Comparison of Five Fungicides on Development of Root, Crown, and Fruit Rot of Chile Pepper and Recovery of *Phytophthora capsici* from Soil

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ABSTRACT

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The activity of five fungicides, azoxystrobin, dimethomorph, fluazinam, fosetyl-Al, and metalaxyl (subsequently replaced with mefenoxam by the manufacturer), was compared for effects on the development of root, crown, and fruit rot of chile pepper and on recovery of *Phytophthora capsici* from naturally infested soil. When inoculated with zoospores, plants survived longer and shoot and root fresh weights were greater for plants drenched with metalaxyl at 10 µg/ml than for plants treated with the same rate of azoxystrobin or dimethomorph. At 100 µg/ml, the duration of plant survival was greater for dimethomorph and fluazinam than for azoxystrobin; however, shoot and root growth did not differ. In soil naturally infested with *P. capsici*, survival and growth of shoots and roots for plants treated with dimethomorph at 100 µg/ml were greater than for those treated with the same rate of azoxystrobin or fluazinam. The most effective compounds for inhibition of lesion development on stems and fruit were mefenoxam at 1,200 µg/ml and dimethomorph at 480 µg/ml. Recovery of *P. capsici* from soil treated with each of the five tested compounds was significantly less than that recorded for soil not receiving a fungicide. The potential and relative value of azoxystrobin, dimethomorph, fosetyl-Al, and fluazinam as chemical management tools for *Phytophthora* blight on chile pepper, in addition to metalaxyl (replaced with mefenoxam), has been demonstrated.

Phytophthora blight of peppers (*Capsicum annuum*), caused by the oomycete pathogen *Phytophthora capsici*, occurs in most regions where this crop is grown (19). Chile pepper production in Arizona (11) and New Mexico (1) can be affected significantly by the destructive effects of *P. capsici*. In Arizona, the root and crown rot phase of the disease appears on plants early in the growing season in areas where soil remains saturated after irrigation. Subsequent irrigations encourage further disease development. As the crop canopy covers the rows within the field, the foliar blight phase of the disease may occur with the onset of the summer rainy season in July and August. During this time, stems, leaves, and developing pepper fruits may be attacked by the pathogen.

The efficacy of the systemic fungicide metalaxyl (trade name Ridomil; Novartis Crop Protection, Greensboro, NC) for control of *Phytophthora* blight on pepper was documented during the 1980s and early 1990s (9,17,21,22). Recently, the manufacturer replaced metalaxyl with mefenoxam (trade name Ridomil Gold). Me-

fenoxam is the active component within the fungicide metalaxyl and is applied in a manner similar to that for metalaxyl, only at lower rates of manufactured product. Several other fungicides, including azoxystrobin (Quadris; Zeneca Ag Products, Wilmington, DE; 7), dimethomorph (Acrobat; American Cyanamid Co., Princeton, NJ; 3,6,10), fluazinam (Zeneca Ag Products, Wilmington, DE; 5,24), and fosetyl-Al (Aliette; Aventis Crop Science, Research Triangle Park, NC; 4,15,23), have an effect on some species of *Phytophthora* and the diseases they cause on crops other than pepper. The effect of these compounds on the growth, sporulation, and zoospore cyst germination of *P. capsici* has been determined (14). The objective of this study was to compare the effects of a soil drench treatment with azoxystrobin, dimethomorph, fluazinam, fosetyl-Al, mefenoxam, or metalaxyl on development of root and crown rot on chile pepper and recovery of *P. capsici* from naturally infested soil. Also examined was the effect of stem and fruit treatment with each fungicide on subsequent growth of fungal lesions after inoculation.

MATERIALS AND METHODS

Fungi and fungicides. Except for studies involving soil naturally infested with *P. capsici*, one isolate (MIS-6C) of the pathogen was used in all investigations. This isolate originated from a chile pepper plant in a commercial field in southeastern Ari-

zona. The following formulations of tested fungicides were used in these studies: azoxystrobin (Quadris 80WG), dimethomorph (Acrobat 50WP), fluazinam (Fluazinam 50WP), fosetyl-Al (Aliette 80WDG), mefenoxam (Ridomil Gold 44WP), and metalaxyl (Ridomil 2E).

Disease development: inoculation with zoospores. In July 1994, seeds of chile pepper (cv. AZ 20; Curry Seed Co., Pearce, AZ) were sown and germinated in vermiculite. Seedlings were transplanted at the three-leaf stage into sterile potting mix (peat:vermiculite 60:40 by volume) in plastic pots (10 cm in diameter by 10 cm deep) and grown in the greenhouse. When plants were 3 months old, the potting mix within each container was drenched with 300 ml of a solution containing the following concentrations of test fungicides: azoxystrobin or dimethomorph at 10, 25, 50, 100, 250, 500, and 1,000 µg/ml; fluazinam at 50, 100, 250, 500 and 1,000 µg/ml; fosetyl-Al at 250, 500, 1,000, and 3,000 µg/ml; and metalaxyl at 10, 25, and 50 µg/ml. Five replicate plants were treated with each concentration of each fungicide. Control plants were treated with water only.

Zoospores of *P. capsici* were produced by previously described procedures (11). Briefly, an isolate of the pathogen (MIS-6C) was grown on V8 juice agar (V8A) at 24°C for 5 days. Four 6-mm-diameter agar disks were removed from the edge of actively growing cultures and placed into each of a series of 60-mm-diameter plastic petri dishes containing 7 ml of a 1.5% nonsterile soil extract. Numerous sporangia formed after incubation of agar disks in darkness for 48 h at 24°C. Sporangia were induced to release zoospores by chilling at 4°C for 20 min. After rewarming at 25°C for 20 min, the contents of each petri dish were decanted into a 250-ml beaker through cheesecloth to remove agar disks and attached mycelia. One milliliter of the resultant zoospore suspension was added to the potting mix in each container 4 days after application of a test fungicide. After infestation of potting mix with zoospores of *P. capsici*, pepper plants were maintained in the greenhouse, watered as needed, and fertilized weekly with water-soluble Miracle Gro fertilizer (15-30-15; Stern's Miracle-Gro Products, Inc., Port Washington, NY) according to label rates. The mean temperature of the potting mix during these tests was 21°C, with average

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low and high daily temperatures of 16 and 31°C, respectively.

During the course of the study, the date was recorded when plants wilted permanently due to disease development. The experiment was terminated after approximately 3 months, when final disease severity was determined by measuring the fresh weights of pepper plant shoots and roots. Infection by *P. capsici* was confirmed by reisolating the pathogen from diseased plants. Four-month-old pepper plants were used for a second run of this experiment; otherwise, all other experimental conditions were similar to the first trial.

Before infestation of the potting mix, 0.1 ml of the zoospore suspension was added to 100 ml of water and thoroughly mixed, after which a 0.5-ml aliquot was distributed evenly over the agar surface within each of five 100-mm-diameter plastic petri dishes containing vancomycin-pimaricin-pentachloronitrobenzene (PVP; 16) medium. These petri dishes, with lids removed, were maintained in a laminar-flow hood for 5 min to remove free moisture from the agar surface. Petri dishes then were incubated in darkness for 48 h at 24°C, after which the number of fungal colonies developing from zoospores was determined. The number of zoospores applied to the potting mix for each pepper plant in the first and second run of this experiment was 2.0 and 2.8×10^4 zoospores/ml, respectively.

Disease development: naturally infested soil. Two-month-old chile pepper plants (cv. Anaheim TMR 23) were purchased from a commercial nursery for these studies. In September 1995, a clay loam soil from a field containing chile pepper plants with symptoms of root and crown rot was collected to a depth of 15 cm and thoroughly mixed. Plants within this field had not been treated with any fungicide prior to collection of soil. A chile pepper seedling was planted into a series of plastic pots (10 cm in diameter by 10 cm deep) containing this naturally infested field soil. The soil in each container then was drenched with 300 ml of a solution containing the same concentrations of test fungicides described above. Five replicate plants (one plant per pot) were treated with each concentration of each fungicide. Control plants were treated with water only. A control treatment consisting of noninfested soil was established by planting seedlings in field soil that had been heat-sterilized (121°C, 102 kPa, 60 min). Plants were maintained in the greenhouse and data collected as described above. The mean temperature of the soil during these tests was 20°C, with average low and high daily temperatures of 15 and 29°C, respectively.

Effect of soil moisture on fungicide efficacy. A clay loam soil from a field containing chile pepper plants with symptoms

of root and crown rot was collected in September 1999, as described above, thoroughly mixed, then distributed into a series of plastic pots (10 cm in diameter by 10 cm deep). This field had been treated once with mefenoxam prior to soil collection. A 2-month-old Anaheim TMR 23 pepper plant was planted in each pot, then the soil was drenched with 300 ml of a solution containing azoxystrobin at 1,000 µg/ml, dimethomorph at 100 µg/ml, fosetyl-Al at 3,000 µg/ml, fluazinam at 1,000 µg/ml, or mefenoxam at 100 µg/ml. Ten replicate plants (one plant per pot) were treated with each fungicide. Control plants were treated with water only. A noninfested control treatment was established by planting seedlings in field soil that had been heat sterilized as described earlier. For each treatment, five plants were watered as needed by wetting the entire soil profile within each pot (usually every 2 days) for the duration of the trial, whereas the other five plants were watered as needed except for a 48-h period every 2 weeks when the soil in each pot was flooded. Plants were maintained in the greenhouse and data collected as described earlier. The mean temperature of the soil in the pots during these tests was 20°C, with average low and high daily temperatures of 9 and 30°C, respectively.

Pepper stem and fruit inoculation.

Two-month-old Anaheim TMR 23 chile pepper plants or mature green chile fruit (from AZ 20 plants) were used in these tests. In October 1999, a circular area of epidermis was removed from the stem of plants with a 5-mm-diameter cork borer, approximately 8 cm above the soil surface. Plants were inverted and the foliage and stem, including the wounded portion, were submerged for 2 s in a 2-liter aqueous solution of one of the following concentrations of fungicide: azoxystrobin at 600 µg/ml; dimethomorph at 480 µg/ml; fluazinam at 1,200 µg/ml; fosetyl-Al at 9,600 µg/ml; maneb at 3,600 µg/ml; or mefenoxam at 1,200 µg/ml. Latron-B-1956 (1.2 ml; Rohm and Haas, Co., Philadelphia), a nonionic surfactant used as a spreader-sticker, was added to each fungicide solution to improve coverage of plant surfaces. Concentrations of maneb and mefenoxam were derived from label rates of these compounds for pepper plants assuming application at a rate of 468.4 liters/ha. Concentrations of azoxystrobin, dimethomorph, fluazinam, and fosetyl-Al were used or being evaluated for control of *Peronospora parasitica* and *Bremia lactucae*, oomycete pathogens that cause downy mildew on cole crops and lettuce, respectively (12,13). After the plant surface was thoroughly dry, a 5-mm-diameter agar disk containing mycelium from an actively growing culture of *P. capsici* on V8A was placed onto the wound on each plant stem and secured in place with plastic tape. Plants then were placed in a series of large

plastic bags, each of which contained a pan with a shallow layer of water to provide a humid environment favorable for infection. After incubation for 48 h at 28°C in the laboratory, plants were removed from the plastic bags and maintained for an additional 4 days at the same temperature. Disease severity was recorded by measuring the length of the canker that formed at the inoculation site.

A circular area of epidermis was removed from the middle of chile pepper fruit, treated with fungicides as described above, and allowed to dry. Chile fruit were placed in rectangular plastic boxes that contained two layers of moist paper towels on the bottom to maintain a high level of humidity. After inoculation at the wound site with an agar disk containing mycelium of *Phytophthora capsici*, lids were placed on the plastic boxes and fruit were incubated in the laboratory for 6 days at 28°C. Disease severity was assessed by measuring the length of developing canker at the inoculation site.

Five replicate plants or fruit were treated with each concentration of each fungicide, whereas inoculated controls were treated with water only and noninoculated controls received an agar disk without mycelium. Removal of the epidermis on stem and fruit inoculation sites was performed to simulate plant damage that can occur during summer thunderstorms, when heavy rainfall, high gusty winds, and occasional hail can damage stems, leaves, and fruit at the same time that propagules of *P. capsici* are dispersed within and between pepper fields.

Recovery of *P. capsici* from soil. Soil was collected from a chile pepper field infested with *P. capsici* in September 1999 and thoroughly mixed; next, 250 cm³ of this soil was dispensed into a series of plastic containers (473 cm³ in capacity) with drain holes. This field had been treated once with mefenoxam prior to soil collection. Five replicate soil samples were drenched with 300 ml of a solution containing the same rate of each fungicide tested in the soil moisture study. Soil samples used as controls were drenched with water only. At 1 day after soil treatment, a mature but green, unblemished Bartlett pear fruit was placed on the surface of the soil in each container, and a 2-cm layer of water was maintained on the soil surface for 48 h in the greenhouse. This was accomplished by inserting the container with drain holes into a similar container without drain holes. After 48 h of incubation in water, pear fruit were removed from the soil, rinsed with tap water, and incubated for an additional 4 days in the greenhouse. The mean soil temperature during these tests was 23°C, with average low and high daily temperatures of 19 and 31°C, respectively. Firm brown spots developed on pear fruit infected with *P. capsici*. A small piece of tissue from each brown spot was placed onto PVP medium, incubated at 24°C in

darkness, and observed for growth of *P. capsici*. The number of lesions caused by the pathogen was recorded.

Analysis of data. Each experiment in these investigations was conducted twice. Data from repeated experiments were combined for analysis, because variances between experiments were homogeneous. Data were processed with the SigmaStat statistical software package (SPSS Sci-

ence, Chicago). Error bars in Figure 1 represent one-half of the 95% confidence intervals. Means with nonoverlapping 95% confidence intervals were considered significantly different (8).

RESULTS

Disease development: inoculation with zoospores. Plants survived longer and shoot and root fresh weights were greater

for plants drenched with metalaxyl at 10 µg/ml than for plants treated with the same rate of azoxystrobin or dimethomorph (Fig. 1). At 100 µg/ml, the duration of plant survival was greater for dimethomorph and fluazinam than for azoxystrobin; however, shoot and root growth did not differ. At a concentration of 1,000 µg/ml, the duration of survival after inoculation was greater with dimethomorph, fluazinam, and fose-

Fig. 1. The duration of plant survival as well as shoot and root fresh weight for chili pepper plants grown either in potting mix infested with zoospores of *Phytophthora capsici* or in soil naturally infested with the pathogen, as a percent of these values for noninfected control plants, after a single treatment with azoxystrobin, dimethomorph, fluazinam, fosetyl-Al, or metalaxyl. Each value is the mean of 10 replicate plants. Error bars represent one-half of the 95% confidence intervals.

tyl-Al than with azoxystrobin; shoot and root fresh weight was greater with fluazinam and fosetyl-Al than with azoxystrobin and dimethomorph (Fig. 1). Phytotoxicity, necrotic leaf spots, and reduced shoot and root growth was evident on plants exposed to dimethomorph at rates of 250, 500 and 1,000 µg/ml.

Disease development: naturally infested soil. Plant survival and shoot and root fresh weight were similar for azoxystrobin, dimethomorph, or metalaxyl at 10 µg/ml (Fig 1). At 100 µg/ml, survival and growth of shoots and roots for plants treated with dimethomorph were greater than for those treated with azoxystrobin and fluazinam. At a concentration of 1,000 µg/ml, survival was higher with azoxystrobin and dimethomorph compared to fluazinam and fosetyl-Al, whereas shoot weight for azoxystrobin was greater than for dimethomorph, fluazinam, and fosetyl-Al; root fresh weight did not differ significantly among the four compounds (Fig. 1).

Phytotoxicity in addition to reduced shoot and root growth, as described earlier for plants grown in potting mix, was evident on plants grown in field soil treated with dimethomorph at rates of 250, 500, and 1,000 µg/ml.

Effect of soil moisture on fungicide efficacy. For plants grown in field soil naturally infested with *P. capsici* and subjected to a 48-h flood period every 2 weeks, the duration of survival and shoot and root fresh weight were greater for plants that received one treatment of dimethomorph at 100 µg/ml or fluazinam at 1,000 µg/ml than plants treated once with azoxystrobin at 1,000 µg/ml or fosetyl-Al at 3,000 µg/ml (Table 1). Plant survival and root fresh weight values for chile pepper plants grown in soil treated with mefenoxam at 100 µg/ml were significantly greater than that recorded in soil treated with fosetyl-Al at 3,000 µg/ml and significantly less than that recorded in soil treated with dimethomorph at 100 µg/ml. On the other

hand, shoot fresh weight for plants treated with dimethomorph or mefenoxam were not different from each other, but both were greater than fosetyl-Al.

When plants were grown in field soil naturally infested with *P. capsici* and watered only as needed, the duration of survival and shoot and root fresh weight were not different between soil treated with dimethomorph at 100 µg/ml, fluazinam at 1,000 µg/ml, or mefenoxam at 100 µg/ml (Table 1). Plant survival and shoot fresh weight values for all three of these fungicides did not differ significantly from those recorded for chile peppers grown in sterilized field soil.

Pepper stem and fruit inoculation. The most effective chemicals for inhibiting the development of lesions on chile pepper plant stems and fruit inoculated with *P. capsici* were mefenoxam at 1,200 µg/ml and dimethomorph at 480 µg/ml (Table 2). Fosetyl-Al at 9,600 µg/ml was equally effective in inhibiting development of lesions on plant stems but less efficacious on pepper fruit. Lesion growth on inoculated stems and fruit treated with fluazinam at 1,200 µg/ml or maneb at 3,600 µg/ml was not significantly different than that recorded on plants and fruit not treated with a fungicide.

Recovery of *P. capsici* from soil. No lesions developed on pear fruit incubated with soil containing *P. capsici* and treated with azoxystrobin at 1,000 µg/ml, dimethomorph at 100 µg/ml, or fluazinam at 1,000 µg/ml (Table 3). A few lesions developed on fruit incubated in soil treated with fosetyl-Al at 3,000 µg/ml or mefenoxam at 100 µg/ml. Recovery of *P. capsici* from soil treated with each of the five tested compounds was significantly less than that recorded for soil not receiving a fungicide.

DISCUSSION

The efficacy of the fungicides examined differed in their activity against root and

Table 1. Effect of fungicides applied to soil on plant survival and root and shoot weight under two soil moisture regimes for chile pepper plants grown in soil naturally infested with *Phytophthora capsici*^y

Treatment	Duration of plant survival (days) ^z	Fresh weight (g)	
		Shoot	Root
Plants flooded for 48 h every 2 weeks			
Sterilized soil	62.0 f	18.2 g	22.4 i
Dimethomorph at 100 µg/ml	62.0 f	13.6 c-f	19.0 hi
Fluazinam at 1,000 µg/ml	58.8 ef	14.3 e-g	18.9 hi
Mefenoxam at 100 µg/ml	49.8 c-e	9.6 bc	13.5 fg
Azoxystrobin at 1,000 µg/ml	45.3 c	7.7 b	8.5 c-e
Fosetyl-Al at 3,000 µg/ml	27.2 b	3.3 a	6.4 a-c
Nonsterilized soil	9.2 a	1.4 a	3.4 ab
Plants watered as needed			
Sterilized soil	62.0 f	17.5 fg	15.4 gh
Dimethomorph at 100 µg/ml	62.0 f	15.1 fg	10.5 c-f
Mefenoxam at 100 µg/ml	58.7 ef	13.9 d-f	11.3 d-g
Fluazinam at 1,000 µg/ml	56.9 def	14.3 d-g	11.8 e-g
Azoxystrobin at 1,000 µg/ml	49.3 cd	10 b-e	7.5 b-d
Fosetyl-Al at 3,000 µg/ml	47.8 cd	10.2 b-d	7.5 b-d
Nonsterilized soil	16.4 a	2.2 a	3.1 a
LSD (<i>P</i> = 0.05)	9.4	4.1	4.2

^y Each value is the mean of 10 replicate plants. Numbers in each column followed by a different letter are significantly different (*P* = 0.05) according to the Duncan-Waller *k*-ratio least significant difference (LSD) test.

^z Each value represents the average elapsed time in days from initiation of the experiment to death of plants. Plants were considered dead when leaves wilted permanently. Fungicide treatments were applied to soil on the same day that peppers were transplanted.

Table 2. Development of lesions on stems and fruit of chile peppers inoculated with *Phytophthora capsici* after application of fungicides

Treatment	Length of lesion (mm) ^z	
	Stem	Fruit
Noninoculated control	0 a	0 a
Mefenoxam at 1,200 µg/ml	2 a	0 a
Fosetyl-Al at 9,600 µg/ml	4 a	50 b
Dimethomorph at 480 µg/ml	22 ab	4 a
Azoxystrobin at 600 µg/ml	38 b	81 c
Maneb at 3,600 µg/ml	89 c	92 c
Fluazinam at 1,200 µg/ml	90 c	87 c
Inoculated control	90 c	88 c
LSD (<i>P</i> = 0.05)	25	17

^z Each value is the mean of 10 replicate plants or pepper fruit. Numbers in each column followed by a different letter are significantly different (*P* = 0.05) according to the Duncan-Waller *k*-ratio least significant difference (LSD) test.

Table 3. Development of lesions on pear fruit incubated with field soil containing *Phytophthora capsici* and drenched with a fungicide

Treatment	No. of lesions on pear fruit ^z
Azoxystrobin at 1,000 µg/ml	0 a
Dimethomorph at 100 µg/ml	0 a
Fluazinam at 1,000 µg/ml	0 a
Fosetyl-Al at 3,000 µg/ml	0.3 a
Mefenoxam at 100 µg/ml	0.6 a
Nontreated soil	33.9 b
LSD (<i>P</i> = 0.05)	5.7

^z Each value is the mean of 10 replicate soil samples. Lesion development was confirmed as resulting from colonization by *P. capsici* by reisolating the pathogen from test fruit. Numbers in each column followed by a different letter are significantly different (*P* = 0.05) according to the Duncan-Waller *k*-ratio least significant difference (LSD) test.

crown rot compared to activity on stem and fruit lesion development caused by *P. capsici*. For example, at an appropriate concentration, azoxystrobin, dimethomorph, fosetyl-Al, fluazinam, mefenoxam, or metalaxyl significantly improved chile pepper growth and survival in potting mix or soil containing *P. capsici* compared to plants not receiving a fungicide. On the other hand, fluazinam did not significantly reduce lesions on inoculated pepper plant stems. Likewise, lesion growth on pepper fruit inoculated with *P. capsici* after treatment with azoxystrobin or fluazinam did not differ from that on nontreated fruit. One factor that may partially account for these differences is that the level of resistance to the root and crown rot phase of *Phytophthora* blight in pepper plants can differ from the resistance to the foliar phase (19). Also, there may be differences in uptake of each fungicide by roots compared to stems or fruit. Perhaps such differences in uptake and in the inherent genetic resistance or susceptibility to the two phases of the disease could partially account for the differential activity of some tested chemistries on the root and crown rot phase compared to the foliar component of *Phytophthora* blight on chile pepper.

The apparent efficacy of tested fungicides against the development of root and crown rot appeared to be affected by the pathogen propagule or propagules that served as inoculum. In these studies, the relative efficacy of a compound when zoospores of *P. capsici* were introduced into potting mix could differ from the performance of the fungicide in soil naturally infested with the pathogen. In general, tested fungicides appeared to perform better in potting mix infested with zoospores of *P. capsici* than in field soil naturally infested with the pathogen. A partial explanation could be the existence of several different propagules of *P. capsici* in field soil, such as oospores, mycelial fragments, and sporangia, in addition to zoospores (2). Also, plants growing in naturally infested field soil would be subject to repeated exposure to zoospores, unlike the single exposure when zoospores were used as inoculum. Earlier studies have demonstrated that mycelial growth, sporangium formation, zoospore motility, and zoospore cyst germination are differentially affected by azoxystrobin, dimethomorph, fosetyl-Al, fluazinam, and metalaxyl (14).

Mefenoxam is registered in the United States for management of *Phytophthora* blight on pepper. When subjected to periodic soil saturation, which favors rapid development of root and crown rot, plant growth and survival in field soil naturally infested with *P. capsici* was lower for plants treated once with mefenoxam at 100 µg/ml compared to those grown in sterilized soil. On the other hand, chile pepper plant growth and survival in infested soil treated once with mefenoxam and watered

as needed were not different from plants grown in sterilized field soil.

Mefenoxam also provided excellent protection against development of stem and fruit lesions. Mefenoxam was widely used for the first time in 1997 in pepper fields in North Carolina and New Jersey, followed by the detection of resistance to this chemistry in 57% of tested field isolates of *P. capsici* in these states (18,19). The greatest number of isolates resistant to mefenoxam was recovered from fields where this compound was used exclusively rather than in combination or alternation with other fungicides (19). Clearly, there is an urgent need for efficacious fungicides in addition to mefenoxam to prevent disease control failure in treated pepper fields subjected to high disease pressure during prolonged periods of plant wetness and saturated soil conditions, and to minimize the development of resistance to this chemistry by *P. capsici*.

Initial disease development occurs on pepper plants when the primary inoculum of *P. capsici* in the soil initiates root infections that progress to crown infections (20). Wilting usually precedes development of crown rot in naturally infested soil (20) and signals that plant death is imminent. At an appropriate concentration, a single soil application of azoxystrobin, dimethomorph, fosetyl-Al, and fluazinam, in addition to mefenoxam, significantly prolonged the life of chile pepper plants growing in field soil naturally infested with *P. capsici* compared to plants not receiving a fungicide treatment. Of these four tested alternative fungicides, dimethomorph at a rate of 100 µg/ml was among the best materials with respect to minimizing plant death and loss of shoot and root mass.

A soil treatment with fosetyl-Al was the least effective of tested fungicides in inhibiting root and crown rot development. The relative effectiveness of azoxystrobin and fluazinam on plant survival and growth in infested field soil generally ranged between those levels recorded for dimethomorph and fosetyl-Al. Earlier research demonstrated the necessity of multiple applications of fosetyl-Al to reduce the level of root rot in potted tomato plants inoculated with zoospores of *P. parasitica* (4). Perhaps multiple applications of compounds examined in these studies would improve the final degree of disease control for chile pepper plants as well.

Previous research with the five fungicides examined in these studies revealed that mycelial growth of *P. capsici* and two additional *Phytophthora* spp. on corn meal agar was most sensitive to dimethomorph, intermediate in sensitivity to fosetyl-Al and metalaxyl, and least sensitive to azoxystrobin and fluazinam (14). Fungicide performance as measured by inhibition of lesion formation on pepper stems and fruit treated with these compounds and inoculated with mycelium of *P. capsici* generally

are in agreement with these earlier *in vitro* studies. The same research (14) revealed that azoxystrobin, dimethomorph, fosetyl-Al, fluazinam, and metalaxyl had a greater impact on sporangium formation than on inhibition of mycelial growth, suggesting that our studies measuring inhibition of mycelial growth may underestimate the potential utility of these compounds in managing the foliar phase of *Phytophthora* blight, which in the field is initiated and sustained by successive cycles of sporangium formation and zoospore release (19). Indeed, previous studies have demonstrated the effectiveness of dimethomorph (3,6) and fluazinam (5) against late blight in potato caused by *P. infestans*. Additionally, azoxystrobin, dimethomorph, and fosetyl-Al provided significant control against downy mildew on broccoli (12) and lettuce (13) caused by the oomycete pathogens *Peronospora parasitica* and *Bremia lactucae*, respectively.

The comparative efficacy of azoxystrobin, dimethomorph, fosetyl-Al, and fluazinam as potential chemical management tools for *Phytophthora* blight on chile pepper plants has been demonstrated. The future availability of one or more of these fungicides would allow fungicide treatment with chemical compounds possessing different modes of action, a development that could prolong the effectiveness of these materials for disease management. However, successful sustainable management of *Phytophthora* blight in chile pepper will require the implementation of a multifaceted disease management system as outlined by Ristaino and Johnston (19), with chemical control as but one component.

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