EVALUATION OF *ERETMOCERUS EREMICUS* AND *ENCARSIA FORMOSA* (HYMENOPTERA: APHELINIDAE) BELTSVILLE STRAIN IN COMMERCIAL GREENHOUSES FOR BIOLOGICAL CONTROL OF *BEMISIA ARGENTIFOLII* (HOMOPTERA: ALEYRODIDAE) ON COLORED POINSETTIA PLANTS

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ABSTRACT

The effectiveness of average weekly inundative releases of female *Eretmocerus eremicus* (evaluated in 2 greenhouses) and *Encarsia formosa* Beltsville strain (evaluated in 2 greenhouses) per plant for control of *Bemisia argentifolii* Bellow and Perring was determined on colored poinsettia plants grown under commercial conditions. Parasitoid efficacy was determined by making weekly population counts of *B. argentifolii* lifestages (excluding eggs) on plants exposed to parasitoids in biological control greenhouses and comparing final per leaf densities of *B. argentifolii* nymphs to those plants in insecticide treated greenhouses. At the 2 sites where *E. eremicus* was used, final nymphal densities ranged from 2-4 per leaf when a sales inspection protocol was employed at time of harvest. On insecticide-treated plants, nymphs ranged 0.02-0.18 per leaf but final whitefly densities in biological control greenhouses and insecticide greenhouses were commercially acceptable. Colored plants at one site where *E. eremicus* was used were harvested and sold without any insecticide use. At the second *E. eremicus* site, two sulfotepp applications were made at week 11 of the 16 week trial and colored plants were harvested without further use of insecticides. In comparison to insecticides, the cost of *E. eremicus* in 1995 ($2.70 per plant) was 30 times higher than using imidacloprid ($0.09 per plant) for *B. argentifolii* control. At the 2 sites where *E. formosa* Beltsville strain was released, trials were terminated early and insecticides were applied when *B. argentifolii* densities reached 4-6 live nymphs and pupae per leaf. Low emergence rates of *E. formosa* Beltsville strain may have been a major factor lowering the efficacy of this parasitoid in commercial greenhouses.

RESUMEN

En invernaderos comerciales se liberaron semanalmente hembras de *Eretmocerus eremicus* (dos invernaderos) y de *Encarsa formosa* raza Beltsville (otros dos invernaderos) para el control de *Bemisia argentifolii* Bellow y Perring en plantas de nochebuena colorida. La efectividad de los parasitoides se evaluó realizando conteos semanales de los estadíos de *B. argentifolii* (excepto huevecillos) en plantas expuestas a los parasitoides en invernaderos de control biológico y en invernaderos tratados con insecticidas. La densidad final de ninfas de *B. argentifolii* por hoja fue comparada entre plantas provenientes de invernaderos de control biológico y de aquellos tratados con insecticida. Cuando se empleó *E. eremicus*, las densidades finales de ninfas variaron de 2-4 por hoja en el momento de realizar una inspección de protocolo para venta de las plantas. En plantas tratadas con insecticida, la densidad de ninfas varió de 0.02-0.18 por hoja, pero la densidad final de mosquitas en plantas tratadas con control biológico o químico fue comercialmente aceptable. En uno de los invernaderos donde se utilizó *E. emericus,* las plantas fueron cosechadas y vendidas sin haberse empleado insecticidas. En el otro invernadero donde fue empleado *E. emericus*, las plantas recibieron dos aplicaciones de sulfotepp (semanas 11 y 16 del ensayo), después de lo cual

fueron cosechadas sin más uso de insecticidas. En 1995, el costo de controlar *B. argentifolii* con *E. emericus* fue 30 veces mayor al de usar el insecticida imidacloprid ($2.70 vs. $0.09 por planta). En los dos invernaderos donde se usó *E. formosa* raza Beltsville, los ensayos fueron suspendidos temprano y se aplicó insecticida cuando las densidades de *B. argentifolii* alcanzaron 4-6 ninfas vivas y pupas por hoja. Las tasas de emergencia de *E. formosa* raza Beltsville fueron bajas, lo cual pudo haber sido un factor importante en la baja efectividad de este parasitoide para controlar *B. argentifolii* en invernaderos comerciales.

Inundative biological control of whitefly pests infesting greenhouse-grown ornamentals is seldom practiced by commercial producers and chemically based pest control strategies prevail. Several reasons for lack of adoption of biological control by growers of greenhouse ornamentals have been identified and include: (1) the high cost of purchasing natural enemies for mass release makes pesticides more attractive financially; (2) inconsistent natural enemy quality, quantity, and availability from commercial suppliers can adversely affect programs making growers wary of biological control; (3) a paucity of rigorous research documenting efficacy and economic cost of biological control makes justification of biological control implementation difficult; (4) lack of crop and pest specific management guidelines with natural enemies for growers to follow means there is no established infrastructure similar to that available for pesticides with which growers are familiar (Cranshaw et al. 1996, O'Neil et al. 1998, Parrella & Jones 1987, Parrella 1990, Parrella et al. 1992, Hoddle et al. 1997, Wearing 1988). In this article we address issues which concern natural enemy efficacy and quality, and the cost effectiveness of biological control for silverleaf whitefly, *Bemisia argentifolii* Bellows & Perring (Homoptera: Aleyrodidae), on colored poinsettias (*Euphorbia pulcherrima* Willd. ex Koltz.) grown under commercial conditions.

Eretmocerus eremicus Rose and Zolnerowich (Hymenoptera: Aphelinidae) has been identified as an effective natural enemy of *B. argentifolii* (Hoddle et al. 1998a). Weekly releases of three female parasitoids per plant per week obviated the need for pesticides on non-colored poinsettias commercially grown for cuttings, and use of *E. eremicus* is recommended for control of *B. argentifolii* on poinsettia stock plants in summer (Hoddle & Van Driesche 1999). However, the ability of *E. eremicus* to control *B. argentifolii* on colored poinsettia plants grown in the fall was uncertain at the time of this trial. Weekly releases of *E. eremicus* in small experimental greenhouses where the release rate was varied over time failed to control *B. argentifolii* on colored poinsettia plants grown in the fall suggesting that this parasitoid and release strategy may be unsuitable for use at this time of year (Hoddle et al. 1999). The efficacy of constant weekly releases *of E. eremicus* for *B. argentifolii* control on colored poinsettia plants during normal fall production periods had not been previously determined in commercial greenhouses at the time work presented here was done.

Encarsia formosa Gahan Beltsville strain (Hymenoptera: Aphelinidae) is a *Bemisia*-adapted strain of *E. formosa* (Heinz & Parrella 1994). Use of this parasitoid in small experimental greenhouses at a rate of three females per plant per week produced final densities of *B. argentifolii* on colored poinsettias that were indistinguishable from those on plants produced commercially with pesticides for sale at Christmas (Hoddle et al. 1997). However, in commercial greenhouses *E. formosa* Beltsville strain failed to control *B. argentifolii* on poinsettias grown for cuttings during summer whereas under similar conditions *E. eremicus* provided acceptable control of *B. argentifolii* (Hoddle & Van Driesche 1999).

These results suggest that *E. eremicus* is the more effective natural enemy for *B. argentifolii* control on stock plants grown in summer and that *E. formosa* Beltsville strain might be more effective on colored poinsettias grown in the fall. The ability of *E. formosa* Beltsville strain to control *B. argentifolii* on commercially produced colored poinsettias, however, has not been determined. Here we present results that compare the efficacy of *E. formosa* Beltsville strain to that of *E. eremicus* against *B. argentifolii* under commercial growing conditions on poinsettias grown in the fall for sale at Christmas.

MATERIALS AND METHODS

Experimental Greenhouses

This experiment was conducted with four commercial growers in Massachusetts, USA, using either *E. eremicus* (two growers) or *E. formosa* Beltsville strain (two growers) for *B. argentifolii* control in greenhouses on colored poinsettia plants grown for the Christmas market. Evaluation trials were run over the period 4 August to 7 December, 1995.

Site one was a 260-m^2 glass greenhouse containing 3,200 plants. Cultivars grown were "Red Sails", red "Lilo", and white and marble "Angelika". Site two was a 156-m^2 glass greenhouse containing 2,300 plants. Cultivars grown were white and marble "Annette Hegg", red "Lilo", red "Celebrate 2", and "Pink Peppermint". Sites one and two received weekly releases of *E. eremicus* and plants were reduced in number during the trial to satisfy spacing and sales requirements. Site three was a 168-m^2 plastic greenhouse with 1,800 plants. A single cultivar, white "Glory V-14", was grown at this site. Site four was a 307-m^2 glass greenhouse, stocked with 2,881 plants. Cultivars grown were "Celebrate 2", marble "Angelika" and pink "Gutbier V-14". Sites three and four received weekly releases of *E. formosa* Beltsville strain.

Estimating Initial Whitefly Infestation Levels and Augmentation of Whitefly Numbers

The colored crops at sites 1 and 2 were started from rooted cuttings produced by each grower in the spring, using cuttings that had been produced using *E. eremicus* as the sole control strategy for *B. argentifolii* (Hoddle & Van Driesche 1999). Cuttings at sites 3 and 4 were produced in-house by the growers and *B. argentifolii* had been controlled chemically on stock plants with foliar insecticides before cuttings were harvested and held for three weeks in misting units for rooting. At the time of potting at each site, 70-90 randomly selected cuttings were numbered. Each leaf on the numbered cuttings was examined and total numbers of live *B. argentifolii* nymphs and pupae (one sampling category), and adults per plant were recorded. The average number of nymphs and pupae, and adult whiteflies per plant was calculated for each site and compared using a one-way ANOVA in SAS (SAS 1989) and Tukey's Studentized Range Test ($P = 0.05$) was used for means separation. At sites 2, 3, and 4 control and parasitoid release cages were stocked with poinsettia plants infested at the same nymphal and pupal density as that occurring in their respective biological control greenhouses (see below for more details on the use of cages). At site 1, all plants examined were free of *B. argentifolii* and augmentative releases of adult whiteflies were made to establish a pest population in the biological control greenhouse. The control and parasitoid release cages were also artificially inoculated with adult whiteflies at the same rate as the biological control greenhouse.

Whitefly augmentation. Because no whiteflies were seen on cuttings at site 1, the whitefly population there was augmented by introducing adult male and female pairs of *B. argentifolii* from our laboratory colony. Our intention was to introduce adult whiteflies to produce similar average per plant densities as that observed across all greenhouses at the time of planting. To do this we released 332 adult whiteflies (166 mating pairs) into the biological control greenhouse which held 3,200 plants at time of release (week 2 of the trial). This produced an average of 0.1 adult whiteflies per plant. The control cage and parasitoid release cage at site 1 (all cages contained 10 plants) were stocked with one male-female pair of adult *B. argentifolii* at the same time.

Experimental Treatments & Weekly Population Counts for *B. argentifolii*

Three treatments were established in each of the four biological control greenhouses: uncaged plants (Treatment 1), cages with whiteflies only (Treatment 2), and cages with parasitoids and whiteflies (Treatment 3). Treatment 2 was the control, and Treatment 3 acted as a check for cage effects for whitefly development in the presence of parasitoids.

To estimate whitefly population densities on uncaged plants, three leaves (one from the bottom, one from the middle, and one from the top) of 90 plants in all experimental greenhouses were inspected weekly for the presence of *B. argentifolii*. The numbers of nymphs and pupae, adults, and whitefly exuviae from which either adult whiteflies or parasitoids had emerged were recorded along with numbers of visibly parasitized whitefly nymphs. Weekly population counts were made at each site until either the grower harvested colored plants or applied insecticides because whitefly numbers had reached unacceptable densities. Final densities of live nymphs and pupae per leaf for Treatment 1 in each greenhouse were compared using a nested ANOVA in SAS (SAS 1989) and Tukey's Studentized Range Test ($P = 0.05$) was used for means separation.

Establishing & Monitoring *B. argentifolii* Population Growth in Cages

Treatments 2 and 3 were established in single cages in each of the four biological control greenhouses. Cages measured 153 cm (length) × 92 cm (width) × 117 cm (height), were constructed of pvc piping, and were enclosed on all sides with polyester mesh screening with a 95 μm opening size. Access to plants within cages was via two sleeves in the front of the cage and whiteflies were counted through a clear acetate panel located between the sleeves. Each cage was stocked with 10 potted poinsettia plants that were chosen from those examined to estimate the initial infestation level at planting. We stocked cages with selected plants to achieve similar average densities of live nymphs and pupae per plant as those in the corresponding biological control greenhouses.

For Treatments 2 and 3, whitefly population density estimates were made weekly on eight randomly selected plants within cages. In Treatment 3, parasitoids were released into cages at a rate of three female parasitoids per plant per week. Based on an expected 50:50 sex ratio and an emergence rate of 60%, 100 *Trialeurodes vaporariorum* (Westwood) (Homoptera: Aleyrodidae) nymphs parasitized by *E. eremicus* were placed weekly in cages at sites 1 and 2 in a single release cup. In the *E. formosa* Beltsville strain release cages at sites 3 and 4, 50 parasitized *B. argentifolii* nymphs were placed in cages weekly. We assumed a 60% emergence rate and an all female population for this parasitoid.

Monitoring of Insecticide-Treated Greenhouses, end of Trial Whitefly Densities, & Cost Analysis

To measure the performance of parasitoids compared to conventional whitefly control practices, two greenhouses treated with insecticides, one at site one and one at site three, were monitored weekly. Live *B. argentifolii* nymphs and pupae were counted on each of three randomly selected leaves (one leaf from the bottom, middle, and top of the plant) on 90 randomly selected plants. Mean numbers of live whitefly nymphs and pupae per leaf were compared to those observed in the biological control greenhouses and parasitoid release cages.

The average number of live whiteflies per leaf was determined using a sampling protocol used from previous studies (Hoddle et al., 1998a, 1999). Fifteen plants were randomly selected from each experimental greenhouse and the number of live whitefly nymphs and pupae were recorded for each of six leaves (two leaves were chosen at random from the bottom, middle, and top of the plant.)

The cost of biological control versus the cost of insecticides was determined at site 1 by analyzing insecticide application records for the insecticide-treated greenhouse, and the cost of using *E. eremicus* in the biological control greenhouse at the same site. The cost of whitefly control using imidacloprid (a systemic chloronicotinyl compound [Cahill et al. 1996]) was based on 1995 catalogue prices for Marathon® (a granular insecticide of 1% imidacloprid, [Olympic Horticultural Products, Mainland, PA]). The cost of using *E. eremicus* was based on the 1995 retail figure of $22 for 1000 parasitized *T. vaporariorum* nymphs. *Encarsia formosa* Beltsville strain was sold to us for $9 per 1000 parasitized *B. argentifolii* nymphs.

Estimating Weekly Parasitoid Release Rates

Parasitoid releases in the biological control greenhouses and parasitoid cages began immediately after greenhouses were filled with poinsettias. The targeted weekly release rate for both parasitoid species was three females per plant per week. *Eretmocerus eremicus* is a bi-parental species (sex ratio is 1:1) and was supplied by Beneficial Insectaries, Oak Run, California USA, as loose parasitized *T. vaporariorum* nymphs which had been reared on tobacco. *Encarsia formosa* Beltsville strain is a uniparental parasitoid, which was reared on *B. argentifolii* on collard greens and supplied by American Insectaries, Escondido, California USA, 25 loose parasitized nymphs.

Parasitized nymphs were distributed throughout greenhouses and cages by placing them in plastic release cups (height 3 cm; diameter, 4 cm). Release cups were attached to stakes that were pushed into the potting media until cups were positioned below the crop canopy. To estimate the number of parasitoids released per plant per week, we measured the number of nymphs per unit weight of material sent by the supplier, the weight of the shipment, and the percentage of nymphs from which parasitoids successfully emerged under greenhouse conditions. Percentage emergence was determined by returning release cups every two weeks to the laboratory and recording the number of nymphs from which parasitoids did and did not emerge. We assumed a 1:1 sex ratio for *E. eremicus* in our calculations.

RESULTS

Initial Whitefly Infestation Levels on Cuttings at Potting

There was a significant difference across sites in the mean number (± SE) of live nymphs and pupae on cuttings at the time of planting ($F = 44.5$, $df = 3$, $p = 0.0001$). At

sites 1, 2, (both *E. eremicus*) 3, and 4 (both *E. formosa* Beltsville strain), the average number of live nymphs and pupae per plant was 0.00 ± 0.00 (n = 90 cuttings) (because no immature whiteflies were found at site 1 it was not included in the ANOVA), 8.19 ± 0.78 (n = 70) [a], 5.86 ± 0.84 (n = 90) [b], and 1.41 ± 0.18 (n = 90) [c], respectively. Means followed by the same letters are not significantly different from each other. Both the *E. eremicus* and *E. formosa* Beltsville strain treatments had one relatively high and one relatively low initial density of whiteflies.

There was also a significant difference across site in the mean number (± SE) of adult whiteflies per plant at time of potting ($F = 8.32$, $df = 2$, $p < 0.00001$). At sites 1, 2, 3, and 4, the average number of live adults per plant was 0.00 ± 0.00 (because no adult whiteflies were found at site 1 it was not included in the ANOVA), 0.06 ± 0.02 [a], 0.4 ± 0.09 [b], 0.1 ± 0.05 [a], respectively. Means followed by the same letters are not significantly different from each other. The average number of adult whiteflies per plant when averaged across all biological control greenhouses (n = 4) was 0.16 ± 0.03.

Actual Parasitoid Release Rates

Emergence rates of adult parasitoids in the two *E. eremicus* greenhouses averaged 53.8% ± 4.8% and 55.6% ± 3.9% for sites 1 and 2 across the entire trial periods, respectively (Table 1). In the two *E. formosa* Beltsville greenhouses, weekly percentage emergence of adult parasitoids averaged 33.0% ± 3.8% and 38.3% ± 5.6% for sites 3 and 4, respectively (Table 1). The average number of female parasitoids released per plant per week at sites 1 and 2 was 2.9 ± 0.2 and 3.7 ± 0.31 respectively, for the two *E. eremicus* greenhouses (Table 1). The average number of female parasitoids released at sites 3 and 4 was 1.9 ± 0.25 and 2.4 ± 0.37 per plant per week, respectively (Table 1). This average weekly release rate for *E. formosa* Beltsville strain were lower than the intended release rate of 3 females per plant per week because of poor emergence of parasitoids following deployment of parasitized *B. argentifolii* nymphs in greenhouses.

Population Density Trends for *B. argentifolii*

Population growth of *B. argentifolii* in cages in the absence of *E. eremicus* (Treatment 2) was substantially higher than that observed for populations receiving parasitoid releases (Treatment 3) (Fig. 1). In control cages at the end of the trials, numbers of live nymphs and pupae exceeded 29 and 117 per leaf at sites 1 and 2, respectively. At the end of the trials in cages treated with *E. eremicus*, populations of live *B. argentifolii* nymphs and pupae per leaf reached 8 and 2 at sites 1 and 2, respectively, (Fig. 1). Upon grower request, cages at sites 3 and 4 where *E. formosa* Beltsville strain was released were removed and trials were terminated in weeks 6 and 4, respectively when insecticides were applied for whitefly control. No useful data was obtained from cages studies at sites 3 and 4 because trials were terminated before *B. argentifolii* population trends became evident.

Colored poinsettia plants were harvested at site 1 without the use of any insecticides. Two insecticide applications were required at site 2 to reduce numbers of adult whiteflies on plants (Fig. 2). The biological control greenhouse was treated with two sulfotepp fumigations (Plantfume smoke generator, ai 15% sulfotepp [Plant Products Corporation, Vero Beach FL]) three days apart during week 11 of the trial. Parasitoid releases continued after fumigation and plants were harvested at week 16 without further insecticide intervention. In greenhouses receiving releases of *E. eremicus* (sites 1 and 2), densities of live nymphs and pupae were less than two per leaf when trials ended. This final density of live nymphs and pupae was acceptable to commercial growers producing colored poinsettias for sale at Christmas (Fig. 2).

TABLE 1. TOTAL NUMBER OF PLANTS, TOTAL NUMBER OF PARASITIZED NYMPHS PLACED IN GREENHOUSES, PERCENTAGE PARASITOID EMERGENCE, AND NUMBER OF FEMALE PARASITOIDS RELEASED PER PLANT IN BIOLOGICAL CONTROL GREENHOUSES TREATED WEEKLY WITH *ERETMOCERUS EREMICUS* AND *ENCARSIA FORMOSA* BELTSVILLE STRAIN.

Wasp	Site	Week no.	Plant no.	No. parasitized nymphs	Parasitoid Emergence (%)	No. females released/ plant
E. eremicus	1	1	3,200	no releases		
		2	3,200	29,023	88.6	4.02
		3	2,550	25,552	42.6	2.13
		4	2,550	25,238	55.3	2.74
		5	1,969	19,722	44.0	2.20
		6	1,219	12,360	42.6	2.16
		7	1,219	12,213	64.0	3.21
		8	1,500	6,572	—	—
		9	800	8,015	58.6	2.94
		10	1,081	10,816	70.6	3.53
		11	500	5,009	50.6	2.53
		12	500	8,339	34.6	2.89
		13	500	8,349	40.0	3.34
		14	500	8,343	—	—
mean (± SE)					53.8 ± 4.8	2.9 ± 0.2
E. eremicus	2	1	2,300	—	—	—
		2	2,300	23,023	63.3	3.17
		3	2,300	23,045	80.0	4.01
		4	1,250	12,518	67.3	3.37
		5	900	9,016	44.0	2.20
		6	621	6,219	46.6	2.33
		7	621	6,212	46.6	2.33
		8	621	6,217	65.0	3.25
		9	621	10,360	67.0	5.59
		10	621	10,370	56.0	4.68
		11	621	10,370	71.3	5.95
		12	621	10,369	50.0	4.17
		13	621	10,368	38.0	3.17
		14	621	10,361	34.0	2.84
		15	621	10,360	48.6	4.05
		16	621	10,360	—	—
mean (± SE)					55.6 ± 3.6	3.7 ± 0.31
E. formosa	3	1	1,800	9,000	31.3	1.57
		2	1,800	9,000	45.3	2.27

TABLE 1. (CONTINUED) TOTAL NUMBER OF PLANTS, TOTAL NUMBER OF PARASITIZED NYMPHS PLACED IN GREENHOUSES, PERCENTAGE PARASITOID EMERGENCE, AND NUMBER OF FEMALE PARASITOIDS RELEASED PER PLANT IN BIOLOGICAL CONTROL GREENHOUSES TREATED WEEKLY WITH *ERETMOCERUS EREMICUS* AND *ENCARSIA FORMOSA* BELTSVILLE STRAIN.

Wasp	Site	Week no.	Plant no.	No. parasitized nymphs	Parasitoid Emergence (%)	No. females released/ plant
		3	1,800	9,000	24.6	1.23
		4	1,800	18,007	26.6	2.66
		5	1,800	8,992	37.3	1.86
		6	1,800	15,875	—	—
mean (± SE)					33.0 ± 3.8	1.9 ± 0.25
E. formosa	4	1	2,881	20,000	23.3	1.60
		2	2,881	16,000	39.3	2.17
		3	2,881	16,281	40.0	2.26
		4	1,508	8,680	50.6	3.38
mean (± SE)					38.3 ± 5.6	2.4 ± 0.37

Parasitism Levels

Parasitism by *E. eremicus* in the biological control greenhouse was first recorded at week 2 at site 2, and steadily increased to reach a maximum of 43% before declining to 15% at the end of the trial (Fig. 3). In contrast, parasitism by *E. eremicus* at site 1 was not detected until week 6. Peak parasitism by *E. eremicus* at site 1 reached 30% at week 8 and then declined to 4-7% for the last four weeks of the trial (Fig. 3). Parasitism did not exceed 5% in the biological control houses at the two sites in which *E. formosa* Beltsville strain was released (Fig. 3).

Insecticide-Treated Greenhouses

Insecticide-treated greenhouses at sites 1 and 3 received one application each of imidacloprid (Marathon®) immediately after greenhouses were filled. This insecticide can give up to 12 weeks protection with a single application (Lopes 1994).

Whitefly Densities at Harvest

The protocol designed to evaluate the mean number of live nymphs and pupae per leaf at time of harvest on 15 randomly selected plants detected significant differences between both sites 1 and 2 treated with *E. eremicus* and to numbers recorded on plants in retail outlets ($F = 37.94$, $df = 2$, $p = 0.0001$) (Table 2). Weekly releases of *E. formosa* Beltsville strain failed to reduce *B. argentifolii* to non-damaging densities and trials at sites 3 and 4 were terminated early and insecticides were applied to the crop prior to the harvesting of colored plants. Consequently, similar comparisons of whitefly numbers in the biological control greenhouses at sites 3 and 4 with insecticide treated plants were not made.

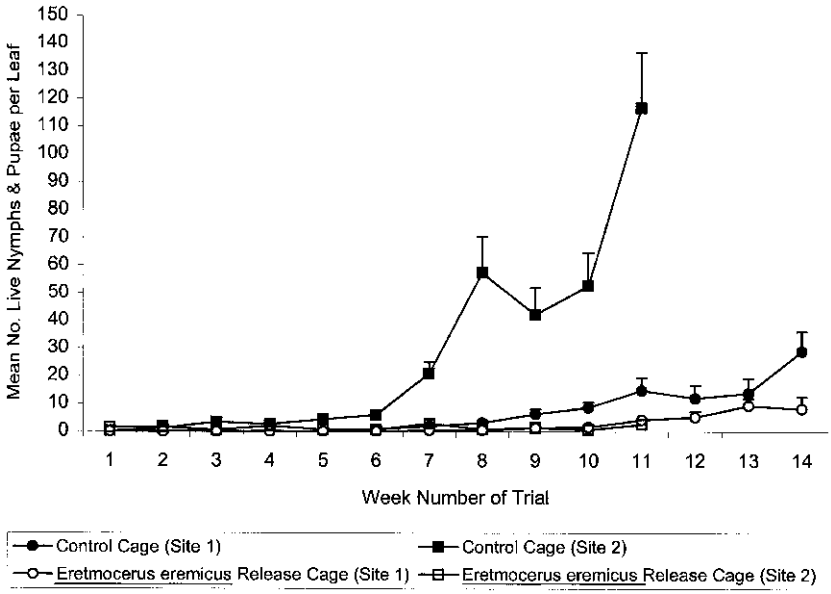

Fig. 1. Mean number of live *Bemisia argentifolii* nymphs and pupae (± SE) per leaf on poinsettia plants in the control and parasitoid release cages in the biological control greenhouses treated with *E. eremicus*.

Cost Analysis

At site 1, the total cost of controlling *B. argentifolii* with an average weekly release rate of 2.9 female *E. eremicus* per plant for 14 weeks was 30 times more expensive than the use of imidacloprid for whitefly control (Table 3). Cost analysis for use of *E. formosa* Beltsville strain at site 3 was not calculated as this trial was terminated early following grower intervention with foliar insecticide applications.

Discussion

Releases of *E. eremicus* at rates of 2.9-3.7 females per plant per week successfully suppressed *B. argentifolii* to non-damaging levels on colored poinsettias. The sales inspection protocol detected 2-4 live *B. argentifolii* nymphs and pupae per leaf and plants were marketable with this level of whitefly infestation at harvest. Mean densities of live *B. argentifolii* nymphs and pupae per leaf on the 90 randomly selected plants at sites 1 and 2 were both less than two (compared to 2-4 live nymphs and pupae from the sales inspection protocol) when trials were ended and plants were harvested. This larger sample size may have resulted in a more accurate assessment of final per leaf densities of *B. argentifolii* at time of harvest indicating that final densities of live *B. argentifolii* nymphs and pupae per leaf being less than two are commercially acceptable.

In one of the two *E. eremicus* greenhouses (site 1) the crop was harvested without any insecticide applications even though *B. argentifolii* were deliberately introduced to produce an initial infestation of 0.1 adult whiteflies per plant, a density similar to that seen in the other biological control greenhouses. At site 1, initial inspection of

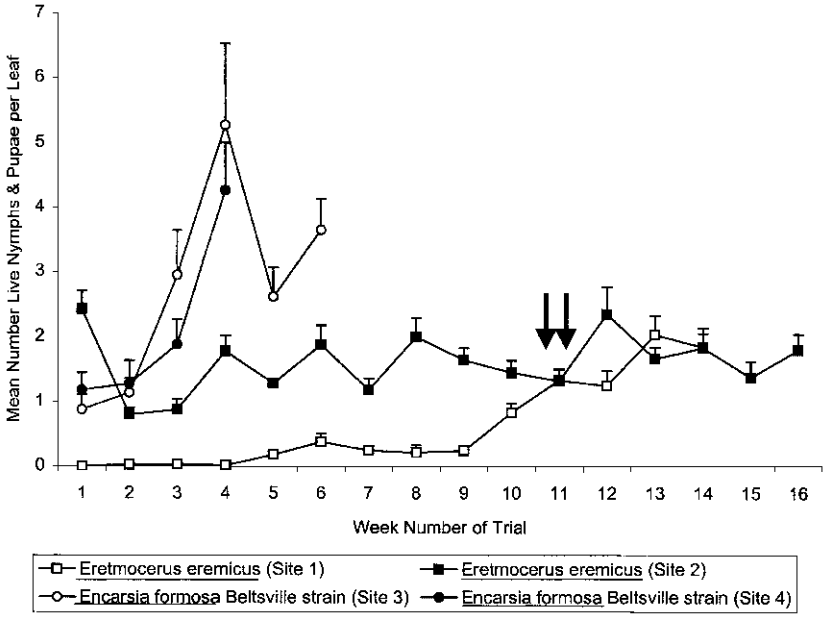

Fig. 2. The mean number of live *Bemisia argentifolii* nymphs and pupae (± SE) per leaf on uncaged poinsettia plants in the biological control greenhouses treated with *Eretmocerus eremicus* (sites 1 and 2) or *Encarsia formosa* Beltsville strain (sites 3 and 4). Trial duration times at sites 3 and 4 were reduced because growers intervened with chemical treatments to suppress *B. argentifolii* population growth. Arrows indicate times of insecticide applications at site 2.

cuttings failed to detect whitefly nymphs prior to parasitoid releases beginning and whitefly nymphs were not deliberately introduced to produce initial nymph densities similar to those seen in the other biological control greenhouses. Because initial whitefly densities at site one were low, whitefly numbers remained consistently lower throughout the duration of the trial and the test of *E. eremicus* for *B. argentifolii* control was not as rigorous as site 2. At the second *E. eremicus* release site (site 2) initial whitefly densities were higher than site 1, and biological control was successfully combined with two fumigatory sulfotepp applications to produce commercially acceptable colored plants.

Data collected at harvest indicates that growers and consumers are tolerant of light whitefly infestations on colored poinsettias and biologically based control programs do not have to achieve zero whitefly densities for plants to be marketable. Trials subsequent to this one have demonstrated that *E. eremicus* can also successfully control another common whitefly pest of poinsettia, *T. vaporariorum*, on colored plants and that growers are able to successfully manage their own biological control program using this parasitoid under commercial growing conditions (Van Driesche et al. 1999a).

A major obstacle to the use of *E. eremicus* for biological control of *B. argentifolii* on greenhouse grown poinsettias is the high cost of this parasitoid in comparison to insecticides for control of this pest. The use of *E. eremicus* for control *B. argentifolii* on

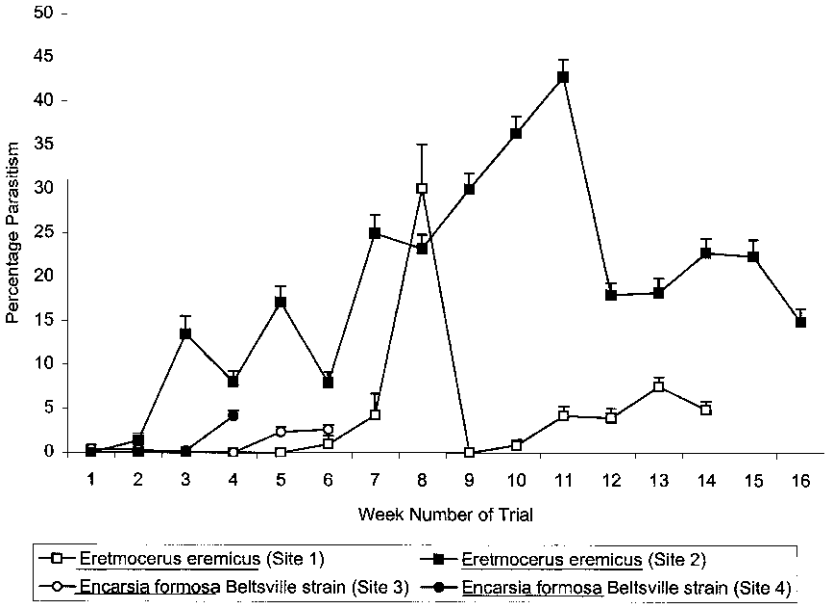

Fig. 3. Percentage parasitism of *Bemisia argentifolii* in biological control greenhouses treated with either *Eretmocerus eremicus* (sites 1 and 2) or *Encarsia formosa* Beltsville strain (sites 3 and 4).

poinsettias grown for cuttings in 1995 was 44 times more expensive than using imidacloprid (Hoddle & Van Driesche 1999). In this study with colored poinsettia plants, *E. eremicus* was 30 times more expensive than the same insecticide in 1995. Since 1995 when this work was done the cost of *E. eremicus* has decreased by 62% and this parasitoid currently retails for $8.30 per 1000 parasitized *T. vaporariorum* nymphs (Hoddle & Van Driesche 1999). At the 1999 cost the use of *E. ermicus* at site 1 in this trial would have been $1.02 per single stem plant, or just 11 times more expensive than imidacloprid.

The cost of using *E. eremicus* in a biologically based pest management program can be reduced further by reducing the numbers of parasitoids released weekly. One way of accomplishing a reduced weekly release rate is to combine *E. eremicus* with compatible insect growth regulators (IGRs). We have identified IGRs that can be successfully used with *E. eremicus* (Hoddle & Van Driesche unpublished). When *E. eremicus* is combined with two mid-season applications of Applaud 70 WP (ai 70% buprofezin [Agrevo USA Company, Wilmington DE]) the weekly parasitoid release rate can be reduced by 66%. Marketable colored poinsettias are produced under commercial conditions using this parasitoid-IGR program at a cost of $0.38 per single stem plant, a price more competitive with imidacloprid which can cost $0.09-$0.14 per plant (Van Driesche et al. 1999b).

Encarsia formosa Beltsville strain failed to provide adequate control of *B. argentifolii* at the two sites at which it was released. This result was due in part to low parasitoid emergence rates (33-38%) in experimental greenhouses. We did not determine whether environmental factors in greenhouses (e.g., aspects of commercial poinsettia

TABLE 2. INFESTATION STATISTICS FOR LIVE *BEMISIA ARGENTIFOLII* NYMPHS AND PUPAE ON POINSETTIA LEAVES FROM EXPERIMENTAL GREENHOUSES AT TIME OF HARVEST IN WHICH *ERETMOCERUS EREMICUS* HAD BEEN RELEASED, AND ON LEAVES OF COLORED POINSETTIAS RECORDED FROM RETAIL OUTLETS AT THE END OF THE 1995 GROWING SEASON.

Treatment	No. plants inspected	% Plants infested	No. leaves examined	% Leaves infested	Nymphs/ Leaf ± SE
Site 1 (*E. eremicus*)	15	87	45	58	3.8 ± 0.9a
Site 2 (*E. eremicus*)	15	93	45	56	1.9 ± 0.8b
Five retail outlets in Amherst, Massachusetts (chemical control)	75	11	225	4	0.08 ± 0.03c

Means followed by different letters are significantly different from each other at the 0.05 level of significance.

production that reduce efficacy of *E. formosa* Beltsville strain) or poor parasitoid quality were responsible for low emergence rates. Because of low rates of parasitoid emergence, 89% of releases failed to reach the intended release rate of three parasitoids per plant per week, a rate which has been shown to be efficacious in small greenhouse trials (Hoddle et al. 1997). During the course of our work (1994-1995) with *E. formosa* Beltsville strain two companies (one European and one American) attempted to commercialize this parasitoid. Restructuring of the European insectary resulted in *E. formosa* Beltsville strain being removed from its product line while persistent production problems (i.e., disease and hyperparasitism by *Encarsia pergandiella* Howard) hampered yield and promoted the ultimate loss of the only commercial *E. formosa* Beltsville strain colony in the USA.

In addition to uncertainty of supply and post-receipt quality, inherent biological attributes may have also prevented *E. formosa* Beltsville strain from being an effective natural enemy of *B. argentifolii* on poinsettias. Under time limited conditions in commercial poinsettia-production greenhouses, *E. formosa* Beltsville strain is disadvantaged because it is slower in discovering *B. argentifolii* patches, finds fewer

TABLE 3. COMPARISON OF THE COSTS OF *BEMISIA ARGENTIFOLII* CONTROL AT SITE 1 IN THE INSECTICIDE GREENHOUSE AND THE BIOLOGICAL CONTROL GREENHOUSE TREATED WITH *ERETMOCERUS EREMICUS*.

	Insecticide greenhouse	Biological control greenhouse
Total cost of imidacloprid	$288.00	NA
Total cost of *E. eremicus*	NA	$3,950.12
Treatment cost per plant	$ 0.09	$ 2.70
Cost m^2	$ 1.11	$ 15.19

patches, kills fewer whitefly nymphs upon patch discovery, and is observed less frequently on patches when compared to similar studies with *E. eremicus* (Hoddle et al. 1998b). The inability of *E. formosa* reared on either *B. argentifolii* or *T. vaporariorum* (the standard insectary host for this parasitoid) to control *B. argentifolii* on poinsettias grown for cuttings (Parrella et al. 1991, Hoddle & Van Driesche 1999) or for color (Hoddle & Van Driesche 1996) suggests this species cannot be recommended for *B. argentifolii* control on commercially grown poinsettias.

In contrast, the efficacy of *E. eremicus* for *B. argentifolii* control continues to be supported by results of trials in poinsettia crops under various growing conditions. Further work on developing programs which use *E. eremicus* in combination with selective insecticides such as IGRs is needed before this parasitoid will be economically competitive with currently employed control programs that rely exclusively on insecticides.

ACKNOWLEDGMENTS

We thank Mr. P. Burnham, Mr. I. Seedholm, Mr. C. Olson, and Mr. W. Mendoza for allowing us to conduct these experiments in their greenhouses. Susan Roy and Mark Mazzola provided meticulous field and laboratory assistance. Our research was supported by funds from the Massachusetts Poinsettia IPM program, and USDA/NRICGP Grant No. 9402481.

REFERENCES CITED

CAHILL, M., I. DENHOLM, K. GORMAN, S. DAY, A. ELBERT, AND R. NUEN. 1996. Baseline determination and detection of resistance in the tobacco whitefly *Bemisia tabaci* (Hemiptera: Aleyrodidae). Bulletin of Entomological Research 85: 181-187.

CRANSHAW, W., D. C. SCLAR, AND D. COOPER. 1996. A review of 1994 pricing and marketing by suppliers of organisms for biological control of arthropods in the United States. Biological Control 6: 291-296.

HEINZ, K. M. AND M. P. PARRELLA. 1994. Poinsettia (*Euphorbia pulcherrima* Willd. Ex. Koltz.) cultivar mediated differences in performance of five natural enemies of *Bemisia argentifolii* Bellows and Perring n. sp. (Homoptera: Aleyrodidae). Biological Control 4: 305-318.

HODDLE, M. S. AND R. G. VAN DRIESCHE. 1996. Evaluation of *Encarsia formosa* (Hymenoptera: Aphelinidae) to control *Bemisia argentfolii* (Homoptera: Aleyrodidae) on poinsettia (*Euphorbia pulcherrima*): a lifetable analysis. Florida Entomologist 79: 1-12.

HODDLE, M. S., R. G. VAN DRIESCHE, AND J. P. SANDERSON. 1997. Biological control of *Bemisia argentifolii* (Homoptera: Aleyrodidae) on poinsettia with inundative releases of *Encarsia formosa* Beltsville strain (Hymenoptera: Aphelinidae): can parasitoid reproduction augment inundative releases? Journal of Economic Entomology 90: 910-924.

HODDLE, M. S., R. G. VAN DRIESCHE, J. P. SANDERSON, AND O. P. J. M. MINKENBERG. 1998a. Biological control of *Bemisia argentifolii* (Hemiptera: Aleyrodidae) on poinsettia with inundative releases of *Eretmocerus eremicus* (Hymenoptera: Aphelinidae): do release rates affect parasitism? Bulletin of Entomological Research 88: 47-58.

HODDLE, M. S., R. G. VAN DRIESCHE, J. S. ELKINTON, AND J. P. SANDERSON. 1998b. Discovery and utilization of *Bemisia argentifolii* patches by *Eretmocerus eremicus* and *Encarsia formosa* (Beltsville strain) in greenhouses. Entomologia Experimentalis et Applicata 87: 15-28.

HODDLE, M. S., J. P. SANDERSON, AND R. G. VAN DRIESCHE. 1999. Biological control of *Bemisia argentifolii* (Hemiptera: Aleyrodidae) on poinsettia with inundative

releases of *Eretmocerus eremicus* (Hymenoptera: Aphelinidae): does varying the weekly release rate affect control? Bulletin of Entomological Research 89: 41-51.

HODDLE, M. S., AND R. G. VAN DRIESCHE. 1999. Evaluation of inundative releases of *Eretmocerus eremicus* and *Encarsia formosa* Beltsville strain in commercial greenhouses for control of *Bemisia argentifolii* on poinsettia stock plants. Journal of Economic Entomology vol. 92, 811-824.

LOPES, P. 1994. What's all the talk about Marathon? Floral Notes 7: 2-4.

O'NEIL, R. J., K. L. GILES, J. J. OBRUCJI, D. L. MAHR, J. C. LEGASPI, AND K. KATOVICH. 1998. Evaluation of the quality of four commercially available natural enemies. Biological Control 11: 1-8.

PARRELLA, M. P. AND V. P. JONES. 1987. Development of integrated pest management strategies in floricultural crops. Bulletin of the Entomological Society of America 33: 28-34.

PARRELLA, M. P. 1990. Biological control in ornamentals: status and perspective. IOBC/WPRS Bulletin 13: 161-168.

PARRELLA, M. P., T. D. PAINE, J. A. BETHKE, K. L. ROBB, AND J. HALL. 1991. Evaluation of *Encarsia formosa* for biological control of sweetpotato whitefly (Homoptera: Aleyrodidae) on poinsettia. Environmental Entomology 20: 713-719.

PARRELLA, M. P., K. M. HEINZ, AND L. NUNNEY. 1992. Biological control through augementative releases of natural enemies: a strategy whose time has come. American Entomologist 38: 172-179.

SAS INSTITUTE. 1989. SAS/STAT User's Guide, Version 6, 4th ed. SAS Institute, Cary, New York.

VAN DRIESCHE, R. G., S. M. LYON, M. S. HODDLE., S. ROY, AND J. P. SANDERSON. 1999a. Assessment of cost and performance of *Eretmocerus eremicus* (Hymenoptera: Aphelinidae) for whitefly (Homoptera: Aleyrodidae) control in commercial poinsettia crops. Florida Entomol. 82: 570-594.

VAN DRIESCHE, R. G., M. S. HODDLE., S. M. LYON, AND J. P. SANDERSON. 1999b. Use of insect growth regulators to reduce rates of *Eretmocerus eremicus* needed for biological control of whiteflies on poinsettia. IOBC/WPRS Bulletin (in press).

WEARING, H. 1988. Evaluating the IPM implementation process. Annual Review of Entomology 33: 17-38.