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Toxicity and repellency of some biorational insecticides to *Bemisia argentifolii* on tomato plants

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Abstract

A mineral oil, an insecticidal soap, and a plant-derived surfactant were compared with a broad-spectrum pyrethroid for residual toxicity and repellency to silverleaf whitefly, *Bemisia argentifolii* Bellows & Perring (Homoptera: Aleyrodidae) on tomatoes (*Lycopersicum esculentum* Miller, cv. Lanai) under greenhouse and laboratory conditions. The materials tested were: Sunspray oil (a mineral oil), M-Pede (an insecticidal soap), *Nicotiana gossei* extract (a sucrose ester surfactant), Garlic Barrier (repellency only), and the pyrethroid bifenthrin (Brigade 10WP), with water as a control. For toxicity studies, whiteflies were confined on leaves which had been dipped in solutions of 0.5 ×, 1 × and 2 × field rate concentrations. Insecticide residues were compared when the leaves were wet and dry. Adult mortalities were greatest with bifenthrin and Sunspray oil, followed by M-Pede, *N. gossei* extract and water. Mortality from dry residue of lower rates of bifenthrin and Sunspray oil was greater than mortality from wet residues, whereas M-Pede lost all activity upon drying. Dual and multiple choice tests for repellency were carried out in the greenhouse or laboratory by spraying plants or individual leaves to runoff with 1 × field concentrations. Bifenthrin and Sunspray oil repelled *B. argentifolii* adults for up to 7 and 5 days, respectively, followed by M-Pede and extract of *N. gossei*, whereas Garlic Barrier was not significantly different from the water control in all tests. Numbers of whitefly eggs were significantly reduced on bifenthrin and Sunspray oil-treated leaves, whereas egg numbers in other treatments were not different from water. Sunspray oil as a dip proved to be at least as effective as the synthetic pyrethroid for whitefly control. A multiple-choice leaf-wheel proved to be a useful device to quickly evaluate repellent effects of several different insecticides to whitefly.

Introduction

Silverleaf whitefly, *Bemisia argentifolii* Bellows & Perring (Bellows *et al.*, 1994), formerly known as sweetpotato whitefly, *B. tabaci* (Gennadius), is a key insect pest of vegetables, field crops and ornamentals in the southern United States. Damage is caused by plant debilitation, sooty mold growth, and in tomato, irregular ripening and transmission of tomato mottle geminivirus (TMoV) (Stansly & Schuster, 1990). Yield reduction from irregular ripening and geminivirus plus control costs for Florida tomato alone were estimated at $125 million for the 1990–1991 season (Schuster *et al.*, 1994). Intensive use of broad-spectrum insecticides results in high costs, decimation of natural enemies, secondary pest outbreaks, insecticide resistance, exposure of farm workers, and environmental hazards. Integrating biological control with present spray-oriented management practices would include specifically targeted control materials, which interfere, either minimally or not at all, with the activities of natural enemies.

The term 'biorational' insecticide was coined by Djerassi *et al.* (1974) who, in lieu of a definition, gave examples of materials characterized by species-specificity (low toxicity to non-target organisms) in contrast to broad-spectrum chemical insecticides. Detergents and oils have shown potential to suppress *B. argentifolii* populations on cotton (Butler *et al.*, 1988, 1989) and vegetable crops (Butler *et al.*, 1993). Such materials have low toxicity to many classes of organism, possibly including parasitoids and predators of whiteflies, and therefore could be considered 'biorational'.

Because *B. argentifolii* adults transmit TMoV (Stansly & Schuster, 1990), repelling whiteflies before they feed on host plants in the field could reduce damage and TMoV infestation. Butler *et al.* (1988, 1989) found that cottonseed oil repelled *B. tabaci* adults for up to 9 days and soybean oil for up to 7 days on cotton. Larew & Locke (1990) using a petroleum-base horticultural oil (Sunspray 6E plus) at a rate of 2% repelled *Trialeurodes vaporariorum* (Westwood) adults from chrysanthemum for more than 11 days after spraying. If the insecticides repel *B. argentifolii* adults from vegetable plants in the field, damage caused by feeding, fungal mold and tomato mottle geminivirus might be significantly reduced.

The objectives of this study were: (1) to assess the mortality of *B. argentifolii* adults from contact with wet and dry residues of 4 insecticides on tomato leaves under laboratory conditions and (2) to evaluate repellent effects of these materials to *B. argentifolii* adults at different rates under laboratory and greenhouse conditions.

Materials and methods

This study was conducted at the Southwest Florida Research and Education Center in Immokalee, Fl. Four biorational insecticides were used at concentrations of 0.5 ×, 1 × and 2 × recommended field rate: M-Pede^{TM}, an insecticidal soap (Mycogen Corp., San Diego, CA), 0.5, 1.0 and 2% for toxicity bioassay, and 1% for repellency tests; Sunspray® Ultra-Fine Spray Oil (Safer Incorporated, Newton, MA), 0.5, 1.0 and 2% for toxicity bioassay, and 1% for repellency tests; Garlic Barrier (Garlic Res. Labs, Los Angeles, CA), 1:10 ratio (v/v) for repellency tests; a sucrose ester extract of *Nicotiana gossei* (Phytochemical Res. Lab., USDA, ARS, Athens, GA), 0.05, 0.10 and 0.2% for toxicity bioassay, and 0.10% for repellency tests.

Materials used to compare with biorational insecticides were a pyrethroid, bifenthrin 10 WP (Brigade®, FMC Corp., Middleport, NY), 0.03, 0.06 and 0.12 g ai/liter water; and purified tap water (7 ppm dissolved solids). Extract of *N. gossei* was prepared as recommended (L. Smith, Phytochemistry Res. Lab., USDA-ARS, Athens, GA, pers. comm.). Two grams of extract was shaken with 18 ml of acetone and gradually stirred into water. We did not use acetone in water controls based on previous tests showing that 0.08% acetone in water did not increase mortality over a water control.

B. argentifolii adults used in this study were maintained in greenhouse and laboratory culture on potted tomato plants. Plants were grown singly in 12 cm or 15 cm pots using Metro-Mix® 300 growing medium (Grace Sierra, Horticultural Products Company, Milpitas, CA) and fertilized once per week using 12-8-6 NPK slow release fertilizer (Diamond R Fertilizer Co., Winter Garden, FL).

Toxicity bioassay. For toxicity bioassays, we used 0.9 liter clear plastic cup-cages with a 9 cm screened opening on top and a corked 1.2 cm hole on the side wall through which whiteflies were introduced. Treated tomato leaves (trifoliate) were placed individually in glass vials (20 ml) filled with purified water. The vials were secured on the bottom of the cage with double-sided adhesive tape. Leaves were dipped in the diluted insecticides and placed in the vials, some with the leaves still wet and some with the leaves air-dried for 2 h. We introduced 15 unsexed whitefly adults (emerged within 48 h) into each cage. The adults were allowed to feed, mate and lay eggs for 24 h at 22.3 °C (±3 ° C), 70% (±5%) r.h. with light-dark regime of L14:D10. Numbers of live and dead adults were recorded. The experiment had eight replicates and was repeated three times.

Greenhouse dual-choice repellency test. This test allowed *B. argentifolii* adults to select either insecticide-treated or untreated tomato plants. Whitefly-free tomato plants were placed on a greenhouse bench surrounded by about 200 heavily infested tomato plants. The youngest terminal leaves and all old leaves of the test plants were removed leaving only the top four fully expanded leaves of each plant to simulate a field condition in which whitefly-free seedlings had just been transplanted. Leaves were sprayed to runoff with the insecticides at recommended field rates. After the leaves had air-dried, the plants were placed randomly on the bench. The surrounding tomato plants were shaken to encourage adult movement to the treated plants. Treated leaves from each plant were gently turned over for visual inspection of whitefly adults at

2 and 4 h and 1, 2, 5 and 7 days. After each inspection, all treated plants were randomly rearranged and treated and untreated plants were shaken so that whiteflies would redistribute. After examining the adults on the 7th day, leaves were removed from the plants and numbers of eggs on four 1 cm^2 areas beside the main vein of the middle leaflet of the trifoliate were recorded using a dissecting microscope. This number was converted to eggs per leaf based on the mean leaf area (31 cm^2) of 20 similar leaves, and eggs per adult was calculated. The experiment had 16 replicates and was repeated two times.

Leaf-wheel multiple-choice repellency test. A rotary leaf-wheel was designed to offer whitefly adults six choices of treated leaves upon which to land, feed and lay eggs. The leafwheel was about 8 cm in diameter and made of six 20 ml glass vials (opening pointed up) taped around a central vial with its opening pointed downward. A wooden dowel (30 cm long and 1.0 cm in diameter) was inserted into the central vial allowing the wheel to rotate. The six peripheral vials held purified water and the treated leaves (Fig. 1). Tomato leaves of uniform age were treated with insecticides at the same rates as in the dual repellency test. One air-dried leaf from each of the six treatments was randomly placed in a vial of the leaf-wheel. The leaf-wheel was held in place like a plant in a plastic pot filled with potting media. In greenhouse tests, leaf-wheels were placed among heavily infested tomato plants. In laboratory tests, leafwheels were caged in a carton box, the top of which was covered by transparent plastic film. A fluorescent light was placed 30 cm above the box to attract whiteflies upward towards the leaves and approximately 80 whitefly adults were released. The number of adults on the leaves were recorded at 30 min, 1, 2, and 4 h and 1, 2, 5, and 7 days. After each recording, the leaf-wheels were rotated and treated leaves were shaken to force whiteflies to relocate. At the end of the test, numbers of eggs on two 1 cm^2 leaf area of each leaf was recorded under a stereo microscope. The number was converted to eggs per leaf and eggs per adult based on the average leaf area (28 cm^2 of 20 leaves. Each experiment had seven replicates and was repeated three times.

Data analysis. Data were subjected to analysis of variance (ANOVA). For repellancey tests where residue time was a variable, a separate analysis for each time was performed upon determination of a time × insecticide interaction. Sources of variation for this analysis were: insecticide, replicate, repetition, and insecticide × replicate. The error term used to test insecticide effects was the mean square for the insecticide replicate interaction (Freund *et al.*, 1986). Degrees of freedom are given in the respective tables. Means were separated using the least significant difference (LSD) test following a significant F-test (SAS Institute, 1988). Correlation between numbers of adults and numbers of eggs per leaf for each treatment in repellency tests was analyzed using a correlation procedure (PROC CORR, SAS Institute, 1988).

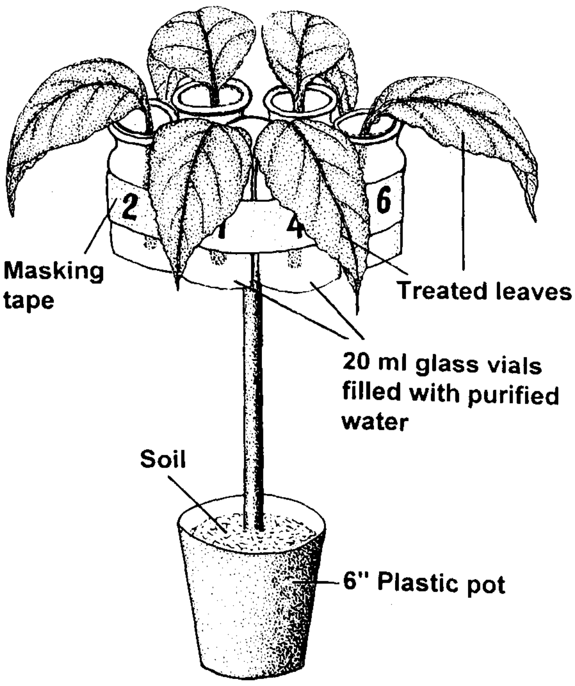

Fig. 1. Multiple-choice leaf-wheel used for repellency tests of insecticides to *Bemisia argentifolii* Bellows & Perring on tomato leaves.

Results and discussion

Toxicity bioassay. Among the treatments assayed while the sprays tested were still wet, the highest mortality was obtained with Sunspray at 2% and 1% rates. Lesser mortality was noted in descending order, with Sunspray at 0.5%, all rates of bifenthrin, M-Pede, and *N. gossei* extract when compared to water (Table 1). Results were similar on dry leaves except that M-Pede, *N. gossei* extract, and water were not significantly different from each other.

Table 1. Toxicity of insecticides to *B. argentifolii* adults on tomato leaves 24 h after confinement on treated leaves

Treatment	Rate	Mortality (%)±s.d.[a]	
		Residue wet	Residue dried
Bifenthrin	0.03 g ai/*l*	48.9±14.3 D b	54.2±16.6 D a
(Brigade 10WP)	0.06 g ai/*l*	64.4±20.2 C a	57.2±20.2 D a
	0.12 g ai/*l*	65.8±17.6 C a	68.1±19.3 C a
Sunspray Oil	0.5%	72.8±16.8 C b	82.2±13.7 B a
	1.0%	82.8±19.4 B b	91.7±10.3 A a
	2.0%	91.9±9.8 A a	95.8±9.0 A a
M-Pede	0.5%	22.8±12.7 F a	6.7±8.8 E b
	1.0%	33.9±11.9 E a	10.6±10.6 E b
	2.0%	30.8±13.8 EF a	11.9±11.1 E b
Gossei extract	0.05%	21.3±10.2 F a	20.3±9.9 E a
	0.10%	25.2±15.2 F a	21.1±12.3 E a
	0.20%	26.7±14.5 F a	26.3±11.2 E a
Water	–	9.6±11.7 G a	8.8±7.9 E a

[a] The mortalities (%) followed by the same upper case letters in the same column, or the same lower case letters in same row are not significantly different based on the arcsine transformed data [arsin $\sqrt{(\%/100)}$] ($P>0.05$, LSD; df = 14, 28; SAS Institute, 1988).

Table 2. Numbers of *B. argentifolii* adults on treated tomato plants in dual-choice tests in the greenhouse

Treatment	Rates	Mean number of adults per leaf ± s.d.[a]					
		2 h	4 h	1 day	2 days	5 days	7 days
Bifenthrin	0.06g ai/l	1.2±1.7 c	2.0±2.5 c	2.4±3.5 c	7.5±6.7 c	5.8±6.5c	13.0±9.6b
Sunspray Oil	1.0%	0.1±0.4 c	0.4±0.7 c	0.9±1.4 c	2.9±2.7 c	10.7±7.8c	22.0±14.Ob
M-Pede	1.0%	20.2±20.8 b	18.2±9.0 b	32.2±32.4 b	59.9±48.8 b	92.2±114.4ab	106.9±80.6a
Gossei extract	0.1%	37.9±43.8 b	18.6±13.2 b	28.5±20.7 b	69.7±53.3 a	79.0±69.3bc	103.1±97.8a
Garlic Barrier	1:10	39.4±27.8 a	35.9±23.1 a	59.0±38.9 a	86.8±47.8 a	87.0±40.7ab	113.6±69.0a
Water		60.3±34.7 a	51.8±30.9 a	76.2±34.7 a	122.4±64.3 a	158.3±81.6a	161.7±72.4a

[a] Mean number at the same column followed by the same letters are not significantly different based on square-root transformed data [$\sqrt{(x)}$] ($P>0.05$, LSD; df = 5, 75; SAS Institute, 1988).

When results from wet and dry insecticidal residues were compared, mortality resulting from Sunspray oil and bifenthrin on the leaves with dry residues was similar to or greater than mortality on the leaves with wet residues. Only M-Pede gave higher whitefly mortality on wet leaves, which confirmed conclusions from field tests showing soaps and detergents to be most active when wet (Butler *et al.*, 1993).

The two highest rates of Sunspray oil gave better control than any other treatment, including bifenthrin. However, phytotoxicity was observed in very tender leaves treated with Sunspray oil at 2%. No phytotoxicity was observed with any other treatments. The strong response to Sunspray oil from both whiteflies and tender leaves may be indicative of the high degree of contact obtained by dipping compared to a normal field spray.

There are numerous methods to assess the mortality of arthropods to insecticides under laboratory conditions. Rosenheim & Hoy (1986) and Spollen & Hoy (1993) stated that where exposure to insecticides in the field is primarily by contact with residues after appli-

Table 3. Density of *B. argentifolii* eggs, egg to adult ratio and correlation between the numbers of adults and eggs per tomato leaf in dual-choice tests in the greenhouse

Treatment	Rate	Eggs/cm^2 ± s.d.[a]	Eggs/Adult s.d.[a]	Correlation coefficient (R)[b]
Bifenthrin	0.06g ai/l	11.1±14.1 c	16.3±6.1 a	0.42
Sunspray Oil	1.0%	12.2±13.9 c	7.8±4.5 c	0.34 NS
M-Pede	1.0%	78.6±76.2 b	15.7±5.8 a	0.90
Gossei extract	0.1%	65.2±90.2 b	12.2±4.2 b	0.94
Garlic Barrier	1:10	53.4±33.9 b	12.5±3.6 b	0.83
Water		100.7±72.2 a	14.7±3.6 ab	0.86

[a] Mean numbers of eggs followed by the same letter are not significantly different ($P>0.05$, LSD, SAS Institute, 1988).
[b] 'NS' is not significant ($P>0.05$).

Table 4. Numbers of *B. argentifolii* adults on treated tomato leaves in leaf-wheel multiple-choice tests in the greenhouse

		Mean number of adults per leaf ±s.d.					
Treatment	Rates	2 h	4 h	1 day	2 days	5 days	7 days
Bifenthrin	0.06g ai/l	0.6±1.3 c	0.4±0.5 c	1.2±2.2 c	0.6±1.2 c	1.3±1.3 c	2.9±2.3 c
Sunspray Oil	1.0%	0.3±0.5 c	0.1±0.3 c	0.8±0.8 c	1.2±1.3 c	0.6±0.7 c	3.5±5.7 c
M-Pede	1.0%	4.4±3.7 b	6.1±3.0 b	16.1±8.2 c	14.7±7.1 b	20.2±16.4 ab	30.6±27.8 b
Gossei extract	0.1%	5.1±2.8 b	6.6±2.3 b	21.0±11.8 bc	24.0±13.5 a	18.7±13.5 b	27.6±23.4 b
Garlic Barrier	1:10	9.0±4.2 a	12.6±6.3 a	49.4±41.9 a	31.6±28.8 a	25.0±13.8 a	35.0±28.5 a
Water	–	7.7±3.5 a	11.6±4.7 a	44.9±26.5 a	32.7±18.3 a	30.8±15.6 a	33.8±37.2 a

[a] Mean number at the same column followed by the same letters are not significantly different based on square-root transformed data [$\sqrt{(x)}$] ($P>0.05$, LSD; df = 5,30; SAS Institute, 1988).

Table 5. Density of *B. argentifolii* eggs, egg to adult ratio and correlation between the number of adults and eggs per tomato leaf in leaf-wheel multiple-choice tests in the greenhouse

Treatment	Rate	Eggs/cm^2 ±SD[b]	Eggs/adult ±SD[a]	Correlation coefficient (R)[b]
Bifenthrin	0.06g ai/l	2.1±2.4 b	7.6±6.9 bc	0.50
Sunspray Oil	1.0%	0.7±1.6 b	3.5±6.0 c	0.23 NS
M-Pede	1.0%	41.2±40.9 a	11.6±6.3 a	0.84
Gossei extract	0.1%	46.4±40.5 a	12.7±4.7 a	0.87
Garlic Barrier	1:10	68.9±91.4 a	10.8±7.2 ab	0.86
Water	–	53.4±36.9 a	10.0±4.1 ab	0.85

[a] Mean numbers of eggs followed by the same letter are not significantly different ($P>0.05$, LSD, SAS Institute, 1988).
[b] 'NS' is not significant ($P>0.05$).

Table 6. Numbers of *B. argentifolii* adults and egg density on treated tomato leaves in leaf-wheel multiple-choice tests in the laboratory

		Mean number of adults per leaf ±s.d.[a]					
Treatment	Rates	30 min	1 h	2 h	4 h	24 h	Eggs/cm^2
Bifenthrin	0.06g ai/l	1.6±1.5 b	0.4±0.7 b	0.4±0.6 c	0.4±0.7 d	0.1±0.4 c	0.5±0.5 b
Sunspray Oil	1.0%	0.9±1.1 b	0.4±0.7 b	0.6±0.9 c	0.8±0.5 d	0.4±0.7 c	0.3±0.5 b
M-Pede	1.0%	9.8±4.3 a	12.4±7.5 b	9.4±4.4 b	7.9±3.4 c	8.0±2.4 b	7.6±1.7 a
Gossei extract	0.1%	9.8±5.7 a	13.5±4.7 b	13.0±5.9 b	12.1±3.7 b	13.5±4.7 a	7.3±2.7 a
Garlic Barrier	1:10	12.1±6.7 a	14.4±6.6 ab	18.5±4.1 a	15.3±3.9 b	15.4±5.1 a	10.5±6.3 a
Water	–	13.6±6.5 a	19.6±8.0 a	22.4±8.6 a	21.7±7.3 a	16.4±4.2 a	10.3±2.4 a

[a] Mean number at the same column followed by the same letters are not significantly different based on square-root transformed data [$\sqrt{(x)}$] ($P>0.05$, LSD; df = 5,30; SAS Institute, 1988).

cation, the confinement of arthropods to treated leaves may be the best method to predict field mortality. We found the toxicity bioassay useful for assessing relative toxicity to whitefly adults of the materials tested, all of which had widely different modes of action.

Greenhouse dual-choice repellency test. When given choices of landing and feeding sites, *B. argentifolii* adults avoided tomato plants treated with bifenthrin and Sunspray oil. Numbers of adults on leaves treated with these materials were significantly reduced for up to seven days following treatment compared with other treatments (Table 2). Significant repellency was obtained with *N. gossei* extract up to five days. There was no significant reduction of adults on plants sprayed with Garlic Barrier at any time interval.

Repellency was further reflected in significantly reduced oviposition of whitefly compared with the water-treated foliage (Table 3). Fewest eggs were found on bifenthrin and Sunspray oil treatments, followed by Garlic Barrier, extract of *N. gossei*, M-Pede, and the water control. Numbers of eggs and adults per leaf were well correlated except for Sunspray oil. Correlation coefficients (R) ranged from 0.83–0.94, except for bifenthrin and Sunspray oil. Low numbers of whiteflies on leaves treated with bifenthrin and Sunspray oil was probably responsible for the low correlation observed. Also, we found that the majority of eggs in the treatments of Sunspray were newly laid (greenish) and first instar crawlers were absent, compared with many purple and black eggs and even nymphs observed in the other treatments. Younger eggs indicated that oviposition had been delayed on oil-sprayed leaves compared to other treatments.

Leaf-wheel multiple-choice repellency test. This method gave results similar to dual-choice tests when tests were carried out at the same location in the greenhouse (Table 4). Bifenthrin and Sunspray oil had the least number of whiteflies for up to 7 days, whereas M-Pede gave repellency for up to 2 days, and *N. gossei* for up to 1 day, whereas Garlic Barrier showed no repellent effect on whiteflies. Egg density followed the trend of adult abundance (Table 5). Leaves treated with bifenthrin and Sunspray oil had the fewest eggs, while numbers of eggs in other treatments were not significantly different. The number of whitefly eggs on the treated leaves were well correlated with the numbers of adults, except again for the bifenthrin and Sunspray oil treatments.

Whitefly adults displayed the same pattern of preferences as in the laboratory as in other repellency tests (Table 6). Significantly fewer whiteflies were found on the treatments of bifenthrin and Sunspray oil through 24 h than on all other treatments. As a result, fewer eggs were also deposited on bifenthrin and Sunspray oil treated leaves. Numbers of adults on leaves treated with M-Pede and *N. gossei* extract were not significantly different from the water treatment at 30 min, but were different at 1, 2 and 4 h. Numbers of whitefly adults on leaves treated with Garlic Barrier were not different from water treatments except at 4 h. Oviposition was not affected by M-Pede, *N. gossei* extract and Garlic Barrier.

In summary, bifenthrin and Sunspray oil had the fewest whitefly adults and eggs in all repellency tests, followed by M-Pede and *N. gossei* extract. Garlic Barrier appeared not to repel whiteflies under either greenhouse or laboratory conditions.

Larew & Locke (1990) observed adults that landed on the Sunspray 6E plus oil-treated chrysanthemum leaves left the leaves quickly. They suspected that repellency is tactile rather than olfactory in nature. We found many dead whitefly adults on both upper and lower leaves treated with Sunspray oil, indicating choice is made after the leaf surface is contacted.

Early research by Kring (1972) showed that repelling insect vectors from the host plants will reduce the spread and damage of plant virus. Stansly & Vavrina (1993) also found that application of mineral oil (Stylet oil) and bifenthrin significantly lowered TMoV infestation. They believed that suppression of TMoV was probably due to repellency of whitefly adults.

Mineral oils, insecticidal soaps and surfactants have shown promises in control of *B. argentifolii* on cotton and vegetable crops (Butler *et al.*, 1989, Stansly & Schuster,,1992, Stansly & Vavrina, 1993). The sucrose ester extract of *N. gossei* has been found effective against early instars of greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood) (Buta *et al.*, 1993), and our preliminary study also showed it is effective to the nymphs of *B. argentifolii*. Utilization of the toxic and repellent properties of these insecticides for whitefly suppression might be compatible with biological control agents and should be considered as a means of reducing selection for resistance to conventional insecticides.

We found that dual-choice and leaf-wheel repellency tests provided similar results. However, the leaf wheel proved convenient to quickly evaluate the repellent effects of several insecticides to whiteflies within a confined space. The ability to reduce location effects by rotating the leaf-wheel as desired was probably the feature responsible for the consistent data observed.

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