Bulletin of Entomological Research (1997) **87**, 525–531

Selectivity of insecticides to *Encarsia pergandiella* (Hymenoptera: Aphelinidae), an endoparasitoid of *Bemisia argentifolii* (Hemiptera: Aleyrodidae)

P.A. Stansly and T.-X. Liu

University of Florida, Southwest Florida Research and Education Center, PO Box 5127, Immokalee, FL 34143-5002, USA

Abstract

Encarsia pergandiella Howard is the most abundant parasitoid of silverleaf whitefly, *Bemisia argentifolii* Bellows & Perring, in south Florida vegetable fields and can contribute significantly to natural biological control of this and other whitefly species. However, quality standards, costs, and risks in commercial tomato production are high, resulting in frequent recourse to chemical control. Therefore, successful utilization of biological control could depend on compatibility of the parasitoid with selective insecticides. We tested a wide range of potentially selective insecticides, represented by a mineral oil, an insecticidal soap, a neem seed extract and synthetic and natural sugar esters, against eggs, first and third instar larvae, pupae and adults, using a pyrethroid, Capture® (20 g bifenthrin/l EC), for comparison. Capture® residues on nymphs exposed to adult parasitoids reduced parasitization more than other materials tested, and were most toxic to all parasitoid stages. Mineral oil caused high mortality to immature parasitoids, and residues reduced parasitization of *E. pergandiella*. However, oil residues were much less toxic to adults if applied as a spray to leaf surfaces than as a dip to a leaf and especially glass surfaces. In contrast, the toxicity of Capture® was high regardless of bioassay method. Neem extract, insecticidal soap and both sugar esters tested had little or no effect on *E. pergandiella*. These latter materials could be considered selective in respect to *E. pergandiella* and might be used to suppress *B. argentifolii* without decimating parasitoid populations.

Introduction

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 fibre crops in the southern United States and elsewhere. Estimated crop damage by the whitefly in the US exceeded one-half billion dollars in 1991 alone (Perring *et al.*, 1993), of which 141 million dollars occurred on tomato in Florida during the 1990–1991 season (Schuster *et al.*, 1996). In response, many tomato growers applied broad-spectrum insecticides two to three times weekly during much of the growing season in Florida. Biological control agents could not be expected to survive well in such an environment, although at least eleven species of parasitoids (Hymenoptera: Aphelinidae) have been discovered parasitizing *B. argentifolii* in Florida, principally *Encarsia pergandiella* Howard, in south Florida, with *E. nigricephala* Dozier, *E. transvena* Timberlake, and *Eretmocerus* nr. *californicus* Howard (Osborne *et al.*, 1990; Evans, 1993) also present. Over 90% parasitism and corresponding low populations of *B. argentifolii* have been observed in organically grown vegetables and unsprayed peanuts and soybeans (Stansly *et al.*, 1994; McAuslane *et al.*, 1994, 1995). It has been suggested that one or a combination of these parasitoids could be used to suppress the pest in vegetables under field conditions (Osborne *et al.*, 1990; Polaszek *et al.*, 1992). Given the capacity of natural biological control to reduce populations of *B. argentifolii* in Florida, impacts of potentially selective insecticides on *E. pergandiella* is an important consideration. We selected materials which exhibited widely different modes of action against *B. argentifolii* including a mineral oil, an insecticidal soap, a plant extract containing insecticidal sugar esters, an extract of neem and used a broad-spectrum pyrethroid for comparison.

Side effects of an extensive list of pesticides used in glasshouses on *E. formosa* Gahan (Hymenoptera: Aphelinidae), a parasitoid of greenhouse whitefly,

Trialeurodes vaporariorum (Westwood) (Hemiptera: Aleyrodidae) were given by Ledieu (1979) and standard tests were described by Hoogcarspel & Jobsen (1984). This and a method for evaluating effects on parasitoid survival of direct contact by pesticides to parasitized pupae was accepted by the International Organization of Biological Control (IOBC/WPRC) working group 'Pesticides and beneficial organisms' (Oomen, 1985). We modified the procedure for adults with a more convenient and available medicine dropper method for testing effects of residues on adults. However, we were concerned that response to residues on glass may not provide a sufficiently realistic model, so also tested residues on leaves to mimic more closely the wasp's normal experience. By using infested leaves and adjusting the rate to allow for survival of the whitefly host, we were able to evaluate impacts of residues on parasitization that would occur through the combined effects of repellency to adults and mortality to parasitoid eggs and young instars. For the test of contact toxicity to pupae we chose rooted over detached leaves as substrate, again in the interest of a realistic model. The long-lived rooted leaves maintained parasitized nymphs indefinitely and allowed for testing effects on parasitoid larvae as well. For this and tests of residue effects on parasitization, a diagnostic dose was chosen for each material close to the LC_{50} for *B. argentifolii* as determined by previous research (Liu & Stansly, 1995b), such that whitefly survival would be sufficient to test for differences between treatments in parasitoid survival. We think combined results from these tests provided a relatively complete picture of expected side effects of these materials, and therefore a potentially useful assessment of compatibility.

Materials and methods

Insects and host plants

Bemisia argentifolii obtained from D.J. Schuster (University of Florida, Bradenton) in 1990 was identified as biotype 'B' of *B. tabaci* by T.M. Perring (University of California, Riverside, California, USA) in 1992, and as *B. argentifolii* by A.C. Bartlett (USDA-ARS, Phoenix, Arizona, USA) in 1994. The colony was maintained in an air conditioned greenhouse on a variety of host plants including tomato (*Lycopersicon esculentum* L.), sweet potato (*Ipomoea batatas* L.), and hibiscus (*Hibiscus rosa-sinensis* L.).

Sweet potato leaves (cv. Carolina Bunch) were used as host plants for all experiments, but one in which effects of insecticide residues on parasitization was also tested on tomato (cv. Florida Lanai). Tomato was used as the whitefly host because whitefly control on tomato was our ultimate objective. Sweet potato plants were propagated in 3.8 l pots in Metro-Mix 300 growing medium (Grace Sierra, Horticultural Products Company, Milpitas, California, USA), and fertilized weekly with 4 g/l Stern's Miracle-Gro (N-P-K: 15-30-15, Stern's Miracle-Gro Products, Inc., Port Washington, New York, USA). Tomato was planted one per 15 cm (1.35 l) pot using the same growing medium and fertilization. Young sweet potato leaves were inserted individually by the petiole into a root cube (3.75 × 3.75 × 3.75 cm, OASIS Growing Media, Smithers-Oasis, USA, Grower Products, Kent, Ohio, USA). Root cubes with sweet potato leaves were kept in plastic trays and immersed in water (2 cm in depth) every two or three days as needed to maintain moisture. Miracle-Gro (1 g/l) was added to the water once a week.

Encarsia pergandiella (identified by G. Evans, Gainesville, Florida, USA) from the local environment appeared in the whitefly greenhouse in 1992. Adult female *E. pergandiella* for all experiments were collected with a clean glass pipette aspirator from the greenhouse colony. Experiments were conducted in an insectary with a photoperiod of L:D 14:10 at 25 ± 2°C and 65 ± 5% r.h. A binocular stereomicroscope was used to count and examine whiteflies and parasitoids. Voucher specimens of parasitoids and whiteflies were deposited in the insect collection at Southwest Florida Research and Education Center, University of Florida at Immokalee, Florida.

We used clip cages made from polystyrene medicine cups attached to metal hair clips for testing toxic effects of residues on parasitoid adults. The 4 cm top diameter of the cup contacted the leaf and the 2.5 cm bottom was removed and covered with 60 mesh nylon screen. We used the wooden-frame cages with two sides covered by 60 mesh nylon screen and the remaining sides and top with clear vinyl film in which to test effects of insecticide residues on parasitization.

Insecticides

The following insecticides and concentrations, based on previous tests with *B. argentifolii* (Liu & Stansly, 1995b) were used depending on the particular experiment: M-Pede (an insecticidal soap, 49% potassium salt of a naturally derived fatty acid; Mycogen Corp., San Diego, California, USA) at 0.25, 0.5, and 1.0% (v/v); Sunspray Ultra-Fine Spray Oil (an emulsified mineral oil; Safer Incorporated, Newton, Massachusetts, USA) at 0.1, 0.2, and 0.4% (v/v); Margosan-O (a neem extract containing 2.5 g/l azadirachtin; Grace-Sierra, Milpitas, California) at 0.06 g ai/l; a sugar ester isolate of *Nicotiana gossei* (a mixture of sucrose and glucose esters) at 0.1, 0.2, and 0.4 g ai/l; a synthetic sugar ester of heptanoic acid (Chortyk *et al.*, 1996), were prepared at 0.1, 0.2, and 0.4 g ai/l, provided by the Phytochemistry Research Laboratory, USDA-ARS, Athens, Georgia, USA, and prepared as described in Liu & Stansly (1995a). A pyrethroid, Capture® (20 g bifenthrin/l EC) (FMC Corp., Middleport, New York, USA) at 0.012, 0.024, and 0.048 g ai/l, and purified tap water (reversed osmosis, 7 ppm dissolved solids) were used as controls. For experiments where only one material was tested, the concentration chosen was closest to the predetermined LC_{50} value for *B. argentifolii* (Liu & Stansly, 1995b) to assure sufficient host survival for assessment of parasitization.

Toxicity to immatures

Rooted, whitefly-free sweet potato leaves were exposed to adult whiteflies for a 24 h oviposition period to obtain cohorts of whitefly eggs. Leaves bearing approximately 150 eggs each were incubated for two weeks until development had proceeded to late second or early third instar, in clear plastic cup cages made from 0.9 l cups ventilated by replacing the 9 cm diameter top with 60 mesh organdy. Third and fourth instar *B. argentifolii* are preferred stages for oviposition by *E. pergandiella*, but second instars are readily accepted (Liu & Stansly, 1996). Infested leaves bearing whitefly cohorts were exposed to parasitoids (five females

and one male) for 48 h. Parasitoids were allowed to develop an additional two days to obtain mature eggs, four days to obtain young larvae, seven days to obtain older larvae, and eleven days to obtain pupae (Gerling, 1966; Liu & Stansly, 1996). Parasitization was evaluated microscopically by checking the parasitoid larvae or pupae inside the whitefly pupae before insecticide treatments for all tests except those on parasitoid eggs which could not be seen. Sweet potato leaves bearing parasitized and unparasitized whitefly nymphs were dipped in appropriate insecticide solutions for 5 s, and air-dried for 2 h before confinement in cup-cages. Successful emergence or death of parasitoids was recorded under a stereomicroscope when most whitefly adults had emerged, i.e. three weeks after treatment of eggs, two weeks after treatment of larvae, and two weeks after treatment of pupae. Each experiment had eight replicates and was repeated three times.

Toxicity of residues to adults

Glass dropper bioassay

Straight glass medicine droppers (76 mm long, 2 ml capacity, Fisher Scientific, Pittsburgh, Pennsylvania, USA) were soaked in 75% ethyl alcohol to remove any surface film, and allowed to dry. The large end was sealed with a piece of small mesh organdy cloth (60 mesh) glued with Duro and Master Epoxy (Extra strength quick set, Loctite Corp., Cleveland, Ohio, USA) and the organdy trimmed. Droppers were suspended to a 10 cm length of string attached at the wide end, and submerged in appropriate solutions for 5 s. Only the mid-range concentration for each insecticide was tested except Capture®, for which the higher field rate was used. Droppers were drained for 5 s, then placed vertically in an open carton box for drying. Parasitoid females were aspirated into each treated dropper, the tips of which were then sealed with parafilm. After a 4 h incubation at room temperature (25 ± 2°C) and 100% r.h. inside a foam ice chest containing water, live and dead parasitoid adults were recorded. Two droppers containing 10–16 parasitoids each were used for each treatment in each replicate for a total of eight replicates and 686 parasitoids.

Leaf-surface bioassay

Cohorts of second and third instar whitefly nymphs were obtained on rooted sweet potato leaves as described above. Leaves were dipped in insecticide solutions for 5 s, and air-dried. Parasitoid adult females (10–14) collected from the greenhouse colony were introduced into clip cages attached to the treated leaves. The experiment had eight replicates, and a total of 495 female parasitoids were used. Living and dead adults from each cage were counted at 24 h.

Leaf-dip versus spray

Another experiment was conducted to compare Capture® and Sunspray oil applied as above, or sprayed with a Potter Spray Tower (Burkard Manufacturing Co. Ltd, Rickmansworth, Hertfordshire, England), using 2 ml of insecticide solution at 69 kPa (0.07 kg/cm^2 or 10 psi) pressure, and allowed to air-dry for 24 h. The experiment had eight replicates using a total of 589 parasitoids.

Effect of residues on parasitization

Effects on parasitization of insecticide residues applied to whitefly-infested leaves before exposure to *E. pergandiella* were tested on sweet potato and tomato. Cohorts of whitefly second and third instar nymphs were initiated on sweet potato as described above. Insecticides and dilutions were the same. Leaves immersed in insecticides at dilutions given above for 5 s, and air-dried for 4 h. Thirty female parasitoids collected from the colony were released into wooden frame cages (n = 8) containing six treated leaves (five different insecticides and water) randomly arranged in a circle of 10 cm radius. Parasitoids were allowed free choice for oviposition until removal after 48 h. Leaves were placed individually in cup cages for approximately two weeks to allow most unparasitized whitefly to emerge. Parasitized, unparasitized, and dead whitefly nymphs and pupae, and exuviae from parasitized and unparasitized pupae were recorded under the binocular microscope. In an additional choice experiment (six replicates), *N. gossei* sugar ester isolate and the synthetic sugar ester were applied as a dip to sweet potato leaves at three concentrations at 0.1, 0.2, and 0.4 g ai/l, with water as control.

For the choice experiment on tomato, the oldest and youngest compound leaves and all but ten leaflets of uniform size were removed from 40 cm plants. Cohorts of whitefly were obtained by placing nine of these tomato plants at a time into 60 × 60 × 60 cm wooden-frame cages into which approximately 3600 adult whiteflies (40 per leaflet) were introduced to oviposit for 24 h. Whiteflies were removed using a hand-held vacuum cleaner and egg-bearing plants maintained for two weeks in the cages until whiteflies had reached second and third instar. Each cohort-bearing leaflet was treated with insecticides applied with a hand-pump sprayer to run-off, air-dried for 2 h then confined, 13 per wooden frame cage, each plant with a different treatment. The experiment was done with eight cages on two different occasions over a two-week interval to give a randomized complete block design with 16 replications. Two female parasitoids per leaflet (520 per cage) were introduced for a 48 h oviposition period. Plants and cage were then carefully cleaned of parasitoids with a hand held vacuum cleaner and plants incubated for two weeks during which most unparasitized whiteflies emerged. Numbers of living and dead pupae, empty pupal exuviae indicative of normal emergence, parasitized pupae and dead third instars were recorded under a binocular stereomicroscope.

Data analysis

Numbers of parasitized, unparasitized/live and unparasitized/dead whitefly nymphs in all experiments were analysed using analysis of variance (ANOVA), and means were separated using the protected least significant difference (LSD) test following a significant F-test at $P = 0.05$ (SAS Institute, 1988). Percentage moralities (100%) in the treatments of Capture® were not included in the ANOVA analysis due to lack of variance. Data for percent emergence and percent parasitization between 1–100% and <30% were transformed by arc sine ($\%/100^{\frac{1}{2}}$) and square root, respectively (Gomez & Gomez, 1984) before analysis, but are presented in untransformed form. The error term used to test insecticide effects on immatures over three repetitions was

Table 1. Effect of selected insecticides on emergence of *Encarsia pergandiella* treated 2, 4, 7 and 11 days after a 48 h access by adult parasitoids to second and third instar nymphs of *Bemisia argentifolii* on sweet potato leaves.

		Parasitoids emerged (% ± SE)			
Insecticides	Rate	2 d[b]	4 d	7 d[c]	11 d
Capture® (g ai/l)	0.02	4.7 ± 1.1c	21.4 ± 4.4c	13.3 ± 4.0c	0.0 ± 0.0c
Sunspray oil (%, v/v)	0.20	1.6 ± 0.9c	15.5 ± 4.4c	44.7 ± 9.8b	0.5 ± 0.3b
M-Pede (%, v/v)	0.50	13.2 ± 2.0b	66.2 ± 6.7b	88.6 ± 2.1a	60.1 ± 2.7a
Margosan-O (g ai/l)	0.06	17.6 ± 2.1b	72.6 ± 6.7b	88.2 ± 3.5a	50.5 ± 4.1a
Nicotiana gossei sugar ester (g ai/l)	0.10	15.1 ± 4.0b	79.4 ± 5.8ab	97.0 ± 0.6a	60.6 ± 2.7a
Water		29.8 ± 2.5a	90.2 ± 3.2a	98.1 ± 0.5a	88.0 ± 1.7a
Mean parasitization (%) before treatment[a]		–	34.9	20.6	32.8

Percentages in the same column followed by the same letters did not differ significantly ($P > 0.05$, LSD, SAS Institute, 1988).
[a]No significant differences ($P > 0.05$) among treatments for all parasitoid stages.
[b]Percent emergence based on total number of surviving whiteflies.
[c]Percent emergence based on number of parasitoid larvae observed before treatment.

the mean square for the insecticide × replicate interaction (Freund *et al.*, 1986).

Results

Toxicity to immatures

Parasitoid eggs

Fewest adult *E. pergandiella* emerged from nymphs treated two to four days after parasitization with Capture® and Sunspray oil compared to other materials tested, from which we concluded that these treatments were most toxic to parasitoid eggs (table 1). A significant reduction in parasitoid emergence was also obtained from parasitized nymphs treated with Margosan-O, M-Pede, and *N. gossei* extract compared with water control, so these treatments must also have been toxic to the parasitoid egg.

Survivorship of larvae and pupae

Survival and emergence of young larval parasitoids from whitefly nymphs parasitized four to seven days previous was lowest if treated with Capture® and Sunspray oil followed by M-Pede and Margosan-O at four days only (table 1). No significant effect was observed from M-Pede and Margosan-O applied seven days after parasitization or *N. gossei* sugar ester isolate at four days or seven days compared to the water control. Capture® and Sunspray oil were again most toxic to older parasitoid larvae (seven to nine days) with all other treatments not significantly different from the water control. Capture® and Sunspray oil killed most parasitoids exposed as pupae 11–13 days old. More than 50% of parasitoid pupae treated with M-Pede, Margosan-O, and *N. gossei* sugar ester isolate survived to emerge, not significantly less than 88% emergence from parasitized nymphs treated with water.

Residual effects on adults

Glass dropper bioassay

Adult *E. pergandiella* mortality responses differed significantly among insecticide treatments ($F = 203.6$; df = 6, 63; $P = 0.0001$) (table 2). Capture® and Sunspray oil caused 96.2 and 93.7% mortality, respectively. Whiteflies became entrapped and died after coming in contact with droplets on oil-treated droppers. Mortality caused by M-Pede, Margosan-O, *N. gossei* sugar ester isolate and the synthetic sugar ester was relatively slight (16.0, 7.9, 8.1, and 7.8% respectively).

Table 2. Mortality of *Encarsia pergandiella* adults to insecticide residues applied by dipping glass droppers and sweet potato leaves into appropriate concentrations.

		Glass dropper		Leaf-surface	
Insecticides	Rate	Parasitoid	% ± SE	Parasitoid	% ± SE
Capture® (g ai/l)	0.048	93	96.2 ± 3.3a	82	100.0 ± 0.0[a]
Sunspray oil (%, v/v)	0.2	99	93.7 ± 5.3a	87	48.6 ± 6.9a
M-Pede (%, v/v)	0.5	93	16.0 ± 5.7b	71	5.6 ± 3.0b
Nicotiana gossei sugar ester (g ai/l)	0.2	106	8.1 ± 4.7bc	69	10.1 ± 5.7b
Synthetic sugar ester (g ai/l)	0.2	97	7.8 ± 3.6bc	68	6.5 ± 2.9b
Margosan-O (g ai/l)	0.06	99	7.9 ± 3.7bc	60	11.0 ± 4.3b
Water		99	5.8 ± 3.1c	63	1.2 ± 1.5b

Means followed by the same letters in the same column did not differ significantly ($P > 0.05$, LSD, SAS Institute, 1988).
[a]Not included in the analysis.

Table 3. Mortality (%) of adult *Encarsia pergandiella* parasitoids to insecticide residues applied as a dip or a spray to sweet potato leaves 24 h after treatment.

		Dip		Spray	
Insecticides	Rate	Parasitoid	% ± SE	Parasitoid	% ± SE
Capture® (g ai/l)	0.048	100	100.0 ± 0.0[a]	105	93.7 ± 5.7A
Sunspray oil (%, v/v)	0.2	99	43.4 ± 12.8Aa	101	13.1 ± 5.2Bb
Water		95	3.0 ± 3.5Ba	89	2.3 ± 2.3Ca

Means followed by same upper case letters in the same column and by same lower case letters in the same row did not differ significantly ($P > 0.05$, LSD, SAS Institute, 1988).
[a]Not included in the analysis.

Leaf-surface bioassays

Mortality responses of *E. pergandiella* adults differed significantly among insecticide treatments ($F = 25.4$; df = 5, 54; $P = 0.0001$) except for Capture® which caused 100% mortality, and was excluded from the analysis (table 2). Sunspray oil caused significantly greater mortality than other insecticides. Smaller droplets of oil coalesced on leaves than glass droppers and mortality on oil-treated leaves (48.6%) was half that on glass droppers. In contrast, *E. pergandiella* adults died shortly after landing on leaves treated with Capture®, giving a similar mortality response to that observed on glass droppers. Residues of M-Pede also appeared to be less toxic on leaf surfaces than glass surfaces (e.g. 5.6% versus 16.0% mortality). The other three insecticides tested gave similar results on either surface. It would appear that the glass dropper bioassay can provide a realistic evaluation of endotoxin-type insecticides but possibly not of materials with physical modes of action such as oils and soaps (Stansly *et al.*, 1996).

Leaf-dip versus spray

Percentage mortality of parasitoids exposed to Capture® residues applied by leaf dip was 100%, which was not included in the analysis (table 3), while percentage mortality in the Potter Tower sprayed treatment was 93.7%. Sunspray oil residues applied as a dip caused three times higher mortality than sprayed-on residues (43.4% versus 13.1%, $F = 12.3$; df = 1, 32; $P = 0.0013$).

Effect of residues on parasitization

Insecticide residues on tomato plants significantly decreased the percentage parasitization in choice tests ($F = 20.8$; df = 13, 240; $P = 0.001$) (table 4). Least parasitization was seen on plants treated with Capture®, Sunspray oil and M-Pede, with no significant differences between these treatments over all three dilutions tested. No reduction of parasitization was seen in response to *N. gossei* sugar ester isolate. In fact, a significant enhancement of parasitization was seen at the lowest (0.1 g ai/l) rate. However, similar enhancement was not seen from residues of the *N. gossei* extract or a synthetic sugar ester isolate on sweet potato (table 5). An additional test on sweet potato at intermediate rates of all materials except for Capture® (tested at the field rate) gave results similar to those on tomato, even though parasitization was lower (table 6). This test included the neem extract Margosan-O, residues of which reduced parasitization of *B. argentifolii* statistically as much as Capture®.

Discussion

Uniform residues on surfaces dipped in Capture® and Sunspray oil greatly reduced parasitization and were highly toxic to parasitoid adults. However, mortality of adults exposed to oil residues varied with surface type and application method, decreasing by a factor of seven from a dipped glass surface at one extreme to a sprayed leaf on the other. Survival appeared to depend on access to oil-free surfaces where entrapment could be avoided, between

Table 4. Parasitization of *Bemisia argentifolii* on sweet potato leaves treated with three concentrations of selected insecticides 2 h prior to free choice exposure to adult *Encarsia pergandiella*.

Insecticides	Rate	Whitefly	Mortality (% ± SE)	Parasitism (% ± SE)
Capture® (g ai/l)	0.012	1578	41.3 ± 2.4cd	2.2 ± 2.3d
	0.024	1554	49.1 ± 2.3c	1.0 ± 1.0d
	0.048	1864	57.7 ± 8.4b	0.5 ± 0.6d
Sunspray oil (%, v/v)	0.1	1275	32.4 ± 4.9de	1.4 ± 2.0d
	0.2	736	59.8 ± 9.4ab	2.4 ± 1.9d
	0.4	1626	67.2 ± 5.4a	0.9 ± 0.8d
M-Pede (%, v/v)	0.25	1525	32.1 ± 4.9e	3.6 ± 2.6d
	0.50	1441	40.2 ± 5.1d	1.3 ± 0.6d
	1.00	987	58.4 ± 2.2b	1.1 ± 1.0d
Nicotiana gossei sugar ester (g ai/l)	0.1	2485	23.4 ± 3.8f	32.9 ± 5.3a
	0.2	1857	39.7 ± 5.3d	22.9 ± 7.0b
	0.4	1578	42.2 ± 4.8cd	15.3 ± 3.7c
Water		3433	6.5 ± 2.2g	15.5 ± 4.9bc

Means followed by the same letters in the same column did not differ significantly ($P > 0.05$, LSD, SAS Institute, 1988).

Table 5. Parasitization of *Bemisia argentifolii* on sweet potato leaves treated with three concentrations of selected insecticides 2 h prior to free choice exposure to adult *Encarsia pergandiella*.

Insecticides	Rate	Whitefly	Mortality (% ± SE)	Parasitism (% ± SE)
Nicotiana gossei sugar ester	0.1	3519	35.3 ± 2.6b	13.0 ± 2.8a
(g ai/l)	0.2	2265	45.4 ± 5.5a	13.0 ± 1.9a
	0.4	2608	46.5 ± 2.4a	13.5 ± 1.6a
Synthetic sugar ester	0.1	3668	29.1 ± 1.6bc	10.0 ± 1.3a
(g ai/l)	0.2	3122	36.2 ± 3.1b	11.0 ± 2.0a
	0.4	3008	48.4 ± 2.9a	8.8 ± 1.3a
Water		3548	20.4 ± 2.2c	12.0 ± 2.2a

Means followed by the same letters in the same column did not differ significantly ($P > 0.05$, LSD, SAS Institute, 1988).

droplets or on untreated surfaces of the clip cage. Oil appears to kill by suffocation (Stansly *et al.*, 1996) and all measured effects on *E. pergandiella* would probably be considerably reduced by less than complete coverage, as in the case of *B. argentifolii* (Liu & Stansly, 1995a). In contrast to oil, mortality responses to Capture® varied little among surfaces or application method; any contact with Capture® was lethal. Our results suggest that parasitoid mortality from exposure to oil residues in the greenhouse or field might be less than expected from laboratory bioassays using a leaf-dip methodology.

We have tested the response of *E. pergandiella* to five types of insecticides: pyrethroid, oil, soap, neem extract, and sugar ester by six criteria: adult mortality, and parasitization of hosts treated 2 h before or two, four, seven and 11 days after exposure to adult wasps. How can this information be integrated into an overall ranking of relative safety to the parasitoids? By all criteria, Capture® exhibited the severest side effects to the parasitoids, and is clearly the least compatible with the wasp (table 7). Following closely but clearly in another category is Sunspray oil, which was indistinguishable from Capture® in its effects on parasitization through four days post-exposure, but had less drastic effects at seven days, and caused less mortality to adults on leaf surfaces. M-Pede and Margosan-O fell in a much lower category of incompatibility, exhibiting little or no toxic effect against adults. However, both reduced parasitization of whiteflies treated before exposure to adults, probably due to repellency rather than subsequent mortality, since application two days after parasitization had only slight effects (table 1). Sugar esters appeared to be most compatible with *E. pergandiella*, showing virtually no measurable side effects except to parasitoid eggs. Bentz & Neal (1995) also found that *N. gossei* extract was less detrimental to *E. formosa* than M-Pede, suggesting the extract could be used in IPM programmes for whitefly control. Harbaugh & Mattson (1976) also suggested use of selective insecticides in conjunction with *E. formosa* based on theoretical models for controlling greenhouse whitefly, *Trialeurodes vaporariorum* in the greenhouse. Granted, we have worked with rates below

Table 6. Parasitization of *Bemisia argentifolii* on tomato plants treated with diagnostic concentrations of selected insecticides 2 h prior to free choice exposure to adult *Encarsia pergandiella*.

Insecticides	Rate	Whitefly	Mortality (% ± SE)	Parasitism (% ± SE)
Capture® (g ai/l)	0.048	1844	81.8 ± 4.3b	1.6 ± 0.4d
Sunspray oil (%, v/v)	0.20	1000	90.9 ± 4.1a	2.9 ± 0.6d
M-Pede (%, v/v)	0.50	2256	44.4 ± 5.4c	6.5 ± 2.9bc
Margosan-O (g ai/l)	0.06	2486	39.1 ± 5.1c	3.7 ± 1.0cd
Nicotiana gossei sugar ester (g ai/l)	0.20	2098	43.1 ± 3.8c	97 ± 2.5a
Water		1932	15.1 ± 3.9d	9.9 ± 3.2a

Means followed by the same letters in the same column did not differ significantly ($P > 0.05$, LSD, SAS Institute, 1988).

Table 7. Relative toxicity insecticides to adult *Encarsia pergandiella* and effect on emergence when applied two days before and two, four, seven and 11 days after exposure to second and third instar *Bemisia argentifolii* to adult wasps.

	Toxicity to adults		Reduced emergence					
Insecticides	Glass	Leaf	−2 h	2 d	4 d	7 d	11 d	Overall
Capture®	xxxx[a]	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
Sunspray oil	xxxx	xx	xxxx	xxxx	xxxx	xxxx	xxx	xxx
M-Pede	x	–	xxx	x	x	0	0	x–
Margosan-O	–	0	xxx	x	x	0	0	x–
Sugar esters	–	–	0	x	–	0	0	–

[a]x, incremental response; –, slight response; 0, no response.

what would normally be sprayed to control whitefly, and therefore below what the parasitoid might experience at certain times and places. However, high insecticide concentrations are at best localized and transitory, and furthermore would not permit evaluation of relative selectivity to immature stages requiring host survival. We believe that selectivity defined with respect to specific life stages of specific beneficial organisms could provide guidelines for planning applications and releases, thus improving integration of biological and chemical control.

Acknowledgements

We thank D.J. Schuster, H.J. McAuslane, and C.S. Vavrina (University of Florida), J.W. Neal, Jr. (Florist and Nursery Crops Laboratory, USDA-ARS, Beltsville, Maryland) and R.K. Yokomi (Horticultural Research Laboratory, USDA-ARS, Orlando, Florida) for reviews, L. Smith and O.S. Chortyk (Phytochemistry Research Laboratory, USDA-ARS, Athens, Georgia) for providing *N. gossei* sugar ester isolate and the synthetic sugar ester, and J.M. Conner, T. Yost and Y.M. Zhang for excellent technical assistance. This study was funded by USDA Competitive Grant no. 93-34103-8433. Florida Agricultural Experiment Station Journal Series R-05014.

References

Bentz, J.-A. & Neal, J.W. Jr. (1995) Effects of a natural insecticide from *Nicotiana gossei* on the whitefly parasitoid *Encarsia formosa* (Hymenoptera: Aphelinidae). *Journal of Economic Entomology* **88**, 1611–1615.

Chortyk, O.T., Pomonis, J.G. & Johnson, A.W. (1996) Syntheses and characterizations of insecticidal sucrose esters. *Journal of Agricultural and Food Chemistry* (in press).

Evans, G. (1993) *Systematic studies of New World* Encarsia *species and a survey of the parasitoids of* Bemisia tabaci *in Florida, the Caribbean and Latin America*. PhD Dissertation, University of Florida, Gainesville, Florida.

Freund, R.J., Littell, R.C. & Spector, P.C. (1986) *SAS system for linear models*. 210 pp. SAS Institute, Cary, North Carolina, USA.

Gerling, D. (1966) Studies with whitefly parasites of Southern California. I. *Encarsia pergandiella* Howard (Hymenoptera: Aphelinidae). *Canadian Entomology* **98**, 707–724.

Gomez, K.A. & Gomez, A.A. (1984) *Statistical procedures for agricultural research*. 680 pp. 2nd edn, New York, John and Wiley.

Harbaugh, B.K. & Mattson, R.H. (1976) Insecticide effects on *Encarsia formosa* Gahan, parasite of the greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood). *Journal of the American Society of Horticultural Sciences* **101**, 228–233.

Hoogcarspel, A.P. & Jobsen, J.A. (1984) Laboratory method for testing the side-effects of pesticides on *Encarsia formosa* (Hymenoptera: Aphelinidae). Results with pesticides used on tomato in glasshouses in the Netherlands. *Journal of Applied Entomology* **97**, 268–278.

Ledieu, M.S. (1979) Laboratory and glasshouse screening of pesticides for adverse effects on the parasite *Encarsia formosa* Gahan. *Pesticide Science* **10**, 123–132.

Liu, T.-X. & Stansly, P.A. (1995a) Toxicity and repellency of biorational insecticides to *Bemisia argentifolii* on tomato plants. *Entomologia Experimentalis et Applicata* **74**, 137–143.

Liu, T.-X. & Stansly, P.A. (1995b) Toxicity of some selected biorational insecticides to *Bemisia argentifolii* (Homoptera: Aleyrodidae) on tomato plants. *Journal of Economic Entomology* **88**, 564–568.

Liu, T.-X. & Stansly, P.A. (1996) Development, oviposition and survivorship of *Encarsia pergandiella* (Hymenoptera: Aphelinidae), parasitoids of *Bemisia argentifolii* (Homoptera: Aleyrodidae). *Annals of the Entomological Society of America* **88**, 96–102.

McAuslane, H.J., Johnson, F.A., Knauft, D.A. & Colvin, D.L. (1994) Seasonal abundance and within-plant distribution of parasitoids of *Bemisia tabaci* (Homoptera: Aleyrodidae) in peanuts. *Environmental Entomology* **22**, 1043–1050.

McAuslane, H.J., Johnson, F.A., Sojack, B. & Colvin, D.L. (1995) Influence of foliar pubescence on abundance and parasitism of *Bemisia argentifolii* (Homoptera: Aleyrodidae) on soybean. *Environmental Entomology* **24**, 1135–1143.

Oomen, P.A. (1985) *Encarsia formosa* Gahan (Aphelinidae: Hymenoptera). pp. 221–222 *in* Hassan, S.A. *et al.* (*Eds*) Standard methods to test the side-effects of pesticides on natural enemies of insects and mites developed by the IOBC/WPRS working group 'Pesticides and beneficial organisms'. *Bulletin of OEPP* **15**, 214–255.

Osborne, L.S., Hoelmer, K.M. & Gerling, D. (1990) Prospects for biological control of *Bemisia tabaci*. *Bulletin of SROP/WPRS* **13**, 153–160.

Perring, T.M., Cooper, A.D., Rodrigez, R.J., Farrar, C.A. & Bellows, T.S. Jr. (1993) Identification of a whitefly species by genomic and behavioral studies. *Science* **259**, 74–78.

Polaszek, A., Evans, G.A. & Bennett, F.D. (1992) *Encarsia* parasitoids of *Bemisia tabaci* (Hymenoptera: Aphelinidae, Homoptera: Aleyrodidae): a preliminary guide to identification. *Bulletin of Entomological Research* **82**, 374–392.

SAS Institute (1988) *SAS/STAT user's guide*. Cary, North Carolina, SAS Institute.

Schuster, D.J., Funderburk, J.E. & Stansly, P.A. (1996) Selected IPM programs: tomato. pp. 387–412. *in* Rosen, D., Bennett, F.D. & Capinera, J.L. (*Eds*) *Pest management in the subtropicals: integrated pest management: a Florida perspective*. Andover, UK, Intercept.

Stansly, P.A., Schuster, D.J. & McAuslane, H.J. (1994) Biological control of silverleaf whitefly: an evolving sustainable technology. pp. 484–491. *in* Campbell, K.L., Graham, W.D. & Bottcher, A.B. (*Eds*) *Environmentally sound agriculture*. Proceedings of the Second Conference, 20–22 April 1994, Orlando, Florida. American Society of Agricultural Engineers, St. Joseph, Michigan.

Stansly, P.A., Liu, T.-X., Schuster, D.J. &. Dean, D.E. (1996) Role of insecticides in management of *Bemisia*. pp. 605–615. *in* Gerling, D. & Mayer, R.T. (*Eds*). Bemisia: *1995 taxonomy, biology, control and management*. Andover UK, Intercept.

(Accepted 30 November 1996)