

Laboratory and Field Evaluation of Exotic Parasitoids of *Bemisia tabaci* (Gennadius) (Biotype "B") (Homoptera: Aleyrodidae) in the Lower Rio Grande Valley of Texas

J. A. Goolsby, M. A. Ciomperlik, B. C. Legaspi, Jr.,* J. C. Legaspi,¹ and L. E. Wendel

USDA-APHIS-PPQ Mission Plant Protection Center, P.O. Box 2140, Mission, Texas 78573; and *USDA-ARS-SARC Beneficial Insects Research Unit, 2413 East Highway 83, Weslaco, Texas, 78596
E-mail: a348jgoolsby@attmail.com

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We evaluated a total of 38 exotic and 2 native parasitoid populations of the sweetpotato whitefly, *Bemisia tabaci* (Gennadius) (Biotype "B") (Homoptera: Aleyrodidae) (=silverleaf whitefly, *Bemisia argentifolii* Bellows and Perring), using laboratory and field experiments. Numbers of *B. tabaci* parasitized were counted in sleeve cages on cantaloupe melons (*Cucumis melo* L. cv "Perlita"), cotton (*Gossypium hirsutum* L. cv "Delta Pine 51"), and broccoli (*Brassica oleracea* L. cv "Patriot"). Highest attack rates were found for *Encarsia* nr. *pergandiella* (Hymenoptera: Aphelinidae) (Brazil) and *Eretmocerus mundus* Mercet (Spain) on melons; *Eretmocerus* sp. (Pakistan) on cotton; and *Eretmocerus mundus* (Spain) on broccoli. In the laboratory, these three exotic parasitoids attacked significantly greater numbers of hosts than the native species of *Encarsia pergandiella* Howard and *Eretmocerus tejanus* Rose and Zolnerowich. Selected exotic parasitoids were evaluated in the field using sleeve cages on melons, cotton, and kale (*Brassica oleracea* L. cv "Siberian kale"). *Eretmocerus* spp. from Spain and India performed well in all crop types. *Encarsia* nr. *pergandiella* (Brazil) performed well on melons, but not on kale or cotton. Selected exotic parasitoids were released at various sites throughout Hidalgo County in the Lower Rio Grande Valley of Texas. Of 29 populations released in the field, eleven were later recovered. Two *Eretmocerus* species (Spain and Pakistan) were commonly recovered throughout the evaluation period. This information will be used to prioritize the parasitoid cultures for mass rearing and release in biocontrol-based IPM programs against *B. tabaci*.

INTRODUCTION

As the primary quarantine facility for the importation of exotic natural enemies of the sweetpotato white-

fly (SPWF), *Bemisia tabaci* (Gennadius) (Biotype B) (Homoptera: Aleyrodidae) (= silverleaf whitefly, *Bemisia argentifolii* Bellows and Perring), the USDA-APHIS-PPQ, Mission Plant Protection Center (MPPC) in Texas has processed to date over 80 shipments of predators, parasitoids, and pathogens sent by collectors worldwide. *Bemisia tabaci* continues to be a serious pest of vegetables, cotton, and ornamentals across the U.S. subtropical growing areas and in greenhouses throughout the country, with estimates of the monetary costs to U.S. agriculture due to crop loss, job displacement, and cost of control approaching \$1B (Bezark, 1995). MPPC imported and cultured over 46 populations of *Encarsia* spp., *Eretmocerus* spp. (both Aphelinidae), and *Serangium* spp. (Coccinellidae), several of which were species new to science. The cost of maintaining these cultures, however, requires only those agents best able to suppress *B. tabaci* under specific environmental and agronomic conditions be retained for further rearing. The species identified through this research will receive priority in future mass rearing and field release efforts, although our findings may be specific to the release sites or areas with similar climates and host plants.

Field evaluations of exotic parasitoids of the SPWF were performed in Hidalgo County in the Lower Rio Grande Valley (LRGV), at the southern tip of Texas (98° 15' 00" W, 26° 24' 00" N), adjacent to the Mexican border (Fig. 1). Climate of the LRGV is subtropical, with year-round crop production. Evaluation of the various geographic strains or species of parasitoids studied at MPPC began in quarantine with an assessment of fecundity on selected crop plants (Goolsby *et al.*, 1996). Promising parasitoid populations² were then

¹ Present address: Texas Agricultural Experiment Station, The Texas A&M University System, 2415 East Highway 83, Weslaco, Texas 78596.

² Throughout this paper, we refer to the parasitoid strains or species under study as "populations" because of the ambiguous systematics of *Encarsia* and *Eretmocerus* species. Quarantine cultures are initially separated according to geographic location and plant host type, but may be joined together if evidence, such as

reared and released onto these same crops in the field in order to measure rates of parasitism under field conditions. To determine if release populations became established, whitefly populations were sampled periodically and whitefly nymphs reared to recover parasitoids. In this study, we report results of these evaluations for 38 exotic and two native parasitoid populations.

MATERIALS AND METHODS

Insect Cultures

Tentative species identifications and unique identification numbers (assigned by MPPC) for each of the 38 exotic and 2 native parasitoid populations studied are listed in Table 1. The native *Eretmocerus* species, *E. tejanus* Rose and Zolnerowich and *E. staufferi* Rose and Zolnerowich are recently described species (Rose and Zolnerowich, 1997). Each population is also characterized by the country from which the population was collected, the collector name(s), host plant, date of collection, and the mode of reproduction. Populations are also differentiated by characteristic DNA patterns obtained using RAPD-PCR techniques (Black *et al.*, 1992; Vacek *et al.*, 1996). Detailed methodology and representative electrophoretic gel patterns for *Eretmocerus* and *Encarsia* parasitoids are contained in Legaspi *et al.* (1996). The whiteflies used as hosts for experiments and for rearing of parasitoid cultures were maintained on hibiscus (*Hibiscus rosasinensis* L.) in environmental growth chambers as described in Goolsby *et al.* (1996) (24–29°C, 50–70% RH, 14:10 L:D photoperiod).

Specimens of all exotic and native parasitoids were vouchered at the Systematic Entomology Laboratory, U.S. National Museum (Washington, DC). Furthermore, original parental material imported into MPPC Quarantine was sent to Texas A&M University. Cohorts of the original parental material were also vouchered at the MPPC Genetic Diagnostic Laboratory.

Laboratory Evaluation

The purpose of our laboratory evaluation tests was to compare the fecundity of the exotic parasitoids on selected crops using the methods of Goolsby *et al.* (1996). Melons (*Cucumis melo* L. cv “Perlita”), cotton (*Gossypium hirsutum* L. cv “Delta Pine 51”), and broccoli (*Brassica oleracea* L. cv “Patriot”) were chosen for the screening because of the considerable economic losses occurring annually on these crops due to *B. tabaci* in the LRGV. The results of these tests were used

to choose exotic populations for further field evaluation in selected field crops.

Plants were grown in pots using Sunshine Mix. No. 1 (Sun Gro Horticulture, Inc., Bellevue, WA) and maintained in the MPPC quarantine greenhouse facility under temperatures and photoperiod similar to field conditions for each crop throughout the screening test. When the plants were 3–4 weeks old, they were infested with adult SPWF and held 2 days for oviposition. From each plant, one leaf with 100–300 eggs was selected for use in experiments. All adult whitefly were removed from test leaves, which were then covered with organza sleeves. Plants were held until the nymphs developed into 1st- or 2nd-instars for the *Eretmocerus* tests and 3rd- or 4th-instars for the *Encarsia* tests. Two presumably mated parasitoid females from a mixed-age culture were released per sleeve, allowed to parasitize whiteflies for 2 days, and were then removed (see Goolsby *et al.*, 1996). Tests for each parasitoid population were replicated 10 times and the entire test was conducted twice. Leaves were removed from the plant 15 days after introduction of the parasitoids and examined for evidence of parasitism. The numbers of parasitized whiteflies were determined on each test leaf.

Field Evaluation

Field evaluations were done using sleeve cages to compare performance of parasitoids in the laboratory tests with parasitism rates under more realistic conditions. Host crops selected were melons (cv “Perlita”) (spring 1995), cotton (cv “Delta Pine 51”) (summer 1995), and kale (*Brassica oleracea* L. cv “Siberian kale”) (winter 1995). Leaves of each crop were selected for experimentation if they were free from contamination by lepidopteran larvae or aphids, and if they had 500–750 whitefly eggs. A sleeve cage was placed over the leaf and tied at the proximal end with a twist tie. This process was repeated until all selected leaves were caged. The parasitoid populations selected for study were separated from laboratory cultures as pupae in small (25-cm³ Plexiglas) organza screened cages. Adult parasitoids were allowed to emerge in the cages and mate. All adult parasitoids were aspirated from each cage every 24 h to insure a uniform age of parasitoids used in the field evaluation. Parasitoids were collected by placing a ¼ dram vial over a wasp until it walked into the vial. The open end of the vial was then sealed with a cotton plug to prevent escape. Adults were sexed using a stereomicroscope and females held for experiments.

Forty females from each population were isolated only hours before release into the sleeve cages. When whitefly immatures were in mixed stages of 2nd- and 3rd-instars, two single female *Eretmocerus* parasitoids

RAPD-PCR, indicates they are not distinguishable. Some of the parasitoids used in this study are clearly new species, but the phylogenetic status of others remains uncertain.

TABLE 1

Parasitoids For Biological Control of *Bemisia tabaci*

Identification	ID No.	DNA	Origin	Collector	Date	Host plant	Reproduction
<i>Encarsia</i> nr. <i>strenua</i>	M92018	EN-1	Parbhani, India	Nguyen	1/92	Not recorded	Autoparasitoid
<i>Encarsia</i> nr. <i>strenua</i>	M95023	EN-1	Thailand	Legaspi and Carruthers	3/95	Not recorded	Autoparasitoid
<i>Encarsia formosa</i> Gahan	M92017	EN-2	Angelohori, Greece	Kashefi	1/92	Bean ^a	Uniparental
<i>Encarsia formosa</i>	M92030	EN-2	Nile Delta, Egypt	Kirk and Lacey	1/92	Lantana	Uniparental
<i>Encarsia formosa</i>	M94051	EN-2	Thailand	Kirk and Lacey	3/94	<i>Cucurbita</i> sp.	Uniparental
<i>Encarsia transvena</i> Timberlake	M94017	EN-3	Shan-Hua, Taiwan	Legaspi, Carruthers, Poprawski	3/94	Poinsettia (<i>Euphorbia pulcherrima</i> Willd. ex Koltzch)	Autoparasitoid
<i>Encarsia transvena</i>	M94019	EN-4	Taiwan	Legaspi, Carruthers, Poprawski	3/94	Soybean (<i>Glycine max</i> (L.) Merr.)	Autoparasitoid
<i>Encarsia transvena</i>	M94041	EN-5	Chiang Mai, Thailand	Kirk and Lacey	3/94	Poinsettia	Autoparasitoid
<i>Encarsia transvena</i>	M94047	EN-5	Kuala Lumpur, Malaysia	Kirk and Lacey	3/94	<i>Mussaenda</i> sp.	Autoparasitoid
<i>Encarsia transvena</i>	M93003	EN-7	Murcia, Spain	Kirk and Lacey	1/93	Lantana	Autoparasitoid
<i>Encarsia lutea</i> Masi	M93064	EN-10	Mazotos, Cyprus	Mercadier and Lacey	1/93	Lantana	Autoparasitoid
<i>Encarsia lutea</i>	M94107	EN-10	Givat Haim, Israel	Kirk and Lacey	10/94	Cotton	Autoparasitoid
<i>Encarsia lutea</i>	M94115	EN-10	Ein Gedi, Dead Sea Israel	Kirk and Lacey	10/94	Lantana	Autoparasitoid
<i>Encarsia lutea</i>	M94129	EN-10	Mazarron Casas Nuevas, Spain	Kirk and Lacey	11/94	<i>Ipomoea</i> sp.	Autoparasitoid
<i>Encarsia transvena</i>	M94014	EN-11	Benguet, Philippines	Legaspi, Carruthers, Poprawski	3/94	White potato (<i>Solanum tuberosum</i> L.)	Autoparasitoid
<i>Encarsia transvena</i>	M94016	EN-11	Shan-Hua, Taiwan	Legaspi, Carruthers, Poprawski	3/94	Poinsettia	Autoparasitoid
<i>Encarsia</i> sp. (Parvella group)	M95001	EN-12	Azua, Dominican Republic	Ciomperlik	1/95	Tomato (<i>Lycopersicon esculentum</i> Mill.)	Autoparasitoid
<i>Encarsia</i> nr. <i>pergandiella</i>	M94055	EN-15	Sete Lagoas, Brazil	Rose	2/94	Poinsettia, soybean	Uniparental
<i>Encarsia</i> nr. <i>hispida</i>	M94056	EN-16	Sete Lagoas, Brazil	Rose	2/94	Poinsettia, soybean	Uniparental
<i>Eretmocerus mundus</i>	M92014	ERET-1	Murcia, Spain	Kirk, Chen and Sobhain	1/92	Cotton	Biparental
<i>Eretmocerus mundus</i>	M92019	ERET-1	Padappai, India	Kirk and Lacey	1/92	Eggplant	Biparental
<i>Eretmocerus mundus</i>	M92027	ERET-1	Cairo, Egypt	Kirk and Lacey	1/92	Lantana	Biparental
<i>Eretmocerus mundus</i>	M93058	ERET-1	Tainan, Taiwan	Moomaw	12/93	Tomato	Biparental
<i>Eretmocerus mundus</i>	M94085	ERET-1	Frascati, Italy	Kirk and Campobasso	9/94	<i>Hibiscus</i> sp.	Biparental
<i>Eretmocerus mundus</i>	M94092	ERET-1	Castel Gondolfo, Italy	Kirk and Campobasso	9/94	<i>Ipomoea</i> sp.	Biparental
<i>Eretmocerus mundus</i>	M94103	ERET-1	Gat, Israel	Kirk and Lacey	10/94	Kohlrabi (<i>B. oleracea</i> var. <i>gongylodes</i> L.)	Biparental
<i>Eretmocerus mundus</i>	M94105	ERET-1	Gat, Israel	Kirk and Lacey	10/94	<i>Sonchus</i> sp.	Biparental
<i>Eretmocerus mundus</i>	M94120	ERET-1	Golan Ma'Alah Gamla, Israel	Kirk and Lacey	10/94	Melons	Biparental
<i>Eretmocerus mundus</i>	M94124	ERET-1	Negev Desert, Israel	Kirk and Lacey	10/94	Cucumber (<i>Cucumis sativus</i> L.)	Biparental
<i>Eretmocerus mundus</i>	M94125	ERET-1	Golan Kibutz, Israel	Kirk and Lacey	10/94	<i>Euphorbia</i> sp.	Biparental
<i>Eretmocerus</i> sp.	M93005	ERET-2	India	Kirk and Lacey	1/93	Not recorded	Biparental
<i>Eretmocerus</i> sp.	M94023	ERET-3	Sai Noi Klong Ha Roi, Thailand	Kirk and Lacey	3/94	Eggplant, melon	Biparental
<i>Eretmocerus</i> sp.	M94036	ERET-3	Thailand	Kirk and Lacey	3/94	<i>Chromolaena odorata</i> (L.) King & Robinson	Biparental
<i>Eretmocerus</i> sp.	M94040	ERET-3	Kampang Saen, Thailand	Kirk and Lacey	3/94	Cotton	Biparental
<i>Eretmocerus</i> sp.	M95097	ERET-3	Taiwan	Talekar and Jones	10/95	Tomato	Biparental
<i>Eretmocerus staufferi</i>	M94002	ERET-5	College Station, Texas	Rose and Stauffer	94	Tomato	Biparental
<i>Eretmocerus tejanus</i>	M94003	ERET-6	Mission, Texas	Rodriguez	1/94	Cabbage (<i>Brassica</i> sp.)	Biparental
<i>Eretmocerus</i> sp.	M95012	ERET-10	Multan, Pakistan	Kirk and Akey	4/95	Eggplant	Biparental
<i>Eretmocerus</i> sp.	M95026	ERET-11	Chiujju, Taiwan	Kirk	5/95	Cabbage	Biparental
<i>Eretmocerus</i> sp.	M95104	ERET-12	United Arab Emirates	Porter and Romadan	11/95	Okra	Biparental

Note. Parasitoids used in this study are listed by identification, identification number, DNA banding pattern (D. Vacek, Mission Plant Protection Center), country of collection, collector(s), date of importation into the US, host plant, and mode of reproduction. Parasitoids were collected from host insects in the *Bemisia tabaci* complex, except where noted as: ^acollected on *Trialeurodes vaporariorum* (Westwood) (Aleyrodidae) (Whitefly identifications by R. Gill, California Dept. Food & Agric., Sacramento, CA).

were introduced into the sleeve cages, following the methods described in Goolsby *et al.* (1996). *Encarsia* spp. parasitoids were introduced during the 3rd- to 4th-instar stage. There were 20 replicates for each parasitoid population, with control sleeves without parasitoids. Controls were used to verify that the whitefly were not contaminated by preexisting parasitism. Female parasitoids were allowed to oviposit for a period of 15 days. Each sleeved leaf was cut from the plant and the entire sleeve cage was then returned to the laboratory where counts of whitefly exuviae and parasitized pupae were taken immediately.

Inoculative Establishment Evaluation

Prerelease studies were conducted twice at each release site to characterize the native parasitoid complex and measure any effects induced by releases of exotic parasitoids. Sampled plants included: okra (*Abelmoschus esculentus* L. Moench.), eggplant (*Solanum melongena* L.), cucurbits, broccoli, hibiscus, Wedelia (*Wedelia trilobata* (L.)), sowthistle (*Sonchus oleraceus* L.), and lantana (*Lantana camara* L.). Twenty leaves containing 4th-instar SPWF were removed from each host plant available at each release site. The leaves were held in paper containers streaked with honey and placed inside a humiditron (DeBach and Rose, 1985) at

~26°C and 70% RH for 30 days. Adult parasitoids that emerged were collected and identified.

Parasitoids were released systematically at various urban and agricultural areas throughout Hidalgo County (Fig. 1). Release sites contained host crops such as melons, okra, eggplant, cabbage (*B. oleracea*), the leguminous forage crop *Lablab purpureus* (L.), and broccoli in a year-round planting schedule. Ideal release sites also contained woody perennial hosts such as hibiscus and *Lantana* sp. Each release location served as a perennial refuge for the natural enemies where broad spectrum insecticide applications were prohibited and plants were irrigated as necessary. Each site received a combination of populations which could be morphologically and/or genetically distinguished from each other and from the native species by DNA patterns using RAPD-PCR techniques (Black *et al.*, 1992). Release rates of the various parasitoid populations were determined by their availability from laboratory rearings. Those easier to rear and available in abundant numbers were released at higher rates. However, releases were not limited to those populations that performed well in the laboratory. Releases were made from May to August 1995. Sites were sampled every 2 weeks from June 1995 to November 1995, and monthly thereafter from December 1995 to July 1996 using the same techniques as in the prerelease evaluations.

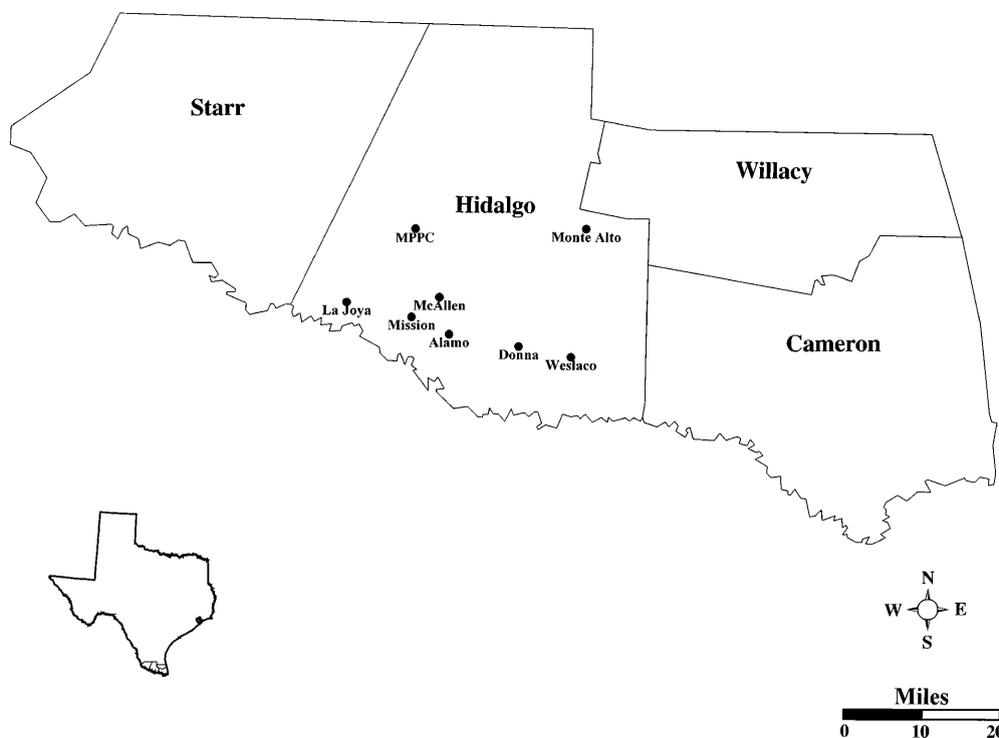


FIG. 1. Release/recovery sites for establishment evaluation of exotic parasitoids. Location of Hidalgo County is highlighted in map of Texas. Hidalgo County map shows location of release sites drawn according to scale.

Statistical Analysis

Statistical analyses were performed using SAS (SAS, 1994). Data for the laboratory and field evaluations were pooled across host plants. The number of whiteflies parasitized was the independent variable, and treatment factors were the host plant and parasitoid population. Total number of whitefly was treated as a covariate. Means effects of the parasitoid population were separated using Fisher's Least Significant Difference (LSD) test with error limits set at $P = 0.05$. The field and laboratory data were also analyzed separately by host plant to determine whether different parasitoid populations attacked higher numbers of whitefly on specific host plants. In these analyses, the numbers of hosts attacked were again the independent variable, the treatment factor was the parasitoid population, and the number of whitefly was specified as the covariate variable.

RESULTS AND DISCUSSION

Laboratory Evaluation

Analysis of the pooled data indicated significant treatment effects (Model: $F = 11.7$; $df = 31$, 857; $P < 0.01$). The population of parasitoid tested had a highly significant effect ($F = 12.1$; $df = 28$, 857; $P < 0.01$), as did host plant used ($F = 6.4$; $df = 2$, 857; $P < 0.01$). Total numbers of whitefly did not cause significant effects as a covariate ($F = 0.6$; $df = 1$, 857; $P = 0.45$), although numbers of whitefly were affected by host plant ($F = 8.0$; $df = 2$, 894; $P < 0.01$). Mean numbers of whitefly per leaf were: broccoli, 304.4 (SE = 10.1; N = 353); cotton, 280.2 (SE = 15.5; N = 183); and melons, 243.2 (SE = 11.5, N = 361). The whitefly counts for melons were significantly lower than for the other two host plants (LSD, $P < 0.05$). The numbers of hosts attacked were significantly affected by host plant ($F = 9.3$; $df = 2$, 893; $P < 0.01$), although the number of whitefly had no covariate effect ($F = 0.004$; $df = 1$, 893; $P = 0.9$). Significantly higher numbers of whitefly were parasitized on broccoli (mean = 21.6; SE = 1.2; N = 353) than on cotton (mean = 16.4; SE = 1.6; N = 183) or melons (mean = 14.7; SE = 1.1; N = 361) (LSD $P < 0.01$). The results of the laboratory evaluations are summarized in Table 2.

When data were analyzed separately by host plant, different populations appeared to attack more whitefly when on specific host plants. In the melon test, the effect of parasitoid population was again highly significant ($F = 7.2$; $df = 17$, 342; $P < 0.01$), while number of whitefly was not a significant covariate ($F = 1.5$; $df = 1$, 342; $P = 0.2$). *Eretmocerius mundus* (M92014, Spain) and *Encarsia nr. pergandiella* (M94055, Brazil) attacked significantly higher numbers of hosts, relative

TABLE 2

Laboratory Evaluation (pooled data)

Identification	ID No.	Origin	N	Mean no. attacked	LSD group
<i>Eretmocerius mundus</i>	M92014	Spain	46	44.7	a
<i>Eretmocerius</i> sp.	M95012	Pakistan	28	41.8	a
<i>Eretmocerius mundus</i>	M94092	Italy	19	38.9	ab
<i>Encarsia</i> sp. (parvella group)	M95001	Dominican Republic	20	36.4	abc
<i>Encarsia nr. strenua</i>	M95023	Thailand	9	27.4	bcd
<i>Eretmocerius</i> sp.	M93005	India	48	26.4	cde
<i>Encarsia nr. pergandiella</i>	M94055	Brazil	50	24.9	cde
<i>Eretmocerius mundus</i>	M94120	Israel	48	24.8	de
<i>Eretmocerius mundus</i>	M92019	India	50	24.1	def
<i>E. pergandiella</i>	(none)	native	19	24.0	cde
<i>Encarsia nr. hispida</i>	M94056	Brazil	49	18.1	defg
<i>Eretmocerius mundus</i>	M92027	Egypt	10	17.3	defgh
<i>Eretmocerius mundus</i>	M93058	Taiwan	27	16.9	defghi
<i>Eretmocerius</i> sp.	M94040	Thailand	66	15.2	efghi
<i>Encarsia transvena</i>	M94019	Taiwan	17	13.1	fghij
<i>Eretmocerius tejanus</i>	M94003	Texas	40	12.8	fghij
<i>Eretmocerius</i> sp.	M95104	UAE	9	11.9	ghijk
<i>Eretmocerius</i> sp.	M95026	Taiwan	20	10.9	ghijk
<i>Encarsia lutea</i>	M94107	Israel	69	8.8	ghijk
<i>Encarsia transvena</i>	M94014	Philippines	18	8.1	ghijk
<i>Encarsia</i> sp. nr.					
<i>strenua</i>	M92018	India	30	8.0	ghijk
<i>Encarsia transvena</i>	M93003	Spain	20	6.8	ghijk
<i>Eretmocerius stauferi</i>	M94002	Texas	30	6.1	hijk
<i>Encarsia transvena</i>	M94047	Malaysia	42	5.8	hijk
<i>Encarsia transvena</i>	M94016	Taiwan	38	5.5	ijk
<i>Eretmocerius nr. mundus</i>	M94092	Italy	10	2.9	jk
<i>Eretmocerius</i> sp.	M95097	Taiwan	10	2.1	jk
<i>Encarsia transvena</i>	M94017	Taiwan	10	1.6	jk
<i>Encarsia transvena</i>	M94041	Thailand	9	0.8	k

Note. Parasitoids are listed by preliminary identification, unique identification number, country of collection, sample size (N = number of replicate leaves), numbers of hosts attacked, and LSD grouping (common letters are not significantly different at $P = 0.05$).

to the other populations (LSD, $P < 0.05$) (Fig. 2A). In broccoli, significantly higher numbers of hosts ($F = 12.4$; $df = 19$, 332; $P < 0.01$) were attacked by the *Eretmocerius mundus* from Spain (M92014) (LSD $P < 0.05$) (Fig. 2B). In cotton, *Eretmocerius* sp. (M95012, Pakistan) attacked significantly more SPWF than the other populations tested ($F = 8.8$; $df = 15$, 166; $P < 0.01$; LSD $P < 0.05$) (Fig. 2C). Whitefly number was again not a significant covariate ($F = 2.0$; $df = 1$, 166; $P = 0.16$).

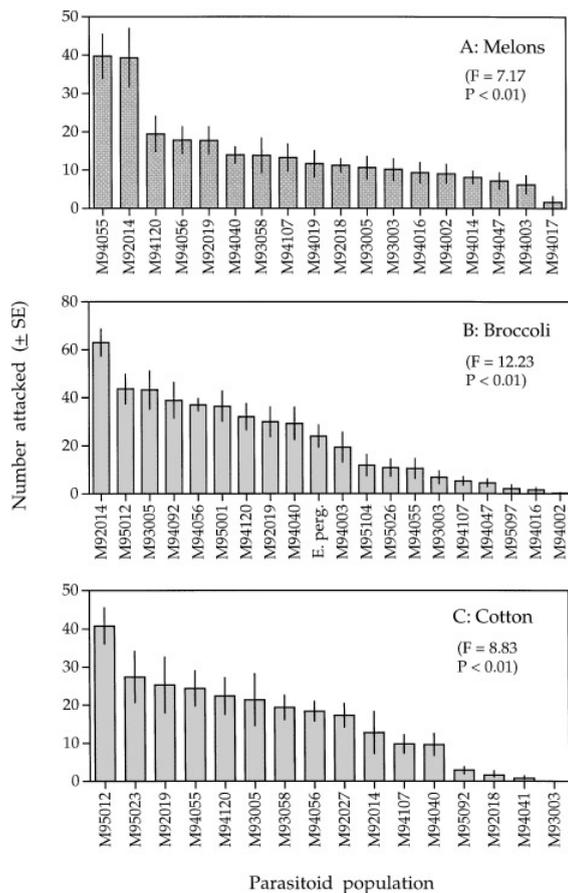


FIG. 2. Numbers of whitefly hosts attacked by different parasitoid populations in laboratory on melons (A), broccoli (B), and cotton (C).

Field Evaluation

Analysis of the pooled field data showed significant effects (Model: $F = 4.2$; $df = 13, 218$; $P < 0.01$) due to the parasitoid population tested ($F = 3.9$; $df = 2, 218$; $P < 0.01$), as well as a covariate effect due to host numbers ($F = 8.3$; $df = 1, 218$; $P < 0.01$). However, host plant had no significant effect ($F = 2.2$; $df = 2, 218$; $P = 0.11$). Across all field treatments, highest numbers of hosts attacked were found for *Eretmocerus mundus* populations from Spain (M92014) and India (M92019). These results are summarized in Table 3. In the field melons, no significant effects were found due to parasitoid population ($F = 0.88$; $df = 7, 80$; $P = 0.5$) or numbers of hosts ($F = 3.6$; $df = 1, 80$; $P = 0.06$) (Fig. 3A). Similarly, no parasitoid effect was found in the field cotton experiments ($F = 1.9$; $df = 4, 66$; $P = 0.1$), although host numbers had a highly significant covariate effect ($F = 40.9$; $df = 1, 66$; $P < 0.01$) (Fig. 3B). This result indicates that any differences in numbers of hosts attacked were due to variations in the numbers of hosts available, rather than to differences in efficacy of the parasitoid populations. However, in the field kale test, parasitoid population produced a highly signifi-

TABLE 3

Field Evaluation (Pooled Data)

Identification	ID No.	Origin	<i>N</i>	Mean no. attacked	LSD group
<i>Eretmocerus mundus</i>	M92014	Spain	47	27.5	a
<i>Eretmocerus mundus</i>	M92019	India	40	19.1	ab
<i>Encarsia lutea</i>	M93064	Cyprus	9	15.2	abc
<i>Eretmocerus</i> sp.	M94023	Thailand	14	14.6	abc
<i>Eretmocerus mundus</i>	M94120	Israel	31	12.1	bc
<i>Encarsia lutea</i>	M94107	Israel	13	12	bc
<i>Eretmocerus</i> sp.	M95012	Pakistan	17	11.8	bc
<i>Eretmocerus</i> sp.	M94036	Thailand	12	10.7	bc
<i>Encarsia</i> nr. <i>pergandiella</i>	M94055	Brazil	22	8.8	bc
<i>Encarsia transvena</i>	M93003	Spain	22	4.7	bc
<i>Encarsia</i> sp. nr. <i>strenua</i>	M92018	India	5	3.4	c

Note. Format identical to Table 2.

cant effect ($F = 5.6$; $df = 4, 63$; $P < 0.01$), while host numbers was not a significant covariate ($F = 0.9$; $df = 1, 63$; $P = 0.3$). Highest numbers of hosts attacked were found in the *Eretmocerus* spp. from Spain (M92014) and India (M92019) (Fig. 3C) (LSD $P < 0.05$).

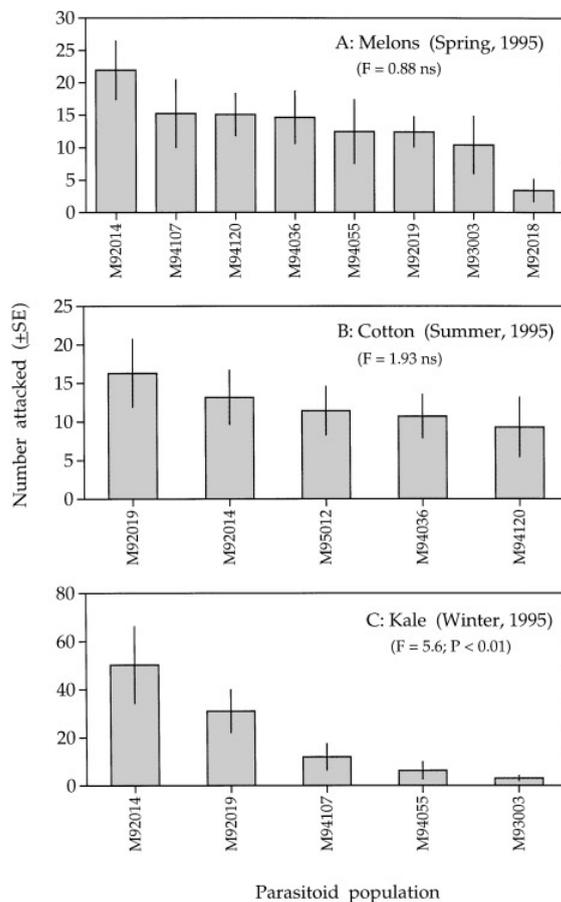


FIG. 3. Numbers of whitefly hosts attacked by different parasitoid populations in field on melons (A), cotton (B), and kale (C), evaluated during spring, summer, and winter, 1995, respectively.

TABLE 4

Releases and Recoveries of Parasitoids from Inoculative Establishment Evaluation

ID number	Population and origin	Release site	Plant host	Release date	Release (1000s)	Recovery
M92014	<i>Eretmocerus mundus</i> (Spain)	Donna	Okra, broccoli, sowthistle	5-6/95	157	5 (35)
		McAllen	Okra	5-6/95	40	2 (2)
		Mission	<i>Malvastrum</i>	8/95	0.5	1 (6)
		La Joya	Cotton	6/94	50	5 (32)
M95012	<i>Eretmocerus sp.</i> (Pakistan)	Mission	Broccoli	8/95	2	1 (2)
		Donna	Okra, broccoli, sowthistle	5-6/95	60	5 (20)
M92019	<i>Eretmocerus mundus</i> (India)	Monte Alto	Okra	N/A	(Dispersal from okra)	1 (1)
		Monte Alto	Prostrate spurge (<i>Euphorbia supina</i> Raf.)			
M93003	<i>Encarsia transvena</i> (Spain)	McAllen	Turks cap (<i>Malva viscus arboreus</i> Cav. var "Mexicanis")	5-6/95	60	1 (1)
M94056	<i>Encarsia nr. hispida</i> (Brazil)	Monte Alto	Lablab	8/95	2.4	2 (2)
M94085	<i>Eretmocerus mundus</i> (Italy)	Delta Lake	Hibiscus	7/95	0.2	1 (1)
M94120	<i>Eretmocerus mundus</i> (Israel)	Edinburg	Cauliflower (<i>Brassica</i> sp.)	6/95	1.0	1 (1)
M93064	<i>Encarsia lutea</i> (Cyprus)	McAllen	Wedelia	5-6/95	5.6	1 (1)
M93005	<i>Eretmocerus sp.</i> (India)	McAllen	Wedelia	5-6/95	3.2	1 (1)
		La Joya	Cotton	6/94	50	2 (4)
M94047	<i>Encarsia transvena</i> (Malaysia)	Mission	Okra	7/95	36	1 (1)
M94002	<i>Eretmocerus staufferi</i> (Texas)	La Joya	Cotton	6/94	50	2 (6)

Note. Parasitoid populations are identified by identification number, preliminary identification and country of collection. Release/recovery sites (Fig. 1) indicate host plant used, approximate release rate (in thousands) and period of release. Recovery rate shows numbers of times the exotic was recovered; numbers in parentheses indicate numbers of individuals recovered. Recoveries were attempted every 2 weeks from June 1995 to November 1995, and monthly thereafter from December 1995 to July 1996.

Inoculative Establishment Evaluation

The prerelease evaluations of the field sites revealed that the dominant native parasitoid was *Encarsia pergandiella* which caused ~94% of the recorded parasitism. The remaining parasitism was caused by the native *Eretmocerus tejanus* (~6%). Both of these native parasitoids were recovered year round. Riley and Ciomperlik (1997) found that *E. tejanus* was most common during spring, whereas *E. pergandiella* predominated in the summer and fall. During the fall, small numbers (<1%) of *Encarsia luteola* Howard and *Encarsia nr. meritoria* Gahan were recovered. The frequency of recovery of the exotic populations, as well as the numbers of individuals recovered are shown in Table 4. Those parasitoids released but not recovered are shown in Table 5. These data should be interpreted qualitatively rather than as precise quantitative measures of establishment because those which were available in higher numbers were released at higher rates. Furthermore, many parasitoids were released only once and sometimes only one parasitoid was recovered for some exotic populations. A true measure of the degree of establishment of the exotic parasitoids, as well as their effect on the host population, can be assessed only after several years of data collection. Our findings allow us to assess establishment only in the short term.

With these limitations in mind, 11 of 29 populations of exotic parasitoids released in the fields were recovered from the release sites. Successful preliminary

recovery and identification of exotics may be due to the suitability of the parasitoid species and release sites selected, together with the techniques developed to isolate and rapidly identify exotic parasitoids. Identification of exotic parasitoids by integrating the use of morphological characters and RAPD-PCR proved to be a very efficient and accurate method of evaluating field establishment. The strains not recovered in the inoculative establishment evaluations were ranked in the middle to bottom of populations tested in the quarantine screenings or field impact evaluations.

After an initial successful field recovery, the *Eretmocerus* spp. from Spain (M92014) and Pakistan (M95012) were consistently recovered. The *Eretmocerus sp.* from Pakistan has a different DNA banding pattern which allows it to be distinguished from the Spanish population in the same release location (Vacek *et al.*, 1996). In one location, these two exotic *Eretmocerus* spp. now comprise >25% of the parasitoids collected. Genetic analysis of the *Eretmocerus* species reared from this location indicates ~66% are the Spanish population and ~33%, the Pakistani.

Our main objective in these studies was to evaluate the performances of as many parasitoid populations as possible, as well as to compare the same population using different criteria, such as impact on the pest or establishment in the field. With >46 populations in quarantine, less promising populations are likely to be eliminated from culture. We realize that the simple

TABLE 5
Parasitoids Not Recovered in Inoculative Establishment Evaluation

ID number	Population and origin	Release site	Plant host	Release (1000s)
M94041	<i>Encarsia transvena</i> (Thailand)	Monte Alto	Okra, kenaf (<i>Hibiscus cannabinus</i> L.)	1.6
M94016	<i>Encarsia transvena</i> (Taiwan)	Mission	Mixed vegetables	2.0
M94023	<i>Eretmocerus</i> sp. (Thailand)	Donna	Mixed vegetables	5.4
M94036	<i>Eretmocerus</i> sp. (Thailand)	Monte Alto	<i>Lablab purpureus</i>	20
M94040	<i>Eretmocerus</i> sp. (Thailand)	Alamo	Mixed vegetables	20
M93058	<i>Eretmocerus</i> sp. (Taiwan)	Monte Alto	<i>Lablab purpureus</i>	5
M92018	<i>Encarsia nr. strenua</i> (India)	Monte Alto	<i>Lablab purpureus</i>	14
M94051	<i>Encarsia formosa</i> (Thailand)	Monte Alto	Peppers, grapes	1
M92017	<i>Encarsia formosa</i> (Greece)	Alamo	Mixed vegetables	50
M92030	<i>Encarsia formosa</i> (Egypt)	Monte Alto	Kale, broccoli	100
M94107	<i>Encarsia lutea</i> (Israel)	Monte Alto	<i>Lablab purpureus</i>	17
M94115	<i>Encarsia lutea</i> (Israel)	McAllen	Mixed vegetables	0.5
M94125	<i>Encarsia lutea</i> (Israel)	McAllen	Mixed vegetables	0.5
M94129	<i>Encarsia lutea</i> (Israel)	Alamo	Mixed vegetables	9.6
M94103	<i>Eretmocerus mundus</i> (Israel)	Mission	Mixed vegetables	34
M94105	<i>Eretmocerus mundus</i> (Israel)	San Juan	Lantana	2.0
M94124	<i>Eretmocerus mundus</i> (Israel)	San Juan	Hibiscus	2.0
M94092	<i>Eretmocerus mundus</i> (Italy)	McAllen	Mixed vegetables	10.4
M94055	<i>Encarsia nr. pergandiella</i> (Brazil) ^a	Alamo	Mixed vegetables	8.4

Note. Parasitoid populations are identified by identification number, preliminary identification, and country of collection. Release/recovery sites (Fig. 1) indicate host plant used and approximate release rate (in thousands). Releases were made in May 1995.

^a *Encarsia nr. pergandiella* from Brazil could not be determined without PCR analysis. Therefore, its recovery status is undetermined.

evaluations we performed may overlook potentially effective control agents and that fecundity in the laboratory and field cage experiments may not necessarily result in effectiveness in the field. However, detailed studies are not possible and perhaps not even necessary given the number of exotics involved.

The evaluations described were not always performed as consistently as we would have preferred. Ideally, all parasitoid populations should have been evaluated under all treatments in the quarantine, field impact, and inoculative establishment evaluations. This was not possible because some parasitoid populations could not be maintained or produced too few individuals for study. In addition, some of the newly imported populations were only available for later evaluations. However, we released as many parasitoid populations in the inoculative establishment evaluation (including those which did poorly in the laboratory) because of the possibility that poor laboratory performance does not necessarily result in poor field performance.

In the inoculative establishment evaluation, successful establishment of an introduced natural enemy cannot be ascertained during a single season. Subsequent sampling over several years will be necessary to determine the degree of establishment of the control agent, as well as its effect on the target pest. Furthermore, the parasitoid release rates were not consistent for all populations, but reflected the availability of certain populations which received high priority for mass rearing. It can be argued that releasing higher

numbers of a certain population increases the probability that it will subsequently be recovered.

The *Eretmocerus* populations from Spain (M92014) and Pakistan (M95012) were generally the most effective parasitoids in both the laboratory and field evaluations. The *Encarsia nr. pergandiella* from Brazil (M94055) produced promising results in the laboratory, but could not be detected in the inoculative establishment evaluations because it can be identified only through the use of PCR techniques, unlike the other populations. These evaluations will be used to prioritize parasitoid populations, designating promising candidates for mass rearing and mass release in the LRGV. Although we are reluctant to eliminate any candidate parasitoid, these evaluations can also identify populations likely to perform poorly should mass rearing resources become limiting in the future.

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