DEVELOPMENT OF PARASITOID INOCULATED SEEDLING TRANSPLANTS FOR AUGMENTATIVE BIOLOGICAL CONTROL OF SILVERLEAF WHITEFLY (HOMOPTERA: ALEYRODIDAE)

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ABSTRACT

Methods are presented for producing banker plants, transplants that are used for augmentation of *Eretmocerus* parasitoids for biological control of *Bemisia argentifolii* in cucurbit crops. Preference tests were conducted with *B. argentifolii* and its parasitoid *Eretmocerus hayati* for ten cantaloupe varieties to determine their suitability for use as banker plants. *Bemisia argentifolii* showed a significant preference for the varieties Copa de Oro and Mission, whereas, *E. hayati* showed the greatest preference for Copa de Oro, Mission and Primo. The impact of imidacloprid on the development of parasitoid immatures on banker plants was evaluated. Thirteen days after release of *E. hayati*, banker plants treated with imidacloprid produced equivalent numbers of parasitoids as did control plants. Field trials, incorporating the use of banker plants and imidacloprid, were conducted for two seasons in spring cantaloupes and one season in fall watermelons. Numbers of parasitoid progeny produced per cantaloupe banker plant were approximately 94.6 and 102.1 in two trials during the Spring of 1997 and 1998. Field release rates per acre in cantaloupe were estimated to be 68,946 and 29,970 for the 1997 and 1998 trials, with banker plants incorporated with regular transplants at a ratio of 1:10 and 1:30 respectively. In the watermelon trial, the mean number of parasitoid progeny produced per banker plant was determined to be 94.6, with an estimated 4156 released per acre with a ratio of 1:30 banker to regular transplants. Banker plants were shown to be a reliable method for field delivery of *Eretmocerus* parasitoids in transplanted and direct seeded cantaloupe or watermelon crops. The methods used to produce parasitoid inoculated banker plants are discussed.

Key Words: augmentation, parasitoids, *Eretmocerus hayati, Bemisia argentifolii*, imidacloprid

RESUMEN

Se discuten métodos para la producción de "banker plants", transplantes en los que se liberan parasitoides de *Eretmocerus*, para el control biológico de la mosca blanca, *Bemisia argentifolii* (= *B. tabaci* biotipo B) en cucurbitáceas. Se realizaron pruebas de preferencia con *B. argentifolii* y su parasitoide *Eretmocerus hayati* en 10 cvs. de melón "cantaloupe" para determinar la efectividad de esta planta como banker. *B. argentifolii* mostró una preferencia significativa por los cvs. Copa de Oro y Mission, mientras que *E. hayati* mostró preferencia por Copa de Oro, Mission y Primo. Se evaluó el impacto de imidacloprid en el desarrollo de parasitoides inmaduros en plantas banker. Trece días después de la liberación de *E. hayati*, las plantas banker tratadas con imidacloprid produjeron la misma cantidad de parasitoides que las plantas no tratadas. Se llevaron a cabo experimentos de campo usando plantas banker e imidacloprid durante dos temporadas en melones de primavera y durante una temporada en sandía de otoño. La progenie de parasitoides producida por cada planta de melón

banker fue de 94.6 y 102.1 en dos ensayos efectuados durante la primavera de 1997 y 1998. En melón, la tasa de liberación en campo por acre se estimó en 68,946 y 29,970 para los ensayos efectuados en 1997 y 1998, en los cuales se incorporaron plantas banker en proporción de 1:10 y 1:30, respectivamente. En sandía, la progenie de parasitoides promedio por planta banker fue 94.6. La cantidad de parasitoides liberada por acre se estimó en 4,156, con una proporción de plantas banker de 1:30. El uso de plantas banker representa un método confiable para la distribución de parasitoides *Eretmocerus* en el campo, tanto en melón o sandía de transplante o siembra directa. Se discuten los métodos empleados para la producción de plantas banker inoculadas.

Bemisia argentifolii (=*Bemisia tabaci* Biotype B), Silverleaf whitefly (SLWF), continues to be a serious pest of annual row crops such as cotton, cole crops, cucurbits, okra, sesame, and tomato, in the subtropical growing areas across the US and worldwide (DeQuattro 1997, Legaspi et al. 1997, Riley & Ciomperlik 1997). Damage is caused not only by direct feeding but also through transmission of geminiviruses (Brown & Bird 1992, Brown 1994, Polsten & Anderson 1997). Estimates of the monetary costs to U.S. agriculture due to crop loss, job displacement and cost of control are now approaching one billion dollars (Bezark 1995, De Barro 1995, Henneberry et al. 1996). Imidacloprid has temporarily reduced the impact of *Bemisia* in some crops, however resistance is now documented (Prabahker et al. 1997). Silverleaf whitefly control strategies are needed which decrease dependence on single control tactics. To this end, over 38 exotic populations of *Bemisia* parasitoids from 16 countries have been imported and evaluated in a comprehensive multi-state, multi-crop biological control program (Kirk et al. 1993, Nguyen & Bennett 1994, Goolsby et al. 1996, Goolsby et al. 1998, Rose & Zolnerowich 1998). Recently, imported exotic *Eretmocerus* spp. have been integrated with selective insecticides and cultural controls into a biological control based Integrated Pest Management (BC-IPM) program (Ciomperlik et al. 1997). This strategy is proposed as the basis for long term sustainable management of silverleaf whitefly.

Several biological control strategies including importation of new natural enemies (classical), natural enemy refugia (conservation), and inoculative releases (augmentation) have been evaluated for management of *B. argentifolii* (Roltsch & Pickett 1995, Carruthers et al. 1996, Corbett 1996, Henneberry et al. 1996, Simmons et al. 1997, Ciomperlik et al. 1997). Implementation of biological control strategies has been difficult in the subtropical agricultural areas where the impact of *B. argentifolii* is most severe. Several reasons may account for this difficulty such as: discontinuity of annual crops, high use of pesticides for other pests, and the lack of refugia for natural enemies, particularly parasitoids (Hoelmer 1995). Augmentation biological control shows potential for overcoming the difficulties of working in these ephemeral cropping systems. Early season releases of *Eretmocerus* spp., integrated with the use of selective insecticides, such as imidacloprid can provide season long control of *B. argentifolli* without the need for late season applications of broadspectrum insecticides (Simmons et al. 1997, Ciomperlik et al. 1997).

The high cost of producing and releasing natural enemies often limits the use of augmentative biological control. Although several field trials have shown that augmentative releases of natural enemies can suppress pests in field and orchard systems, the cost of application precludes their use (Pickett & Bugg 1998). Typically augmentative biological control is used in high value crops with a large budget for production costs, i.e. strawberries, glasshouse crops (Ravensberg 1992, Trumble &

Morse 1993). Cucurbit crops such as spring cantaloupe melons also fit these criteria making it economically feasible to use augmentative biological control. In all of these crops, increasing the efficiency of field delivery systems can reduce application costs. This is especially critical to short season annual crops where the window of time for effective pest management is short in contrast to perennial systems.

It has been demonstrated that releases of the newly imported exotic *Eretmocerus* spp. can suppress *B. argentifolii* populations in spring cantaloupe melon crops (Simmons et al. 1997, Ciomperlik et al. 1997). In these tests hand releases have been used to augment parasitoid populations. A method is needed which allows for efficient early season mass release of parasitoids in cucurbit crops. Herein we propose a novel approach for augmenting *Eretmocerus* that can increase the efficiency of delivery over hand releases.

Methods were developed and tested using greenhouse grown seedling transplants inoculated with parasitoids, called "banker plants," specifically for augmenting parasitoids in annual cucurbit crops, and with possible application in other transplanted vegetable crops such as tomatoes and cole crops. The term banker plant was used by Vet et al. (1980) to describe the use of parasitoid inoculated tomato plants for release of *Encarsia formosa* Gahan to control *Trialeurodes vaporarium* (Westwood) in greenhouses. Similarly, Bennison (1992) described the use of banker plants to augment aphid parasitoids in greenhouse cucumbers. We have extended the use of the term "banker plants" to describe parasitoid inoculated seedling transplants for use in field settings.

Banker plants have many advantages for field release of natural enemies in annual crops such as spring melons. Large numbers of transplants can be inoculated in the greenhouse, capitalizing on the inherent distribution system of transplant nurseries, and moved to many widely dispersed fields. Transplanting is mechanized which allows for efficient, large scale planting of banker and regular transplants in field crops. Parasitoids transported to the field by banker plants are immatures on the underside of the leaf which are not as susceptible to mortality factors such as rain, heat, wind, etc., as are adults or pupae released on clipped leaf material. Banker plants also aid in the dispersal of parasitoids within a field. As the transplants are planted, banker plants can be evenly spaced with regular seedlings to provide uniform distribution and emergence of parasitoids across the field. This should increase searching efficiency of parasitoids since they can search a smaller area before finding a host. This is critical during early season when pests are highly clumped in distribution and difficult to find. Lastly, banker plants allow for early season release of parasitoids in precise synchrony with the establishment of the crop and with timing of the insecticide imidacloprid, Admire®.

A series of field and lab experiments were conducted in 1996, 1997 and 1998 to develop methods for producing banker plants. Plant screening determined the suitability of varieties for use as banker plants. We predicted that some varieties would not be suitable for use as banker plants because of their susceptibility to *B. argentifolii*. Ten varieties were selected Riley's (1995) report, *Melon cultivar response to Bemisia*. The selections we made represented the most popular varieties in terms of acres planted and/or varieties which were listed as susceptible to *B. argentifolii.* Lab tests measured the impact of imidacloprid on developing parasitoids. This insecticide is systemic, widely used by melon producers, and is considered critical to season long whitefly control (Castle et al. 1996). Finally, field trials were conducted in spring cantaloupe and fall watermelon plantings to quantify the numbers of parasitoids produced using banker plants. *Eretmocerus hayati* Rose & Zolnerowich (accession # M95012) from Multan, Pakistan, was used in all the tests based on its performance in

previous laboratory and field evaluations (Goolsby et al. 1998). Our target release rate in cantaloupe was 23,000 per acre or one parasitoid per plant. This release rate was based on field studies conducted from 1993 to 1996 (Ciomperlik & Goolsby, unpublished data). Field tests during the Spring of 1997 with spring melons were conducted on the research farm at the Mission Biological Control Center, Moore Airbase, Mission, TX. Later trials were conducted with growers to determine the feasibility of large-scale transplanting of banker plants in commercial agriculture. In all of these trials we determined both the numbers of parasitoids produced per banker plant and release rate per acre. Efficacy of the augmentation program is discussed elsewhere.

Materials and Methods

Banker Plant Inoculation Methods

Cantaloupe and watermelon transplants used in the tests were grown in styrofoam flats with 128 cells 3.8 cm in diameter with a depth of 7.62 cm in a greenhouse held at 27 ± 2°C with a natural 14:10 L:D photoperiod. Flats were covered with an organza material shroud and were inoculated with adult *B. argentifolii* when the first true leaves were 1.8 cm across at the widest portion. Whitefly adults were collected from eggplants using a high volume, low velocity vacuum and transferred into clear one-gallon plastic containers for counting. The numbers of adult whitefly were estimated by counting the number of settled adults in ten separate 1 cm^2 discs located on the sides of the container. The average number of adults per cm^2 were multiplied by the surface area of the container to obtain the total estimated number of whitefly. Approximately 5000 adult whitefly were released per shrouded flat. Subsequent egg densities were determined by counting the number of eggs on a 1 cm^2 disc on the first true leaf of seedlings selected randomly from each flat.

Four hundred and fifty adult *E. hayati,* reared from *B. argentifolii* on eggplant, aged 24-48 h old, were released in each production flat. Parasitoids were collected from emergence cages in petri plates and had a male to female sex ratio of 40:60. Each plate was provisioned with a streak of honey and the parasitoids were held at 15°C until release. Parasitoids were released onto the plants when the majority of the whitefly eggs had hatched and the crawlers became settled first instars.

Counts to estimate the mean number of *E. hayati* per transplant were made 20 days after inoculation or when the majority of parasitoids had emerged. Counts were conducted in the laboratory using dissecting microscopes to determine the status of every individual on the 1 cm^2 leaf disc being recorded on a data sheet. Categories for the status of individual determinations were as follows: eggs; small nymphs (1st, 2nd, and 3rd instar), large nymphs (4th instar), (live, dead); emerged whitefly; parasitoid immatures; parasitoid mummies. Large nymphs were used to calculate percent parasitism because we could clearly determine if they were parasitized or not.

Cantaloupe Variety Screening

We used choice tests to evaluate the effect of cantaloupe variety on fecundity of SLWF and parasitoids. Ten varieties were tested: 'Primo', 'Explorer' (Rogers Seed), 'Cruiser' (Harris-Moran Seed), 'Marco Polo', 'Copa de Oro', 'Mission', 'Pacstart' (Asgrow Vegetable Seeds), 'Mainpak' (Sun Seeds), and 'Laredo', and 'Durango' (Peto Seed). Ten plants of each variety were planted in each of 4 flats. Cantaloupe seeds were planted at the same time and maintained in a greenhouse at 27°C with a natural

15:9 L:D photoperiod. Cages consisted of 100 seedlings in styrofoam transplant flats surrounded by an aluminum frame (38 × 80 × 40 cm), covered with organza. Seedlings were inoculated with adult whitefly and parasitoids using the methods described above. Twenty days after introduction of the parasitoids the leaf samples were removed and nymphal SLWF were analyzed with a stereo microscope to determine incidence of parasitism. Percent parasitism was calculated as the number of parasitized 4th instar nymphs and parasitoid mummies divided by the total number of parasitized and non-parasitized nymphs.

Statistical comparisons were analyzed using ANOVA and means were separated by the Tukey Studentized range test (SAS Institute 1998). The following parameters were compared: 1) total numbers of SLWF; 2) total numbers of parasitoids produced; and 3) percent parasitism. Percent parasitism data was arcsin transformed for the analysis.

Toxicity of Imidacloprid to Parasitoids

The impact of imidacloprid on immature *E. hayati* was measured. Eight flats of seedling plants were grown in a greenhouse at 32 ± 5°C under the natural 16:8 L:D regime which occurs during early summer. Cantaloupes *var.* 'Primo' were shrouded with organza and infested with whitefly and parasitoids using the same methods described above. Imidacloprid, Admire 2F®, was applied in a sequence to selected flats on days 0, 2, 4, 6, 8, 10, and 13 following release of the parasitoids. An eighth flat was not treated with imidacloprid and served as a control. Each flat was treated using a micro pipet with 0.53 mls imidacloprid per 2 gals of water, which is equivalent to the dose the same number of plants would receive in the field (pers. comm., S. Fraser, Miles, Inc.).

To assess the impact of imidacloprid on parasitoid immatures, the first true leaf from each plant was sampled 20 days after inoculation to allow live parasitoids to emerge. Categories for the status of individual determinations were as follows: small nymphs (1st, 2nd, and 3rd instar), large nymphs (4th instar), (live, dead); parasitoids (live, dead) and emerged whitefly. Unemerged parasitoids were considered to be dead.

Field Estimates of Release Rates

Banker plants used for transplanting were grown in a greenhouse and inoculated using the methods described above. Transplanting was conducted 2-6 after inoculation of whitefly with parasitoids, and depended on rainfall and grower schedules. Growers applied midacloprid by a drip system, in all of the tests, between one and three weeks after transplanting. No other insecticides were applied to the crop, however selected fungicides were used later in the season after emergence of the parasitoids.

To estimate the number of parasitoid progeny produced per banker plant, counts were made from a randomly collected field sample of banker plants. Similar emergence studies were conducted from a random sample of three banker plants from each flat held in the greenhouse. We sampled the first true leaf of the banker plants to estimate the numbers of parasitoids produced per plant. In some cases, we also counted the second true leaf if parasitoid pupae or mummies were observed.

To compare fruit yields between banker and regular transplants we counted the total number of marketable cantaloupes on 30 vines each respectively. We considered a marketable melon to be any size between #9 and #15 (Miller, 1997). Yield counts were conducted one day before the first initial harvest of the field. The numbers of fruit per vine between banker and regular transplants were analyzed by t-test (SAS Institute 1998).

Cantaloupe *var* 'Primo' was selected for both 1997 and 1998 field trials based on earlier screening work. The first field evaluation of banker plants was conducted in April of 1997 at the Biological Control Demonstration Farm at Moore Airbase. Banker plants were mechanically transplanted simultaneously with the regular transplants at a ratio of 1:10, banker to regular transplants. The second cantaloupe banker plant trial was transplanted at a ratio of 1:30 on Feb. 17, 1998 into a commercial field in San Juan, TX which was direct seeded on Jan. 20, 1998. In the Fall 1997, watermelon trials were conducted on a commercial farm in Mission, TX. At each location one half of the transplants were a triploid seedless watermelon *var.* Abbott & Cobb # 5441, in a mix of every other transplant with a diploid watermelon *var.* 'Royal Sweet'. We inoculated 1 out of 15 diploid watermelon transplants, which resulted in a ratio of 1:30 banker plants to regular transplants. The field in Mission, TX was hand transplanted on Aug. 1, 1997.

Results and Discussion

Cantaloupe Variety Evaluation

Varieties Copa de Oro and Mission had significantly higher densities of large nymphs than the other varieties tested ($F = 4.46$; $df = 9, 403$; $P < .0001$) (Fig. 1). Simmons and McCreight (1996) also found differences in whitefly preference for selected cantaloupe germplasm. We compared nymphal densities which may be an indicator of survival of nymphs after oviposition, more than an indicator of adult SLWF preference. However, mortality of the 1st instar crawlers was very low (<5%), based on the status of individual counts, which suggests that nymphal densities corresponded with adult oviposition rates. Copa de Oro, Mission, and Primo produced significantly more parasitoids than the other varieties ($F = 4.08$; $df = 9, 403$; $P < 0.0001$). Primo produced equivalent numbers of parasitoids to Asgrow and Mission, even though the latter two varieties had significantly higher SLWF densities. This suggests that parasitoids may show a preference for Primo. Primo also had the highest mean level of parasitism, but it was not significantly different from the other varieties ($F = 1.06$; $9, 403$; $P > 0.3948$). Based on these results, the cultivar Primo was selected for further development of the banker plant delivery system.

These tests indicate there may be differences between cantaloupe varieties that could influence densities of whitefly, and subsequently the number of parasitoids that can be produced on banker plants. It appears that Primo is a suitable variety for testing the banker plant delivery system. However, other varieties could likely be used as banker plants if whitefly densities were manipulated during infestation of the seedlings. Fortuitously, Primo is also one of the most commonly planted cantaloupe varieties in the Lower Rio Grande Valley of Texas.

Toxicity of Imidacloprid to Parasitoids

The effect of imidacloprid on the mean number of parasitoids produced was significant for treatment date ($F = 17.91$; $df = 7, 205$; $P < .0001$), (Fig. 2). It appears that imidacloprid caused high levels of mortality in developing parasitoid immatures up to six days after inoculation. By day 13, there was no significant difference in numbers of parasitoids produced as compared to the control.

The method by which the parasitoid larvae escaped the effect of imidacloprid is not known. One explanation may be that by day six the parasitoid larvae had matured to the point where it had killed the host. After death, the whitefly ceases to uptake plant

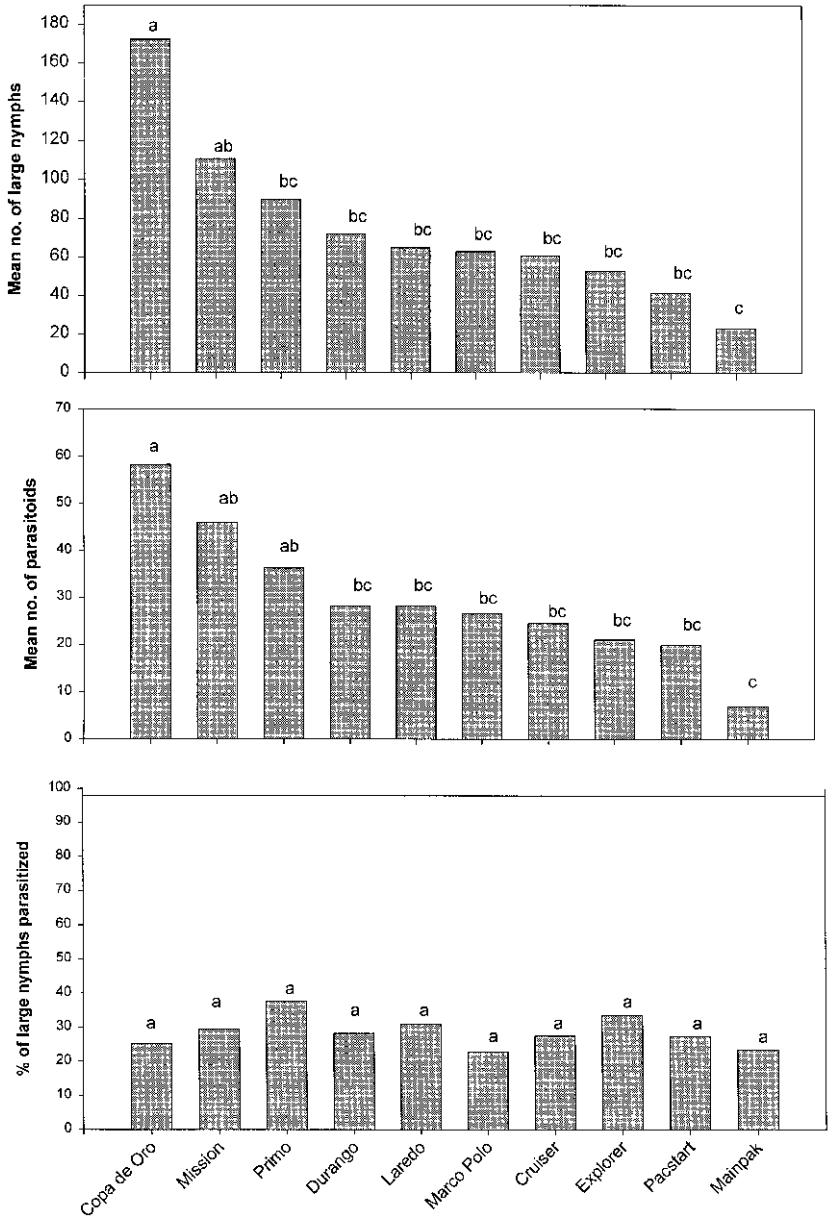

Fig. 1. Summary of cantaloupe variety evaluation. Numbers of *B. argentifolii* and parasitoids are per leaf (~ 25 cm^2). Bars with the same letter are not significantly different (P = 0.05).

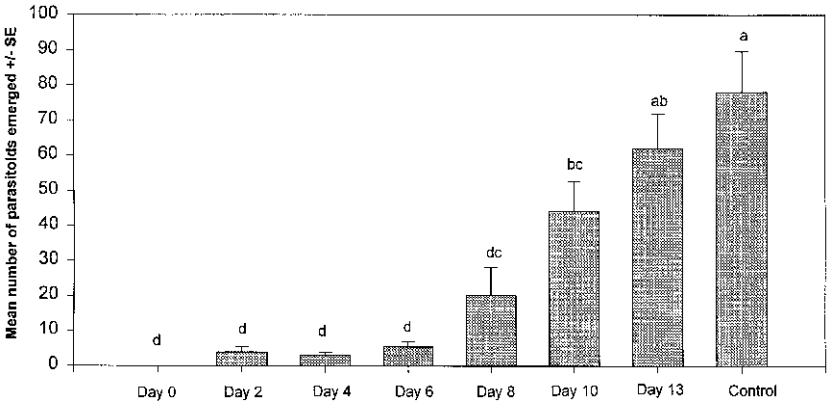

Fig. 2. Mean number of *E. hayati* adults produced per leaf (~ 25 cm^2) after application of imidacloprid insecticide. Bars represent the day banker plants were treated with imidacloprid following inoculation with parasitoids on Day 0. Bars followed by the same letter are not significantly different (P = 0.05) in total number of parasitoids produced.

fluids containing the imidacloprid. For practical purposes, if applications of imidacloprid could be delayed for one week after transplanting, or if banker plants could be planted one week after they are inoculated with parasitoids, the impact on developing parasitoids would be minimized. Timing of the imidacloprid application should be temperature dependent. If cool weather delays development of the whitefly immatures and parasitoids, the insecticide application may need to be delayed.

Field Production Estimates

1997 Cantaloupe. Numbers of whitefly and parasitoids used to inoculate the transplants are listed in Table 1. The egg density was estimated to be 88 per cm^2. Overall whitefly density appeared to have had an adverse effect on plant health due to early senescence of leaves. Egg and nymphal densities this high are routine in mass rearing procedures using mature eggplant and hibiscus plants (Goolsby, unpublished data). However, young cantaloupe seedlings may not be able to tolerate this level of infestation. Despite some early senescence of the parasitoid bearing 1st true leaves, parasitoid production met the target release rate (Table 2). Fecundity per female was high with a 26.7 fold increase across 40 flats of banker plants. In comparison, a 12 fold increase is typical in other outdoor rearing systems (Goolsby, unpublished data). The higher fecundity may be due to the confinement of the parasitoids with the whitefly infested transplants in the shroud cages along with moderate temperature and humidity found in the greenhouse environment. Field estimates of the number of parasitoids produced per banker plant was hampered by persistent rains that drenched the crop during the month of March. Hence, we were unable to sample the banker plants in the field to determine the release rate. We estimated the release rate based on subsample of banker plants which we held in the greenhouse to be approximately three times the target release rate of 23,000 per acre (Table 3). We determined from these trials that the ratio of banker plants per acre could be reduced to 1:30 while still producing the target release rate.

TABLE 1. WHITEFLY AND PARASITOID INPUTS PER BANKER FLAT.

	Cantaloupe Spring 97	Cantaloupe Spring 98	Watermelon Fall 97
Mean no. of adult whitefly released ± SE	6239 ± 302	4633 ± 342	5335 ± 177
Mean egg density ± SE	85.6 ± 8.8	43.9 ± 6.5	43.6 ± 4.9
Mean no. of parasitoid females released ± SE	246.4 ± 18.1	523.7 ± 13.7	296.6 ± 26.2
Sex ratio of parental material M:F	32:64	43:57	n/a

1998 Cantaloupe. Egg density was determined to be 43.9 per cm^2. This appears to be nearly the optimum density for health of the banker plant as compared to 88 per cm^2 recorded in the earlier 1997 trial. At this egg density, very few of the first true leaves senesced, which resulted in a higher mean number of inoculating parasitoids produced per banker plant (Table 2). Lower densities of nymphs and higher numbers of parasitoid females resulted in higher levels of parasitism as compared to the 1997 trial. Fecundity per female was also higher at 38.6 than the 97 trial (Table 2). Estimates of the mean number of parasitoid progeny produced per banker plant were 102.1 and 32.8 from the greenhouse and field, respectively. The actual number of progeny produced per plant is likely to fall between these two estimates. Field counts underestimate progeny production due to the fact that mummies may fall off after emergence of the parasitoid (Table 2). Other workers have also found that parasitoid mummies are sometimes dislodged from the plant leaf (Naranjo, pers. comm.). The mean number of parasitoids produced by pooling both estimates is 67.5 per banker plant which translates to 29,970 per acre (Table 3). This rate is slightly higher than the target rate of 23,000 per acre. Based on these estimates, the number of banker

TABLE 2. PRODUCTION ESTIMATES OF BANKER PLANT PRODUCTION.

	Cantaloupe Spring 97	Cantaloupe Spring 98	Watermelon Fall 97
Greenhouse Estimate			
Parasitoids per banker plant ± SE	94.6 ± 17.9	102.1 ± 14.5	94.6 ± 16.7
Mean percent parasitism	49.4%	57.3%	56.0%
Mean fecundity per female	26.7	38.6	40.8
Field Estimate			
Parasitoids per banker plant ± SE	n/a	32.8 ± 5.8	9.3 ± 7.2
Average percent parasitism	n/a	41.8%	71.8%
Mean fecundity per female	n/a	14.6	4

TABLE 3. FIELD RELEASE RATE BASED ON POOLED GREENHOUSE AND FIELD ESTIMATES.

	Cantaloupe Spring 97	Cantaloupe Spring 98	Watermelon Fall 97
No. of banker plants: regular transplants	1:10	1:30	1:0
No. of banker plants per acre	906	444	80
Estimated no. released per acre	68,946[1]	29,970	4,156
Target release rate	23,000	20,000	1,100
No. of acres in test	5	45	45

[1]Rate based on greenhouse estimate alone.

plants per acre could be lowered for several reasons. Spring cantaloupe fields in the LRGV are usually planted in January when whitefly levels arevery low (Riley & Ciomperlik 1998). Earlier banker plant trials were conducted with cantaloupes planted in March at ratios of 1:10. Banker to regular transplant ratios of 1:50 or 1:100 may be suitable for early planted spring crops when whitefly levels are low and augmented parasitoids have additional time to build their populations.

1997 Watermelons. Numbers of whitefly and parasitoids used to inoculate the watermelon transplants are listed in Table 1. The egg density was determined to be 43.6 per cm^2. This appears to be nearly the appropriate density for watermelons and cantaloupe banker plants. At this whitefly density, plants maintain good vigor throughout the seedling growth stage and in the field as transplants. Percent parasitism ranged from 56% in samples of greenhouse banker plants to 71.8% from the field collected material. This level of parasitism in watermelon is slightly higher than experienced in the cantaloupe trials, even though lower numbers of parasitoid females were used in their inoculation (Table 1). Similarly, the mean number of parasitoid progeny produced per female was higher in the watermelon transplants (40.8) as compared with cantaloupes (38.6). The higher level of parasitism and mean progeny production per female may be in part due to differences between the watermelon and cantaloupe transplants. Watermelon transplants are typically grown to about twice the size of the cantaloupe before transplanting. The larger transplant has two true leaves available for infestation with whitefly. Mutual interference of searching females may be minimized by the larger leaf surface area of the watermelon seedling.

Progeny production estimates of greenhouse and field grown banker plants were 94.6 and 9.3 respectively (Table 2). The large difference between the two estimates is likely due to the harsh field conditions experienced during August in the LRGV. When the field was transplanted, water stress and strong winds adversely affected the young seedlings. Some of the developing parasitoids may not have survived, and many of the parasitoid mummies may have been dislodged from the leaf. Pooling the two estimates leads to a field release rate of 4156 parasitoids per acre (Table 3). Given the high rate of whitefly migration into the young watermelons from surrounding areas of defoliated cotton, the current banker to regular transplant ratio in watermelons seemed appropriate for these growing conditions. Inoculating 2 diploid transplants out of 15 would increase the banker plant ratio to 1:15. Using the higher banker plant to transplant ratio may be advisable during periods of heavy whitefly migration.

This research demonstrates that the use of banker plants is a reliable method for augmenting *Eretmocerus* parasitoids in both cantaloupe and watermelon crops. Varietal differences in cantaloupes seemed to affect oviposition by *Bemisia* and rates of parasitism by *E. hayati*. However, differences were not so great as to exclude the use of a particular variety for use as a banker plant. Manipulation of adult whitefly and parasitoid numbers should overcome any varietal restraints. We recommend the same species of plant and variety be used for the banker plants as the field crop. Irrigation timing, weed control practices, fertility, etc., will be directed towards the crop. By using the same variety as the crop, unpredicted effects of different varieties or plant species can be avoided. In addition, the banker plant will produce a normal yield, thus offsetting the cost of the plant in using parasitoid inoculated transplants. In our tests, cantaloupe melon production was not significantly different between regular and banker plant vines (Table 4).

Laboratory studies document the potential for integrating imidacloprid with banker plants and augmentation strategies for management of SLWF. Our tests show that parasitoid immatures in the later stages of development were not effected by imidacloprid. Use of imidacloprid is standard practice in most subtropical growing areas of the U.S. and worldwide. Combining the use of imidacloprid, a density independent mortality factor, combined with parasitoids, a density dependent factor, may be synergistic in providing better control of *B. argentifolii* than would occur if the two factors were used separately. *Eretmocerus hayati* is capable of finding low density whitefly immatures that are typical after imidacloprid applications. This strategy may provide season long control of *Bemisia*, thus avoiding late season applications of broadspectrum insecticides, or unlabelled applications of imidacloprid which could increase the likelihood of resistance.

From our work using banker plants in direct seeded melon crops, another alternative for timing of imidacloprid became apparent. Imidacloprid could be applied to the direct seeded crop at planting providing full protection to the seedlings as they emerge. The banker plants could be held in the greenhouse until parasitoids have reached the late larval or early pupal stage and then be transplanted. If banker plants were held in the greenhouse for an additional week at 27°C, parasitoids on the transplants should not be affected by imidacloprid.

The production and use of banker plants for augmentation does not require any additional technological hurdles for implementation. Production of sufficient numbers of parasitoids for inoculation of banker plants for many thousand acres of cucurbits is feasible. Growers have the option of using banker plants with their regular transplants or in direct seeded crops, both of which have been demonstrated successfully in our field trials. Additional benefits from these augmentation programs may be

TABLE 4. COMPARISON OF CANTALOUPE FRUIT YIELDS BETWEEN BANKER PLANTS AND REGULAR TRANSPLANTS.

	Mean no. ± SE Fruits	
Year	Regular Plants	Banker Plants
1997	1.5 ± 0.2[a]	1.4 ± 0.1[a]
1998	1.1 ± 0.1[a]	0.8 ± 0.1[a]

Means within rows followed by the same letter are not significantly different (P = 0.05).

derived if the exotic parasitoid is able to migrate in sufficient numbers to surrounding summer crops such as cotton, soybean, and alfalfa, or to fall crops such as cucumber and cole crops. Whitefly may be regulated at lower levels if sufficient numbers of parasitoids colonize the summer and fall crops. Studies are needed to quantify the dispersal capabilities of *E. hayati,* from fields where it has been augmented, to surrounding fields. Banker plant delivery methods could be used to implement area-wide biological control programs directed against SLWF. Area wide releases of parasitoids via banker plants could potentially moderate whitefly levels at a regional level. Lastly, more detailed studies evaluating the efficacy of augmentation using banker plants as compared to other release methods are needed.

Parasitoid inoculated seedling banker plants represent a novel method for field release of parasitoids in field settings. Banker plant methods could be used to augment many different parasitoid species against a variety of pests. For instance, parasitoids could be augmented via cabbage and broccoli banker plants for control of SLWF. Likewise, parasitoids of *Plutella xylostella* (L.), the diamondback moth, could be augmented on broccoli using the banker plant delivery methods. In many cases, early season augmentation of parasitoids has already shown to be effective for controlling a variety of insect and mite pests (Parker & Pinnell 1972, Biever & Chauvin 1992, Hoffman & Frodsham 1993). Parasitoid inoculated banker plant methods could enable other augmentation programs and extend the use of biological control in annual cropping systems.

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