Evaluation of Foliar-Applied Insecticides on Abundance of Parasitoids of *Bemisia argentifolii* (Homoptera: Aleyrodidae) in Vegetables[1,2]

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Abstract The relative abundance of parasitoids of *Bemisia argentifolii* Bellows & Perring was studied in insecticide-treated and untreated field plots of cantaloupe, collard, cucumber, and tomato. Treatments were made using foliar-applied chlorpyrifos (Lorsban®, DowElanco, Indianapolis, IN) in 1994, and foliar-applied imidacloprid (Provado®, Bayer Corporation, Kansas City, MO) in 1995 and 1996. Yellow sticky cards were used to monitor parasitoids associated with *B. argentifolii* in plots untreated or treated weekly in 1994 and bi-weekly in 1995 and 1996 with insecticide over 10 wks. The abundance of parasitoids varied among fields and across years. Five species of parasitoids were captured: *Eretmocerus* sp., *Encarsia nigricephala* Dozier, *E. pergandiella* Howard, *E. quaintancei* Howard, and *E. strenua* (Silvestri). The first three species comprised approximately 95% of the captured parasitoids. Parasitoids persisted in all field locations and crops whether the vegetables were treated or not. Parasitoids were captured in the treated plots throughout the study, although in fewer numbers than in the untreated plots. Overall, about 60 to 70% of parasitoids captured were from plots without insecticide. Whitefly captures on the sticky traps were relatively high in collard compared with the other crops studied. In addition, more *E. nigricephala* and *E. pergandiella* were collected in collard than in the other vegetable crops.

Key Words *Bemisia argentifolii, Bemisia tabaci* B strain, parasitoids, *Encarsia, Eretmocerus,* biological control, sticky trap, vegetable, imidacloprid

Many vegetable hosts are attacked by *Bemisia argentifolii* Bellows & Perring from the time the plant emerges and through the end of the growing season (Simmons 1994). *Bemisia argentifolii* is synonymous with the B-strain of *Bemisia tabaci* Gennadius (Perring et al. 1993, Bellows et al. 1994). It has become a serious agricultural pest in recent years, especially in the irrigated crops of the southwestern United States (Byrne et al. 1990). Growers have had an immediate need to manage whiteflies; their main resolution has been a reliance on insecticides. Although there is prevalent use of insecticides in the management of whiteflies, the impact of these compounds on parasitoids and predators has not been well documented. It would be desirable if available compounds were compatible with parasitoids and predators in

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[2]This article reports the results of research only. Mention of a proprietary product does not constitute an endorsement or a recommendation for its use by USDA.

the targeted cropping system. Parasitism and predation are pliable methods of helping to manage whiteflies in vegetable production. At least five species of indigenous parasitoids of *B. argentifolii* occur in South Carolina; the most abundant species are *Encarsia nigricephala* Dozier, *Encarsia pergandiella* Howard, and *Eretmocerus* sp. (Simmons 1998). Because of moderate winter temperatures, feral populations of *B. argentifolii* persist year round in South Carolina (Simmons and Elsey 1995).

Alterations of insect behavior have been attributed to sub-lethal concentrations of insecticides and residues (Haynes 1988). Adverse influences of chemicals on parasitoid behavior may include a reduction in search time and an increase in grooming frequency (Longley and Jepson 1996). In addition, the chemicals can affect parasitoid survival. In a leaf residue study, Jones et al. (1995) demonstrated that species of whitefly parasitoids can differ in their tolerance to cotton insecticides.

Yellow sticky traps have been evaluated for use in control of whiteflies in vegetables (Nitzany et al. 1964, Cohen and Marco 1973, Valdez and Wolfenbarger 1995). Dowell and Cherry (1981) suggested that yellow sticky traps may be used to survey and monitor populations of parasitoids and other natural enemies of the citrus blackfly, *Aleurocanthus woglumi* Ashby (Homoptera: Aleyrodidae). Subsequently, Simmons (1998) utilized sticky traps to survey and monitor parasitoids of *B. argentifolii.* The objective of our study was to evaluate the effects of foliar-applied insecticides on the abundance of *B. argentifolii* parasitoids in selected vegetable crops. How yellow sticky trap capture of *Bemisia* parasitoids relates to parasitism will be the subject of a subsequent report by K. A. Hoelmer and A. M. Simmons.

Materials and Methods

Three fields were established over three years (1994, 1995, and 1996) at the USDA-ARS, U.S. Vegetable Laboratory in Charleston, SC. These fields were selected to provide varied environments with different whitefly and parasitoid populations. The same three fields were used each year. Field 8LW was 0.7 km from field 2F; field 2F was 0.5 km from field 4B; and field 8LW was 1.2 km from field 4B. One side of fields 4B and 8LW was adjacent to woodland. Assorted vegetable crops were in the vicinity of the fields during the study. Plots of cantaloupe, *Cucumis melo* L., 'Mainstream'; collard, *Brassica oleracea* var. *acephala* de Condolle, 'Georgian'; and tomato, *Lycopersicon esculentum* Miller, 'Homestead,' were established annually in each field. Cucumber, *Cucumis sativus* L., 'Poinsett,' was also planted in the three fields, but only during 1994. Tomato and collard transplants, grown from seed in a greenhouse, were used to establish field plots. Field plots of cantaloupe and cucumber were seeded 15 July in 1994, and the cantaloupe was seeded 15 August in 1995 and 16 July in 1996. Collard and tomato were transplanted into each field at the time of emergence (cotyledon stage) of direct-seeded cantaloupe and cucumber. Plots for all vegetable species were established in each field. Within a field, the crops were randomly assigned to plots and were divided into two subplots. Foliar insecticides were randomly applied to one subplot while the other subplot served as an untreated plot. Subplots were 30.5 m long. The width of all treated and untreated subplots within a field were the same; among fields, subplots ranged from 28.4 to 36.6 m wide. In 1994, collard was established on 102-cm row spacing, while the other crops were on 203-cm rows. In 1995 and 1996, all crops were on 203-cm row spacing. Only preplant herbicides were used in all plots. Additional weed control was either manual or mechanical.

The foliar insecticide evaluated in 1994 was chlorpyrifos (Lorsban® 50 WP, Dow-Elanco, Indianapolis, IN, at 2,246.4 g (AI)/ha), while in 1995 and 1996, foliar imidacloprid (Provado® 1.6 F, Bayer Corporation, Kansas City, MO, at 112.3 g (AI)/ha) was applied. No post-planting pesticide was used in the untreated plots. In 1996, tomato plants were treated with methomyl before transplant because of a greenhouse infestation of tomato pinworms, *Keiferia lycopersicella* (Walsingham). Insecticide plots were treated with insecticide starting 2 wks after transplanting, and continued weekly in 1994 and at a 2-wk interval in 1995 and 1996. Plots were treated 10 times in 1994 and 5 times in 1995 and 1996.

One day after each insecticide treatment, two yellow sticky card traps in 1994 and five yellow sticky card traps in 1995 and 1996 were placed in each subplot per crop per field. Sticky cards were placed horizontally on a 15-cm clay pot, and a wire was passed through the card and anchored to the ground. Sticky cards were collected after 1 wk, placed in clear rigid plastic bags, and frozen until processed with the aid of a dissecting microscope. Sticky trap data were collected on the number of *B. argentifolii* adults and its parasitoids. No sticky cards were in the field the week preceding the insecticide applications in 1995 and 1996, only the week after the treatments. Parasitoid species were identified using a parasitoid key (Polaszek et al. 1992) and comparison with slide specimens that were identified by G. Evans (University of Florida, Gainesville, FL). In an earlier survey of *B. argentifolii* parasitoids in South Carolina (Simmons 1998), G. Evans and K. Hoelmer (USDA-APHIS, Brawley, CA) identified specimens of each of these species from coastal South Carolina.

All statistical procedures were completed using Statistical Analysis Systems (SAS Institute 1994). Analysis of variance was used to evaluate counts of whiteflies and parasitoids in relation to insecticide, field location, and crop for each year. Data were analyzed for each year with a factorial experimental design with insecticide treatment having 1 df, location having 2 df, and crop having 3 df for year 1994 and 2 df for years 1995 and 1996. Log (base 10 [x + 1]) transformation was used before all analyses. Means were separated using the Student-Newman-Keuls test at the 0.05 level of significance. All means are presented using back-transformed values. The ratio of host to parasitoid adults was determined based on the number of parasitoids captured relative to the number of *B. argentifolii* captured.

Results and Discussion

Parasitoids of *B. argentifolii* were collected during each 1-wk sample period in both treated and untreated plots in each year (except for a few plots in July 1994). The number of parasitoids and number of *B. argentifolii* captured per sticky card varied among years ($P < 0.05$). They were most abundant in 1994 and least abundant in 1995. Five species of parasitoids were collected. The three most frequently collected parasitoid species during each year (from 1994 to 1996) were *E. nigricephala* (50, 56, and 26%), *E. pergandiella* (31, 24, and 26%), and *Eretmocerus* sp. (17, 17, and 44%). In addition, *Encarsia strenua* (Silvestri) and *Encarsia quaintancei* Howard comprised about 5% of the parasitoids collected in both treated and untreated fields plots during each year. In comparison, a survey on sweetpotato, *Ipomoea batatas* (L.) Lam., fields in coastal South Carolina in 1993-94, from 6 to 13% of the parasitoids were *E. strenua* and *E. quaintancei;* the most abundant were *E. nigricephala, E. pergandiella,* and *Eretmocerus* sp., in ranking order of most to least abundant (Simmons 1998).

Across fields and crops, significantly more parasitoids were captured in untreated plots than in treated plots each year (Table 1). In 1994, 65% of the parasitoids were from untreated plots. Similarly, 61% and 68% of the parasitoids were from untreated plots in 1995 and 1996, respectively. Lazare and Gerling (1993) reported no influence of insecticide sprays on parasitism of *B. tabaci* in cotton in Israel, although they did not report which insecticide and parasitoids were studied. The number of *B. argentifolii* captured in 1994 and 1995 was similar for the untreated and treated plots (Table 1). However, almost twice as many whiteflies were collected in the untreated plots compared with the treated plots in 1996. Nevertheless, the ratio of whitefly to parasitoid collected was consistently lower in each year in the untreated plots compared with the treated plots.

Captures of *B. argentifolii* varied by crop. A greater number of the whiteflies was captured from collard than from the other crops, but not in 1995 (Table 2). Averaged across years, significantly ($P < 0.05$) more *E. nigricephala* and *E. pergandiella,* but not *Eretmocerus* sp., were collected from collard than from the other crops. Compared with several other vegetable crops, collard can support high populations of *B. argentifolii* (Simmons 1994, Simmons and Elsey 1995) and remain a suitable host for a relatively long time. It should be noted that in 1995 and 1996, the quality of cantaloupe declined during the latter part of the season because of a severe outbreak of powdery mildew. Most cantaloupe plants were dying or dead over the last two sampling weeks. During 1995 and 1996, the ratio of whitefly to parasitoid was lowest on cantaloupe

Table 1. Mean (±SEM) number of *B. argentifolii* and its parasitoids captured on yellow sticky cards in treated and untreated vegetable crops during three years

Treatment	Mean no. whiteflies per trap	Mean no. parasitoids per trap	Number of whiteflies per parasitoid
	1994		
Untreated	63.5 ± 8.9a	1.3 ± 0.1a	48.8
Insecticide	60.5 ± 8.8a	0.7 ± 0.1b	86.4
	1995		
Untreated	19.8 ± 1.2a	3.4 ± 0.4a	5.8
Insecticide	17.1 ± 1.6a	2.2 ± 0.3b	7.7
	1996		
Untreated	55.1 ± 3.5a	4.8 ± 0.4a	11.5
Insecticide	30.5 ± 3.4b	2.3 ± 0.3b	13.3

Foliar applications of insecticide were made with chlorpyrifos in 1994 and imidacloprid in 1995 and 1996. Means followed by the same letter within a column for each year are not significantly different ($P > 0.05$) according to the Student-Newman-Keuls test (SAS Institute 1994).

Table 2. Mean (±SEM) number of *B. argentifolii* and its parasitoids captured on yellow sticky cards in vegetable crops during three years

Crop	Mean no. whiteflies per trap	Mean no. parasitoids per trap	Number of whiteflies per parasitoid
	1994		
Collard	113.8 ± 12.5a	0.9 ± 0.2a	126.4
Tomato	42.2 ± 12.5b	1.3 ± 0.2a	32.5
Cantaloupe	40.9 ± 12.4b	1.0 ± 0.2a	40.9
Cucumber	51.2 ± 12.4b	0.9 ± 0.2a	56.9
	1995		
Collard	15.6 ± 1.7b	2.3 ± 0.4b	6.8
Tomato	24.0 ± 1.7a	2.0 ± 0.4b	12.0
Cantaloupe	14.7 ± 1.7b	3.6 ± 0.4a	4.1
	1996		
Collard	69.2 ± 4.2a	5.5 ± 0.4a	12.6
Tomato	34.0 ± 4.2b	2.6 ± 0.4b	13.1
Cantaloupe	26.4 ± 4.3b	2.5 ± 0.4b	10.6

Data are combined for insecticide treated and untreated plots. Means followed by the same letter within a column for each year are not significantly different ($P > 0.05$) according to the Student-Newman-Keuls test (SAS Institute 1994).

(Table 2). Azab et al. (1969) illustrated that parasitism of *B. tabaci* may vary among host plants. They suggested that host plants may exhibit different attractants that affect the parasitoids. The lower whitefly to parasitoid ratio in cantaloupe may be related to the lower whitefly abundance in cantaloupe compared with the other two crops in 1995 and 1996. Headrick et al. (1996) demonstrated in the laboratory that whitefly parasitism can vary among plant species. They concluded that the variation resulted from varying searching effectiveness by the parasitoids on different hosts.

In all cases, captures of both *B. argentifolii* and its parasitoids were especially low during the early growth of the plantings. Captures were higher later, which may reflect immigration and reproduction. Bellows and Arakawa (1988) noticed that parasitism of *B. tabaci* was similar in commercial cotton fields treated with organophosphate and pyrethoids compared with untreated research plots. In their study, parasitism was low (about 10%) early in the season and about 65% in October. Also, in their study, parasitism generally remained at elevated levels (about 50%) after defoliants were applied. Poor insecticide coverage applied by using different applicators, such as by aircraft, may also facilitate abundance of parasitoid populations (Bellows and Arakawa 1988).

The population densities of *B. argentifolii* and its parasitoids were not the same at each location in the study (Table 3). The numbers of whiteflies were consistently greatest in field 2F and lowest in field 8LW in each year. However, more ($P < 0.05$) *E. nigricephala* were collected from 8LW than either of the other locations during the three years. The rank order of abundance of the parasitoids varied among years for the locations. However, the field with the lowest whitefly capture consistently had a comparatively low ratio of whitefly to parasitoid. This suggests that low whitefly activity may not necessarily correspond to low parasitoid activity. Nevertheless, results from the different locations indicate a consistent trend of the insecticide treatment even though species composition and relative abundance differed.

The degree of migration by whitefly and parasitoids among plots is not known. Because of the duration of each sample period, i.e., 1 wk, it is suspected that some of the variability may have been from local migration. However, trends between the untreated and insecticide treated plots were consistent for each field, crop, and year. Abundance of *B. argentifolii* and its parasitoids can vary by field location, crop, and year. This study illustrates that *B. argentifolii* can be managed with a moderate regime of foliar applications of insecticide, and its parasitoids can still persist, albeit at re-

Table 3. Mean (±SEM) number of *B. argentifolii* and its parasitoids captured on yellow sticky cards at different field locations in vegetable crops during three years

Field location	Mean no. whiteflies per trap	Mean no. parasitoids per trap	Number of whiteflies per parasitoid
	1994		
2F	82.8 ± 10.8a	1.0 ± 0.1a	82.8
4B	72.0 ± 10.8a	0.8 ± 0.1a	90.0
8LW	31.2 ± 10.8b	1.3 ± 0.1a	24.0
	1995		
2F	26.2 ± 1.7a	2.4 ± 0.3b	10.9
4B	18.5 ± 1.7b	1.7 ± 0.3b	10.9
8LW	9.7 ± 1.7c	3.9 ± 0.3a	2.5
	1996		
2F	63.2 ± 4.2a	5.0 ± 0.4a	12.6
4B	50.2 ± 4.1b	3.1 ± 0.4b	16.2
8LW	15.3 ± 4.3c	2.5 ± 0.4b	6.1

Data are combined for insecticide treated and untreated plots. Means followed by the same letter within a column for each year are not significantly different ($P > 0.05$) according to the Student-Newman-Keuls test (SAS Institute 1994).

duced populations. We suspect that the parasitoids persist following insecticide applications in a manner similar to the whiteflies, i.e., by being protected during the immature stage and from local immigration.

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