The Effect of In-furrow Applications of Acibenzolar-S-Methyl on Tomato Spotted Wilt Virus and Thrips in Peanut

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ABSTRACT

Tomato spotted wilt virus (TSWV) (family: Bunyaviridae) is a continuing threat to several crops in the Southeastern U.S. Acibenzolar-S-methyl is a plant immune-response activator which has been shown to suppress TSWV in tobacco. The following treatments were evaluated for TSWV and thrips suppression: untreated, phorate in-furrow, acibenzolar-S-methyl applied in-furrow, acibenzolar-S-methyl in-furrow + foliar, and acibenzolar-S-methyl in-furrow + phorate in-furrow. Although in-furrow applications of acibenzolar-S-methyl alone and in combination with phorate led to numerical reductions of TSWV during each year of the study, differences were significant only during 1997. Foliar applications of acibenzolar-S-methyl did not provide enough disease suppression during 1997 to warrant additional sprays. However, Acibenzolar-S-methyl also may reduce populations of thrips larvae and suppresses feeding damageby thrips up to 30 d after planting. Acibenzolar-S-methyl applied in-furrow was comparable with in-furrow applications of phorate in its effect on TSWV of peanut; however, acibenzolar-S-methyl does not provide enough benefit alone to justify its use in peanut management at this time.

Key Words: Acibenzolar-S-methyl, *Frankliniella fusca*, *Frankliniella occidentalis*, Tospovirus, TSWV.

Tomato spotted wilt virus (TSWV) (family: Bunyaviridae) is a continuing threat to peanut (*Arachis hypogaea* L.), tobacco (*Nicotiana tabacum* L.), tomato (*Lycopersicon esculentum* Miller), and pepper (*Capsicum frutescens* L.) in the Southeastern U.S. Annual losses due to TSWV are estimated to be $100 million in Georgia crops (Williams-Woodward, 2000). TSWV is transmitted by at least seven species of thrips (Ullman *et al.*, 1997). In Georgia,

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Frankliniella fusca Hinds (tobacco thrips) and *F. occidentalis* Pergande (western flower thrips) are the primary vectors associated with peanut (Todd *et al.*, 1995). Adult and larval thrips are found in peanut terminals, which are considered the primary site for oviposition and larval feeding, as well as in peanut flowers (Smith and Sams, 1977). TSWV is acquired only by larval thrips feeding on an infected plant and the virus is transmitted in a persistent manner to other plants by adult feeding (Cho *et al.*, 1988).

The most effective progress in minimizing the impact of TSWV in peanut has been the development of resistant cultivars (Culbreath *et al.*, 1999). The use of such cultivars in combination with a variety of other factors such as insecticide application, planting date, plant population, row pattern, tillage, and history of the virus in a particular location provide Georgia peanut producers with effective tools to combat the virus (Brown *et al.*, 2002).

TSWV infection of peanut appears to occur mainly through primary inoculation by viruliferous thrips entering the field from outside reservoirs (Chamberlin *et al.*, 1992). Effective suppression of viral diseases through chemical control of insect vectors has been rare and unreliable (Perring *et al.*, 1999). In the case of TSWV, much of the ineffectiveness of disease suppression through chemical vector control is due to the large number of vectors outside the crop and the large host range of thrips and TSWV. However, the insecticide phorate has demonstrated consistent, low-level suppression of TSWV in peanut (Todd *et al.*, 1996). Although the actual mechanism responsible for this suppression remains unknown, it is believed that phorate may activate the plant's immune system (Todd *et al.*, 1996). Phorate is currently recommended as a component in the Georgia TSWV suppression program for peanut (Brown *et al.*, 2002). Recently, applications of acibenzolar-S-methyl in combination with imidacloprid have been shown to effectively suppress TSWV in Georgia flue-cured tobacco (Pappu *et al.*, 2000). This treatment seems to be most effective when the material reaches the root system early in the growing season in the form of a greenhouse tray-drench or transplant water treatment (Csinos *et al.*, 2001). Acibenzolar-S-methyl is a plant activator which is designed to activate the plant's defense mechanisms (Lawton *et al.*, 1996; Ruess *et al.*, 1996). The objective of this study was to evaluate the effectiveness of in-furrow and foliar applications of acibenzolar-S-methyl alone and in combination with phorate for reducing the impact of TSWV and thrips on peanut.

Materials and Methods

1997. During 1997, field tests were conducted at the Univ. of Georgia Attapulgus Res. Farm, Decatur Co, GA. Two cultivars, Georgia Green and Georgia Runner, were planted on 18 April using 0.9-m row spacing. Plots were arranged in a split-plot randomized complete block design with five replications. Main plot effects (four rows by 15 m) were cultivar and split plot effects (two rows by 15 m) were chemical treatment. Chemical applications evaluated were (a) in-furrow and foliar applications of acibenzolar-S-methyl (Actigard® 50 WG; Syngenta, Basel, Switzerland) at 3.5 g ai/ha; (b) in-furrow application of phorate (Thimet® 15G; BASF, Research Triangle Park, NC) at 181g ai/ha; and (c) untreated control. In-furrow applications were applied at planting. Foliar applications of acibenzolar-S-methyl began 4 wk after planting and continued on a 7-d schedule throughout the season (16 total applications).

1998. During 1998, field tests were conducted at the Univ. of Georgia Lang Res. Farm, Tift Co., GA. All plots were planted to Georgia Green on 25 June 1998 and were arranged in a randomized complete block design with four replications. Plots were two rows, 7.6 m in length with 0.9-m row spacing. All plots were bordered on both sides by two rows of TSWV-susceptible cultivar GK-7. One additional treatment was added to the study during 1998 which consisted of an in-furrow application of acibenzolar-S-methyl (3.5 g ai/ha). Otherwise, all chemical applications were the same as during 1997. Foliar applications of acibenzolar-S-methyl began 4 wk after planting and continued on a 7-d schedule throughout the season (16 total applications).

2000 and 2001. Field tests were conducted at the Univ. of Georgia Lang Res. Farm, Tift Co., GA. In 2000, Georgia Green was planted on 9 June. In 2001, a TSWV-susceptible peanut cultivar, Sun Oleic 97R, was planted on 18 May to increase virus pressure. All plots during both years were arranged in a randomized complete block design. Plots were two rows, 7.6 m in length with 0.9-m row spacing. All plots during 2000 were bordered on both sides by two rows of TSWV-susceptible cultivar GK-7. No border rows were used in the 2001 test. Treatments evaluated during both years were (a) untreated, (b) phorate at 181g ai/ha, (c) acibenzolar-S-methyl at 3.5 g ai/ha, (d) acibenzolar-S-methyl at 3.5 g ai/ha + phorate at 181g ai/ha. All treatments were applied in-furrow at planting. Seven and five replications of the untreated control were used during 2000 and 2001, respectively. All other treatments were replicated six and eight times during 2000 and 2001, respectively.

Plants were dug and inverted in all tests at approximate optimum maturity based on the hull-scrape maturity index (Williams and Drexler, 1981) and visual maturity estimates. Inverted plants were dried in the windrow for 3-7 d. Pods were harvested mechanically, and pod yields were determined for each plot.

Disease Evaluation. During 1997, 2000, and 2001, plants were evaluated on five dates for symptoms of spotted wilt by a disease intensity rating that represents a combination of incidence and severity. Plants were only evaluated once at the end of the growing season during 1998 due to low disease pressure. The number of loci of plants severely affected by spotted wilt were counted for each plot. A locus represented 0.3 m or less of linear row with plants severely stunted, killed, or showing severe chlorosis from spotted wilt. Distinct reductions in height or width, significant chlorosis, wilting, or death of the peanut row were required before portions of row would be considered severely affected (Culbreath *et al.*, 1996). Numbers of loci were converted to percentage of row length for comparison of TSWV incidence between treatments.

Thrips Sampling. Ten partially unfolded terminal quadrifoliate leaves per plot were collected 40 d after planting (DAP) during 1997, 40 DAP during 1998, 28 DAP during 2000, and 26 DAP during 2001. Immediately after collection, terminals were placed in vials of 70% ethyl alcohol and refrigerated until thrips could be removed and counted in the laboratory. Thrips were sorted and counted according to species, sex, and life stage. Due to extreme difficulty in differentiating *Frankliniella* larvae, larvae were counted without regard to species. Previous studies indicate that these larvae are almost exclusively *F. fusca* (Todd *et al.*, 1995). Thrips feeding damage was rated in all plots 30 DAP during 2001. Feeding damage was assessed visually and scores from 0-5 were assigned based on the severity of thrips feeding damage on peanut plants, with 0 indicating no visual damage, and 5 indicating the highest level of feeding damage or scarring from thrips feeding.

Statistical Analysis. Based on previous data, the final disease rating for TSWV has a higher correlation with yield than an average of the disease rating over time or AUDPC (Culbreath *et al.*, 1997); therefore, only final disease ratings were used for analyzing differences between treatments with respect to disease. Data for 1997 were subjected to split-plot analysis of variance (ANOVA). All data during 1998, 2000, and 2001 were subjected to analysis of variance (ANOVA) and means were separated using Duncan's multiple range test each year (SAS Inst., 1985). Differences referred to in the text are significant at $P < 0.05$. Data on TSWV incidence, thrips damage and thrips populations were square root transformed but the transformation did not affect the outcome of the results; therefore, all results presented here are from untransformed data.

Results

Final Disease Incidence and Yield. Disease pressure was low early on in the 1997 study; however, TSWV increased rapidly in the untreated plots at about 80 DAP (Fig. 1). Very little disease was observed during the first 30 d of the 2001 study (Fig. 2); therefore, no disease ratings were taken until 50 DAP during 2001. Due in part to the late 2000 planting date and the use of the moderately resistant Georgia Green cultivar, disease pressure during that year was relatively low (Fig. 2). The high final disease incidence observed in all treatments during 2001 probably resulted from the use of the more susceptible cultivar Sun Oleic 97R. A significant ($F = 8.25$; df = 2, 24; $P = 0.002$) treatment × cultivar interaction was observed for final disease incidence during 1997. As a result, treatment × cultivar was used as the error term for analysis of disease incidence. Disease incidence was higher ($F = 11.68$; df = 1, 2; $P = 0.002$) for Georgia Runner than for Georgia Green (Table 1). The acibenzolar-S-methyl and phorate treatments reduced ($F = 6.13$; df = 2, 2; $P = 0.007$) the final incidence of TSWV during 1997 in both cultivars; however, no treatment effect was observed during 1998 ($F = 1.03$; df = 3, 12; $P = 0.41$) (Table 1). Treatment did not have a significant effect on incidence of TSWV during 2000 ($F = 2.49$; df = 3, 27; $P = 0.08$) nor during 2001 ($F = 1.10$; df = 3, 19; $P = 0.08$) (Table 2).

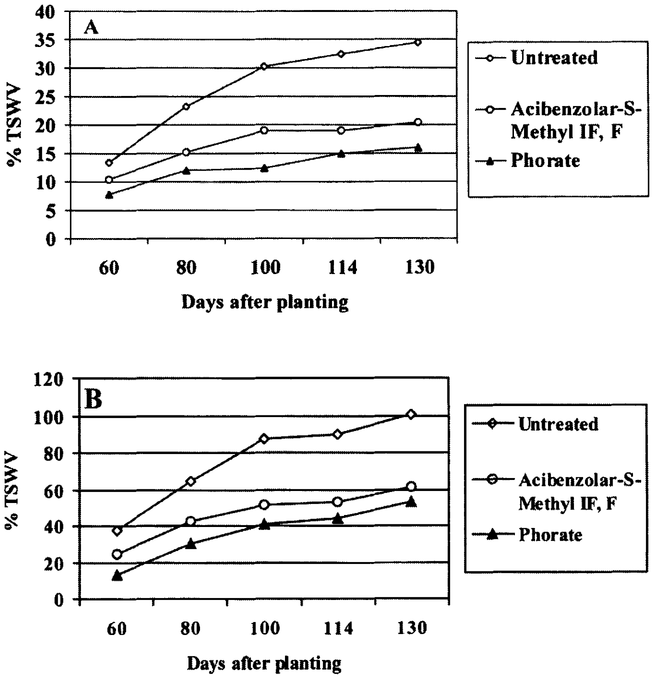

Fig. 1. Effect of in-furrow and foliar applications of acibenzolar-S-methyl and in-furrow application of phorate on disease progress of tomato spotted wilt virus in Georgia Green (A) and Georgia Runner (B) peanut in Decatur County, GA during 1997.

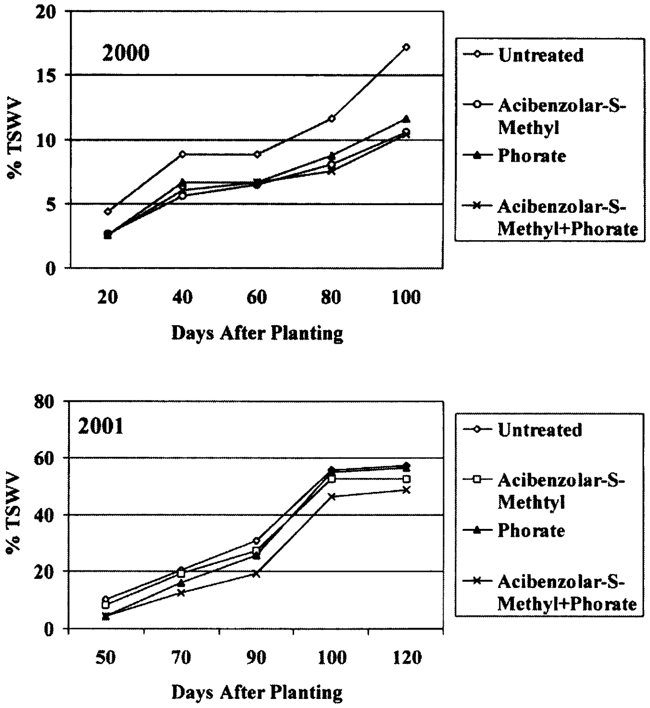

Fig. 2. Effect of in-furrow applications of acibenzolar-S-methyl and phorate on disease progress of tomato spotted wilt virus in Tift County, GA during 2000 and 2001.

Yield was significantly ($F = 1.68$; df = 1, 24; $P = 0.002$) higher for Georgia Green than for Georgia Runner during 1997. Yield was not affected by treatment during 1997 ($F = 2.75$; df = 2, 12; $P = 0.10$), 1998 ($F = 1.32$; df = 3, 12; $P = 0.31$), 2000 ($F = 1.16$; df = 3, 27; $P = 0.34$), or 2001 ($F = 1.05$; df = 3, 19; $P = 0.39$) (Table 2). There was a 700-kg reduction in yield for untreated Georgia Runner during 1997 when compared with the phorate treatment for that cultivar. Spotted wilt incidence was 100 and 53% for untreated and phorate-treated Georgia

Table 1. Effect of in-furrow and foliar applications of acibenzolar-S-methyl and phorate in-furrow on final incidence of tomato spotted wilt virus, thrips populations, and yield in peanut during 1997 and 1998, Tift County, GA.[a]

Year (cultivar) Treatment (application; rate)	TSWV incidence[b]	TT[c]		WFT[d]		Thrips larvae	Yield
		Males	Females	Males	Females		
	no.	no.		no.		no.	kg/ha
1997 (Georgia Green)							
Untreated	34.8 a	0.8 a	1.8 a	0.0	0.0	23.6 a	3825 a
Phorate (IF; 181g ai/ha)	15.2 b	0.2 a	1.0 a	0.0	0.0	10.0 b	4425 a
Acibenzolar-S-methyl (IF, F; 3.5 g ai/ha)	20.4 b	0.8 a	1.0 a	0.0	0.0	25.6 a	4168 a
1997 (Georgia Runner)							
Untreated	100.0 a	1.0 a	1.8 a	0.0	0.0	28.4 a	3204 a
Phorate (IF; 181g ai/ha)	53.0 b	0.0 a	1.6 a	0.0	0.0	6.8 b	3977 a
Acibenzolar-S-methyl (IF, F; 3.5 g ai/ha)	61.2 b	0.0 a	3.2 a	0.0	0.0	22.8 a	3578 a
1998 (Georgia Green)							
Untreated	33.0 a	0.25 a	0.25 a	0.0	0.0 a	22.8 a	3061 a
Phorate (IF; 181g ai/ha)	23.0 a	0.0 a	0.75 a	0.0	0.2 a	20.3 a	3726 a
Acibenzolar-S-methyl (IF, F; 3.5 g ai/ha)	23.0 a	0.0 a	1.3 a	0.0	0.2 a	24.5 a	3054 a
Acibenzolar-S-methyl (IF 3.5 g ai/ha)	30.5 a	0.5 a	2.0 a	0.0	0.5 a	20.3 a	3412 a

[a] Means with different letters within a column are significantly different at $P \leq 0.05$.

[b] Percentage of row feet severely affected by TSWV based on final disease rating.

[c] Number of individuals per partially unfolded quadrifoliate; TT = tobacco thrips.

[d] WFT = western flower thrips.

Table 2. Effect of in-furrow applications of acibenzolar-S-methyl and phorate on final incidence of tomato spotted wilt virus, thrips populations, and yield in peanut during 2000 and 2001, Tift County, GA.[a]

Year Treatment and rate	TSWV incidence[b]	TT[c]		WFT[d]		Thrips larvae	Yield	Feeding damage
		Males	Females	Males	Females			
	no.	no.		no.		no.	kg/ha	
2000								
Untreated	17.2 a	0.29 a	3.7 a	0.0	0.0	11.0 ab	1475 a	-------
Phorate (181g ai/ha)	11.6 a	0.75 a	4.5 a	0.0	0.0	17.5 a	1359 a	-------
Acibenzolar-S-methyl (3.5 g ai/ha)	10.6 a	0.25 a	3.6 a	0.0	0.0	4.5 b	1167 a	------
Phorate (181g ai/ha) + Acibenzolar-S-methyl (3.5 g ai/ha)	10.4 a	0.38 a	3.0 a	0.0	0.0	13.4 a	1348 a	-------
2001								
Untreated	57.2 a	0.0 a	0.8 a	0.0	0.0 a	91.6 a	1808 a	4.4 a
Phorate (181g ai/ha)	56.3 a	0.2 a	2.0 a	0.0	0.2 a	9.8 c	1794 a	1.8 c
Acibenzolar-S-methyl (3.5 g ai/ha)	52.3 a	0.0 a	1.3 a	0.0	0.2 a	35.5 bc	2336 a	3.7 b
Phorate (181g ai/ha) + Acibenzolar-S-methyl (3.5 g ai/ha)	48.6 a	0.0 a	2.7 a	0.0	0.5 a	6.2 c	1832 a	2.0 c

[a] Means with different letters within a column are significantly different at $P \leq 0.05$.

[b] Percentage of row feet severely affected by TSWV based on final disease rating.

[c] Number of individuals per partially unfolded quadrifoliate; TT = tobacco thrips.

[d] WFT = western flower thrips.

Runner during that year as well; however, yield was not influenced to a statistically significant degree by treatment during any of the years of this study (Table 1). Because yield is influenced by a variety of factors, only one of which is TSWV, it is difficult to attribute any yield variation in the current test to one particular factor.

Thrips Abundance and Damage. Cultivar did not influence the numbers of thrips larvae ($F = 0.02$; $df = 1, 24$;

P = 0.88), adult female (F = 3.16; df = 1, 24; P = 0.09), or adult male tobacco thrips (F = 1.52; df = 1, 24; P = 0.23) collected during 1997. Neither were differences observed with respect to the number of female tobacco thrips (F = 1.0; df = 2, 12; P = 0.39) between treatments during 1997; however, a difference (F = 4.67; df = 2, 24; P = 0.02) was observed for male tobacco thrips (Table 1). No western flower thrips were collected during 1997, 1998, or 2000. Treatment had no effect on male (F = 1.57; df = 3, 12; P = 0.25) or female (F = 2.18; df = 3, 12; P = 0.14) tobacco thrips during 1998 (Table 1). Neither female (F = 0.43; df = 3, 27; P = 0.73) nor male (F = 0.91; df = 3, 27; P = 0.45) tobacco thrips were significantly affected by treatment during 2000 (Table 2). During 2001, treatment had no effect on numbers of female tobacco thrips (F = 1.85; df = 3, 19; P = 0.17) or on numbers of female western flower thrips (F = 0.91; df = 3, 19; P = 0.45). Male tobacco thrips were not significantly affected by treatment (F = 0.94; df = 3, 19; P = 0.44), and no male western flower thrips were collected. Treatment did have a significant effect on thrips larvae during 1997 (F = 5.5; df = 2, 12; P = 0.02), 2000 (F = 5.06; df = 3, 27; P = 0.006), and 2001 (F = 90.8; df = 3, 19; $P < 0.001$), but not during 1998 (F = 0.59; df = 3, 12; P = 0.63) (Tables 1 and 2). Thrips feeding damage also was reduced in 2001 (F = 35.2; df = 3, 19; $P \leq 0.0001$) by the treatments (Table 2).

Discussion

In-furrow applications of acibenzolar-S-methyl alone and in combination with phorate led to numerical reductions of TSWV incidence during each year of the study, although the differences were only significant during 1997 (Tables 1 and 2). The in-furrow application for peanut is designed to act in a manner similar to the greenhouse tray drench and transplant water applications in tobacco (Csinos *et al.*, 2001), potentially providing protection to the plant via the seed and root system early in the growing season when protection from disease transmission appears most important. Foliar applications of acibenzolar-S-methyl did not appear to provide enough disease suppression beyond that seen with in-furrow applications alone to warrant additional sprays. The acibenzolar-S-methyl + phorate combination in peanut may provide two diverse modes of action for disease suppression similar to what is seen with the acibenzolar-S-methyl and imidacloprid combination in tobacco (Pappu *et al.*, 2000), although this theory should be evaluated more closely.

The reduction in incidence of TSWV in peanut provided by acibenzolar-S-methyl alone and in combination with phorate probably would not provide enough benefit to justify use when used alone for suppression of TSWV. Just as phorate is more effective when used in combination with other disease-suppressive factors recommended by the TSWV risk assessment index than when used alone, acibenzolar-S-methyl also may be of more benefit when used in combination with other disease suppressive factors.

Adult thrips populations did not show a great response to treatment during the study; however, the response of thrips larvae to the treatments was more obvious. Phorate reduced the numbers of thrips larvae during 1997 and 2001 but not during 1998 and 2000. The disparity in these results could have been influenced by the planting dates. Reductions in numbers of thrips larvae by phorate treatments occurred during years in which tests were planted in April or May. No such reductions were observed when tests were planted in June. Thrips larvae were reduced by the acibenzolar-S-methyl treatment relative to the control during 2000 and 2001. This may indicate a sublethal effect of acibenzolar-S-methyl on thrips populations with respect to reproduction or acibenzolar-S-methyl may have a more direct effect on thrips larvae than on adults. Acibenzolar-S-methyl also reduced thrips populations on flue-cured tobacco up to 28 DAP (Pappu *et al.*, 2000). Conflicting results were observed between 2000 and 2001 data for the phorate and acibenzolar-S-methyl + phorate treatments with respect to their effect on thrips larvae. Cultivar probably was not as important as planting date in the disparity of the results of these two treatments for these 2 yr of the study. Thrips feeding damage also appeared to be reduced by acibenzolar-S-methyl and phorate when used alone or in combination (Fig. 1); however, this apparently had little effect on disease transmission.

Based on our results, acibenzolar-S-methyl applied in-furrow appears to be comparable with phorate in its effect on TSWV in peanut. Acibenzolar-S-methyl also appears to reduce populations of thrips larvae, potentially through sublethal effects affecting reproduction of adults. This is a theory that should be addressed in further studies. Reductions in TSWV incidence provided by the treatments used in this study do not appear to be enough to provide consistent control of the disease, at least to a level that would be of benefit to growers. However, when used in combination with other management factors, phorate is considered a useful tool for TSWV suppression (Brown *et al.*, 2002). Integration of acibenzolar-S-methyl with other TSWV management practices—such as strip tillage, planting date, twin rows, etc.—should be examined as well in order to fully explore the potential benefits of this plant activator to TSWV and thrips management in peanut.

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