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Application of Mycotrol and Naturalis-L (*Beauveria bassiana*) for Management of *Bemisia argentifolii* (Homoptera: Aleyrodidae) on Vegetables, Cotton and Ornamentals in Southern United States

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ABSTRACT

Two different strains of *Beauveria bassiana* (Balsamo) Vuillemin, formulated as Mycotrol® and Naturalis-L®, were tested against *Bemisia argentifolii* Bellows & Perring in Arizona, California, Florida, and Texas. Laboratory bioassays, greenhouse and field experiments were conducted on hibiscus, sweetpotato, cantaloupe, cucumber, tomato, eggplants and cotton. Mycotrol caused 76-94% mortality of *B. argentifolii* nymphs under laboratory and greenhouse conditions, where relative humidity was maintained above 90%. In Arizona, on subsurface drip irrigated cantaloupe that was under moderate to light whitefly pressure, Mycotrol provided significant control of whitefly with 68-79% population reduction, whereas Naturalis-L did not. After 3 applications at the labeled rate (1.12 kg/ha), Mycotrol had the cumulative effect of maintaining adult whitefly populations below the economic threshold of 3 per leaf for 28 d after the initial treatment. In the Imperial Valley, California, on cotton and in southwest Florida on field tomato and eggplant, multiple applications of Mycotrol at weekly intervals did not reduce whitefly population compared with untreated control. Naturalis-L was effective against *B. argentifolii* under laboratory conditions, and provided fairly good control on cotton in southern Texas, but did not give sufficient control on cucumber in south Texas or on cantaloupe in Arizona. It appears that applications of *B. bassiana* products, i.e. Mycotrol and Naturalis-L, could play a role in whitefly management, although their usefulness may be limited to high humidity conditions and complete spray coverage.

RESUMEN

Dos cepas diferentes de *Beauveria basiana* (Balsamo) Vuillemin, formuladas como Mycotrol® y Naturalis-L®, fueron probadas contra *Bemisia argentifolii* Bellows & Perring en Arizona, California, Florida y Texas. Se condujeron bioensayos de laboratorio e invernadero y experimentos de campo en tulipán, camote, pepino, tomate, berenjena y algodón. Mycotrol causó la mortalidad del 76-94% de las ninfas de *B. argentifolii* bajo condiciones de laboratorio e invernadero, donde la humedad relativa se mantuvo arriba del 90%. En Arizona, en melón irrigado por goteo bajo la superficie creciendo bajo una ligera a moderada presión poblacional de la mosquita blanca, Mycotrol brindó un control significativo de esta y provocó una reducción de la población del 68 al 79%, mientras que Naturalis-L no brindó control. Después de 3 aplicaciones a la dosis marcada en la etiqueta (1.12 kg/ha), Mycotrol tuvo el efecto acumulativo de mantener las poblaciones de adultos de la mosquita blanca por debajo del umbral económico de 3 por hoja a los 28 días después del tratamiento inicial. En algodón en el Valle Imperial de California, y en tomate y berenjena en campo en el sudoeste de Florida, las aplicaciones múltiples de Mycotrol a intervalos semanales no redujeron la población de mosquita blanca en comparación con el control no tratado. Naturalis-L fue eficaz contra *B. argentifolii* bajo condiciones del laboratorio y brindó un control bastante bueno en algodón en el sur de Texas, pero no proporcionó suficiente control en el pepino en el sur de Texas o en el melón en Arizona. Parece ser que las aplicaciones de productos consistentes en *B. bassiana*, por ejemplo Mycotrol y Naturalis-L, podrían desempeñar un papel en el manejo de la mosquita blanca, aunque su utilidad podría estar limitada a condiciones de alta humedad y de cobertura de aspersión completa.

Additional index words: Entomopathogen, biological control, microbials, sweetpotato whitefly, silverleaf whitefly

Silverleaf whitefly, *Bemisia argentifolii* Bellows & Perring, formerly known as 'Biotype B' of the sweet potato whitefly, *B. tabaci* (Gennadius) (Hemiptera: Aleyrodidae), is a serious insect pest of many food and fiber crops in the southern United States and elsewhere. Perring et al. (1993) estimated that crop damage caused by the whitefly in the U.S. exceeded one-half billion dollars in 1991 alone. The development of pesticide resistance by *B. argentifolii* and increasing regulation of chemical pesticide use have sparked interest, research and investments in biological control with parasitoids, predators, and entomopathogenic fungi, such as *Beauveria bassiana* (Balsamo) Vuillemin, a fungal pathogen with a wide range of insect hosts.

Beauveria bassiana is a common pathogen of many different insects (McCoy et al. 1988). Although susceptibility varies among insect species to particular strains of *B. bassiana*, this fungus has been extensively studied and used for controlling various pests including *B. argentifolii* (Lacey et al. 1996). To date, two commercial products are available in the United States: Naturalis (Troy Biosciences, Phoenix, AZ), and Mycotrol (Mycotech, Butte, MT). Ben-Zeev et al. (1994) and Lacey et al. (1996) reported that *B. bassiana* is only an occasional pathogen of whiteflies. However, Akey and Henneberry (1994), Carruthers et al. (1993), and Jaronski and Lord (1995) have reported that it has great potential as a mycoinsecticide for controlling *B. argentifolii* under both laboratory and field conditions.

Our objective was to determine the efficacy of several formulations of Mycotrol and Naturalis-L against nymphs and pupae of *B. argentifolii* on crops in different regions of the southern United States. We report the results from laboratory, greenhouse, and field trials on hibiscus, sweet potato, tomato, eggplant, cantaloupe, cucumber, and cotton in Arizona, California, Florida, and Texas.

MATERIALS AND METHODS

Laboratory, greenhouse, and field experiments were conducted on cotton (*Gossypium hirsutum* L.), cantaloupe (*Cucumis melo* L.), cucumber (*Cucumis sativus* L.), eggplant (*Solanum melongena* L.), hibiscus (*Hibiscus rosa-sinensis* L.), sweet potato (*Ipomoea batatas* L.), and tomato (Lycopersicon *esculentum* Mill.) in Arizona (Vicksberg, La Paz Co.), California (Imperial Valley), Florida (Immokalee), and Texas (Weslaco).

Insecticides. Two separate strains of *Beauveria bassiana* with four different formulations were used: 4 formulations of strain GHA, Mycotrol WP, WP9503, WP9504, ES (all 22% AI by weight, and 4.4 x 10^{10} spores/g) by Mycotech Corp., Butte, MT, and 1 formulation of a proprietary strain, Naturalis-L (2.3 x 10^7 spores/ml), by Troy BioSciences, Phoenix, AZ. Other insecticides, surfactants or wetting agents were used in various trials, and were shown in the specific trials.

Laboratory and Greenhouse Bioassays in Florida. In the laboratory bioassay, 3 wettable powder formulations of Mycotrol (WP, WP9503, and WP9504) were used at the recommended rate of 10^8 conidia/ml. Materials were suspended in 0.03% aqueous Silwet L-7 (Loveland industries, Greeley, CO). Silwet L-77 (0.03%) and water were used as 2 separate controls. Sweetpotato leaves bearing 1st instars were sprayed with 3.0 ml suspension using a Potter Spray Tower (Burkard Manufacturing Co. Ltd., Rickmansworth, Hertfordshire, England) at 0.70 kg/cm^2 (10 psi) pressure. Leaves were placed individually in 20 ml water-filled glass vials and maintained at 100% relative humidity (RH) for 24 h. Saturated humidity was maintained by placing the vials with leaves in a pan filled with water and covering the whole set-up with a plastic bag. Leaves were then removed from the plastic bag and incubated thereafter at 25 ± 2ºC, and 70% (± 5%) RH under fluorescent illumination set for 14:10 (L:D) h.

The entire experiment was repeated twice. In the first trial, mortality of each nymphal instar was recorded 8 and 15 d after treatment. In the second trial, Naturalis-L was also tested using 7.925 ml/liter (30 ml/gal). In this trial, both mortality and infection rates were determined 8 d after treatment. Since the GHA Strain (all 4 formulations from Mycotech) produces a red pigment when it infects whiteflies making it possible to visually detect infections, numbers of red nymphs were also recorded.

In the greenhouse, the efficacy of Mycotrol ES (2.1 x 10^{10} spores/ml) against *B. argentifolii* nymphs was tested on 2 cultivars of hibiscus, 'Versicolor Pink', and 'Brilliant Red', at 2 rates: 2.5 and 1.25 ml/liter (5.25 x 10^7 spores/liter and 2.625 x 10^7 spores/liter). Water was used as control. Plant height was 30-40 cm, with 2-4 branches and 6-9 fully expanded leaves. Only the top 3 fully expanded young leaves were used for the bioassay, and the old and small leaves were removed. To infest the plants with whitefly eggs, 120 adults were placed on each plant in a large wood-frame cage (80 x 80 x 240 cm) enclosed with 52-mesh organdy screen (Chicopee, Gainesville, GA). Adults were allowed to oviposit for 4 h before the plants were removed. *B. argentifolii* eggs were allowed to hatch, and nymphs were incubated for 5 d. Leaves bearing 1st (≈70%) and 2nd (≈30%) instar nymphs were sprayed to run-off using a hand-held pump sprayer (Spritzer, Bel-Art Products, Pequannock, NJ). After drying, plants were returned to the large cages where RH was maintained at >95% by misting for 10 min at hourly intervals between 7:00 a.m. to 7:00 p.m using a fine mist system. Leaves bearing treated nymphs were collected from the plants 10 d after treatment, and live and dead nymphs were examined under a stereo microscope.

Field Trial on Cantaloupe in Arizona. Drip irrigated cantaloupe ('Durango') were planted in slant beds on 2 m centers in Aug., 1995 near Vicksberg. All plots received an application of Admire (2F, imidacloprid, Bayer, Kansas City, MO) at the labeled rate (0.45 kg/ha) injected through the drip irrigation system after planting. Additionally, all plots received applications of Thiodan (3EC, endosulfan, FMC, Middle Port, NY) at 165 g [AI]/ha) on 6 Oct., Agri-Mek (0.15EC abamectin, Novartis, Greensboro, NC) at 560 g [AI]/ha) + Pounce (3.2EC, permethrin, FMC) at 140 g [AI]/ha on 9 Oct. for controlling leafminers (*Liriomyza* spp.), and sulfur (Golden Dew, 11 kg [AI]/ha) on 16 and 26 Oct. for controlling diseases. Individual plots were 9 2-m beds wide by 366 m long with a total area of 0.66 ha (1.65 acres). Treatments were replicated twice in a randomized complete block (RCB) design. Treatments wereinitiated on 2 Oct. when whitefly numbers had reached 30 nymphs per 5.0 cm^2 leaf disk, and repeated on 9 and 23 Oct.

Afternoon temperatures were 33.3°C, 32.8°C, and 24.4°C, and daily solar radiation accumulated was 533, 491, and 447 Langleys, respectively for the application dates. There were 6 treatments: (1) a growers' standard practice of Admire injected at stand establishment without further control; (2) Mycotrol WP at 0.227 kg/ha with Kinetic (Setre Chemical, Memphis, TN) at 300 mg/liter; (3) Mycotrol WP at 0.454 kg/ha with Kinetic at 300 mg/liter; (4) Mycotrol ES at 1.169 liter/ha; (5) Mycotrol WP at 0.227 kg/ha with Kinetic 300 mg/liter + Pounce at 111 g [AI]/ha; and (6) Naturalis-L at 70 g/ha. Applications were made with an FMC air blast sprayer at an application volume of 281 liter/ha (30 gal/ac). Water used to prepare each spray solution was buffered at a pH of 6.0.

Whitefly adults were counted on the first mature leaf by the leaf turn method (Palumbo et al.1994) on 2 Oct. (day 0), 13 Oct. (day 11), 16 Oct. (day 14), 23 Oct. (day 21), and 30 Oct. (day 28). The 7th leaf from the terminal of the main vine from the plant were sampled, and whitefly immatures were counted on 5.0 cm^2 leaf disk from each of the 40 randomly selected leaves from each plot on days 0, 14, 21 and 28.

Field trials on Cotton and Cucumber in South Texas. Two small plot field trials were conducted on cotton in 1992 and 1993, and one small plot trial was conducted on cucumber in 1992 at the Texas A&M Research and Extension Center in Weslaco. All plots in the 3 trails were arranged in RCB designs with 4 replications. All insecticides used in this trial were applied as broadcast treatments with a CO_2 pressurized backpack sprayer with three hollow cone nozzles per row (one over-the-top and one on drops on each side of the row) in a finished volume of 234 liter/ha (25 gal/ac). Naturalis-L was applied at the suggested rate of 8 ml/liter (rate per ha varied based on total spray volume) plus 580 ml/ha of Nu-Film 17 (pinolene, Miller Chemical & Fertilizer, Hanover, PA).

Trials on Cotton. In the 1992 cotton test, plots were established in late July in a cotton ('DPL-50') field planted late in the growing season. Plants were ≈50 cm tall at the time of treatment. Insecticides were applied on 31 July and 5 Aug. Naturalis-L was applied at a rate of 1853 ml/ha formulated product. The standard treatment for this trial was Thiodan at a rate of 1.1 kg (AI)/ha. Adult whiteflies were sampled with the leaf turn technique on the third leaf from the terminal on three plants per plot. Immature stages were sampled on 7 and 12 Aug. by selecting the 5th leaf from the terminal on 3 randomly selected plants per plot and examining 2 3.8 cm^2 (2.2 cm diam)

Table 1. Mortality and percentage of red nymphs of *Bemisia argentifolii* infested by *Beauveria bassiana* on day 8 and day 15 after treatment in the laboratory.

	Trial 1								Trial 2	
		Red nymphs								
	Mortality	Total		Second instar	Third instar		Fourth instar		Mortality	Red nymphs
Treatment	Day 8	Day 8	Day 15	Day 8	Day 8	Day 15	Day 8	Day 15	Day 8	Day 8
	%									
Mycotrol WP	81.1±4.6b[z]	25.1b	56.9a	7.1a	33.9b	31.0b	43.7b	73.9a	79.2±4.0c	48.9±2.9a
Mycotrol WP9503	93.6±1.4a	30.4b	60.3a	6.6a	56.2a	44.3a	57.4 a	75.7a	76.4±3.2bc	41.0±4.2bc
Mycotrol WP9504	76.8±5.5b	40.8a	57.0a	9.2a	49.6a	39.2a	51.4ab	70.7a	87.2±2.4a	45.4±5.0a
Naturalis-L									81.4±4.6a	0.0±0.0c[y]
Silwet L-77	81.8±3.6b	-[y]	-	-	-	-	-	-	65.8±3.9cd	0.0±0.0c[y]
Water (control)	16.7±2.6c	-	-	-	-	-	-	-	15.3±3.0d	0.0±0.0c[y]

[z]Means in the same column followed by the same letter do not differ significantly (P>0.05, LSD [SAS Institute 1988]).
[y]Did not cause red nymphs.

Table 2. Mortality of *Bemisia argentifolii* nymphs on two cultivars of hibiscus on day 10 after treatment with *Beauveria bassiana* in the greenhouse.

		Mortality (% ± SE)[z]	
Treatment	Rate	'Brilliant Red'	'Versicolor Pink'
	ml/liter		
Mycotrol ES	1.25	62.1±4.6a	74.3±5.1a
Mycotrol ES	2.50	71.4±5.9a	84.2±5.0a
Control (water)	-	5.0±1.3b	7.4±1.5b

[z]Means in the same column with the same letters do not differ significantly (P>0.05, LSD [SAS Institute 1988]).

Table 3. Number of *B. argentifolii* nymphs, pupae and infected red pupae on staked tomato and eggplant after applications of Mycotrol ES (*B. bassiana)* in 1995 (Immokalee, FL).

	Number/cm^2 ± SE[z]		
Treatment	Nymph	Uninfected pupae	Percent red pupae
Treated eggplant	3.2±0.6a	1.2±0.2a	40.1±0.2a
Treated tomato	3.9±0.7a	0.5±0.2a	50.0±0.2a
Untreated eggplant	3.3±0.5a	1.2±0.3a	0.0±0.0b
Untreated tomato	3.3±0.6a	0.8±0.3a	0.0±0.0b

[z]Means in the same column with the same letters do not differ significantly (P>0.05, LSD [SAS Institute 1988]).

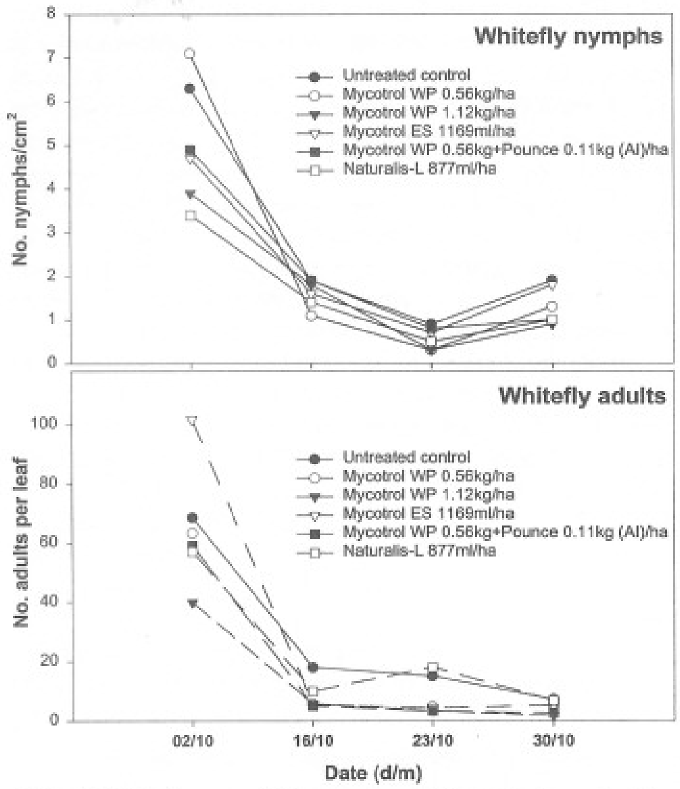

Fig. 1. Effectiveness of Mycotrol and Naturalis-L against *B. argentifolii* on fall cantaloupe (Vicksberg, AZ). Materials were applied on 2, 9 and 13 Oct. 1995.

disks per leaf (one from each side of the main vein; total of 6 leaf disks per plot). On 24 Aug., whitefly immatures were sampled in a similar manner with both the 5th and 6th leaf selected from 3 plants per plot and 4 disks examined from each leaf (total of 24 disks per plot).

In the 1993 cotton test, plots were 4 rows (1 m centers) by 13.7 m, with two buffer rows of untreated cotton between plots. Insecticides were applied with a tractor-mounted sprayer in a finished volume of 280 liter/ha. The insecticides used as the standard treatment in this trial varied with the application date. Phaser (3EC, endosulfan, FMC) was used at a rate of 1.1 kg (AI)/ha on 2, 6, 9, 20 and 23 July and 9 Aug. Danitol (2.4EC, fenpropathrin, Valent USA, Walnut Creek, CA) at 0.22 kg (AI)/ha + Orthene (75 S, acephate, Valent USA) at 0.52 kg (AI)/ha were applied on 4 and 28 July and 3 Aug. Naturalis-L was applied on all 9 dates at the rate of 2.2 liter/ha of formulated product. Adult whiteflies were sampled on the 3rd leaf from the terminal on 3 plants per plot. Large nymphs (primarily 4th instar) were counted on 2 disks (2.2 cm diam) from the 5th leaf from the terminal on 5 leaves per plot.

Trials on Cucumber. In the 1992 cucumber trial, plots were one row (1 m center) by 7.6 m with one row of Sudan grass between plots. All insecticide applications were initiated at the 3-leaf stage, with applications on 1, 7, and 12 Oct. Insecticides were applied with a CO_2 pressurized backpack sprayer in a finished spray volume of 468 liter/ha. Naturalis-L was applied at rate of 3.7 liter/ha of formulated product. The standard insecticide in this trial was Danitol at 0.22 kg (AI)/ha + Orthene at 0.56 kg (AI)/ha. Adult whiteflies were sampled 24 h after each application by counting the number of adults on the first fully expanded leaf from the growing terminal on 3 randomly selected vines per plot. Immature stages were sampled by selecting the 5th and 7th leaf from the terminal on two randomly selected vines per plot and examining 2 disks (2.2 cm diam) on each leaf (8 disks per plot).

Field Trial on Cotton in southern California. The trial was conducted on cotton in Brawley, Imperial Valley, in 1995. The experimental design was a RCB design with 4 replications. Each plot was 4 rows, 1 m wide, and 13.3 m long. There were 4 rows between plots and 10 m alleys that separated blocks. The partial isolation of each plot was to reduce migration of *B. argentifolii* adults between plots. Cotton ('Deltapine 5461') was planted on 10 March. Insecticides were applied with a tractor-mounted sprayer operated at 70 kg/cm^2 (100 psi) pressure with a delivery rate of 215 liter/ha. The application was initiated when whitefly adult density was at 4.1 adults per leaf turn on 12 June. The treatments included (1) Danitol (0.22 kg [AI]/ha) + Orthene (0.0556 kg [AI]/ha), (2) Mycotrol WP (1.12 kg/ha), (3) Mycotrol WP (1.12 kg/ha) + Danitol (0.22 kg [AI]/ha), (4) Mycotrol WP (1.12 kg/ha) + Knack (0.86 EC, pyriproxyfen, Valent, Walnut Creek, CA) (49.4 g [AI]/ha), and an untreated control. A total of 8 weekly applications were conducted. The last application was on 1 Aug.

Whitefly eggs, nymphs and adults were sampled once per week from 22 May for 12 wk. Five plants were randomly selected from each plot, and whitefly adults were sampled by gently turning the 5th leaf from the terminal (Naranjo and Flint 1995), and eggs and nymphs were sampled by removing the 5th leaf from the main stem (Naranjo and Flint 1994). Eggs and nymphs from a leaf disk (3.8 cm^2) from each leaf were counted under a stereo microscope in the laboratory.

Field Trial on Tomato and Eggplant in southwest Florida. This trial was conducted on eggplant ('Black Beauty') and tomato ('Agriset') at the Southwest Florida Research and Education Center in Immokalee. Raised beds 91 cm wide on 180 cm centers were fertilized with a bottom mix of 569 kg/ha of 5-16-8 N:P:K and a top mix of 1065 kg/ha of 19-0-30, fumigated with Vampam (37% metham-sodium) at the rate of 374.15 liter/ha, and covered immediately with black polyethylene, 3 wk before setting transplants at 51 cm spacing. Manzate 200 (1.68 kg/ha), Tri-basic Copper (3.36 kg/ha), Bravo (2.34 liter/ha), and Dipel (1.12 kg/ha), were applied weekly to control diseases and lepidopterous pests. Eggplant rows were divided into 5 plots which were 6.5 m long, separated at either end by a 1 m unplanted and untreated buffer. All plots were arranged in a RCB design with 8 replications. The plots were assigned to either untreated control or treatment with Mycotrol WP9504 (4.4×10^{10} spores/g) at the recommended rate of 0.907 kg/ha. Mycotrol was applied 5 times at weekly intervals starting from 21 April. Weekly samples for *B. argentifolii* immatures starting on 24 April consisted of a leaf (6th or 7th leaf from the terminal) from 3 randomly selected plants per plot, collected into plastic zip-lock bags, and brought back to the laboratory. *B. argentifolii* immatures (eggs, nymphs and pupae) were examined on 4 1-cm^2 disks, 2 on each side of the mid-vein. Eggs, young (1st

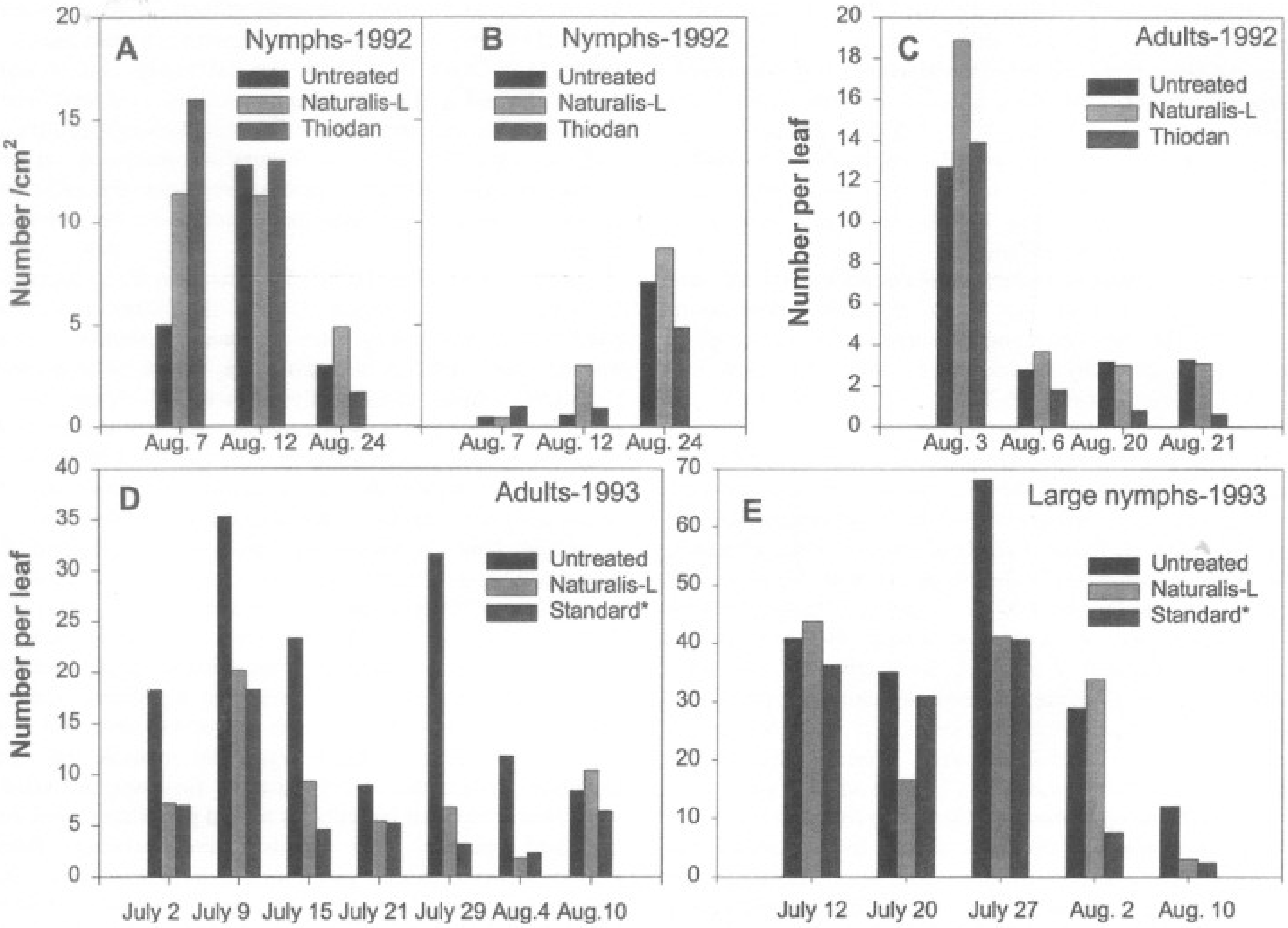

Fig. 2. Effectiveness of Naturalis-L against *B. argentifolii* on cotton (Weslaco, TX). In 1992, Naturalis-L was applied on 31 July and 5 Aug., and in 1993, Naturalis-L was used on 2, 6, 9, 14, 20, 23, 28 July and 3 and 9 Aug. *Standards were Phaser (endosulfan) and Danitol+Orthene. Phaser was applied on 2, 6, 9, 20 July, and 23 and 9 Aug., and Danitol + Orthene was applied on 14 and 28 July and 3 Aug.

and 2nd instar) and old (3rd and 4th instar) nymphs and pupae (red-eyed nymphs) were counted on 12 cm^2 leaf area under a stereo microscope in the laboratory.

Data Analysis. For laboratory and greenhouse data, percent mortality of *B. argentifolii* nymphs and pupae was subjected to one- or two-way analysis of variance (ANOVA, SAS Institute 1988) after the data were transformed to arsine $\sqrt{}(x/100)$. For field data, number of whitefly adults per leaf and immatures per cm^2 were analyzed using ANOVA (SAS Institute 1988), and means were separated using the least significant difference test (LSD) at $P = 0.05$.

RESULTS

Laboratory and Greenhouse Bioassays. Mortality of whitefly nymphs was significantly greater (77 to 94%) with all treatments of Mycotrol than the water-treated control (17%) but only greater than the Silwet L-77 control (82%) with Mycotrol WP9503 (Table 1). Red nymphs as evidence of infection by the fungus (production of secondary metabolite) were seen on 2nd, 3rd and 4th instar nymphs and pupae (red-eyed nymphs). There were no red 1st instar nymphs and few 2nd instar nymphs found probably because they died before the fungus could grow or develop sufficiently. More red nymphs were found on day 15 than on day 8. In the 2nd trial, Mycotrol WP9504 and Naturalis-L gave greater nymph mortality than Mycotrol WP and Mycotrol WP9503. More red nymphs were found in the treatments of Mycotrol WP and Mycotrol WP9504 than in that of Mycotrol WP9503. There were no red nymphs treated with Naturalis-L because this strain does not produce red pigment.

In the greenhouse, percent mortalities of whitefly nymphs caused by Mycotrol ES were significantly different among the rates for both 'Brillinat Red' ($F = 50.92$; df = 2, 42; $P = 0.001$) and 'Versicolor Pink' ($F = 76.39$; df = 2, 42; $P = 0.0001$) (Table 2), ranging from 62.1% with the low rate on 'Brilliant Red' to 84.2% with the high rate on 'Pink Versicolor'. However, percent mortalities of the same rates of Mycotrol ES between the two hibiscus cultivars were not significantly different (*F*-values: 2.73-3015; df = 2, 42; P-values: 0.0977-0.1206), and nor was the interaction of cultivars x rates ($F = 0.93$; df = 2, 42; $P = 0.4013$).

Field Trial on Cantaloupe in Arizona. Number of whitefly adult and immature remained relatively low on cantaloupe for the duration of the study (Fig. 1). There was a trend for lower numbers of whitefly immatures on leaf disks sampled from plots treated with Mycotrol and Naturalis-L compared to untreated plots, although differences were not significant (F-values 1.06-2.18; $P > 0.05$). In this study, total whitefly immature counts at all sample dates following initiation of treatments were too low to show any significant differences, and were too low to have any impact on cantaloupe fruit quality and yields.

Whitefly population plummeted during the 1st wk, and remained low thereafter (Fig. 1). Nevertheless, differences in adult whitefly numbers among treatments for all sampling dates were statistically significant (F-values: 8.42-30.9, $P < 0.0001$). Fewer whitefly adults per leaf were found in the Mycotrol treated plots than in the untreated control and Naturalis-L plots, but Mycotrol only gave 55% control at the end of the trial. Although the Mycotrol at both 0.56 and 1.12 kg/ha resulted in significant control (68-79%) compared to the untreated plots, numbers of adults still exceeded the economic threshold of 3 per leaf. In the treatments with Mycotrol WP (1.12 kg/ha) and Mycotrol WP (0.56 kg/ha) + Pounce (0.11 kg [AI]/ha), adult populations were reduced to 66-87% compared to untreated plots 28 d after the 1st application. The adult whiteflies were below the economic threshold of 3 per leaf at this time. Mycotrol WP at the rate of 1.12 kg/ha resulted in adequate whitefly control following 3 weekly applications under low adult whitefly density (7.2-18.3 adults/leaf).

Field Trials on Cotton and Cucumber in Southern Texas. *Trials on Cotton.* In the 1992 cotton trial, Thiodan and Naturalis-L treatments failed to provide significant control of any stage of *B. argentifolii* (Fig. 2A-C). In the 1993 cotton trial, efficacy of both Naturalis-L and the chemical insecticides against adult whiteflies is similar, with significant reductions as compared to the check occurring in both the Naturalis and standard treatments (chemical combinations) on most dates (F-values: 7.28-28.60; df = 2, 30; $P < 0.01$) (Fig. 2D). Nymph counts showed a slightly different picture, with significant differences on only three of the five sample dates (20 July, 2 and 10 Aug.) (Fig. 2E). The Naturalis-L treatment did not appear to reduce nymph densities over time, but rather to prevent population increases that occurred in the untreated check.

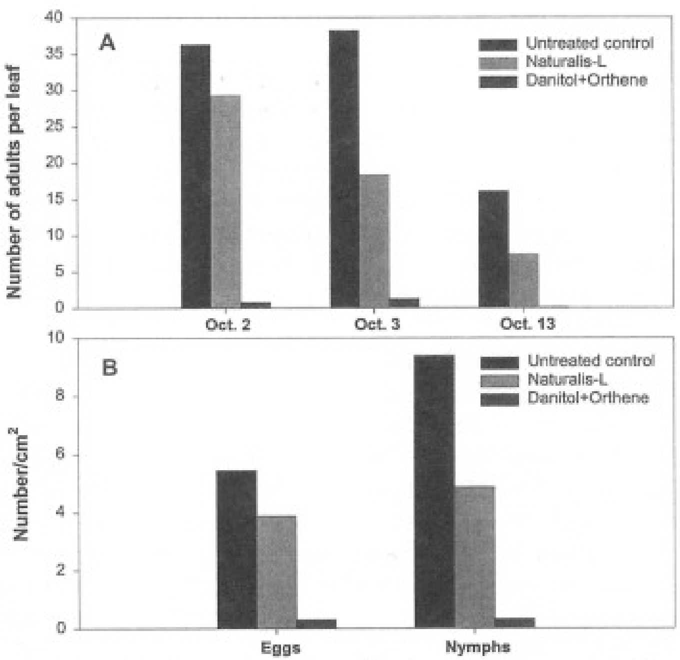

Fig. 3. Effectiveness of Naturalis-L against *B. argentifolii* on cucumber (Weslaco, TX). Naturalis-L was applied on 1, 7, and 12 Oct.

Trial on Cucumber. In the 1992 cucumber trial, Naturalis-L was directly compared with the Danitol-Orthene combination, which has since become the standard foliar treatment for whiteflies in South Texas. Effects on adults and immature stages consistently showed an insignificant reduction of ≈50% with the Naturalis-L treatment as compared with the untreated control (Fig. 3). The Danitol+Orthene treatment consistently showed greater than 90% reduction in adults and immatures as compared to the untreated control.

Field Trial on Cotton in California. Numbers of *B. argentifolii* eggs, nymphs and adults on cotton leaves were significantly different among the 5 treatments (F values, 17.8-23.6, df = 4, 12; $P < 0.0001$) (Fig. 4). The mixture of Danitol+Orthene provided the best control of all whitefly stages. Other treatments did not give significant control compared to the untreated plots. Mycotrol alone did not significantly reduce whitefly eggs and nymphs, but did eventually reduce the adult population. However, lint yields were greater from all insecticides treated plants than from the untreated plants. Lint yields were greatest from Danitol+Orthene treated plants (3,826 kg/ha), followed by Mycotrol + Danitol (3,162 kg/ha) and Mycotrol + Knack (2,860 kg/ha). Mycotrol alone (2,430 kg/ha), and the untreated control had the lowest yields (1,764 kg/ha).

Field Trial on Tomato and Eggplant in Immokalee, Florida. Mycotrol did not provide control of *B. argentifolii* on either tomato or eggplant, and the number of whitefly nymphs and pupae on leaves of tomato and eggplant were not significantly different from untreated plants (Table 3). However, some red pupae were found on treated plants: 40.7% on eggplant and 50% on tomato, indicating that Mycotrol did successfully infect some whiteflies.

DISCUSSION

Under laboratory and greenhouse conditions where high humidity and complete coverage were manipulated, both Mycotrol and Naturalis-L were highly effective against immature *B. argentifolii* on cantaloupe. However, the field results from Arizona, where Mycotrol and Naturalis-L gave significant control *B. argentifolii*, were different from those obtained on cotton in California and on tomato and eggplant in Florida, where Mycotrol did not provide significant control.

The low whitefly population at that time can probably be attributed to the great population of the predator. Mycotrol alone may not provide adequate control under heavy whitefly infestations, although it gave significant control of *B. argentifolii* (68-79% control) compared to untreated plots. Because whitefly pressure was relatively light in fall cantaloupe grown in this study than in previous seasons (TCK, unpublished data), 3 applications of Mycotrol WP at the 1.12 kg/ha rate had a cumulative effect of maintaining adult whitefly counts below the currently recommended economic threshold of 3 adults per leaf.

Although we cannot compare the differences in effectiveness of the two strains of *B. bassiana* between the field trials in Arizona relative to those in California, Florida and Texas, application interval and rates could be important factors in determining effectiveness. It has been found that conidial sprays of 4.94 x 10^{13}/ha with Mycotrol applied at 4-5 d intervals in spring and fall melons produced between 75-95% whitefly nymph reduction 21 d after application, whereas 20-45% reduction in whitefly nymphs occurred when the spray interval was extended to 7-10 d, or with a 4-5 d spray interval and a reduced rate of 1.235 x 10^{13} conidia/ha (Wraight et al. 1995, 1996). Even at a rate of 2.1 x 10^{13} conidia/ha, low levels of control were found in cotton and tomato (Wraight et al.1996). One possible reason for poor control of whitefly on field tomato and eggplant trial in south Florida and on cotton in California, might be that the applications were conducted at weekly intervals rather than 3-5 d, as required for sufficient control. However, field application at 3-5 days intervals may not be realistic nor economically feasible for many growers.

In the cotton trials in southern Texas, the lack of differences in adult counts may be partially attributable to movement of adults among plots, particularly in counts taken later than 24 h after treatment. However, counts taken 24 h after the second treatment also showed no significant reduction with either material. Egg densities could have also been affected by adult movement and oviposition among plots. However, because nymphs are immobile except as crawlers, the lack of significant reductions in nymph densities clearly indicates a lack of efficacy for both products against nymphs of the whitefly. In the 1993 trial on cotton, within the standard treatment, the reductions in nymphs appeared to result from applications of the Danitol-Orthene combination, with populations actually increasing on July 27 after applications of Phaser. Although the Naturalis-L treatment performed similar to the standard in this season-long test (with 9 applications on a 3-6 d schedule), it is important to note that plot ratings taken at the end of the season resulted in marginally acceptable control ratings for both treatments.

Field studies by Wraight et al. (1997) with Mycotrol indicated that complete spray coverage with high pressure (>140 kg/cm²) is one of the most important elements of successful control of *B. argentifolii*, particularly on cucurbits, as is the case with most insecticides. Coverage on the lower leaf surface where the target insects are located is particularly important for Mycotrol and Naturalis-L because their active ingredients (fungal conidia) must contact the insect cuticle for germination. The poor efficacy in the field trials in California and Florida might have resulted from inadequate spray coverage.

Pathogenicity of *B. bassiana* is also a function of environmental conditions with conidial germination being favored by warm temperatures and particularly by high relative humidity. Thus, the fungus might be expected to work well

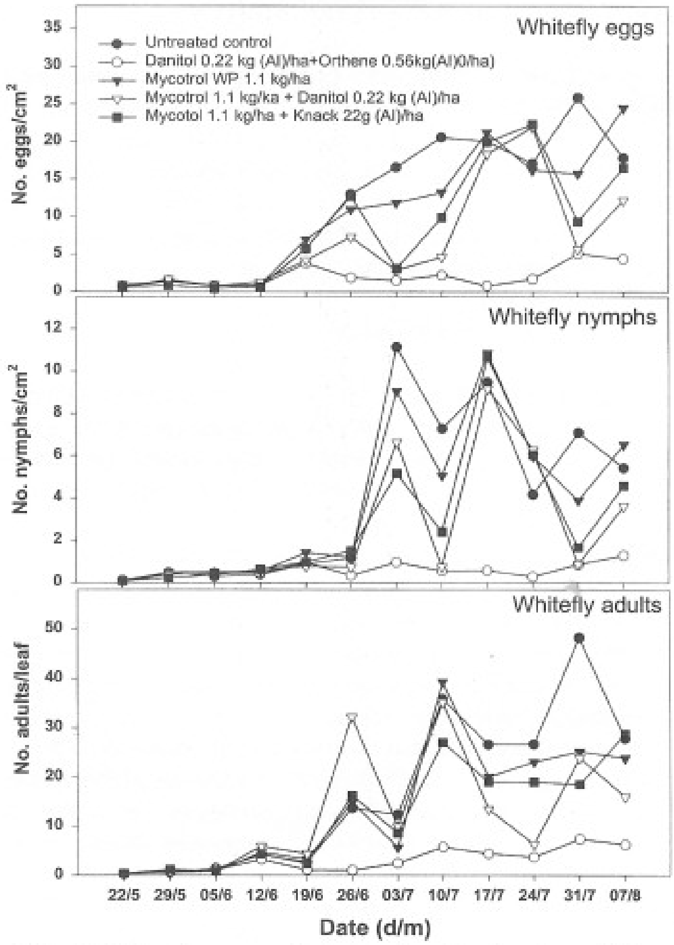

Fig. 4. Effectiveness of Mycotrol and other insecticides against *B. argentifolii* on cotton (Brawley, CA), Mycotrol was applied on 12, 19, 26 June, 3, 10, 17, 24 July and 1 Aug.

under conditions typical of propagation greenhouses. For application of *B. bassiana* under field conditions, spray should be conducted at night or late afternoon when temperature is not too high and RH is high.

Integration of microbial pathogens with other pesticides may have potential because the pathogen may weaken the pests enough to make the insects less resistant to other pesticides and other control measures. The pesticides in turn may weaken the pests sufficiently to make them more susceptible for infection by the pathogens and other control agents. Lacey et al. (1996) listed several reasons why *B. bassiana* (as well as other species of entomopathogenic fungi) could become an effective microbial insecticide: (a) it has high virulence towards whiteflies, (b) grows on artificial media, (c) remains viable for a relatively long period in storage, (d) is easily applied with standard spray equipment, (e) is able to survive in the plant canopy, and (f) is compatible with natural enemies. *B. bassiana* could be a useful tool for control of *B. argentifolii* on plants where the necessary conditions through coverage and high humidity could be guaranteed. However, in conventional field production systems with moderate or high whitefly pressure, inconsistency in coverage and humidity, combined with an apparent need for multiple applications on a short spray interval, pose considerable obstacles to use of these products.

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