Suppression of Phytophthora Root and Crown Rot on Pepper Plants Treated with Acibenzolar-S-Methyl

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ABSTRACT

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The fungicide mefenoxam is registered for the control of Phytophthora blight of peppers caused by *Phytophthora capsici*. Isolates of the pathogen that are insensitive to mefenoxam, however, have been detected in some locations. Consequently, alternative methods are needed to control Phytophthora blight of peppers. Acibenzolar-S-methyl (ABM, Actigard) is a chemical activator of plant disease resistance that has potential for the management of Phytophthora blight of peppers. The effect of foliar applications of ABM on the development of root and crown rot on pepper plants grown in the greenhouse and inoculated with *Phytophthora capsici* or in soil naturally infested with the pathogen was evaluated. Inhibition of stem canker development on pepper cvs. Bell Tower and AZ9 after four treatments with ABM (75 µg/ml) was significantly greater than on plants receiving a single application of the chemical. Stem canker length on Bell Tower or AZ9 peppers was inhibited by 93.2 to 97.2% and 87.4 to 92.4% when plants were inoculated with *P. capsici* at 1 or 5 weeks, respectively, after the fourth application of ABM. Survival of chile pepper plants grown in field soil naturally infested with *P. capsici* was significantly increased by three foliar applications of ABM (75 µg/ml) compared with nontreated plants in all three trials when pots were watered daily and in two of three trials when pots were flooded for 48 h every 2 weeks. When soil was flooded every 2 weeks to establish conditions highly favorable for disease development, plants treated once with mefenoxam (100 µg/ml) survived significantly longer than those treated with ABM. On the other hand, when water was provided daily without periodic flooding to establish conditions less favorable for disease development, plant survival between the two chemicals was not different in two of three trials. Length of survival among chile pepper plants treated twice with 25, 50, or 75 µg/ml of ABM and grown in soil infested with *P. capsici* was not different. This work indicates that ABM could be an important management tool for Phytophthora root and crown rot on pepper plants.

Phytophthora blight of peppers (*Capsicum annuum*), caused by the oomycete pathogen *Phytophthora capsici*, occurs in most regions where this crop is grown (20). The root and crown rot phase of the disease can appear initially on plants early in the growing season in areas of the field where the soil remains saturated with water after an irrigation or rainfall. Subsequent periods of soil saturation encourage further disease development. As the crop canopy develops and covers the rows within the field, the foliar blight phase of the disease may occur on the stems, leaves, and developing pepper fruits.

The efficacy of the systemic fungicide metalaxyl (Ridomil, Syngenta Crop Protection, Inc., Greensboro, NC) for control of Phytophthora blight on pepper has been documented (7,17,23,25). Recently, the manufacturer replaced metalaxyl with mefenoxam (Ridomil Gold), an active

isomeric form of metalaxyl, which is applied the same as metalaxyl, but at lower rates. Mefenoxam was widely used for the first time in 1997 in pepper fields in North Carolina and New Jersey, after which resistance to this chemistry was detected in 57% of field isolates of *P. capsici* tested in these states (18,20). The greatest number of isolates resistant to mefenoxam was recovered from fields where this compound was used exclusively, rather than in combination or in rotation with other fungicides (20). There is an urgent need for efficacious materials in addition to mefenoxam to minimize the development of resistance to this chemistry by *P. capsici* and to prevent failure of disease control in treated pepper fields.

Acibenzolar-S-methyl (ABM, Actigard, Syngenta Crop Protection, Inc., Greensboro, NC), a benzothiadiazole, is a chemical activator of plant disease resistance (6). The chemical has no known direct antifungal effects and is thought to mimic salicylic acid in the signal transduction pathway that leads to systemic acquired resistance (SAR) (11). A single application of ABM to wheat provided protection against powdery mildew for an entire growing season (6). Multiple applications of the compound have reduced the severity

of downy mildew on broccoli (14) and lettuce (13), white rust on spinach (3), and blue mold on tobacco (22). The purpose of this study was to evaluate the potential efficacy of preinfection treatments with ABM for management of the root and crown rot phases of Phytophthora blight on pepper plants grown in pots in the greenhouse.

MATERIALS AND METHODS

***P. capsici* isolate and growth of pepper plants.** Except for experiments involving soil naturally infested with the pathogen, isolate MIS-6C of *P. capsici* was used in all investigations. This isolate originated from a chile pepper plant in a commercial field in southeastern Arizona.

Seeds of bell pepper cvs. Bell Tower (Syngenta Seeds, Inc., Gilroy, CA) and Emerald Isle (Harris Moran Seed Co., Modesto, CA), and chile pepper cvs. AZ9 and AZ20 (Curry Seed Co., Pearce, AZ) were germinated in vermiculite, then transplanted at the three-leaf stage in pasteurized potting mix (60% peat:40% vermiculite, by volume) in 10-cm-diameter × 10-cm-deep plastic pots. In all experiments, unless indicated otherwise, plants were maintained in the greenhouse, watered daily, and fertilized weekly with water-soluble Miracle Gro fertilizer (15-30-15, Stern's Miracle-Gro Products, Inc., Port Washington, NY). The mean air and soil temperatures in the greenhouse during the experiments were 20°C, with average low and high daily temperatures of 12 and 30°C, respectively.

Stem inoculation experiments. The first experiment was conducted to compare the effect of one to four applications of ABM and one application of mefenoxam prior to inoculation with *P. capsici* on stem canker development on bell pepper and chile pepper plants. Leaves and stems of five, 2-month-old (age determined from seeding date) plants each of Bell Tower and AZ9 were treated from one to four times (with a 7-day interval between treatments) with ABM (Actigard 50W) using a handheld sprayer. Leaves and stems of each plant were thoroughly wetted with 5.9 ml spray solution (75 µg a.i./ml). Treatments were scheduled so plants receiving one application of ABM were sprayed on the same day the other sets of plants were receiving their last treatment. When the last treatment of ABM was administered, five plants of each pepper cultivar were sprayed with 3.0 ml of

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solution containing 3.1 mg a.i. mefenoxam (Ridomil Gold 44WP) on the lower stem of each plant, with the excess fungicide running into the potting mix. Controls were nontreated plants.

One week after the last application of ABM or mefenoxam, the stem of each plant was inoculated with *P. capsici*. A circular wound just deep enough to remove the epidermis was made on the stem approximately 8 cm above the soil surface with a 5-mm-diameter cork borer. A 5-mm-diameter agar disk containing mycelium from an actively growing culture of *P. capsici* on V8 juice agar was placed on the wound and secured in place with plastic tape. After 2 weeks, disease severity was recorded by measuring the length of the canker at the inoculation site. This experiment was conducted three times.

Another experiment was conducted to compare the duration of protection induced by one or two applications of ABM on bell pepper and chile pepper prior to inoculation with *P. capsici*. Leaves and stems of five, 3-month-old plants each of Bell Tower and Emerald Isle bell pepper, and of AZ9 and AZ20 chile pepper were treated either once or twice (with a 10-day interval between treatments) with ABM (75 µg a.i./ml), as described earlier. Controls were nontreated plants. At 1 or 4 weeks after the last treatment, stems of plants were inoculated with *P. capsici*, as outlined above. Seven days after inoculation, disease severity was recorded by measuring the length of canker at each inoculation site. This experiment was conducted twice.

A third stem-inoculation experiment was performed to compare the duration of protection after four applications of ABM to one application of mefenoxam. Leaves and stems of five, 2-month-old plants each of Bell Tower and AZ9 were treated four times (with a 7-day interval between treatments) with ABM (75 µg a.i./ml), as described earlier. When the last treatment of ABM was administered, five plants of each pepper cultivar were treated with mefenoxam (Ridomil Gold 44WP), as described earlier. Controls were nontreated plants. At 1 and 5 weeks after the last treatment, stems of plants were inoculated with *P. capsici*. Plants were maintained in the greenhouse for 2 weeks, and rated for disease severity by measuring the length of the canker at the inoculation site. This experiment was performed twice.

Disease development in naturally infested soil. Two-month-old chile pepper plants (Anaheim TMR-23) were purchased from a commercial nursery for these experiments. Stems and leaves of plants were treated three times (with approximately a 10-day interval between treatments) with ABM (75 µg a.i./ml), as described earlier. Between the second and third application of ABM, the pepper seedlings were transplanted into 10-cm-diameter × 10-cm-deep plastic pots containing a clay-loam soil

collected from a field containing chile pepper plants with symptoms of Phytophthora root and crown rot. A set of pepper plants not treated with ABM were transplanted into the field soil and treated with mefenoxam by drenching the soil in each pot with 200 ml of fungicide solution (100 µg a.i./ml). Control plants were treated with water only. An additional control treatment was established by planting seedlings in field soil that had been heat-sterilized (121°C, 102 kPa, 60 min). Peppers were maintained in the greenhouse for 2 months with one set of plants receiving irrigation water daily and the other set of plants watered daily and the soil flooded for 48 h every 2 weeks. Flooding was accomplished by placing the plastic pot containing a pepper plant into a slightly larger container, filling the container with water and maintaining the water in the container for 48 h. Each treatment contained 10 replicate plants. During the course of the experiment, the date when plants wilted permanently due to development of Phytophthora root and crown rot was recorded. The experiment was terminated after 60 to 63 days and the fresh weight of pepper plant shoots and roots was measured. Infection by *P. capsici* was confirmed by isolating the pathogen from infected plants. This experiment was conducted three times. The protocol of the third trial of the experiment differed from the first two trials in the following aspects: (i) chile pepper seedlings were planted in infested soil 2 days after the third application of ABM, (ii) inclusion of an additional treatment consisting of three applications of ABM (75 µg a.i./ml) before transplanting into infested soil and one application of mefenoxam (100 µg a.i./ml) on the day of transplanting, (iii) termination of the experiment after 103 days.

Another experiment was conducted to evaluate the effect of concentration of ABM on disease development. Leaves and stems of 2-month-old chile pepper plants (Anaheim TMR-23) were treated two times (with an 8-day interval between treatments) with ABM, as described previously, at 25, 50, or 75 µg a.i./ml. One week

after the second treatment, peppers were transplanted into field soil naturally infested with *P. capsici*. Plants not treated with ABM and transplanted into infested soil were positive controls and plants not treated with ABM and transplanted into heat-pasteurized infested soil were the negative controls. During the course of the experiment, the date when plants wilted permanently due to development of Phytophthora root and crown rot was recorded. Pepper plants were maintained in the greenhouse for approximately 3 months. Each treatment contained six replicate plants and the experiment was conducted twice.

Analysis of data. Each experiment was conducted at least twice. Data from repeated trials of an experiment were combined for analysis if variances among trials were homogeneous according to Bartlett's test. Significant differences among main effects and any interactions in each experiment were determined by analysis of variance, and treatment means were separated according to Duncan-Waller *k*-ratio (LSD) test. Since the chemical rates in Table 1 represent quantitative values, 95% confidence intervals were used to compare treatment means. Means that did not overlap at the 95% confidence interval were considered significantly different (5). Data were processed with the Sigmasat statistical software package (SPSS Science, Chicago, IL).

RESULTS

Stem inoculation experiments. Data from the three trials on the effect of ABM and mefenoxam on the development of stem canker were homogeneous and were combined for analysis (Table 2). The reduction in stem canker length was significantly different among chemical treatments and between cultivars, but the interaction was not significant. The mean canker length on nontreated Bell Tower (109 mm) and AZ9 (60 mm) pepper plants was significantly different ($P \leq 0.01$). The mean percentage reduction in the length of the stem canker on Bell Tower (70.3%) and AZ9 (83.5%) plants treated one to four

Table 1. Effect of concentration of acibenzolar-*S*-methyl (ABM) on survival of chile pepper plants grown in field soil naturally infested with *Phytophthora capsici*

Treatment ^x	Duration of plant survival ^y		
	Trial 1	Trial 2	Both trials
Nontreated plants in infested soil	28	35	31.1 ± 7.3 ^z
ABM, 25 µg/ml	71	57	63.9 ± 7.7
ABM, 50 µg/ml	71	54	62.1 ± 14.2
ABM, 75 µg/ml	73	62	67.7 ± 8.6
Nontreated plants in sterilized soil	83	83	83 ± 0

^x Plants were treated two times (with an 8-day interval between treatments) with ABM, and transplanted into soil infested with *P. capsici* 1 week after the second application of ABM.

^y 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. Each trial was terminated after 83 days.

^z Each value is the mean (± 95% confidence interval) of 12 replicate plants from two trials of the experiment. Means that do not overlap at the 95% confidence interval were significantly different.

times with ABM was significantly different ($P \leq 0.01$). The reduction in the length of stem cankers on Bell Tower and AZ9 pepper plants after four treatments with ABM was significantly greater than on plants treated once with ABM, but was not significantly different from peppers treated once with mefenoxam.

Data for both trials that evaluated the duration of protection provided by one or two applications of ABM on stem canker development were homogeneous and were combined for analysis. The greater reduction in stem canker length with two applications compared with one application of ABM, as well as the reduction in inhibition when inoculation occurred at 4 weeks compared with 1 week after treatment, were both significantly different (Table 3). The cultivar $\times$ number of applications ($P \leq 0.01$) and number of applications $\times$ time

of inoculation ($P \leq 0.05$) interactions were significant, but the time of inoculation $\times$ cultivar interaction was not significant. Mean percentage reduction in length of stem canker for all four cultivars inoculated 1 week after one and two applications of ABM was 45.8 and 64.1%, respectively, and for all four cultivars inoculated 4 weeks after one and two applications was 26.3 and 47.6%, respectively. The reduction in the length of the stem canker among cultivars was also significantly different. Chile pepper plants (AZ9 and AZ20) had a significantly greater reduction in stem canker length than bell pepper plants inoculated 1 week after two applications of ABM. When plants were inoculated 4 weeks after two applications of ABM, AZ20 had a significantly greater reduction in stem canker than the other pepper cultivars. Reduction in stem canker length

among cultivars inoculated after one application of ABM were not different after 4 weeks, but canker length on AZ20 was reduced to a greater extent compared to the other cultivars after 1 week. The mean canker lengths on nontreated bell pepper cultivars Bell Tower and Emerald Isle (164 and 166 mm, respectively) were significantly larger ($P \leq 0.01$) than cankers on chile pepper cultivars AZ9 and AZ20 (134 and 136 mm, respectively).

For both trials that evaluated the development of stem canker on plants inoculated 1 or 5 weeks after treatment with mefenoxam, or after the fourth application of ABM, the data were homogeneous and were combined for analysis (Table 4). Reduction in stem canker length was significantly different between chemical treatments and pepper cultivars. The interaction between chemical treatments and inoculation date was significant ($P \leq 0.05$), but the interaction between cultivar and chemical treatments or cultivar and inoculation date was not significant. The reduction in length of stem canker by mefenoxam was significantly greater than ABM on pepper cultivar AZ9, but not on Bell Tower, regardless of the inoculation date. The reduction in the length of the stem canker at 1 week compared with 5 weeks after application of ABM or mefenoxam was not significantly different ($P \geq 0.05$) for either pepper cultivar.

Disease development in naturally infested soil. Data for the three trials on the development of *Phytophthora* blight on chile peppers treated with ABM or mefenoxam and planted in naturally infested soil were not homogenous and were analyzed separately (Table 5). The interaction for irrigation and chemical treatment on the duration of survival in trial 1 ($P \leq 0.01$), and fresh shoot weights in trial 1 ($P \leq 0.05$), and trial 2 ($P \leq 0.05$) were significant. Survival of Anaheim TMR-23 chile pepper plants that were treated three times with ABM at 75 μg a.i./ml and grown in field soil naturally infested with *P. capsici* was significantly greater than nontreated plants in nonsterile soil in all three trials when watered daily, and in two of three trials when flooded for 48 h every 2 weeks. When the soil was flooded every 2 weeks to establish conditions highly favorable for disease development, plants treated once with mefenoxam survived significantly longer than plants treated with ABM. On the other hand, when watered daily without periodic flooding to establish conditions less favorable for disease development, survival of plants treated with ABM or mefenoxam was not significantly different in two of three trials. When soil was flooded periodically, plants receiving three foliar applications of ABM plus a soil treatment of mefenoxam survived significantly longer and produced a greater shoot growth than those treated only with ABM or mefenoxam. When irrigated daily, there

Table 2. Reduction in length of stem canker on two pepper cultivars inoculated with *Phytophthora capsici* after treatment with one to four applications of acibenzolar-S-methyl (ABM) or one application of mefenoxam

Treatment	Reduction in stem canker length (%) ^y	
	Bell Tower	AZ9
ABM: 1 application	57.7 a ^z	69.2 a ^z
ABM: 2 applications	67.3 a	90.9 b
ABM: 3 applications	69.9 ab	84.5 b
ABM: 4 applications	86.1 bc	90.0 b
Mefenoxam: 1 application	97.3 c	96.9 b

^y Percent reduction in stem canker length on plants treated with ABM or mefenoxam compared with nontreated plants. Mean canker length on nontreated Bell Tower (109 mm) and AZ9 (60 mm) pepper plants was significantly different ($P = 0.05$). ABM was applied on a 7-day interval with 5.9 ml of spray solution (7.5 μg a.i./ml). Mefenoxam was applied in 3 ml of solution (1.0 mg a.i./ml) on the lower stem of plants. Plants were inoculated with *P. capsici* 1 week after final treatment with ABM or mefenoxam.

^z Each value is the mean of 15 replicate plants from three trials of the experiment. Values in each column followed by the same letter are not significantly different ($P = 0.05$) according to Duncan-Waller *k*-ratio (LSD) test.

Table 3. Reduction in length of stem canker on four pepper cultivars inoculated with *Phytophthora capsici* after treatment with one or two applications of acibenzolar-S-methyl (ABM)

Pepper cultivar	Reduction in stem canker length (%) ^w	
	1 week ^x	4 weeks ^x
One application of ABM		
Bell Tower	15.2 a ^y	21.0 a ^y
Emerald Isle	32.4 ab	29.0 ab
AZ9	47.2 b	27.7 a
AZ20	88.3 c	27.5 a
Mean ^z	45.8	26.3
Two applications of ABM		
Bell Tower	40.8 b	27.6 a
Emerald Isle	35.2 b	43.4 bc
AZ9	83.5 c	49.0 c
AZ20	96.8 c	70.6 d
Mean ^z	64.1	47.6

^w Percent reduction of stem canker length on plants treated with ABM (75 μg a.i./ml) compared with nontreated plants. There was a 10-day interval between the first and second application of ABM. The mean canker lengths on the nontreated bell pepper cvs. Bell Tower and Emerald Isle (164 and 166 mm, respectively) and on the nontreated chile pepper cvs. AZ9 and AZ20 (134 and 136 mm, respectively) were significantly different.

^x Weeks after last treatment prior to inoculation with *P. capsici*.

^y Each value is the mean of 10 replicate plants from two trials of the experiment. Values in each column followed by the same letter are not significantly different ($P = 0.05$) according to the Duncan-Waller *k*-ratio (LSD) test.

^z The combined mean for all four cultivars for the percentage reduction in stem canker length is significantly different between one and two applications of ABM, and between the 1 and 4 week interval prior to inoculation.

was no difference in survival among plants treated with ABM, mefenoxam, or ABM + mefenoxam. Shoot growth on plants treated with ABM was significantly greater than on nontreated plants in nonsterile soil in all three trials when watered daily, but was significantly greater in only one of three trials under periodic soil flooding. When watered daily, shoot growth after treatment with ABM was greater than on plants treated with mefenoxam or ABM + mefenoxam, whereas root growth after treatment with ABM was significantly greater than on plants treated with ABM + mefenoxam, but not mefenoxam alone. Root growth was significantly greater following treatment with ABM compared with nontreated plants in nonsterile soil in two of three trials under both watering regimes.

Data from both trials on the effect of two applications of different rates of ABM on the development of *Phytophthora* blight in naturally infested soils were combined for analysis. There were no significant

differences in the survival of chile pepper plants grown in soil infested with *P. capsici* and treated twice with 25, 50, or 75 µg of ABM (Table 1). Plants treated with ABM survived longer than nontreated plants growing in infested soil. On the other hand, plants treated with ABM and grown in the presence of *P. capsici* survived for a significantly shorter time than nontreated plants grown in sterilized soil.

DISCUSSION

Systemic acquired resistance (SAR) is a host-governed resistance that may be triggered by pathogen necrosis, microbial extracts, chemical treatment, or colonization of the rhizosphere by certain plant growth-promoting rhizobacteria (16,19,27). Local, as well as systemic resistant responses, may occur within the plant. Acibenzolar-*S*-methyl (ABM), a benzothiadiazole, mimics SAR, resulting in the accumulation of pathogenesis-related (PR) proteins (11). ABM is a true SAR compound by way of the same signal transduc-

tion pathway as pathogen inoculation (9). At the local level, PR proteins such as chitinase and β-1,3-glucanase may have growth inhibiting activity on the pathogen. These PR proteins accumulate during the onset of resistance and may play a major role in the systemic response. ABM has been shown to confer resistance to certain fungi, bacteria, and viruses in a variety of crops (26).

Compared with nontreated plants, resistance induced by ABM suppressed stem lesion growth on AZ9 and AZ20 with some resistance to *Phytophthora* crown rot, and on Bell Tower and Emerald Isle that are susceptible to the disease. In an earlier report, application of ABM provided control of bacterial leaf spot for bell pepper cultivars with no known resistance genes, as well as pepper cultivars possessing major resistance genes (2,21). Similar results were noted for powdery mildew on lettuce (15). The independence and additive nature of genetic resistance and ABM-induced resistance suggests that both disease management tools could be used concurrently, along with other disease management strategies, to achieve a high degree of disease control.

The number of applications, interval between applications, and the rate of ABM may affect the level of induced resistance. In our studies, when inoculation with *P. capsici* occurred 4 weeks after application of ABM at 75 µg a.i./ml, suppression of canker growth on Bell Tower and AZ9 increased from 24.3% following a single application to 38.3% following two applications. Furthermore, canker inhibition increased to 89.9% when plants were inoculated 5 weeks after four applications of ABM at the same rate. Kousik and Subramanya (10) also reported increased suppression of *Phytophthora* blight on bell pepper following four applications of ABM

Table 4. Reduction in length of stem canker after four applications of acibenzolar-*S*-methyl (ABM) or one application of mefenoxam on two pepper cultivars inoculated with *Phytophthora capsici*

Treatment	Reduction in stem canker length (%) ^x	
	1 week ^y	5 weeks ^y
Bell Tower		
ABM	97.2 b ^z	92.4 ab ^z
Mefenoxam	100.0 b	95.9 b
AZ 9		
ABM	93.2 a	87.4 a
Mefenoxam	97.8 b	97.6 b

^x Percent reduction of stem canker length on plants treated four times (with a 7-day interval between treatments) with ABM (75 µg/ml) or once with 3.1 mg mefenoxam/plant compared with nontreated plants. The mean canker length on nontreated Bell Tower and AZ9 pepper plants was 116 and 50 mm, respectively.

^y Weeks after last treatment prior to inoculation with *P. capsici*.

^z Each value is the mean of 10 replicate plants from two trials of the experiment. Values in each column followed by the same letter are not significantly different ($P = 0.05$) according to the Duncan-Waller *k*-ratio (LSD) test.

Table 5. Effect of acibenzolar-*S*-methyl (ABM) and mefenoxam on chile pepper plant survival, and root and shoot weight under two soil moisture regimes for plants grown in soil naturally infested with *Phytophthora capsici*

Treatment ^x	Duration of plant survival ^y			Fresh weight of shoots (g)			Fresh weight of roots (g)		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
Plants flooded for 48 h every 2 weeks									
Nontreated/nonsterile soil	9 a ^z	9 a	33 a	1.0 a	1.8 a	3.3 a	1.2 a	5.6 a	1.1 a
ABM ^x	25 b	28 b	50 a	7.1 b	4.0 a	6.2 a	7.5 bc	5.3 a	4.0 bc
Mefenoxam	40 c	60 c	81 b	2.7 a	16.5 bc	15.5 b	5.8 bc	21.3 bc	5.9 cd
ABM + mefenoxam	...	...	101 c	...	...	30.2 c	...	...	7.9 de
Nontreated/sterilized soil	63 d	60 c	103 c	16.0 d	20.4 d	30.2 c	17.0 d	25.9 c	7.1 de
Plants watered daily									
Nontreated/nonsterile soil	17 ab	22 b	42 a	3.4 a	3.5 a	6.8 a	4.2 ab	4.9 a	2.9 ab
ABM ^x	44 c	54 c	103 c	11.9 c	15.4 b	41.2 d	8.8 c	7.9 a	11.2 g
Mefenoxam	57 d	60 c	84 bc	8.1 b	19.7 cd	16.6 b	6.5 bc	16.1 b	9.2 efg
ABM + mefenoxam	...	...	103 c	...	...	31.9 c	...	...	8.6 ef
Nontreated/sterilized soil	63 d	60 c	103 c	15.7 d	19.4 cd	21.9 b	14.4 d	16.4 b	10.6 f

^x Foliage and stems of plants were treated three times (with a 10-day interval between treatments) with ABM (75 µg a.i./ml). For trials 1 and 2, plants were transplanted into soil naturally infested with *P. capsici* between the second and third application of the compound. For trial 3, plants were transplanted into the infested soil 2 days after the third application of ABM. Mefenoxam (100 µg a.i./ml) was applied in 200 ml of solution as a soil drench on the day of transplanting into infested soil.

^y 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. Trials 1, 2, and 3 were terminated after 63, 60, and 103 days, respectively.

^z Each value is the mean of 10 replicate plants. Values in each column followed by the same letter are not significantly different ($P = 0.05$) according to the Duncan-Waller *k*-ratio (LSD) test.

compared with one application. Frequency of application also can affect the level of induced resistance and subsequent degree of disease control. Weekly applications of ABM controlled fireblight on apple trees more effectively than an application every 2 weeks (8). Although rates of ABM may affect the level of induced resistance, there was no difference in the severity of Phytophthora blight of bell peppers treated with ABM at 38 and 75 µg a.i./ml (10). In our studies, rates of ABM ranging from 25 to 75 µg a.i./ml induced similar levels of resistance to Phytophthora crown and root rot of chile pepper plants as measured by survival.

The duration of effective induced resistance for disease control with ABM appears dependent on the type of plant treated, the pathogen, and the disease. A single application of ABM to wheat provided protection against powdery mildew for an entire growing season (6). Tobacco plants receiving only one application of ABM while in the seedbed demonstrated some resistance to frogeye, caused by *Cercospora nicotianae*, up to final leaf harvest (1). Two to three additional applications of ABM enhanced the level of induced resistance. According to Friedrich, et al. (4), ABM is highly mobile in tobacco and an elevated level of induced resistance could be detected for at least 3 weeks after application of the chemical. In our studies, stem canker suppression remained at a high level when chile pepper plants were inoculated with *P. capsici* 5 weeks after the fourth application of ABM. In another study, induced resistance to bacterial spot in bell pepper plants was expressed as early as 3 days after treatment and continued for at least 2 weeks (21).

Under conditions of periodic soil saturation that favor disease development, survival of chile pepper plants grown in infested soil and treated with ABM usually was significantly lower than for plants grown in sterilized soil, but greater than plants grown in infested soil without ABM treatment. This suggests that ABM could be a beneficial component of a Phytophthora root and crown rot management program, but may not be completely effective alone. Indeed, survival and growth of chile pepper plants treated with ABM plus mefenoxam and grown in the presence of *P. capsici* were similar to plants grown in sterile soil.

Resistance to mefenoxam by *P. capsici* in pepper fields in North Carolina and New Jersey has been detected (18,20). ABM can be used in combination or in alternation with mefenoxam to manage disease and help reduce the development of resistance to mefenoxam by *P. capsici*. When ABM is applied to a plant, several mechanisms appear to be activated concurrently against pathogen attack (6), which would likely limit the risk of development of pathogen insensitivity to the SAR activated defense responses (12).

Bacterial spot can severely damage pepper plants and reduce yield (24) under similar warm and humid environmental conditions that favor *P. capsici* activity. Romero et al. (21) found that application of ABM provided control of bacterial leaf spot on bell pepper cultivars; however, yield was reduced with seven or eight weekly applications of the compound at rates of 17 to 35 g a.i./h. The researchers noted that yields on plants stressed due to infestation with weeds or the presence of moderate to severe bacterial spot were reduced by ABM compared with yield on plants treated with copper and maneb. On the other hand, yield was not reduced in plots treated with ABM, when plants grew optimally from transplanting through harvest and were free of bacterial spot (21). Lowering the number of applications to the crop might alleviate the adverse effect of ABM on yield. Yield of pepper plants was not determined in this study. Studies are needed to evaluate the effect of plant stress, plant age, treatment rate, treatment frequency, other disease management chemicals, and time interval between applications, on yield and control of Phytophthora blight of pepper.

The efficacy of ABM as a potential chemical management tool for Phytophthora root and crown rot on pepper plants has been demonstrated in these greenhouse studies. Field evaluation of ABM is needed to determine if the product is efficacious in different pepper production regions where Phytophthora root and crown rot is prevalent. The effect of the compound on the foliar blight phase of the disease was not addressed in these studies; however, a recent field trial in Florida demonstrated the ability of four applications of ABM to provide significant suppression of Phytophthora blight on bell pepper (10). The availability of ABM as a chemical disease management tool, with a different mode of action than mefenoxam, could prolong the effectiveness of mefenoxam for disease control. But the successful sustainable management of Phytophthora blight on bell and chile peppers will require the implementation of a multifaceted disease management system with chemical inputs as one component (20).

LITERATURE CITED

1. Cole, D. L. 1999. The efficacy of acibenzolar-S-methyl, an inducer of systemic acquired resistance, against bacterial and fungal diseases of tobacco. *Crop Prot.* 18:267-273.
2. Damicone, J. P., Hammer, T. H., and Bostain, D. B. 2000. Responses of bell pepper cultivars to spray programs for control of bacterial spot, 1999. *Fungic. Nematicide Tests* 55: 186.
3. Damicone, J. P., Hammer, T. H., and Bostain, D. B. 2000. Evaluation of spray programs for control of white rust in over-wintered spinach, 1999. *Fungic. Nematicide Tests* 55:257.
4. Friedrich, L., Lawton, K., Ruess, W., Masner, P., Specker, N., Gut-Rella, M., Meier, B., Dincher, S., Staub, T., Uknes, S., Métraux, J. P., Kessman, H., and Ryals, J. 1996. A benzothiadiazole derivative induces systemic ac-

- quired resistance in tobacco. *Plant J.* 10:61-70.
5. Glantz, S. A. 1992. *Primer of Biostatistics*, 3rd ed. McGraw-Hill Book Co., New York.
6. Görlach, J., Volrath, S., Knauf-Beiter, G., Hengy, G., Beckhove, U., Kogel, K.-H., Oostendorp, S., Staub, T., Ward, E., Kessmann, H., and Ryals, J. 1996. Benzothiadiazole, a novel class of inducers of systemic acquired resistance, activates gene expression and disease resistance in wheat. *Plant Cell* 8:629-643.
7. Johnston, S. A., 1990. Control of Phytophthora blight of peppers by injection of metalaxyl through drip irrigation. (Abstr.) *Phytopathology* 80:120.
8. Jones, A. L., and Maxson, K. L. 2000. Field evaluations of Actigard for control of fire blight in apple, 1999. *Fungic. Nematicide Tests* 55:17.
9. Kessmann, H., Staub, T., Hofmann, C., Maetzke, T., Herzog, J., Ward, E., Uknes, S., and Ryals, J. 1994. Induction of systemic acquired resistance in plants by chemicals. *Annu. Rev. Phytopathol.* 32:439-459.
10. Kousik, C. S., and Subramanya, S. R. 2001. Evaluation of Actigard 50WG treatments for management of Phytophthora blight and Erwinia soft rot on bell pepper, 2000. *Fungic. Nematicide Tests*. On-line, publication/2001:V34.
11. Lawton, K. A., Friedrich, L., Hunt, M., Weymann, K., Delaney, T., Kessmann, H., Staub, T., and Ryals, J. 1996. Benzothiadiazole induces disease resistance in *Arabidopsis* by activation of the systemic acquired resistance signal transduction pathway. *Plant J.* 10:71-82.
12. Lyon, G. D., and Newton, A. C. 1999. Implementation of elicitor mediated induced resistance to agriculture. Pages 299-318 in: *Induced Plant Defenses Against Pathogens and Herbivores*. Biochemistry, Ecology, and Agriculture. A. A. Agrawal, S. Tuzun, and E. Bent, eds. The American Phytopathological Society, St. Paul, MN.
13. Matheron, M. E., and Porchas, M. 1999. Comparative efficacy of fungicides for management of downy and powdery mildew on lettuce, 1998. *Fungic. Nematicide Tests* 54:150-151.
14. Matheron, M. E., and Porchas, M. 2000. Assessment of fungicide performance for management of downy mildew on broccoli, 1999. *Fungic. Nematicide Tests* 55:148.
15. Matheron, M. E., and Porchas, M. 2000. Effect of cultivar and Actigard on development of powdery mildew on lettuce. Pages 122-124 in: *2000 Vegetable Report*, The University of Arizona, College of Agric. and Life Sciences. Publ. AZ1177.
16. Métraux, J. P., Goy, P. A., Staub, T., Speich, J., Steinemann, A., Ryals, J., and Ward, E. 1991. Induced systemic resistance in cucumber in response to 2,6-dichloroisonicotinic acid and pathogens. *Adv. Mol. Genet. Plant-Microbe Interact.* 1:432-439.
17. Papavizas, G. C., and Bowers, J. H. 1981. Comparative fungitoxicity of captan and metalaxyl to *Phytophthora capsici*. *Phytopathology* 71:123-128.
18. Parra, G., and Ristaino, J. 1998. Insensitivity to Ridomil Gold (mefenoxam) found among field isolates of *Phytophthora capsici* causing Phytophthora blight on bell pepper in North Carolina and New Jersey. *Plant Dis.* 82:711.
19. Pieterse, C. M. J., van Wees, S. C. M., Hoffland, E., van Pelt, J. A., and van Loon, L. C. 1996. Systemic resistance in *Arabidopsis* induced by biocontrol bacteria is independent of salicylic acid accumulation and pathogenesis-related gene expression. *Plant Cell* 8:1225-1237.
20. Ristaino, J. B., and Johnston, S. A. 1999.

- Ecologically based approaches to management of Phytophthora blight on bell pepper. Plant Dis. 83:1080-1089.
21. Romero, A. M., Kousik, C. S., and Ritchie, D. F. 2001. Resistance to bacterial spot in bell pepper induced by acibenzolar-S-methyl. Plant Dis. 85:189-194.
 22. Shoemaker, P. B. 2000. Fungicides and resistance for tobacco blue mold at Laurel Springs, NC, 1999. Fungic. Nematicide Tests 55:421.
 23. Simons, J. N., Simons, J. E., and Winsberg, T. 1991. Control of Phytophthora crown rot in bell pepper with directed sprays of metalaxyl. Proc. Annu. Meet. Fla. State Hortic. Soc. 103:120-121.
 24. Stall, R. E. 1993. *Xanthomonas campestris* pv. *vesicatoria*: cause of bacterial spot of tomato and pepper. Pages 57-60 in: *Xanthomonas*. J. G. Swings and E. L. Civerolo, eds. Chapman and Hall, London.
 25. Sung, N. K., and Hwang, B. K. 1988. Comparative efficacy and in vitro activity of metalaxyl and metalaxyl-copper oxychloride mixture for control of Phytophthora blight of pepper plants. Korean J. Pathol. 4:185-196.
 26. Tally, A., Oostendorp, M., Lawton, K., Staub, T., and Bassi, B. 1999. Commercial development of elicitors of induced resistance to pathogens. Pages 357-370 in: Induced Plant Defenses Against Pathogens and Herbivores. Biochemistry, Ecology, and Agriculture. A. A. Agrawal, S. Tuzun, and E. Bent, eds. The American Phytopathological Society, St. Paul, MN.
 27. Ukenes, S., Mauch-Mani, B., Moyer, M., Potter, S., Williams, S., Dincher, S., Chandler, D., Slusarenko, A., Ward, E., and Ryals, J. 1992. Acquired resistance in Arabidopsis. Plant Cell 4:645-656.