell wall development during the exposure period but apparently have little effect when fumigation is discontinued. Fenapanil vapors inhibited hyphal growth, but leaves recently fumigated with fenapanil and inoculated with untreated conidia supported abundant growth of the fungus.

These experiments show that powdery mildew can be effectively controlled in greenhouses by heating fungicides. Volatilization of fungicides greatly reduces application costs, is amenable to automation, has potential for decreasing worker exposure, eliminates visible residue, and provides more uniform distribution and thus disease control than conventional spray application.

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