Toxicity of Biorational Insecticides to *Bemisia argentifolii* (Homoptera: Aleyrodidae) on Tomato Leaves

TONG-XIAN LIU AND PHILIP A. STANSLY

Southwest Florida Research and Education Center, University of Florida, Institute of Food & Agricultural Sciences, P.O. Drawer 5127, Immokalee, FL 33934

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ABSTRACT Bioassays were conducted to test the toxicity of insecticide leaf residue to adults, and contact toxicity to eggs and nymphs of silverleaf whitefly, *Bemisia argentifolii* Bellows & Perring. Four insecticides were tested: insecticidal soap (Sunspray oil), mineral oil (M-Pede), extract of *Nicotiana gossei* Domin (a detergent-like acylsugar), and bifenthrin (a pyrethroid). Purified tap water was used as a control. Bioassays of adults were conducted by dipping whitefly-free tomato leaves into serial dilutions of the insecticides, air-drying for prescribed periods, and exposing adults to leaves in large cup cages for 24 h. Residues of Sunspray oil caused greatest mortality to adults for up to 5 d after treatment, and the LC_{50} of 24 h residue to adults was 0.029%. Two-hour leaf residues of bifenthrin at the field rate (0.06 g [AI]/liter) or higher (0.12–0.24 g [AI]/liter) gave >68% mortality of adults, but efficacy was reduced with residues of 24 h (LC_{50} = 0.034 g [AI]/liter) or older. Dried residues of insecticidal soap and *N. gossei* extract were not effective on adults. Contact bioassays were also conducted on tomato leaves infested with uniform cohorts of eggs or nymphs. Response patterns to insecticides were similar among developmental stages of the whitefly, with young nymphs being the most susceptible, followed by older nymphs and eggs. LC_{50}s of Sunspray oil to young and old nymphs were 0.032 and 0.088%, and of bifenthrin were 0.001 and 0.106 g (AI)/liter, respectively. Insecticidal soap and *N. gossei* extract were all effective on young nymphs, even at very low rates (LC_{50}, 0.15% and 0.08 g [AI]/liter, respectively), but had no significant effect on eggs. *N. gossei* extract was effective on older nymphs at low rates (LC_{50} = 0.14 g [AI]/liter), whereas insecticidal soap was not (LC_{50} = 0.51%).

KEY WORDS sweetpotato whitefly, silverleaf whitefly, insecticide

SILVERLEAF WHITEFLY,[1] *Bemisia argentifolii* Perring & Bellows, formerly known as sweetpotato whitefly, *B. tabaci* (Gennadius) strain B, is a key insect pest of vegetables, field crops, and ornamental crops in the southern United States. Damage results from plant debilitation, sooty mold growth, and, in tomato, irregular ripening and transmission of tomato mottle geminivirus (TMoV) (Stansly & Schuster 1990). Crop damage was estimated at >500 million dollars in the United States in 1991 (Perring et al. 1993), and 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. 1995). Intensive use of broad-spectrum insecticides incurs economic, health, and environmental costs and may cause pest resurgence and secondary pest outbreaks through decimation of natural enemies. Furthermore, documented loss of susceptibility by *B. tabaci* to some of the most commonly used insecticides suggests that their efficacy will be of limited duration (Prabhaker et al. 1985, 1992; Stansly & Schuster 1992). Therefore, it is necessary to develop insecticides with alternative modes of action that do not obviate the activity of natural enemies.

Mineral oils, detergents, and insecticidal soaps have demonstrated efficacy against *B. tabaci* on cotton and several vegetable crops under field conditions (Butler et al. 1988, 1989, 1993; Stansly & Vavrina 1993). These biorationals were used to control greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood), on vegetable and ornamental crops under greenhouse conditions (Larew & Locke 1990, Buta et al. 1993). However, their activity on particular whitefly stages has not been reported in detail. The aim of this study was to evaluate the residual toxicity of potential biorational insecticides on adults and the contact toxicity on eggs and nymphs of *B. argentifolii* on tomato plants under laboratory conditions.

Materials and Methods

Insecticides. Three biorational insecticides were used: M-Pede, an insecticidal soap (49% potassium salt of a naturally derived fatty acid) (Mycogen, San Diego, CA), Sunspray Ultra-Fine (min-

[1] The name has not been approved for use by the ESA Committee on Common Names of Insects.

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eral) Spray Oil (Safer, Newton, MA), and a detergent-like acylsugar extracted from *Nicotiana gossei* Domin obtained from the Phytochemistry Research Laboratory, USDA–ARS, Athens, GA, and prepared as recommended (L. Smith, personal communication) (Liu & Stansly 1994). A pyrethroid, bifenthrin (Brigade 10 WP [wettable powder], FMC, Middleport, NY), was tested for comparison and purified tap water (7 ppm dissolved solids) was used as a control. The concentrations of each insecticide for each whitefly stage varied based on our preliminary tests: M-Pede, 0.2, 0.5, 1.0, 2.0, 3.0, 4.0, 6.0, and 8.0% vol:vol; Sunspray Oil, 0.025, 0.05, 0.1, 0.5, 1.0, 2.0, and 3.0% vol:vol; *N. gossei* extract, 0.125, 0.25, 0.5, 1.0, 2.0, 4.0, 6.0, 8.0, and 10.0 g (AI)/liter; and bifenthrin, 0.015, 0.03, 0.06, 0.12, 0.24, and 0.48 g (AI)/liter (see related tables). The extremely high and low rates were applied to have high and low whitefly mortalities for the probit analyses of LC_{50} and LC_{90}.

Whiteflies and Plants. *B. argentifolii* used in this study was obtained from D. Schuster in Bradenton, FL, in 1990, and was identified as *B. tabaci* 'Biotype B' in 1992 (T. M. Perring, University of California at Riverside, personal communication) and as *B. argentifolii* in 1994 (A. C. Bartlett, USDA–ARS, Phoenix, AZ, personal communication). The colony was maintained in established greenhouse culture on potted tomato plants, *Lycopersicum esculentum* Miller, 'Lanai' (one in each 15-cm pot), grown in Metro-Mix 300 growing medium (Grace Sierra, Horticultural Products, Milpitas, CA). Plants were fertilized with a slow-release fertilizer (N:P:K, 12:8:6) (Diamond R Fertilizer, Winter Garden, FL).

Adults. Tomato leaves bearing whitefly pupae were collected 3 d before the test and placed in a wooden framed cage (30 by 30 by 30 cm) with sides covered in 60-mesh nylon screen and the top covered with clear vinyl film. For the bioassay, newly emerged whitefly adults were collected using an aspirator and were placed into 0.9-liter, clear, plastic cup cages with a 9-cm screened opening on top and a corked access hole (1.2 cm in diameter) on the side.

Immature Stages. Whitefly-free tomato plants were placed in the whitefly colony and infested with adults by agitating adjacent plants. After an oviposition period of 24 h, the newly infested plants were removed from the colony and cleaned of adults using a hand-held vacuum cleaner (AC Insect Vac, BioQuip, Gardena, CA). The egg-bearing leaves were incubated in whitefly-free cages at 25 ± 2°C, 75% RH, and a photoperiod of 14:10 (L:D) h until the appropriate nymphal stages were ready for treatments. Three whitefly developmental stages were obtained and used in the tests: eggs (24 h old), young nymphs (7 d old, most were first instars), and old nymphs (14 d old, most were third instars).

Bioassays. Tomato leaves (trifoliates) were treated by dipping for 5 s in the appropriate solutions, then air-dried for 2 h, and placed individually into glass vials (petiole down) filled with 20 ml of water. A vial was secured in the center of a cup cage with double-stick cellophane tape. For residue toxicity bioassays of adults, 15 unsexed individuals were introduced into the cup-cage following a 1, 2, or 5 d waiting period. Each treatment had eight cup cages (one cage as a replicate) with a total of 360 whiteflies. The experiment was repeated three times. Live and dead adults were recorded after 24 h under a stereo microscope. Adults were considered dead if no movement was detected when touched with a needle.

For bioassay of young nymphs, the treated leaf was placed in the vial filled with water inside the cage for 4 d, and later examined using a dissecting microscope. An average of 54 (SD = 14) young nymphs per leaf were examined. Nymphs which had dried or detached from the leaf surface were considered dead. For bioassays of old nymphs (third instars or older), treated leaves were caged for 10–14 d to allow surviving nymphs to pupate before scoring for dead and live nymphs. Number of old nymphs on each leaf was averaged 67 (SD = 33). Each treatment had eight leaves, and the experiment was repeated three times.

For bioassays of whitefly eggs, treated egg-bearing leaves were incubated individually in vials placed in cages and incubated for 7 d. Number of eggs on each leaf was averaged 94 (SD = 63). The experiment had eight replicates and was repeated three times. An egg was considered to have hatched when microscopic examination revealed that the crawler had successfully eclosed and separated itself from the chorion.

All experiments were conducted in a laboratory, and all treated leaves were then kept in an insectary at 25 ± 2°C, 70 ± 5% RH, and illuminated with fluorescent lights set for a photoperiod of 14:10 (L:D) h.

Data Analysis. Mortalities (percentages) of adults and nymphs were transformed to the arcsine square root [arcsine (percent mortality/100)$^{1/2}$] before analysis to stabilize error variance (Steel & Torrie 1960, Gomez & Gomez 1984), and mean mortalities were analyzed using analysis of variance (ANOVA), and were separated using the least significant difference (LSD) test following a significant F test. Although all tests of significance were based on the transformed data, we report the untransformed percent mortality (percent mean ± SD). Regression analysis (PROC REG procedure) was used for toxicity test data for eggs, and slopes of two insecticides were compared using PROC GLM procedure with two dummy variables. LC_{50} and LC_{90} were computed using a probit procedure (PROC PROBIT LOG10, SAS Institute 1988).

Results and Discussion

Adults. Residues of Sunspray oil at concentrations of 0.5, 1.0, and 2.0% proved to be the most

Table 1. Residual toxicity of insecticides to *B. argentifolii* adults at various intervals after exposure for 24 h on tomato leaves dipped in insecticide solutions

Treatment	Rate	% mortality after treatments ± SD			
		2 h	1 d	2 d	5 d
Bifenthrin	0.03	53.3 ± 19.1d	44.4 ± 15.9bc	38.9 ± 20.9bc	43.9 ± 12.5cd
(g [AI]/liter)	0.06	68.9 ± 12.5c	52.2 ± 14.4bc	49.4 ± 18.3bc	49.4 ± 10.8cd
	0.12	86.7 ± 9.4b	63.3 ± 12.9b	60.0 ± 15.8bc	61.7 ± 7.6bc
Sunspray oil	0.5%	97.8 ± 4.3a	87.2 ± 12.2a	81.7 ± 20.5a	84.4 ± 13.4ab
(vol:vol)	1.0%	98.3 ± 5.8a	87.8 ± 11.3a	83.3 ± 13.8a	77.8 ± 21.5ab
	2.0%	99.4 ± 1.9a	94.4 ± 6.2a	92.8 ± 8.3a	85.0 ± 15.3a
M-Pede (vol:vol)	0.5%	6.7 ± 7.5g	8.3 ± 8.1f	7.2 ± 10.4d	8.9 ± 5.2e
	1.0%	10.0 ± 17.2g	12.8 ± 14.3ef	10.0 ± 9.6d	9.4 ± 8.7ef
	2.0%	10.6 ± 9.2g	14.4 ± 10.9ef	12.8 ± 12.2d	6.1 ± 9.2ef
N. gossei extract	0.5	20.0 ± 11.7f	9.4 ± 7.2ef	7.8 ± 8.0d	8.3 ± 9.9ef
(g [AI]/liter)	1.0	36.7 ± 16.2e	17.8 ± 8.7de	19.4 ± 10.4cd	14.4 ± 8.9e
	2.0	52.2 ± 20.3d	29.4 ± 13.5cd	34.4 ± 13.9bc	26.7 ± 11.4d
Water	—	8.5 ± 10.8g	3.1 ± 5.0f	4.3 ± 7.1d	7.0 ± 6.8f

Mean mortalities (%) followed by the same lowercase letters in the same column are not significantly different, based on analysis of transformed data ($P > 0.05$, LSD, SAS Institute 1988).

effective treatments against whitefly adults for up to 5 d after treatment (Table 1). Sunspray oil was effective against adults giving LC_{50} and LC_{90} values of 0.29 and 1.20%, respectively (Table 2). However, the chi-square value was greater than tabular value (12.6 at df = 6, $P = 0.05$) indicating that the data did not fit the probit model.

Adult response to Sunspray oil departed most from the model between the concentrations of 0.25 and 0.5% which caused 23.3 and 87.2% mortality, respectively. We found large number of adults contacting the residue were trapped and died. Butler et al. (1989) made a similar observations. Possibly, there is a threshold thickness of the oil film, below which whiteflies are not trapped. We found dead adults on both upper and lower leaf surfaces, suggesting that death occurred after contact with oil residues. Two-hour leaf residues of bifenthrin caused 86.7% mortality at the highest rate (0.12 g [AI]/liter), but as time increased, effectiveness decreased slightly. Mortality at lower rates of bifenthrin (0.03 and 0.06 g [AI]/liter) from leaf residues older than 24 h caused only 40–60% mortality. Toxicity bioassays of bifenthrin gave similar results (LC_{50} = 0.034 g [AI]/liter). Dry residues of M-Pede had little or no effect on adults compared with the water treatment. Previous studies (Butler et al. 1993, Liu & Stansly 1994) showed that soap and other surfactants function primarily when wet. All rates at 2 h, two higher rates at 1 d and the highest rate at 2 and 5 d of *N. gossei* extract still gave significantly higher mortality than the water controls. However, goodness-of-fit test indicated that the data set did not fit the probit model ($\chi^2 > 12.6$). The lack of fit was resulted from the poor rate response even at high concentrations (29.4% mortality at 4.0 g [AI]/liter).

Eggs. The egg was the least susceptible stage to all test insecticides (Table 2). However, Sunspray oil gave 63.6% egg mortality at recommended field rate of 1.0%, and 28.9% at 0.1%. We found that many first-instar crawlers died while attempting to eclose from oil-sprayed leaves, indicating that activity was not primarily upon the egg itself. Bifenthrin had slight toxicity against eggs, causing 30.5% mortality at recommended field rate of 0.06 g (AI)/liter (equivalent to 0.05 lb[AI]/100 gal/acre). M-Pede was not effective to eggs except for the highest rate (3.0%), which caused 25.3% mortality. Regression analysis indicated the relationship between the concentrations ($\log_{10}$[c]) and percent mortalities in M-Pede were not significant ($P > 0.05$). Slopes among the three insecticides were not significantly different (F values: 0.03–0.64; $P > 0.05$).

Nymphs. All test insecticides were effective on young nymphs (Table 3). Bifenthrin was extremely toxic to young nymphs with LC_{50}s = 0.001 g (AI)/liter, but less toxic to old nymphs (LC_{50}s = 0.106 g [AI]/liter). Sunspray oil gave excellent control of both young and old nymphs with LC_{50}s < 0.1%. M-Pede was effective against young nymphs (LC_{50}

Table 2. Toxicity of insecticides to *B. argentifolii* eggs on tomato leaves in the laboratory (concentrations [c] were transformed to log10[c])

Insecticide	Intercept ± SEM	Slope ± SEM	R^2	df	P
Bifenthrin (g [AI]/liter)	47.3 ± 5.3	19.2 ± 4.1	0.88	118	0.018
Sunspray oil (%, vol:vol)	55.0 ± 2.6	26.6 ± 4.8	0.91	118	0.012
M-Pede (%, vol:vol)	14.2 ± 2.3	10.1 ± 5.5	0.53	118	0.164

Slopes of insecticides are not significantly different with F values at 0.25–0.73; df = 1, 236; $P > 0.05$ (SAS Institute 1988).

Table 3. Summary of toxicity of insecticides to *B. argentifolii* on tomato leaves in laboratory bioassays

Insecticide	*n*	Slope ± SEM	LC_{50}	95% FL	LC_{90}	95% FL	χ^2
			Adults				
Bifenthrin[a]	2,160	0.90 ± 0.11	0.034	0.023–0.045	0.906	0.524–2.123	6.8
Sunspray oil	2,160	2.12 ± 0.46	0.290	0.130–0.620	1.180	0.570–1.440	18.9[b]
M-Pede[c]	NA	NA	NA	NA	NA	NA	NA
N. gossei extract[d]	2,160	1.53 ± 0.26	5.878	3.727–12.47	40.60	16.97–56.30	14.0[b]
			Young nymphs				
Bifenthrin	5,694	0.87 ± 0.09	0.001	0.001–0.002	0.032	0.023–0.059	0.9
Sunspray oil	4,992	1.01 ± 0.10	0.032	0.018–0.050	0.594	0.348–1.293	10.4
M-Pede	4,992	1.71 ± 0.15	0.149	0.110–0.197	0.836	0.577–1.400	9.4
N. gossei extract	4,581	1.35 ± 0.09	0.076	0.061–0.091	0.678	0.526–0.925	6.2
			Old nymphs				
Bifenthrin	5,980	1.23 ± 0.11	0.106	0.087–0.132	1.171	0.759–2.146	2.0
Sunspray oil	4,112	1.35 ± 0.16	0.088	0.051–0.139	0.783	0.454–1.841	10.5
M-Pede	3,607	2.22 ± 0.18	0.507	0.433–0.584	1.918	1.589–2.436	0.7
N. gossei extract	3,793	1.66 ± 0.17	0.142	0.098–0.199	0.841	0.541–1.622	8.3

NA, not applicable.
[a] Units: bifenthrin and *N. gossei* extract are in g (AI)/liter, and Sunspray oil and M-Pede are in percent concentration (vol:vol).
[b] $\chi^2 > 12.6$ (tabular χ^2 with df = 6, $P = 0.05$).
[c] Mortalities were too low to compute LC_{50} and LC_{90} values.
[d] Concentration of 0.59% would cause severe phytotoxicity on tomato leaves.

= 0.15%) but only at high rates to old nymphs (LC_{50} = 0.51%). *N. gossei* extract was effective against both young and old nymphs (LC_{50}s ≈0.1 g [AI]/liter).

All test insecticides at recommended field rates gave excellent control to young nymphs with mortalities >90% (Table 4). Bifenthrin, however, gave the lowest mortality (38.1%) to old nymphs, followed by M-Pede (72.1%). Sunspray oil and *N. gossei* extract gave best control on old nymphs.

We observed that the nymphs treated with M-Pede and *N. gossei* extracts dried quickly and detached from the leaf surface, with dorsal and ventral surfaces of the body compressed together. Nymphs killed by bifenthrin also dried eventually though not as quickly. These nymphs did not detach from the leaf surface, nor did the dorsal and ventral surfaces of the body compress together. Effectiveness of all four insecticides on old nymphs was similar to young nymphs except for bifenthrin and low rates of M-Pede. Thus our impression was that M-Pede and *N. gossei* extract were killing nymphs by desiccation in contrast to bifenthrin where the nymphs appeared to desiccate subsequent to death.

Table 4. Toxicity of insecticides to *B. argentifolii* nymphs at recommended field rates on tomato leaves in laboratory

Treatment	Rate	% mortality ± SD	
		Young nymphs	Old nymphs
Bifenthrin	0.06 g (AI)/liter	92.1 ± 5.0a	38.1 ± 11.1c
Sunspray oil	1.0%	90.4 ± 8.6a	88.8 ± 5.9a
M-Pede	2.0%	97.0 ± 3.3a	72.1 ± 9.7b
N. gossei extract	1.0 g (AI)/liter	92.0 ± 8.4a	88.7 ± 3.1a
Water		3.0 ± 3.2b	6.4 ± 4.7d

Means followed by the same letter for each insecticide in the same column are not significantly different ($P > 0.05$, LSD, SAS Institute 1988).

The highest rate (3%) of Sunspray oil and the higher rates (>0.2%) of *N. gossei* extract caused obvious phytotoxicity to young tomato leaves producing irregular chlorotic spots, desiccated margins, or total desiccation. Severe phytotoxicity led to dried leaves. No phytotoxicity was noticed on the leaves from any other treatments.

We were able to achieve a uniform, standardized, and repeatable index of contact toxicity of insecticides with a wide range of activities using the leaf dip method. Rosenheim & Hoy (1986) and Spollen & Hoy (1993) have claimed that the leaf dip method yields reliable predictions of the relative field mortality of different insecticides. Our results also indicate the potential usefulness of oils and surfactants for control of *B. argentifolii*. We believe these materials could play an important role in the integrated pest management *B. argentifolii* due to their distinct modes of action to conventional insecticides and their possible selective characteristics. Additional research is needed to compare results from leaf-dip bioassays with bioassays employing spray techniques which achieve different degrees of coverage, and to test the effects of these materials on natural enemies of *B. argentifolii*.

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