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Biological Control of *Bemisia tabaci* (Homoptera: Aleyrodidae) in a Greenhouse Using *Chrysoperla rufilabris* (Neuroptera: Chrysopidae)

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First and second instar *Chrysoperla rufilabris* (Burmeister) were evaluated as control agents for sweet potato whitefly, *Bemisia tabaci* (Gennadius), on *Hibiscus rosa-sinensis* L. in a greenhouse. Two inundative releases of 25 or 50 *C. rufilabris* larvae per plant at an interval of 2 weeks maintained all plants in a marketable condition. Two releases of 100 *C. rufilabris* larvae toward the center of 12 plants also maintained marketability. While most plants with 5 *C. rufilabris* larvae each remained marketable, the majority of the untreated plants were unmarketable at the end of the experiment. Qualitative evaluation of plant marketability was based on the presence of sooty mold and physical effects of *B. tabaci* on the plants 2 weeks after the last release of *C. rufilabris* larvae.

KEY WORDS: ***Bemisia tabaci;* sweet potato whitefly; *Chrysoperla rufilabris; Hibiscus rosa-sinensis;* predation ecology; biological control.**

INTRODUCTION

The sweet potato whitefly, *Bemisia tabaci* (Gennadius), attacks hundreds of plant species and is found in tropical and warm temperate regions around the world (Costa, 1976; Mound and Halsey, 1978). Injury to plants by *B. tabaci* results from transmission of viruses (Duffus and Flock, 1982; Muniyappa, 1980), honeydew excretion that creates favorable conditions for the rapid growth of sooty mold fungi (Perkins, 1987; Byrne and Bellows, 1991), and direct damage to plants from stress if it is present in sufficiently high populations (Pollard, 1955).

Experimental trials using predators for control of *B. tabaci* have been largely limited to species of predacious phytoseiid mites (Meyerdirk and Coudriet, 1986), which may show limited application for controlling this pest in California. Gerling (1986) listed over 20 species of predators that attack *B. tabaci* (precise number unknown due to grouping of predator species). Included as predators were 6 species of Chrysopidae, 11 Coccinellidae (Coleoptera), 1 Anthocoridae (Hemiptera), 1 Ceraphronidae (Hymenoptera), 5 mite species (Acari: Phytoseiidae), and a category of predators with an apparently undetermined number of species described as "spiders" (Araneae). The *B. tabaci* life stage attacked by predators recorded by Gerling (1986), except for *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae), was not reported and he suggested that most of the predators listed had a fortuitous association with *B. tabaci* and were not effective control agents.

Parrella *et al.* (1991) used augmentative releases of *Encarsia formosa* Gahan (Hymenoptera: Aphelinidae) for biological control of sweet potato whitefly on commercially grown ornamental poinsettia in California. *B. tabaci* was maintained at low populations using a combination of *E. formosa*, insecticidal soap applications, and roguing infested cuttings to produce commercially acceptable crops. Using *E. formosa* alone to control *B. tabaci* was viewed as inadequate since a nearly 100% control rate is commonly believed to be necessary by producers (Parrella *et al.*, 1991). In the last decade, biological control of pest insects in greenhouses has been very successful (van Lenteren and Woets, 1988) and its applications are increasing.

The greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood), a similar species, was maintained below damaging populations on marigolds in California greenhouses by the inundative release of *E. formosa*, with the supplementary release of *C. carnea* (Heinz and Parrella, 1990). However, mortality of *T. vaporariorum* was not partitioned between the beneficial species; that is, no data were gathered on the relative efficacy of the predators/parasitoids or on other mortality factors that may have been involved. Butler and Henneberry (1988) noted that *C. carnea* successfully consumed *B. tabaci* eggs and immatures in laboratory tests.

Chemical control, especially when aerially applied, is mitigated by the preference of *B. tabaci* for lower leaf surfaces (Johnson *et al.*, 1982). Resistance to permethrin, DDT, and a broad spectrum of organophos-

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phates also occurs in *B. tabaci* (Prabhaker *et al.*, 1985). Furthermore, evidence of increased reproductive capability of *B. tabaci* when individuals are exposed to certain insecticides has been reported (Dittrich *et al.*, 1985).

The recent overwhelming increase of sweet potato whitefly in greenhouses and field crops in southern Texas, problems encountered in controlling the insect with chemicals, and current public sensitivity to pesticides placed our research emphasis squarely on biological control. The purpose of this study was to determine if *Chrysoperla rufilabris* (Burmeister), a commercially available predator, can provide an acceptable level of *B. tabaci* control on *Hibiscus* in greenhouses.

MATERIALS AND METHODS

Greenhouse-rooted cuttings of *Hibiscus rosa-sinensis* L. cv. Jane Cowl, a cultivar that frequently develops heavy *B. tabaci* infestations in southern Texas greenhouses, were planted in round 1.7-liter containers filled with potting medium (15 cm depth). The cuttings were pinched once to promote early lateral shoot development. Nearly uniform plants (n = 144 per experiment) were selected when lateral shoots supported five to six leaves.

A reproductive *B. tabaci* nursery maintained on *Hibiscus* plants in a separate greenhouse provided the hosts used in these experiments. Infestation of the experimental plants was initially accomplished by exposing them for a few days to plants taken from the *B. tabaci* nursery. Since a small number of adult hymenopteran parasitoids were found trapped on yellow sticky cards, but not parasitizing *B. tabaci* nymphs within the cages, later experiments employed aspirating large numbers of *B. tabaci* adults into plastic vials from their nursery and releasing them directly into the cages to avoid incidental transmission. *B. tabaci* in an experimental cage was allowed to increase until it became easily detectable, which is a "threshold" used in commercial greenhouses where insecticide applications begin. Actual densities of *B. tabaci* are not used as a threshold by nursery operators in south Texas.

The *C. rufilabris* used in the experiments were obtained from the USDA, ARS, SARL, Biological Control of Pests Research Unit at Weslaco, Texas, maintained as described by Nordlund and Morrison (1992), and were released on the *Hibiscus* as first and second instar larvae.

A row of twelve cages (1.2 × 1.8 × 2.4 m) with 5 × 5-cm contiguous wooden frames was assembled along the center of the greenhouse directly on the concrete floor. The top of the cages was covered with 0.15-mm (6 ml) clear plastic; organdy material was installed on the side walls and between cages. Seams and joints of the cages were sealed with caulk to prevent arthropod dispersal. *Hibiscus* plants were placed equidistantly in each cage in two rows of six plants, each separated from its nearest neighbor by ca. 40 cm. In Experiments 1 and 2, 5, 25, and 50 *C. rufilabris* larvae per plant were released and replicated three times with a control containing *B. tabaci* only. An additional release of *C. rufilabris* larvae at the above populations was made again after a 2-week interval. Experiments 1 and 2 began on 7 December 1990 and 22 March 1991, respectively.

In Experiment 3 (initiated 10 May 1991), the first of four treatments (three replications per treatment) consisted of 100 *C. rufilabris* larvae released on the center of 12 plants having contiguous leaf contact (this was the only treatment where adjacent plants were in contact). The second treatment was identical to the first except that leaves of neighboring plants were not in contact, but were positioned ca. 40 cm apart, as in Experiments 1 and 2. A second release of 100 per plant, leaves touching and not touching, was made 2 weeks later. Treatment 3 consisted of two *C. rufilabris* releases of 50 larvae per plant at 2-week intervals. Treatment 4 was the untreated control. Plants in Treatments 2 through 4 were spaced ca. 40 cm apart identical to those in Experiments 1 and 2. All treatments had a completely randomized design and lasted 5 weeks.

Populations of *B. tabaci* immatures (eggs and nymphs) were sampled by cutting small disks (7 mm diameter) from plant leaves using a hole punch. Leaf samples were taken from upper (9 leaf disks) and lower (9 leaf disks) leaves of four plants (72 leaf disks per replication). The number of eggs and first through fourth instar nymphs on each leaf disk were counted using a microscope and were recorded. Treatment totals for each replication (n = 3) were used in the analysis.

A single yellow sticky card (125 × 25 mm) was used to monitor *B. tabaci* adults in each cage twice weekly beginning 3 days before predator release. Each card was hung on a string, ca. 5 cm long, attached to the plastic cage top between the two rows of plants near the door.

Sampling data (immatures and adults) were log (y + 1) transformed and initially analyzed using repeated measures ANOVA (SAS Institute, 1985). Results indicated a significant sampling date by treatment interaction ($P > 0.001$). Data were then analyzed by individual sampling date using a one-way ANOVA; treatment means were separated using the Ryan–Elinot–Gabriel–Welsch (REGWQ) multiple range test (SAS Institute, 1985). Untransformed means are presented for comparison.

Relative *B. tabaci* control was determined by qualitative evaluation of plants 2 weeks after the last release of *C. rufilabris* larvae (4 weeks after the start of each experiment). Evaluation was based on a rating scale of 1 to 5; 1, severe coverage of sooty mold, yellow and abscissed leaves, plants unmarketable; 2, relatively high incidence of sooty mold with some yellowing and leaf abscission,

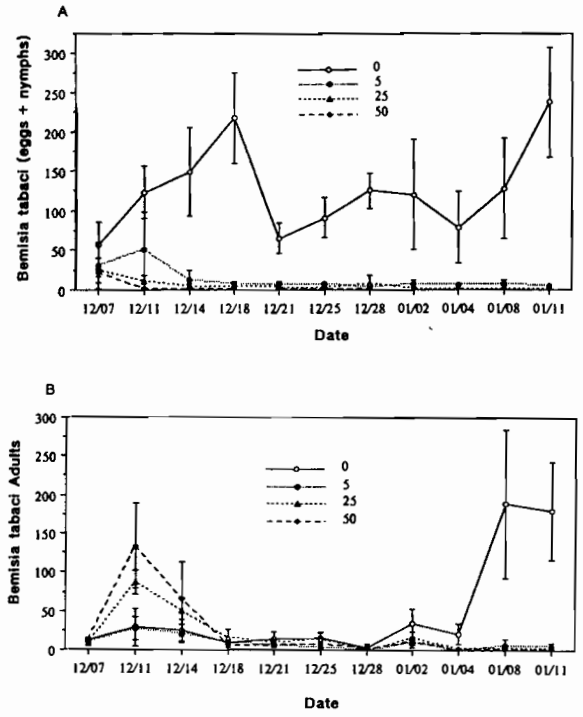

FIG. 1. (A) *Bemisia tabaci* immature densities (mean ± SD) from 72 *Hibiscus* leaf punch samples (n = 3) taken in cages with 0, 5, 25, or 50 *Chrysoperla rufilabris* released per plant. (B) *B. tabaci* adult densities (mean ± SD) from yellow sticky traps sampled in the same cages.

most plants unmarketable; 3, moderate incidence of sooty mold and yellowing of leaves, some plants unmarketable; 4, light incidence sooty mold, all plants marketable; and 5, sooty mold, yellow leaves or other *B. tabaci*-induced symptoms absent, all plants marketable. Data were analyzed using the Kruskal–Wallis k sample test (Steel and Torrie, 1980).

Hygrothermographs were operated during all experiments, one in a cage and one in the greenhouse next to the cages. Temperature data were analyzed by a two-way ANOVA without replication, with experiment and date as factors (SAS Institute, 1985).

RESULTS

Experiment 1. Initial populations of *B. tabaci* immatures were similar across treatments (P = 0.307), but from the second sample to the conclusion of the experiment, *B. tabaci* density was always significantly higher in the control cages than in the predator release cages (Fig. 1; $P < 0.001$, mean separation results not shown). Differences in *B. tabaci* density were also apparent among predator release rates. In 8 of the 11 sample dates, the 50 *C. rufilabris* per plant treatment contained significantly lower numbers of *B. tabaci* than the 5 per plant treatment.

Significant reduction in *B. tabaci* adults captured on yellow sticky cards in the predator release cages was not evident until the last three samples (Fig. 1). There were no differences in adult *B. tabaci* density among predator release rates.

Qualitatively, the range of ratings used to determine marketable plants was significantly different among predator release rates ($P < 0.005$). *Hibiscus* treated with 50 *C. rufilabris* larvae per plant remained marketable with negligible *B. tabaci* damage (range of rating, 4 to 5). Plants treated with 25 *C. rufilabris* larvae were also marketable (ratings, 3 to 5), although moderate sooty mold was observed on some plants. The 5 *C. rufilabris* larvae per plant treatment had ratings from 2 to 3, indicating that many of the plants remained marketable. The controls not treated with *C. rufilabris* larvae were unmarketable (all with rating of 1).

Experiment 2. *B. tabaci* populations reached higher densities during this experiment than in Experiment 1 (Fig. 2). Significant differences among predator release rates occurred from the second sample to the conclusion

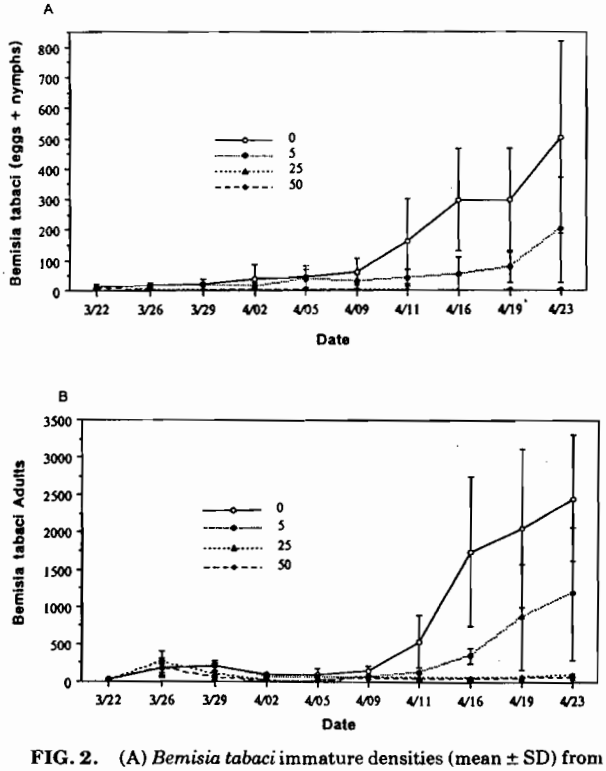

FIG. 2. (A) *Bemisia tabaci* immature densities (mean ± SD) from 72 *Hibiscus* leaf punch samples (n = 3) taken in cages with 0, 5, 25, or 50 *Chrysoperla rufilabris* released per plant. (B) *B. tabaci* adult densities (mean ± SD) from yellow sticky traps sampled in the same cages.

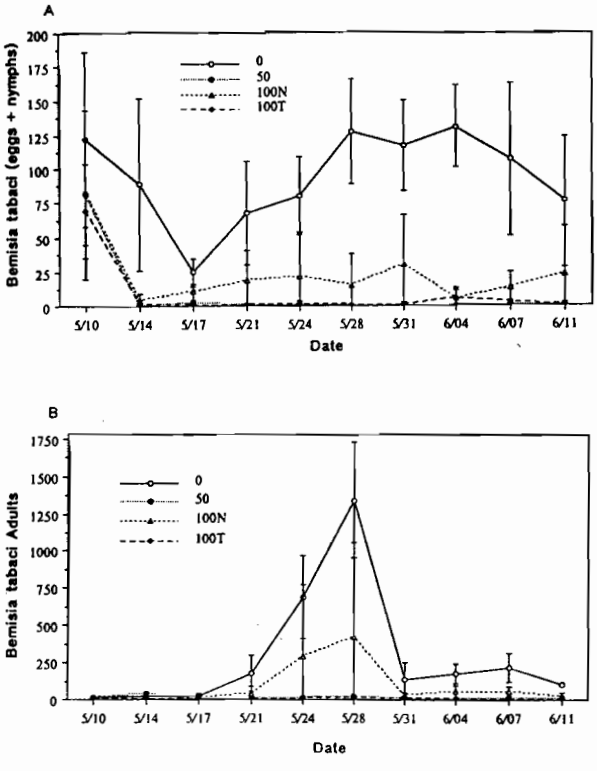

FIG. 3. (A) *Bemisia tabaci* immature densities (mean ± SD) from 72 *Hibiscus* leaf punch samples (n = 3) taken in cages with 0 or 50 *Chrysoperla rufilabris* released per plant or 100 per cage with plant leaves touching (100T) or plant leaves not touching (100N). (B) *B. tabaci* adult densities (mean ± SD) from yellow sticky traps sampled in the same cages.

of the experiment (except for the 2 April sample) ($P < 0.001$), and in most samples the 0 and 5 *C. rufilabris* per plant treatments had significantly higher numbers than the 25 and 50 *C. rufilabris* per plant treatments.

Adult *B. tabaci* levels remained relatively low until the last half of the experiment, at which point they reached an average of >2400 adults per trap (Fig. 2). Treatment differences were common after the 5 April sample, with the 5 *C. rufilabris* per plant treatment generally not different from the control.

Generally, *B. tabaci* control and qualitative ranks were higher in Experiment 2 than in Experiment 1, and the range of ratings was significantly different among predator release rates ($P < 0.005$). All plants treated with 50 *C. rufilabris* larvae rated 5, and plants with 25 larvae rated 4 to 5. Most plants were marketable for the 5 *C. rufilabris* larvae release (rating, 3), while most control plants were unmarketable (rating, 1 to 3).

Experiment 3. Immature *B. tabaci* numbers were comparable to those from Experiment 1, but adult numbers were higher (Fig. 3). As in the other experiments, *B. tabaci* numbers were significantly lower in the predator release cages after the second sample ($P < 0.01$). The 100 released, plants touching and the 50 per plant treatments always produced the lowest *B. tabaci* density.

Adult *B. tabaci* peaked at the 28 May sample and declined and remained relatively low after that point (Fig. 3). Significant differences among treatments were evident after the third sample, and the 100 release, plants not touching treatment was generally intermediate in *B. tabaci* density.

The range of ratings was significantly different among predator release rates in Experiment 3 ($P < 0.01$), with all *C. rufilabris*-treated plants remaining marketable (rating, 3 to 5). Some of the control plants were marketable, while others showed signs of sooty mold and yellow leaves (rating, 2 to 3).

Daily mean temperatures within cages were significantly different among experiments (Experiment 1, 24.4°C ± 5.3; Experiment 2, 34.8°C ± 3.4; and Experiment 3, 39.2°C ± 1.2; $P < 0.001$). Although the design of Experiments 1 and 2 was identical, their data were analyzed separately because of the significantly different temperatures.

DISCUSSION

C. rufilabris larvae feed voraciously on *B. tabaci* eggs and nymphs on the lower surface of leaves. Immature *B. tabaci* were recognized by *C. rufilabris* larvae as a potential food source shortly after they were introduced on plants. *B. tabaci* eggs and nymphs were controlled by *C. rufilabris* when compared both qualitatively and quantitatively. The differences in results between treated and untreated cages were often visibly striking. *Hibiscus* plants in the control cages were severely damaged, as evidenced by sooty mold, leaf yellowing, and leaf abscission. Untreated plants in Experiments 2 and 3 ranked somewhat better in overall appearance than those of the first experiment, but were still largely unmarketable. Treatments with five lacewing larvae released per plant produced both marketable and unmarketable plants. All plants in the 25 or 50 *C. rufilabris* larvae per plant treatments remained healthy and marketable.

Interference, another conspecific interaction among *C. rufilabris* individuals, or barrier effects became apparent in Experiment 3, as did environmental differences favoring plants grouped together with leaves touching. Evidence of *B. tabaci* control was strongest on plants with touching leaves, although only 100 *C. rufilabris* larvae ($\bar{x}$ = 8.3 larvae per plant) were released. The predators were apparently capable of more efficient dispersal and subsequent control of *B. tabaci* when leaves of adjacent plants were in contact. Placing plants in this manner likely improved dispersal of the larvae and perhaps decreased their opportunity for cannibalism. Growing conditions conducive for healthy *Hibiscus* were en-

hanced when plants had their leaves in contact with other plants since they were noticeably taller with larger leaves.

Releasing 100 *C. rufilabris* larvae in the center of 12 plants with leaves not touching also produced good *B. tabaci* control, although the lower ratings suggest that the larvae could not disperse as effectively under these conditions or that cannibalism may have taken too heavy a toll on larvae before dispersal.

The capture of *B. tabaci* in yellow sticky traps may vary greatly with their relative size, height above ground, shape (cylindrical, rectangular), and other factors (Byrne *et al.*, 1986). Because of this variability, the yellow sticky traps were used to measure the presence or absence and to provide a general index of relative abundance of *B. tabaci* adults without expecting precision in the predictability of density or its effect on plants.

Although *C. rufilabris* larvae were occasionally observed capturing and consuming *B. tabaci* adults, it is not likely that they had a significant impact on adult populations. Therefore the mortality of *B. tabaci* adults in the cages was attributed to their attrition through advancing age with no or little replacement.

Our experiments involved testing of *C. rufilabris* under inundative releases. This generalist predator was not expected nor required to produce a stable *B. tabaci* equilibrium; to survive to reproduce and continue its existence while maintaining low populations of *B. tabaci* in the greenhouse. Rather, since the system in which the predators were used is short lived (as are many greenhouse production systems), the predators were intended to invade and consume until prey was eliminated and predator mortality through starvation occurred. These specialized objectives effectively negate many requirements of classical biological control theory such as maintaining target pest species in stable equilibrium at low density, host specificity, a synchronous predator/prey life cycle, and the ability to reproduce rapidly when pest populations increase (Beddington *et al.*, 1978; May, 1978). *C. rufilabris* reflects certain characteristics of a predator with nonequilibrium search and destroy strategies similar to those in the concept introduced by Murdoch *et al.* (1985). Like search and destroy predators of Murdoch *et al.*, whitefly immatures are essentially the only prey available under these greenhouse circumstances (facultative monophagy, Nyffeler *et al.*, 1990), and *C. rufilabris* demonstrates a remarkable efficacy for seeking out and consuming *B. tabaci* prey. Unlike the predators in Murdoch *et al.* (1985), the capacity for elevated rates of a numerical response in the form of population increase by *C. rufilabris* is not present, but it is not required since enough predators to accomplish the desired localized effect are distributed at the outset and the system is an ephemeral one (Murdoch, 1973, 1975; Ehler, 1977; Ehler and Miller, 1978).

A potential problem exists for greenhouses in areas with dense populations of *B. tabaci* and their consequent overwhelming migration. Many greenhouses use cardboard cooling pads which are permeable to *B. tabaci* under intense migration pressure, unless the pads are blocked with organdy or another suitable barrier. It is unlikely that control of *B. tabaci* by *C. rufilabris* larvae will be effective in greenhouses with this type of cooling system and under elevated *B. tabaci* migration pressure.

The results of this study show that *C. rufilabris* has the potential for controlling *B. tabaci* under greenhouse conditions. *C. rufilabris* larvae prey on a variety of insect pests and can be used to control a number of greenhouse pests in many situations. Additionally, in a companion study, *C. rufilabris* larvae were not significantly influenced by the residual activity of insecticidal soaps, including undiluted concentrations (R. G. Breene, unpublished data). Thus, application of insecticidal soaps shortly before the initial release of *C. rufilabris* larvae may increase *B. tabaci* control overall or it may serve to accelerate a controlling effect. We anticipate the technology for mass production of *C. rufilabris* to improve significantly over the next few years which should increase their use in biological control programs and make them more competitive with traditional methods for controlling *B. tabaci*.

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