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Apparent Parasitism of *Bemisia argentifolii* (Homoptera: Aleyrodidae) by Aphelinidae (Hymenoptera) on Vegetable Crops and Associated Weeds in South Florida

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Apparent parasitism of silverleaf whitefly, *Bemisia argentifolii* Bellows & Perring, by *Encarsia* spp. and *Eretmocerus* spp. was surveyed on several crop and weed species in southern Florida from 1990 to 1995. Apparent parasitism levels varied between crops, seasons, and years, but generally were high on okra and cotton among crops, lantana and Spanish needles among weeds. *E. pergandiella* Howard was the most dominant parasitoid species (43.7–100%), whereas incidence of *E. transvena* (Timberlake), *E. nigricephala* Dozier, *E. quaintancei* Howard, and *Eretmocerus* nr. *californicus* Howard varied by host plant and location. A greater proportion of *B. argentifolii* was parasitized by *E. pergandiella* on tomato than on collard and eggplant in a greenhouse choice test. © 1997 Academic Press

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The sweet potato whitefly, *Bemisia tabaci* (Gennadius), has been noted in Florida since the late 1880s (Quaintance, 1900), but was not considered a serious pest until 1986 (Hamon and Salguero, 1987; Price *et al.*, 1987). Increased pest status, attributed to invasion of a new biotype subsequently described as the species *B. argentifolii* Bellows & Perring (Perring *et al.*, 1993; Bellows *et al.*, 1994), coincided with a broadened host range and manifestation of new physiological disorders such as squash silverleaf and tomato irregular ripening (Maynard and Cantliff, 1989). The whitefly quickly became a major pest of broadleaf field crops, vegetables, and ornamental plants in California, Arizona, Texas, and Florida, where losses and control costs exceeded $200 and $500 million in 1991 and 1992, respectively (Faust and Coppedge, 1995).

Although chemical control has been the principal weapon used in these cropping systems, a diverse fauna of at least 11 parasitoid species attack *B. argentifolii* in Florida and the Caribbean (Osborne *et al.*, 1990; Polaszek *et al.*, 1992; Evans, 1993). This ensemble was considered responsible for much of the observed regulation of *B. argentifolii* populations on weeds in Florida during fallow periods, on a multicrop organic vegetable farm, and in unsprayed peanuts (Stansly *et al.*, 1994; Schuster, 1995; McAuslane *et al.*, 1993, 1994, 1995). These habitats were characterized by more plant diversity than conventional vegetable farms, and the absence of broad-spectrum insecticides.

One means of improving diversity and ecological stability of inherently unstable annual cropping systems might be provision of more refuge habitat for natural enemies as staging ground for crop colonization. Refuge crops should serve as a net source of natural enemies and therefore be long-lived relative to the main crop, attractive to parasitoids and predators, but less so to pest species. An example might be roselle (*Hibiscus sabdariffa* L.), which has been shown to provide a favorable environment for parasitoids in the Imperial Valley of California (Gruenhagen *et al.*, 1995; Roltsch and Pickett, 1995). However, estimates of relative attractiveness to parasitoids have been inconsistent over parasitoid species, locations, and cropping systems. Azab *et al.* (1969) found the greatest parasitism of *B. tabaci* by *Encarsia* sp. and *Eretmocerus* sp. on poinsettia (48.7%), followed by sweet potato (17.5%), tomato (13.7%), and last, cauliflower (8.8%), whereas Sharaf (1982) found apparent parasitism of *B. tabaci* by *Eretmocerus mundus* (Mercet) and *Encarsia* (*Prosaltella*) sp. in November to be greatest on pepper (90%), followed by cucumber (75%), bean (33.3%), eggplant (19.4%), tomato (13.1%), and squash (12.2%). Effects of host plants and varieties of cotton on parasitoid development and parasitism were evaluated by Kapadia and Puri (1991, 1993) and Li *et al.* (1987), who observed that trichome densities on the lower surface of leaves also influenced the searching behavior of *E. formosa* Gahan, parasitizing *Trialeurodes vaporariorum* (Westwood) on tomato. McAuslane *et al.* (1995) found in central Florida that *Encarsia nigricephala* Dozier and *E. transvena*

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(Timberlake) parasitized more whitefly on peanut and glabrous soybean than hairy soybean varieties, whereas the opposite tendencies were seen with *E. pergandiella* and *Eretmocerus* nr. *californicus*.

We evaluated relationships and interactions between dominant parasitoid species and the vegetable crops and associated weeds in southern Florida. Our objective was to obtain information on host plant effects on parasitism of *B. argentifolii* in the field. The ultimate goal is to design systems of crop associations that would enhance biological control of this pest.

MATERIAL AND METHODS

Field Crops and Weeds Investigated

The following host plants of *B. argentifolii* (10 crops and 10 weeds) were included in some or all surveys or experiments from 1990 to 1995. Crop species included collard (*Brassica oleracea* var. *acephalata* L. var "Georgia LS"), cotton (*Gossypium hirsutum* L., var. "Nacajuca," a cultivar of indeterminant growth habit obtained by P.A.S. in 1990 from Chontal Indians in Nacajuca, Tabasco), cowpea [*Vigna unguiculata* (L.) Walp, var. "Ironclay"], cucumber (*Cucumis sativus* L., var. "Dasher"), eggplant (*Solanum melongena* L., var. "Black Beauty"), green bean (*Phaseolus vulgaris* L., var. "Blue Lake"), okra [*Abelmoschus esculentus* (L.) Moench, var. "Spineless"], squash (*Cucurbita pepo* L., var. "Senator"), sweet potato [*Ipomoea batatas* (L.) Lam, var. "Carolina Bunch"], tomato (*Lycopersicon esculentum* Mill., several varieties), watermelon [*Citrullus lanatus* (Thunb.) Matsum. & Nakai, var. "Crimson Sweet"], and winter melon (*Cucumis melo indorus* Naud., var. unknown). Cotton was included in the study because it is a whitefly host plant often grown in association with vegetables, albeit not in south Florida. Weed species included Spanish needles (*Bidens* sp.), Ceaser weed (*Urena lobata* Cadillo), common ragweed (*Ambrosia artemisiifolia* L.), cutleaf ground cherry (*Physalis angulata* L.), hairy indigo (*Indigofera hirsuta* L.), hairy spurge (*Euphorbia hirta* L.), lantana (*Lantana* sp.), nightshade (*Solanum americanum* L.), primrose willow [*Ludwigia peruviana* (L.) Hara], southern sida (*Sida acuta* Burm.f.), spiny sonchus [*Sonchus asper* (L.) Hill], and wild poinsettia (*Euphorbia heterophylla* L.).

Replicated Plots, SWFREC

Summer 1990. Whitefly and parasitoid abundance was evaluated at Southwest Florida Research and Education Center (SWFREC) in Immokalee on the following crops: cotton, cowpea, cucumber, eggplant, green bean, okra, sweet potato, tomato, watermelon, and zucchini. Green bean, okra, and sweet potato were planted, and the others were transplanted between 5 and 10 May, 50 cm between plants in replicated ($n = 4$) 4-m plots on three single-row, polyethylene-covered beds 0.9 m wide on 1.8-m centers in a seepage-irrigated field. Crops overlapped approximately 1 month with 12 adjacent rows of whitefly-infested tomato. Ten weekly samples from 25 July to 25 September were taken from each plot and consisted of 1 leaf per plant for squash or 3 leaves per plant for other species. In addition, four plants each of four weed species located on adjacent ditch banks were sampled on 10 June and 27 July: hairy indigo, nightshade, primrose willow, and spurge. Samples were placed in plastic ziplock bags and refrigerated at 8 to 12°C until examined for parasitized and unparasitized whitefly pupae under a stereo microscope. Leaves without whitefly pupae were discarded and were not included in the analysis. Leaf areas were measured with a portable leaf area meter (LI-Cor, Model LI-3000A, Lincoln, NE). Leaves were separately placed in cardboard ice cream cans (0.5 liter) and stored in the laboratory for 3 to 4 weeks for emergence of whiteflies and parasitoids. Emerged whitefly adults and parasitoids, if any, were gently brushed into petri dishes and counted. Parasitoids were mounted on microscopic slides in Hoyer's medium for species identification. Apparent parasitism was computed as described by McAuslane *et al.* (1993):

$$P = 100 \times P_e \div (W_e + P_e),$$

where P is the percentage parasitism, P_e is the number of parasitoids emerged, and W_e is the number of whiteflies emerged.

Summer 1993. Four beds prepared at SWFREC as above were each divided into four 18-m plots, each planted in late spring to one of four crops: cotton, eggplant, okra, and cowpea in a randomized complete block design with four replications. Plots were located adjacent to 12 rows of infested tomato which was subsequently removed. Samples consisted of 10 leaves per plot collected at random at a height in the plant canopy consistent with the youngest foliage containing empty whitefly exuviae. In addition, samples were also taken from 3 rows of collard planted 6 months previously. The numbers of whitefly nymphs, pupae, and parasitized pupae in 4 cm^2 per leaf were determined in the laboratory under a stereoscopic microscope. Parasitoid adults were allowed to emerge in cardboard cans and processed for identification as described above.

Spring 1994. The field at SWFREC was divided into eight main plots each 73 m long by 16.5 m feet wide. Each plot contained two pairs of beds 0.9 m wide on 1.8-m centers. Pairs of beds were separated by a 4.5-m drive middle with 6.4 m between beds in adjacent plots. Rows adjacent to drive middles were planted on 25 February to tomato var. "Sunbeam," while the other row of each pair was divided into four subplots, two of which were randomly assigned to tomato and the other two either to zucchini var. "Senator" or to an alternating sequence of cucumber var. "Dasher," watermelon var. "Crimson Sweet," and winter melon. Weekly samples for whitefly immatures from 29 March to 3 May consisted of a single leaf from three randomly selected plants per plot, collected into plastic ziplock bags, and brought back to the laboratory. For tomato, three trifoliates from each leaf were taken from the sixth node from the top of each of the three randomly selected plants. For cucurbits, three plants were randomly selected from each plot, and the fifth leaf from the vine's terminal was selected. Whiteflies and parasitoids were allowed to emerge in cardboard cans and processed as above. Apparent parasitism was calculated for each plant, based on emerged whiteflies and parasitoid adults as described above.

Spring 1995. Tomatoes were planted either in 16 75-m single-row plots or in 16 12-m plots alternated with a row of eggplant of equal length. Plants were sampled and processed as above from 16 March through May 1995. Adult whitefly density was evaluated by striking a rectangular black pie pan (32 by 22 cm) coated with a 9:1 vegetable oil:detergent mixture in an upward sweep against the foliage. One leaf was sampled for immature whiteflies and parasitoids at the sixth node from the top of each of the three randomly selected plants per plot. Parasitism from microscopic examination was computed, and emerged adults were identified.

Organic Vegetable Farm 1992–1994

Incidence of whitefly and apparent parasitism was evaluated in a 12-acre field of organically grown vegetables on Pine Island, western Lee County in southwest Florida, where the only vegetable production was of pepper (rarely a source of *B. argentifolii*) with additional commercial production for at least 20 miles. The field was divided into 24 blocks about 200 m in length and four to eight beds in width. Beds were covered with polyethylene mulch and drip irrigated. Each block was subdivided into 10 to 18 plots 30 m in length and three or four beds wide. Blocks planted to eggplant or tomato were sampled at 2-week intervals from October 1992 to January 1993 and October 1993 to March 1994 by counting the number of whitefly nymphs and pupae on 4 cm^2 of foliage collected from the fifth to the seventh node depending on precollection observations to determine the youngest leaves to carry whitefly pupal exuviae. In addition, five leaves collected every 2 weeks from each plot were held in cylindrical cardboard cans in the laboratory for emergence of whitefly adults and parasitoids, which were counted and the latter mounted and identified as above.

Area-Wide Surveys

B. argentifolii was surveyed for parasitoids at nine locations in southern Florida: Bradenton (including Gulf Coastal Research & Education Center or GCREC), Homestead (three sites: Tropical Research & Education Center or TREC, Strano Farm, and Rainbow Farm), Immokalee (including SWFREC), Parish, and Ruskin, from January to May 1994. Surveyed plants included seven species of field crops: cotton, cowpea, collard, cucumber, eggplant, tomato, and watermelon; and 11 species of weeds surrounding the crop fields: *Bidens* sp., ceaser weed, common ragweed, hairy indigo, lantana, nightshade, primrose willow, southern sida, spiny sonchus, and wild poinsettia. Ten leaves containing whitefly nymphs or pupae were sampled from the upper to the lower canopy. Whiteflies and parasitoids were held in cardboard cans, and parasitoids were mounted and identified as described above. Additional weekly samples were used to survey for relative abundance of parasitoid species on seven field crop species at SWFREC from June 1993 to January 1994.

Choice Tests

Cage study. All but the top four of five to eight fully expanded leaves were removed from 30-cm-tall collard (Georgia LS), eggplant (Black Beauty), and tomato (Lanai). Plants were exposed for 48 h to a greenhouse colony of *B. argentifolii* at SWFREC on 9 December 1994, after which adults were removed using a handheld vacuum cleaner (BioQuip, Gardena, CA). Nine plants were randomly arranged in four wooden-frame screened cages (60 by 60 by 60 cm) and held for 14 days until whiteflies had reached late second or early third instar. Adult *E. pergandiella* were collected from a greenhouse colony using an aspirator, and 54 were introduced into each cage. All leaves were inspected 2 weeks later using a stereoscopic microscope to evaluate whitefly pupae and pupal exuviae for parasitism. Pubescence of the lower leaf surface was quantified by counting the number of hairs/cm^2 from 10 leaves subsampled from the top (young), middle (mid-aged) and bottom (old) of each test plant.

Greenhouse study. For this study to simulate field conditions, three rows, three plants each of tomato (Lanai), eggplant (Black Beauty), and squash (Dixie Hybrid) were set out in a randomized complete block design. At the ends of the rows were a total six weeds, two each of primrose willow, hairy indigo, and hairy spurge in 15-cm pots. Weeds had been previously infested with *B. argentifolii* parasitized with *E. pergandiella* in a separate greenhouse. The vegetables were placed on a bench in a greenhouse. Whiteflies and parasitoids from the weeds were allowed to colonize for 3 weeks, after which leaves bearing parasitized whitefly pupae were collected and placed into cylindrical ice cream cartons and held in the laboratory for emergence of whitefly and parasitoids.

Data Analysis

Data on percentage parasitism were subjected to analysis of variance (ANOVA), and mean percentages were separated using least significant difference test (LSD) following a significant *F* test at $P < 0.05$ (SAS Institute, 1988). Correlation between number of hairs on lower surface of tomato and eggplant in the choice tests and parasitism of *B. argentifolii* was determined using PROC CORR (SAS Institute, 1988).

RESULTS

Replicated Plots

Summer 1990. Whitefly incidence and apparent parasitism differed significantly among 10 crop species ($F = 14.8$ and 9.9 for whitefly and apparent parasitism respectively, $df = 9{,}264$, $P < 0.0001$). Significantly more whitefly pupae were observed on cucumber than all other crop species, followed by zucchini, eggplant and watermelon, with the fewest on sweet potato, cowpea, and cotton (Fig. 1). Apparent parasitism followed different trends, being highest on cotton, okra, and cowpea, although differences with other plants were not significant except for tomato. Apparent parasitism tended to increase over the season until plant quality declined and whitefly became too sparse to count. In contrast, long-lived and heat-loving crop species (sweet potato and cotton) maintained sufficient whitefly to support parasites through the summer.

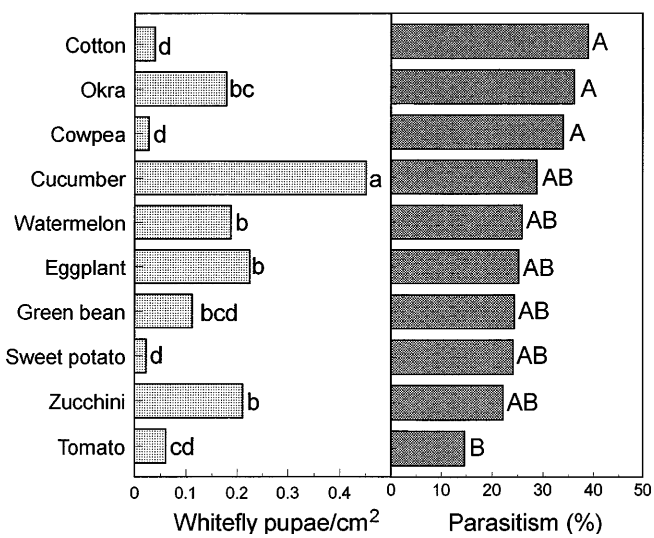

FIG. 1. Mean density and apparent parasitism of *B. argentifolii* pupae on 10 crop species over the period 25 July to 25 September, 1990 (Immokalee, FL).

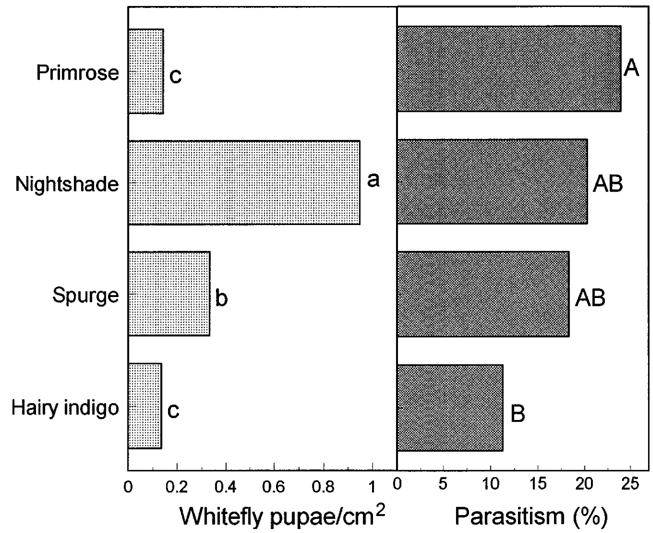

FIG. 2. Mean density and apparent parasitism of *B. argentifolii* pupae on each of four weed species and three crop species sampled on 20 and 27 June, 1990 (Immokalee, FL).

Whitefly populations and apparent parasitism also differed significantly among the four nearby weed species observed ($F = 40.1$ and 14.9 for whitefly and apparent parasitism, respectively; $df = 13$, 352; $P = 0.0001$). Most whitefly was seen on nightshade and least on primrose willow and hairy indigo, while most apparent parasitism was observed on primrose willow and least on hairy indigo (Fig. 2). Once again, trends in whitefly infestation did not correspond either positively or negatively to trends in apparent parasitism.

Summer 1993. Apparent parasitism differed significantly among five field crops, with the highest percentage (mean 56.4%) again observed on okra over the 5-week period from 24 June to 16 July (Table 1). The highest apparent parasitism on any one sample was also observed on okra: 88.4% on 6 July. Differences among other crops were not consistently significant, although the lowest overall apparent parasitism (11.8%) was seen on cowpea.

Spring of 1994 and 1995. The greatest apparent parasitism of *B. argentifolii* pupae among the five field crops evaluated in 1994 was seen on cucumber, tomato, and squash and the lowest on winter melon and watermelon, although differences were not significant ($F = 1.47$; $df = 4$, 81; $P = 0.22$) (Table 2). *E. pergandiella* tended to predominate on squash and tomato, while approximately equal proportions of *E. pergandiella* and *Eretmocerus* nr. *californicus* were seen on cucumber, watermelon, and winter melon.

Pan counts of adult whiteflies in 1995 were twice as high on eggplant (15.6 per sample, SE = 1.02) as tomato (8.9 per sample, SE = 0.70) in 1995. However, neither density of whitefly immature stages ($F = 1.53$, $df = 1$, 55; $P = 0.24$) nor apparent parasitism of whitefly pupae by *E. pergandiella* (the only species observed)

TABLE 1

Apparent Parasitism of *Bemisia argentifolii* Pupae by *Encarsia* spp. and *Eretmocerus* nr. *californicus* on 10 Leaves from Five Crop Host Species at Immokalee, Florida, in 1993

Host plant	Parasitism % ± SE (*n*)						
	Total pupae						
	24 June	29 June	6 July	12 July	16 July	Mean	Per 10 cm^2
Collard	38.3 ± 11.6 (14)b	23.8 ± 11.4 (7)b	23.6 ± 10.4 (15)b	15.6 ± 6.5 (22)b	28.6 ± 7.8 (22)b	25.4 ± 8.1 (80)bc	0.24 ± 0.04a
Cotton	65.3 ± 6.9 (32)a	2.9 ± 1.6 (27)b	24.6 ± 7.0 (29)b	27.6 ± 9.5 (18)ab	27.8 ± 10.1 (18)b	31.3 ± 3.7 (124)b	0.06 ± 0.01b
Cowpea	12.5 ± 12.5 (8)c	0.0 ± 0.0 (3)b	50.0 ± 50.0 (5)ab	0.0 ± 0.0 (1)b	0.0 ± 0.0 (3)b	11.8 ± 8.1 (20)c	0.01 ± 0.01b
Eggplant	25.8 ± 12.2 (11)cb	50.0 ± 18.9 (8)a	20.0 ± 20.0 (5)b	50.0 ± 28.9 (4)ab	5.6 ± 3.9 (15)b	24.8 ± 6.3 (43)bc	0.03 ± 0.01b
Okra	46.8 ± 7.6 (29)ab	7.7 ± 4.1 (28)b	88.4 ± 6.1 (23)a	79.2 ± 7.0 (27)a	71.9 ± 9.5 (19)a	56.4 ± 4.0 (126)a	0.04 ± 0.01b
F	5.0**	9.3**	15.9**	7.5**	11.6**	11.7**	23.9**

Means in the same column followed by the same letter do not differ significantly [$P > 0.05$, LSD (SAS Institute, 1988)].
** Significant at $P = 0.01$.

was different between these two crops ($F = 0.7$, $df = 1, 55$; $P = 0.62$) (Table 2).

Mixed Organic Vegetable Farm 1992–1994

Whitefly populations were relatively high on both tomato and eggplant early in the 1992–1993 season (Fig. 3). Apparent parasitism increased steadily over the season, reaching 80% on tomato and >80% on eggplant. Commensurately, whitefly populations declined, reaching their lowest point at crop maturity. Initial whitefly populations were lower during the 1993–1994 season on both tomato and eggplant, increasing to their highest point in the early November, then declining steadily (Fig. 3). Although parasitism rates were lower than the previous season, a similar pattern of decreasing whitefly population over the season was observed.

Area-Wide Survey

The predominant parasitoids reared from *B. argentifolii* in south Florida were three species of *Encarsia*, *E. pergandiella*, *E. transvena*, and *E. nigricephala*, and one species *Eretmocerus* nr. *californicus*. The highest overall whitefly apparent parasitism among crop host plants was observed on collard, eggplant, and okra and the lowest on squash and watermelon (Table 3). *E. pergandiella* predominated on all plant species, with *E. transvena* and *E. nigricephala* reaching their highest proportionate levels on cucumber and *Eretmocerus* nr. *californicus* on cotton. Among weed species, apparent parasitism of whitefly was highest on hairy indigo, *Bidens*, and lantana and lowest on ragweed, although these differences may reflect infestation levels to some degree, rather than relative attractiveness for parasitoids. *E. pergandiella* again predominated on all plant

TABLE 2

Apparent Parasitism of *B. argentifolii* Pupae and Relative Abundance of Parasitoid Species Reared from Leaves of Five Crop Species Spring (29 March to 10 May) 1994 and Spring (16 March to 10 May) 1995 (Immokalee, FL)

Host plant	Parasitism (%)	Parasitoids	Proportion (%) ± SE		
			Eretmocerus spp.	*E. pergandiella*	*E. nigricephala*
Spring 1994[a]					
Cucumber	34.5 ± 9.6	106	47.2 ± 8.5	41.6 ± 11.6	1.3 ± 1.3
Squash	24.3 ± 4.5	357	29.7 ± 10.4	65.5 ± 11.0	0.9 ± 0.6
Tomato	32.5 ± 5.6	179	34.2 ± 6.9	63.1 ± 9.2	0.8 ± 0.8
Watermelon	21.8 ± 6.4	36	50.6 ± 17.2	46.0 ± 16.9	3.4 ± 2.2
Winter melon	12.3 ± 3.4	29	50.7 ± 7.9	41.5 ± 12.1	7.8 ± 6.5
Spring 1995[b]					
Eggplant	15.9 ± 2.7	93		100.0 ± 0.0	
Tomato	14.8 ± 4.1	64		100.0 ± 0.0	

[a] Parasitism was calculated using the emerged whiteflies and parasitoid adults (see text for detail).
[b] Parasitism was calculated using the parasitized and unparasitized pupae from microscopic examination.

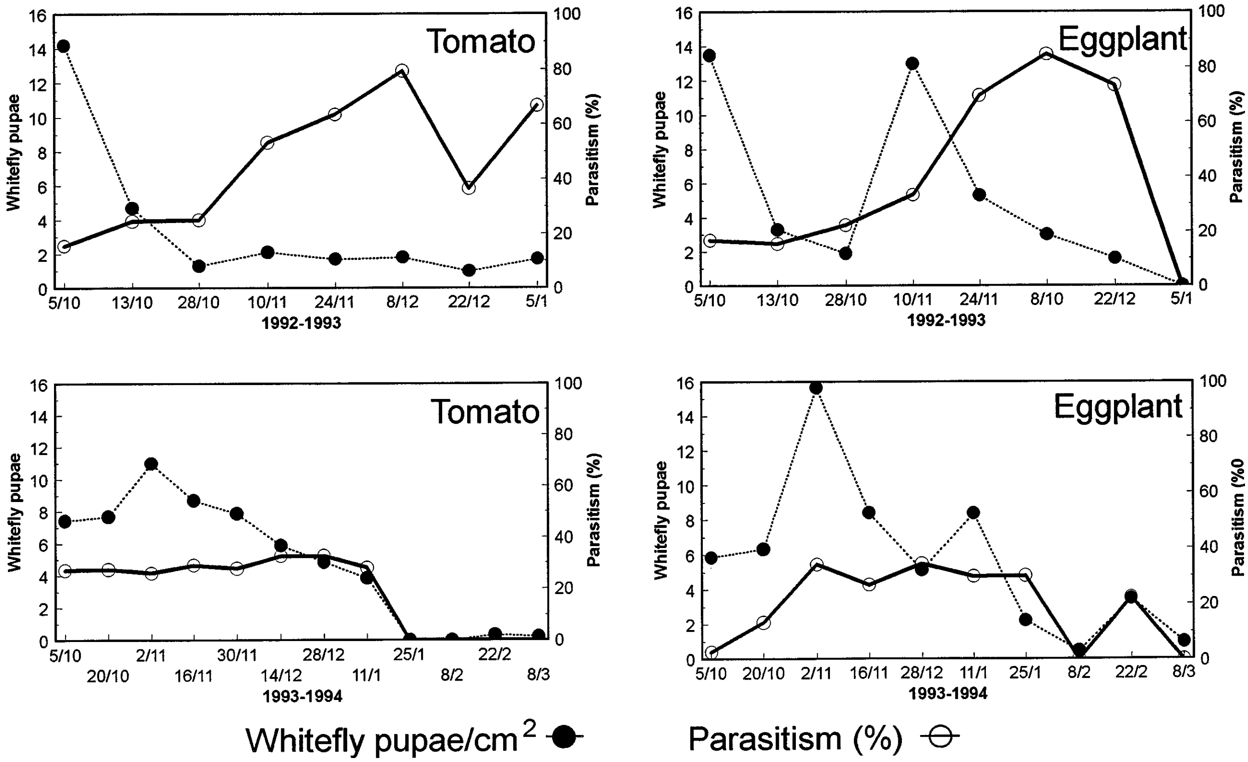

FIG. 3. Mean density and apparent parasitism of *B. argentifolii* pupae on tomato and eggplant during the 1992–1993 and 1993–1994 seasons at Pine Island Organics (Lee Co., FL).

TABLE 3

Apparent Parasitism and Relative Abundance of Parasitoids Reared from Pupae of *B. argentifolii* on 18 Plant Species (8 crops and 10 weeds) in Southern Florida from January to May 1994

						% Proportion			
Plants	Sites[a]	Samples (leaves)	Whiteflies emerged	Parasitoids emerged	Parasitism (%)	*E. pergandiella*	*E. transvena*	*E. nigricephala*	*Eretmocerus* sp.
Collard	I	9 (39)	170	172	49.7	86.6	5.2	1.7	5.2
Cotton	I	4 (35)	20	5	20.0	60.0	0.0	0.0	40.0
Cucumber	I	4 (19)	64	19	22.9	47.3	31.6	15.8	0.0
Eggplant	I	6 (20)	171	160	48.3	85.0	0.0	1.9	12.5
Okra	BI	4 (26)	93	74	44.3	90.5	2.7	0.0	6.8
Squash	H	2 (7)	112	4	3.4	100.0	0.0	0.0	0.0
Tomato	BHIR	19 (190)	573	114	16.6	81.6	1.8	0.9	8.8
Watermelon	B	1 (20)	64	2	3.0	100.0	0.0	0.0	0.0
Bidens sp.	H	5 (70)	19	21	52.5	85.7	1.0	0.0	0.0
Ragweed	HI	7 (72)	229	31	11.9	83.9	0.0	3.2	6.5
Ground cherry	IP	2 (20)	50	13	20.6	92.3	0.0	0.0	0.0
Hairy indigo	P	3 (40)	6	12	66.7	50.0	0.0	0.0	50.0
Lantana	H	2 (27)	2	2	50.0	100.0	0.0	0.0	0.0
Nightshade	BHIP	13 (120)	111	40	26.5	80.0	7.5	0.0	7.5
Primrose willow	BIPR	17 (161)	471	130	21.6	80.0	0.0	3.8	16.2
Southern sida	H	8 (94)	28	15	34.9	66.7	0.0	6.7	20.0
Spiny sonchus	BHIPR	27 (290)	1153	311	21.2	87.8	0.3	1.3	9.6
Wild poinsettia	HP	8 (110)	49	26	34.7	73.0	3.8	0.0	23.1

[a] Sites sampled in southern Florida are abbreviated as: B, Bradenton (including Gulf Coastal Research & Education Center or GCREC); H, Homestead (three sites: Tropical Research & Education Center or TREC, Strano Farm, and Rainbow Farm); I, Immokalee (including Southwest Florida Research & Education Center or SWFREC); P, Parish; R, Ruskin.

host species, with the highest relative abundance of *Eretmocerus* nr. *californicus* seen on hairy indigo. *E. transvena* and *E. nigricephala* were relatively rare.

Among the five species identified in seven field crops surveyed in June 1994 to January 1995 at SWFREC, *E. pergandiella* was again the predominant parasitoid species, constituting 30.3, 33.3, 46.4, 72.2, 75.5, 84.0, and 100% of parasitoids reared from watermelon, collard, okra, eggplant, cotton, and cowpea, respectively. *E. transvena* was only found on okra and cotton, where it was relatively rare (2.4 and 0.5%), and also on collard, where it contributed 12.8% to apparent parasitism. *E. nigricephala* was found on all crops to varying degrees except cowpea, with 60.6% relative abundance on watermelon, where it was encountered twice as often as *E. pergandiella*. In comparison, *E. nigricephala* represented 38.1% of parasitoids reared from okra, only slightly less than *E. pergandiella* (46.4%), but only 4.0 and 7.7% on tomato and cotton, respectively. Surprisingly, the incidence of *E. quaintancei* Howard, a previously unobserved species, was equal to that of *E. pergandiella* on collard in the fall (33.3%). The relative incidence of *Eretmocerus* nr. *californicus* was always less than 20%, constituting 19.2% of parasitoids reared from collard, 14.5% from eggplant and 12.4% from cotton.

Choice Tests

Significant differences in parasitization of *B. argentifolii* were observed among host plants in the cage study ($F = 5.6$; $df = 2, 119$; $P = 0.004$). The highest proportion of whiteflies were parasitized on tomato, with no significant differences between collard and eggplant (Table 4). Parasitization was not different among the three leaf positions on collard and tomato, although more whiteflies were parasitized on middle and bottom leaves of eggplant than top leaves ($F = 3.8$; $df = 2, 119$; $P = 0.025$). Leaf pubescence and parasitism among tomato leaves was negatively correlated ($r = -0.998$, $P = 0.039$), but not among eggplant leaves ($P = 0.5021$).

Colonization by *B. argentifolii* of the three crop hosts was comparable in the greenhouse study to simulate field conditions: 7.6 (±2.2) adults/cm^2 on eggplant, 11.2 (±3.0) on squash, and 10.9 (±1.0) on tomato. However, density of colonizing *E. pergandiella* was 0.1 (±0.1), 0.9 (±0.2), and 3.3 (±0.9) per cm^2 leaf surface of squash, eggplant, and tomato, respectively. As a result, apparent parasitism by *E. pergandiella* moving in from the weedy border was twice as high on tomato (21.7 ± 4.1%) as eggplant (10.3 ± 2.3%), with squash a distant third (1.6 ± 0.6%).

DISCUSSION

E. pergandiella was the most common species of parasitoid attacking *B. argentifolii* in south Florida. In comparison, *E. transvena* was reported to be the most common species observed in central Florida (Osborne *et al.*, 1990), while *E. nigricephala* was the most abundant species observed on peanuts in north central Florida (McAuslane *et al.*, 1993). Seasonal fluctuation of certain species of parasitoids was also found on different host plants and different seasons. Stansly *et al.* (1991) found that on tomato, *E. pergandiella* was the predominant species year round, while on nightshade *E. nigricephala* was the most common species during July to December, with *E. pergandiella* predominating from December to June. In southern California, Gerling (1966) reported that *E. pergandiella* was more abundant in the early season (spring) than the late season (fall).

The apparent preference of *E. pergandiella* for tomato compared with collard or eggplant at SWFREC and the negative correlation between hairiness of tomato and apparent parasitism (Table 4) could indicate a preference of the wasp for moderately hirsute leaf surfaces. De Ponti *et al.* (1990) and Li *et al.* (1987) reported that physical properties and structure of cucumber leaves, including number and density of trichomes, influenced the movement and search behavior of *E. formosa* parasitizing *T. vaporariorum* sufficiently to reduce whitefly biological control. They

TABLE 4

Apparent Parasitism of *B. argentifolii* Pupae by *E. pergandiella* on Three Crop Species in the Greenhouse, and Correlation between Parasitism and Pubescence of the Lower Leaf Surface (Immokalee, FL)

Host plant	Parasitism (%) ± SE				Hairs/cm^2 leaf area ± SE				Correlation (R)*
	Top leaf	Middle leaf	Bottom leaf	Overall	Top leaf	Middle leaf	Bottom leaf	Overall	
Collard	10.7 ± 2.9	8.8 ± 1.8	12.0 ± 2.2	10.5 ± 7.4b					
Eggplant	8.1 ± 1.3	14.2 ± 2.2	14.5 ± 2.0	12.2 ± 8.1b	10.1 ± 1.7	13.6 ± 2.2	25.6 ± 3.7	16.4 ± 2.5b	0.70
Tomato	14.1 ± 2.0	13.8 ± 2.0	19.6 ± 2.4	15.9 ± 3.5a	88.7 ± 4.3	88.0 ± 2.8	72.6 ± 3.4	83.4 ± 3.5a	−0.99*

Note. Means in the same column followed by the same letter do not differ significantly [$P > 0.05$, LSD (SAS Institute, 1988)].
* Significant at $P = 0.05$.

found that parasitoid movement was hampered on varieties with numerous, large trichomes, but was so rapid on glabrous varieties that hosts were overlooked. They observed the greatest parasitism on varieties with intermediate numbers of trichomes, which enhanced the movement and searching ability of parasitoids.

We observed higher rates of apparent parasitism in the field on moderately hirsute plants, such as okra and cotton, which could be used as companion refugia for less attractive crops. Abundant nectar may also add to the attractiveness of these and other Malvaceae. Although watermelon and winter melon hosted more *Eretmocerus* than *E. pergandiella*, overall parasitism was higher on squash, perhaps due to its relative preference by *E. pergandiella*. Weeds such as primrose willow, hairy indigo, spurge, and *Bidens* around field perimeters also serve as sources both of *B. argentifolii* and of parasitoids to colonize crops.

Higher levels of apparent parasitism were observed in organically grown vegetables than in plots at SWFREC, perhaps due to the absence of broad-spectrum insecticides and the relative isolation of the particular location on Pine Island from known sources of migrating whitefly. Furthermore, we evaluated the organic farm in the fall when whitefly populations were low and whitefly sources were primarily weeds. In contrast, field experiments at SWFREC were conducted in spring when whitefly populations were high and whitefly sources were nearby commercial vegetables. Nevertheless, the apparent ability of parasitoids to regulate whitefly at the organic farm demonstrated the potential of biological control of *B. argentifolii* on vegetables in Florida.

Rapid colonization by natural enemies would be required for successful biological control of *B. argentifolii* in ephemeral crops. Refuge crops and weedy margins may afford a means of providing stable populations of beneficial arthropods for rapid movement onto crop plants. For best effect, such refugia should be designed to accommodate key natural enemies such as (in south Florida) *E. pergandiella*. Our data indicate that moderately hirsute crops, especially okra, cotton, or weeds such as primrose willow, hairy indigo and lantana, may provide favorable characteristics as refugia.

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