Biological Control of *Bemisia argentifolii* (Homoptera: Aleyrodidae) Infesting *Euphorbia pulcherrima*: Evaluations of Releases of *Encarsia luteola* (Hympenoptera: Aphelinidae) and *Delphastus pusillus* (Coleoptera: Coccinellidae)

KEVIN M. HEINZ AND MICHAEL P. PARRELLA

Department of Entomology, University of California, Davis, CA 95616

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ABSTRACT Releases of *Encarsia luteola* Howard and *Delphastus pusillus* LeConte were evaluated for their ability to control *Bemisia argentifolii* Bellows & Perring, n. sp. greenhouse-grown poinsettias. Three treatments, each replicated three times, were used to assess the impact of natural enemy releases on *B. argentifolii* populations: (1) a complete exclusion of natural enemies cage, (2) an identical exclusion cage receiving natural enemy releases as a control for cage effects, and (3) releases of natural enemies onto plants within the greenhouse but outside of either cage. Weekly releases of the parasitoid *E. luteola* were initiated the week the plants entered the greenhouse and three releases of *D. pusillus*, 1 wk apart, were made when *B. argentifolii* populations rose dramatically 9 wk into the trial. Release rates for both natural enemies were one insect per plant per week. Weekly collected leaf samples were examined with the aid of a dissecting microscope. The numbers of live whiteflies were recorded by developmental stage as were the numbers of dead (resulting from natural causes, *D. pusillus* predation, or *E. luteola* host-feeding) and parasitized whitefly nymphs. The lack of a significant difference in whitefly densities between the two natural enemy release treatments suggested the absence of a cage effect on whitefly populations. Whitefly densities within the complete exclosure cages were significantly greater than the whitefly densities in either of the two natural enemy release treatments, indicating a significant impact of natural enemy releases on *B. argentifolii* infestations. Whitefly damage to harvested plants within the natural enemy release areas was not significantly different from the damage level observed in the grower-treated area. The direct cost associated with *B. argentifolii* biological control ($166.32 per greenhouse section) was ≈5 times greater than the insecticide-based *B. argentifolii* management program currently used by poinsettia growers. This cost differential can be reduced if the indirect environmental and worker-safety costs associated with insecticide use are included, and further reductions should accompany increased commercial availability of *D. pusillus*.

KEY WORDS *Bemisia argentifolii, Encarsia luteola, Delphastus pusillus*

THE SILVERLEAF WHITEFLY, *Bemisia argentifolii* Bellows & Perring, n. sp.— = the B strain of the sweetpotato whitefly [Stoetzel 1989], *Bemisia tabaci* (Gennadius) (Perring et al. 1993, Bellows et al. 1994), is the major arthropod pest of poinsettia grown in the United States (Ecke et al. 1990). Economic damage to commercial poinsettia production arises from the simple presence of whitefly nymphs at very low densities (0.3–0.7 per cm^2 [Helgeson & Tauber 1977]) or from small amounts of honeydew excreted by whitefly adults and immatures. These forms of damage reduce the aesthetic quality of the crop and, thus, reduce its marketability. Few reports of *Bemisia* sp.-transmitted diseases of poinsettia have been reported to date and, therefore, disease transmission is of relatively little concern (Byrne et al. 1990).

Management of *Bemisia* sp. infesting poinsettia has traditionally relied heavily on regular applications of insecticides to produce a crop with a high aesthetic quality (Byrne et al. 1990, Dittrich et al. 1990). However, concerns of environmental toxicity (Pimentel & Lehman 1993) and the development of resistance to insecticides in *Bemisia* sp. populations (Probhaker et al. 1985, Dittrich et al. 1990) mandate that alternatives to conventional chemical control be developed.

Augmentative releases of the parasitoid *Encarsia formosa* Gahan for suppression of greenhouse

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whitefly, *Trialeurodes vaporariorum* (Westwood) often are cited as premier examples of successful biological control in glasshouse-grown vegetables (for reviews, see Hussey & Scopes 1985, van Lenteren 1986). Similar success has not been reported from *E. formosa* released into greenhouse-grown poinsettias for biological control of *B. argentifolii* (Parrella et al. 1991). Regardless, several features unique to poinsettia production support the use of biological control in this cropping system, provided an effective *B. argentifolii* natural enemy is discovered.

Whiteflies are the only major arthropod pest of poinsettia (Ecke et al. 1990); thus, tailoring a biological control program for this single species is relatively simple compared with managing a complex of pests commonly associated with other ornamental crops (Pirone 1978). Although poinsettia propagation occurs throughout the year (Ecke et al. 1990), the majority of poinsettia production occurs from June through December, during which time entire greenhouses are often devoted solely to growing a single poinsettia cultivar. Greenhouses must be emptied completely to facilitate this isolated production cycle, suggesting that *B. argentifolii* populations at the beginning of the crop cycle will be low relative to population levels in continuous cropping cycles. Simultaneous production of a few poinsettia cultivars may also minimize spatially heterogeneous population fluctuations associated with cultivar preference and performance (Murdoch 1984, Sanderson 1992). In addition, based on their results from a comparative examination of five *B. argentifolii* natural enemies, Heinz & Parrella (1994) hypothesize that *Encarsia luteola* Howard and *Delphastus pusillus* LeConte may be superior biological agents relative to *E. formosa*. The purpose of this study was to evaluate releases of *E. luteola* and *D. pusillus* and their ability to control *B. argentifolii* infesting greenhouse-grown poinsettias without compromising the demand for producing a crop high in aesthetic quality.

Materials and Methods

Study Site. Trials were conducted in an isolated portion of a commercial greenhouse located in Sacramento, CA. Three contiguous sections (each 7.3 m by 11.0 m) were established in the northwest corner of the greenhouse by constructing barriers of 6 mm-thick clear polyethylene film or of double-layers of 5 mm-thick spunbounded polyester fabric. The polyethylene walls isolated the three sections (hereafter labeled as the east, middle, and west sections) from the remaining portion of the greenhouse and prevented drift from pesticides applied to this area from entering the three sections used in the trials. To minimize the effect of the barriers on the ventilation pattern within the greenhouse, polyester fabric walls were used to separate the middle section from the east and west sections.

Each partitioned section contained six benches and each bench held 66 poinsettias ('Freedom') potted in 15.2-cm diameter pots spaced equidistant from each other. Poinsettia plants were moved into the greenhouse from a separate propagation area on August 26. Except for differences in *B. argentifolii* management, all of the plants included in these trials were grown as a normal poinsettia crop by the cooperating grower.

Experimental Design. The effectiveness of natural enemy releases to control *B. argentifolii* was determined by comparing whitefly populations within exclosures (which excluded natural enemies) with whitefly populations in the greenhouse sections receiving natural enemy releases. The use of exclosures provided an experimental approach to quantify the effect of natural enemies on *B. argentifolii* (see Luck et al. [1988] for a review of evaluation techniques), and it permitted the separation of host mortality caused by intraspecific interactions, host-plant suitability, and environmental factors from natural enemy-induced mortality. The effect of natural enemy releases on *B. argentifolii* was assessed with three treatments per greenhouse section: (1) a complete exclusion of natural enemies cage, (2) an identical exclusion cage receiving natural enemy releases as a control for cage effects, and (3) releases of natural enemies onto plants outside of either cage.

The exclosure-cage frames measured 1.2 m wide, 1 m high, and 1.7 m long. The sides and bottom were covered with fine-mesh, nylon organdy, and the tops were covered with clear acetate. Lighting within each cage was augmented by two 1.3-m long daylight fluorescent lights suspended 10 cm above the top of each cage and set to a photoperiod of 14:10 (L:D) h. A small fan, suspended from the center of each exclosure, ran concurrently with the augmented lighting to generate a temperature and air flow pattern similar to that of the surrounding greenhouse. The numbers of *B. argentifolii* nymphs on each of the 396 plants in each treatment were scored 2 d before installing the exclosure cages, and plants were positioned as necessary to ensure that each treatment within a greenhouse would start with equal whitefly densities. On 9 September, before initiating natural enemy releases, two exclosure cages, each covering 18 plants, were placed within each greenhouse section. One of the two cages was arbitrarily designated to receive natural enemy releases while the remaining cage permitted *B. argentifolii* populations to develop in the absence of introduced natural enemies. At the same time, a two-channel temperature recorder (Omnidata model DP212 with a DSM1000 data storage module and TP10V temperature probe) (Omnidata International, Logan, UT) was positioned in the east and west greenhouse sec-

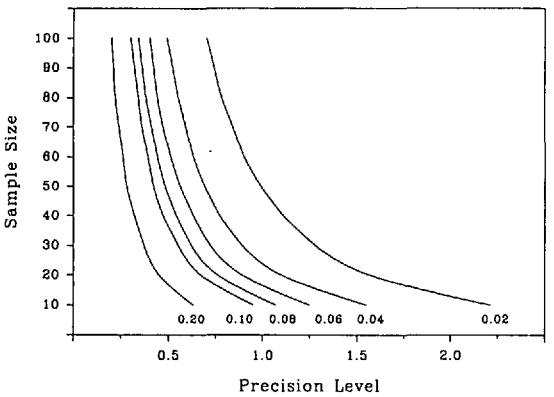

Fig. 1. Relationship between optimum sample size and level of sampling precision for various infestation levels, expressed as the proportion of leaves infested [$P(I)$ = 0.02, 0.04, 0.06, 0.08, 0.10 & 0.20]. Sampling precision values were obtained from equation derived by Karandinos (1976).

tions to record temperatures at 2-h intervals in one of the exclosure cages and within the greenhouse.

Natural Enemy Evaluation. Adult *E. luteola* were collected weekly from *B. argentifolii* infested poinsettias cultured at the University of California, Davis, and the California Department of Food and Agriculture, Biological Control Unit, Sacramento, CA. Beginning 9 September, wasps were released weekly at the rate of one wasp per plant into each of the greenhouse sections and each of the exclosure cages receiving natural enemy releases. On the basis of their laboratory evaluations, Heinz & Parrella (1994) suggest that *D. pusillus* releases may be most efficient in suppressing locally restricted whitefly outbreaks. Although this predator exhibits a high prey consumption rate, reproduction ceases at low whitefly densities. Therefore, *D. pusillus* releases were initiated only when *B. argentifolii* populations were observed to escape from possible suppression exhibited by *E. luteola*. Because the densities of immature *B. argentifolii* rose dramatically during the last 2 wk in October, *D. pusillus* were released at the rate of one beetle per plant on 4, 11, and 18 November. Beetles released into the greenhouse sections originated from cultures maintained on *B. argentifolii* infested poinsettias housed at the University of California, Davis.

Using a single poinsettia leaf as the sample unit, an optimum sample size was determined based on the formula derived by Karandinos (1976). Fig. 1 illustrates the relationship between the level of sampling precision and optimum sample size for various infestation levels, expressed as the proportion of leaves infested, $P(I)$. As previously stated by Jones & Parrella (1986), high levels of precision at low infestation levels are obtained at prohibitively large sample sizes that would also greatly reduce the aesthetic quality and marketability of the crop. Therefore, a sample size dramatically smaller than that derived from the formulae of Karandinos (1976) is required. Although the width in the confidence interval about a population size estimate based on a given sample size increases as $P(I)$ increases until $P(I) = 0.5$, this relationship causes little problem in estimating population densities because of the nonlinear relationship between mean population density and $P(I)$ (Jones & Parrella 1986). In an attempt to maximize the level of sampling precision and to minimize the effect of sampling on aesthetic quality, 30 leaves per week were removed at random from the plants within each cage, and 40 leaves per week were removed at random from the plants within each greenhouse section.

Leaf sampling commenced before the first release of *E. luteola* on 9 September and concluded with crop harvest. The adaxial surface of each leaf was examined with the aid of a dissecting microscope and the numbers of live whiteflies were recorded by developmental stage as were the numbers of dead (resulting from natural causes, *D. pusillus* predation, or *E. luteola* host-feeding) and parasitized whitefly nymphs. Poinsettia leaves with parasitized nymphs were held in individual petri dishes and emerging wasps were identified to species. Parasitized *B. argentifolii* nymphs were characterized by the presence of a translucent *E. luteola* larva pressed against the whitefly cuticle. This stage of *E. luteola* development occurred ≈7 d after oviposition. At ≈14 d after oviposition, parasitized whitefly nymphs were characterized by tan pupae that were retracted from the walls of the whitefly cuticle. In view of these morphological changes associated with *E. luteola* development, measures of parasitization represented wasp activity 1 wk before actual sample dates and each measure was mutually exclusive of previous or subsequent measures. Because it is not possible to determine the time at which a whitefly nymph was killed by host-feeding or predation, it should be noted that whitefly mortality data collected over time represent cumulative rather than instantaneous measures of parasitoid host-feeding and beetle predation.

Death of a whitefly because of *D. pusillus* predation can easily be distinguished from death by other causes. Complete consumption leaves only a flattened, empty whitefly cuticle, whereas an incompletely consumed whitefly exhibits visibly disrupted internal organs. Host-feeding by an *Encarsia* sp. is initiated by piercing the dorsal integument of a whitefly nymph and may be followed by repeated introductions into the same hole to enlarge it before feeding (Gerling 1990). With proper illumination, these enlarged holes can be seen easily with the aid of a dissecting microscope (50 power). Host feeding by *E. lute-*

ola is always a destructive process and is nonconcurrent with oviposition. Upon completing this microscopic examination, the adaxial surface area of each leaf was determined with an area meter (LI-COR LI-3100 area meter) (LI-COR, Lincoln, NE)

At harvest, all leaves from 30 plants selected at random from each greenhouse section and 30 plants selected at random from the grower-treated portion of the greenhouse were inspected for the presence of whiteflies. For each plant, the percentage of leaves infested with *B. argentifolii* nymphs and the numbers of nymphs per infested leaf were determined.

Analyses. An analysis of variance (ANOVA) (SAS Institute 1988) was used to detect significant between-treatment variations in temperature within the trials. In the ANOVA model, treatments (greenhouses versus exclosure cages) were defined as main effects and sample dates and times of day were defined as covariates of the main effects. Planned contrasts between treatment means were performed using a Scheffé's test.

Between-treatment variations in *B. argentifolii* densities over sample dates were detected using a repeated measures ANOVA (GLM procedure) (SAS Institute 1988). Within the ANOVA, a polynomial transformation was used because the levels of the repeated measure represented quantitative values within a treatment (SAS Institute 1988). Whitefly densities per sample date were weighted by the number of leaves within a sample, and leaf areas were standardized to the average leaf area observed over all leaf samples (mean adaxial area per leaf = 64.7 cm^2, SEM = 0.45, n = 3,900 leaves). Each cage and greenhouse section acted as replicates to yield n = 3 per treatment per sample date. Planned contrasts between treatment means were performed using a Scheffé's test.

Significant deviation of the levels of *B. argentifolii* infestations observed within the natural enemy release areas of the greenhouse at harvest from the expected infestation level observed in the grower-treated area was detected using a Wilcoxon matched pairs test (StatSoft 1993). Percentage of infestation data were arcsine (x) transformed before the analysis.

The direct costs associated with biological control were compared with the costs associated with conventional insecticide practices utilized by the grower in the greenhouse area adjacent to the biological control trials. Although *E. luteola* is not commercially available at this time, natural enemy costs were calculated from the average prices of the commercially available congener, *E. formosa*, and from the average price for *D. pusillus* charged by commercial insectaries (Hunter 1992). Because the monitoring techniques used in the biological control greenhouse were more intensive than necessary, costs associated with monitoring were not included in the analysis. The time required to release the natural enemies into each greenhouse section was negligible; hence, post-purchase labor costs associated with natural enemy releases were assumed to be zero.

Results

Temperatures varied significantly across localities (F = 22.587; df = 3, 3002; $P < 0.001$), but not in a manner that would bias the interpretation of the results obtained from the natural enemy releases. Although temperatures varied significantly across replicates ($P < 0.05$ for comparisons between greenhouse sections or exclosure cages), no between-treatment temperature differences within greenhouse sections were detected ($P > 0.05$ for comparisons between the biological control greenhouses and exclosure cages within the greenhouse sections). The mean daily temperature within the west biological control greenhouse was 16.47°C (SEM = 0.15) and within the west exclosure cage it was 16.78°C (SEM = 0.16). Because of their greater distance from the cooling system relative to the west treatments, the mean daily temperatures within the east biological control greenhouse (mean = 17.58°C, SEM = 0.19) and within the east exclosure cage (mean = 17.87°C, SEM = 0.19) were consistently higher than the temperatures in the west treatments.

Densities of live *B. argentifolii* nymphs varied significantly among the three treatments (F = 28.40; df = 2, 6; $P < 0.001$) (Fig. 2). The presence of a significant treatment-by-time interaction (F = 35.17; df = 24, 72; $P < 0.001$) is an unavoidable artifact of starting with similar whitefly densities at the beginning of the trial and finishing with nearly a 10-fold between-treatment difference in whitefly densities at the end of the trial (Fig. 2). Whitefly densities within the greenhouse sections were not significantly different from the densities observed in the exclosure cages receiving natural enemy releases (P = 0.09, Scheffé's planned comparison test). Therefore, populations within the complete exclosure cages presumably mimic the dynamics of greenhouse *B. argentifolii* populations in the absence of natural enemy releases. Whitefly densities within the complete exclosure cages were significantly greater than the whitefly densities in either of the two natural enemy release treatments ($P < 0.05$, Scheffé's planned comparison test).

Although parasitoid development was incomplete in 8 of the 20 parasitized whitefly nymphs recovered from foliage samples collected from the biological control greenhouse sections, adult *E. luteola* emerged from all of the remaining parasitized nymphs. In addition, adult *D. pusillus* were the only *B. argentifolii* predators observed in the biological control greenhouses

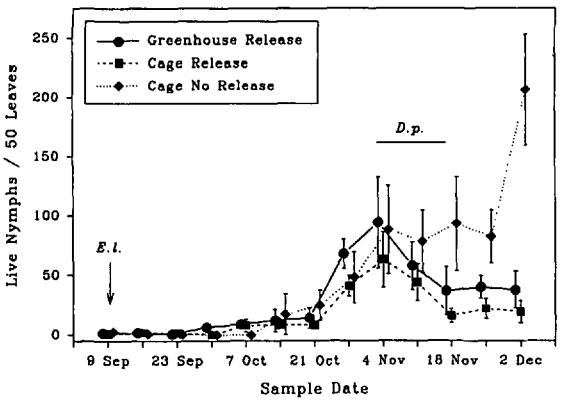

Fig. 2. Densities of live *B. argentifolii* nymphs in each of the three treatments: (1) a complete exclusion of natural enemies cage (◆), (2) an identical exclusion cage receiving natural enemy releases as a control for cage effects (■), and (3) releases of natural enemies onto plants outside of either cage (●). Weekly releases of *E. formosa* began on 9 September, and *D. pusillus* were released on 4, 11, and 18 November. Values are expressed as the mean ± 1 SEM (vertical bars) number of live nymphs per 50 leaves over the three greenhouse sections. Values have been standardized to the average leaf size observed from all leaves sampled (mean adaxial surface area per leaf = 64.7 cm^2, n = 3,900 leaves).

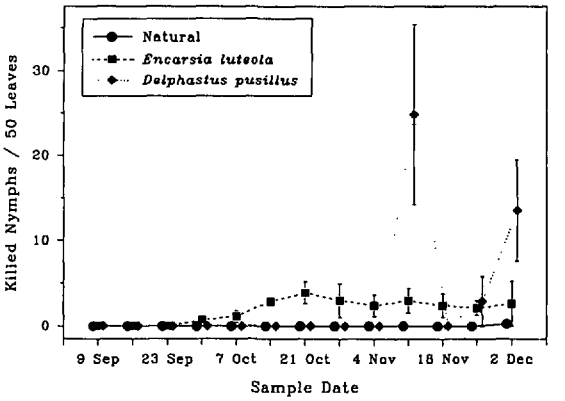

Fig. 3. Sources of whitefly mortality in the three biological control greenhouses receiving releases of natural enemies. *B. argentifolii* nymphs died from three mutually exclusive causes: (1) natural causes, (2) *D. pusillus* predation, or (3) *E. luteola* host-feeding and parasitization. Values are expressed as mean ± 1 SEM (vertical bars) number of killed nymphs per 50 leaves over the three greenhouse sections. Values have been standardized to the average leaf size observed from all leaves sampled as in Fig. 2.

over the duration of the trial. These observations justify our delineation of only three causes of whitefly mortality: (1) mortality resulting from *D. pusillus* predation, (2) mortality resulting from *E. luteola* host-feeding and parasitization, and (3) mortality resulting from natural causes. The relative contributions of these mortality factors in suppressing *B. argentifolii* populations in the biological control greenhouses are illustrated in Fig. 3.

Naturally occurring *B. argentifolii* mortality was virtually nonexistent throughout the trial. The number of whitefly nymphs killed from *E. luteola* host-feeding and parasitization closely tracked the number of live whitefly nymphs until 21 October, at which time the numbers of *E. luteola*-killed whiteflies plateaued (Fig. 3) and the numbers of live whitefly nymphs rose dramatically (Fig. 2). The frequency of nymphs killed from host-feeding (53.2%) was slightly greater than the frequency of nymphs killed from parasitization (46.8%) when both behaviors were pooled over the entire trial. Because host-feeding data represent cumulative measures over time, and as previously reported by Heinz & Parrella (1994), the majority of *E. luteola*-induced mortality was probably resulting from parasitization. Once *E. luteola*-induced mortality was detected (30 September), the proportion of mortality resulting from parasitization (with a time lag of one week) was positively and significantly correlated (r^2 = 0.478; F = 7.329; df = 1, 8; P = 0.027) with the proportion of preferred third-and early fourth-instar nymphs (Fig. 4). An identical positive and significant correlation was also detected for the complementary measures of the proportion of mortality resulting from host-feeding (with a time lag of 1 wk) versus the proportion of nonpreferred first-, second- and late fourth-instar nymphs.

After their release into the greenhouses on 4 November, predation by *D. pusillus* killed an average of 24.8 whitefly nymphs per 50 leaves within the 1st wk (Fig. 3), which subsequently lead to rapid declines in the *B. argentifolii* populations (Fig. 2). A second peak of whitefly predation was noted on 2 December. Although determination of an instantaneous predation rate is again not possible, three *D. pusillus* beetles

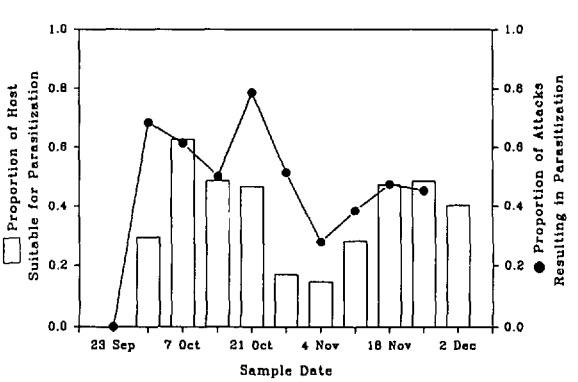

Fig. 4. Relationship between proportion of hosts suitable for parasitization (the proportion of third-and early fourth-instar nymphs) and the proportion of *E. luteola* attacks resulting in parasitization with a 7-d time lag.

Table 1. *B. argentifolii* damage to poinsettia plants (n = 30 per treatment) at harvest

Treatment	% Infested plants	Infested leaves per plant (mean ± 1 SEM)	Nymphs per plant (mean ± 1 SEM)
Grower	46.7	1.1 ± 0.3	5.4 ± 2.2
East biological control greenhouse	76.7	2.7 ± 0.8	22.4 ± 9.5
Middle biological control greenhouse	36.7	1.1 ± 0.5	5.1 ± 2.2
West biological control greenhouse	66.7	1.5 ± 0.3	6.8 ± 1.6

Damage was scored as the presence and density of whitefly nymphs on the foliage.

were collected with the 2 December foliage samples, suggesting that the beetles were still actively foraging within the greenhouse on this date.

Damage to harvested plants within the greenhouse sections receiving releases of natural enemies, scored as the density of *B. argentifolii* nymphs on the poinsettia foliage, was not significantly different from the damage level observed in the grower-treated area (Table 1). No significant between-treatment differences were observed in the percentages of plants infested (Z = 1.07; n = 3; P = 0.29), the numbers of infested leaves per plant (Z = 1.06; n = 3; P = 0.11), or the numbers of nymphs per plant (Z = 1.06; n = 3; P = 0.29).

The cost associated with *B. argentifolii* biological control was compared with the costs associated with the pesticide program used by the cooperating grower in an area sufficiently separated from the biological control area to prevent cross-contamination between treatments. Twelve *E. luteola* releases were made into each greenhouse section during the crop cycle at an estimated price of $4.95 per release, and three *D. pusillus* releases were made at an estimated price of $35.64 per release. These costs, multiplied by the total number of releases, yielded a total cost of $166.32 for the biological control programs in each greenhouse section. The cooperating grower relied on an insecticide-based pest management program that involved two applications of kinoprene (Sandoz Agro, Muttenz, Switzerland) at a cost of $3.52 per application, and six fumigations with sulfotep (Bayer AG, Bayerwerk, Germany) at a cost of $4.53 per application. The total cost of this insecticide-based control program was $34.22 for an area the size of each section of greenhouse used in the biological control treatments.

Discussion

B. argentifolii was first reported as a serious pest of greenhouse-grown poinsettias in 1986 (Parrella et al. 1992); hence, examples of biological control of this pest infesting greenhouse crops are sparse. Unlike the situation with *T. vaporariorum* (Lindquist 1988), biological control of *Bemisia* sp. with releases of *E. formosa* have yielded mixed results. In commercial poinsettia stock production, complete dependence on inundative releases of *E. formosa* was not sufficient in limiting *B. argentifolii* egg deposition on terminal growth, which is the harvestable product of this crop (Parrella et al. 1991). However, integration of *E. formosa* releases with a compatible pesticide (insecticidal soap) and physical–cultural control (rouging infested cuttings) produced a crop of poinsettia cuttings within the acceptable range defined by the cooperating grower (0.014–0.509 *B. argentifolii* eggs and immatures per cutting) (Parrella et al. 1991). In the case of poinsettia cuttings, the demand for whitefly-free plants is much higher than in a Christmas poinsettia crop, where a higher level of whiteflies can be tolerated. This increased damage tolerance should greatly increase the chances of achieving successful biological control of *Bemisia* sp. in potted poinsettia.

In Germany and Italy, *B. tabaci* can be satisfactorily controlled on potted poinsettias through weekly releases of *E. formosa* (Albert 1990, Benuzzi et al. 1990). However, in both cases *E. formosa* were released into mixed populations of *B. tabaci* and *T. vaporariorum*. *Bemisia* sp. is generally not as good of a host for *E. formosa* as *T. vaporariorum* as evidenced by an increased oviposition rate, a considerably lower immature mortality, and a higher overall quality of emergent adults for wasps using *T. vaporariorum* compared with *B. tabaci* as hosts (Boisclair et al. 1990). This population mix may facilitate whitefly biological control by increasing the average quality of *E. formosa* offspring by comparison to the average quality of offspring produced on a population of only *B. tabaci*. The results presented from this study represent the first report of successful biological control of an infestation of only *B. argentifolii* on poinsettia.

Host-feeding by whitefly parasitoids has been previously observed for several species within the genus *Encarsia* (Gerling 1990). Parasitoids often host-feed on hosts that are smaller in size than those receiving parasitic eggs (Flanders 1953, Gerling et al. 1987, Heinz & Parrella 1988). A similar pattern was detected for *E. luteola* attacking *B. argentifolii* nymphs during these biological control trials. Although it has been broadly suggested that host-feeding promotes oogenesis (van Lenteren et al. 1987), this suggestion should be considered a hypothesis until further data are collected. Regardless of its implications for *E. luteola* biology, host-feeding was a significant source of *B. argentifolii* mortality and, therefore, probably contributed greatly to the successful biological control of this pest.

Several studies have indicated that in agricultural systems, as in nature, several natural enemies acting together can achieve a higher level of control of a pest than one alone (Zwölfer 1971, Miller 1980; however, see Meyers et al. 1989 for another view). One concern regarding multiple-species releases has been that interspecific interactions among biological control organisms may reduce their effectiveness against the target species (Ehler 1990). This is a particularly important consideration when control at low densities is required (as in the case of poinsettias grown for their aesthetic value), causing natural enemies to compete for the same hosts. Potential negative interspecific interactions between *D. pusillus* and whitefly parasitoids were addressed in pre-release evaluations conducted by Heinz et al. (1994). Results from these experiments indicated that *D. pusillus* larvae and adults become more discriminating as a parasitoid develops within its host. Larvae and adult predation on parasitoid larvae (≤7 d old) indicated that parasitoid populations could be adversely affected by *D. pusillus*. Despite this potential, we were unable to detect any cases of *D. pusillus* predation on developing *E. luteola* in either of the two natural enemy release treatments.

The direct cost associated with this *B. argentifolii* biological control program was ≈5 times greater than the costs associated with the insecticide-based management program utilized by the cooperating grower. Precise timing of *E. luteola* releases with peak occurrences of suitable *B. argentifolii*, compared to weekly parasitoid releases, could reduce the number of parasitoids necessary to achieve successful biological control (Helgesen & Tauber 1977, Heinz et al. 1993). However, *Bemisia* sp. distribution data obtained from poinsettia (Liu et al. 1993) has not yet been used to develop an accurate sampling method necessary for determining the precise timing or rate of natural enemy releases.

Stinner (1977) suggests that where there is a single key pest species infesting a crop, inundative or inoculative releases could provide control for no more cost than currently used pesticide treatments provided commercial natural enemy costs are competitive. With only a few commercial insectaries maintaining rather small supplies of *D. pusillus* (see Hunter 1992 for the number of suppliers), the costs associated with rearing and releasing this predator could surely be reduced with an increase in mass-producers or improved mass-rearing techniques (van Lenteren 1986). Inclusion of indirect costs associated with chemical control may further balance the overall costs between the two treatments. The indirect costs associated with biological control are lower than the costs associated with insecticide-based control because: the production and application of natural enemies are safer, there are no environmental risks associated with biological control, and the chance of resistance to natural enemies is small (van Lenteren 1986, Parrella & Jones 1987).

Concerns with possible differential costs between the two control treatments should abate considering the threat posed by *B. argentifolii* to the poinsettia industry. The use of weekly releases of *E. luteola* together with additional releases of *D. pusillus* when the biological control is threatened, can result in the production of a poinsettia crop that will meet the high aesthetic standards imposed by poinsettia growers. This natural enemy release strategy provides a successful *B. argentifolii* management alternative to traditional insecticide-based programs.

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