# Insecticidal Activity of Natural and Synthetic Sugar Esters Against *Bemisia argentifolii* (Homoptera: Aleyrodidae)

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**ABSTRACT** Insecticidal activities of natural sugar ester isolates of *Nicotiana* spp. and synthetic sugar esters were tested against *Bemisia argentifolii* Bellows & Perring in laboratory bioassays and a tomato field trial on staked tomato. A mixture of the pyrethroid cyfluthrin and methamidophos, as well as the juvenile analog pyriproxyfen, were used for comparison in the field trial. Mortality of adults immobilized on yellow sticky cards and sprayed to run-off (≈100% coverage) with sugar ester isolates of *Nicotiana* spp. (including *N. gossei*) approached 100%. In contrast, mortality of immobilized adults treated in a Potter spray tower (≈70% coverage) with the same concentrations of *N. gossei* was <50%. Sugar ester isolates of *N. gossei, N. amplexicaulis, N. glutinosa, N. langsdorffii, N. trigonophylla,* and *N. palmeri* and a synthetic sucrose ester were more toxic to 2nd-instar nymphs at a rate of 1 g (AI)/liter than were isolates of *N. cavicola, N. simulans, N. pauciflora, N. plumbaginifolia, N. noctiflora,* and *N. otophora.* Whitefly populations on tomato sprayed weekly in the field with a sugar ester isolate of *N. trigonophylla* or 4 synthetic preparations were reduced by 40–98% for immatures and 43–73% for adults compared with untreated plants. Sugar ester isolate and synthetic sugar esters in the field tomato trials compared favorably with commercial insecticides for whitefly control.

**KEY WORDS** Bemisia argentifolii, Bemisia tabaci, *Nicotiana* sugar ester isolates, botanical insecticides, synthetic sugar esters

A GROUP OF natural sucrose and glucose esters from sugar ester isolates of *Nicotiana gossei* Domin and other *Nicotiana* species have been demonstrated to be highly effective against nymphal stages of the greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood), and *Bemisia tabaci* (Gennadius) (*Bemisia argentifolii* Bellows & Perring) (Neal et al. 1987; Buta et al. 1993; Neal et al. 1994; Liu and Stansly 1995a, b, c). These results have aroused interest in sugar ester isolates from additional *Nicotiana* species as well as synthetic sugar esters and also the ability of these materials to reduce populations of *B. argentifolii* when applied in the field with conventional spray equipment. We tested the insecticidal activity of sugar ester isolates from 11 species of *Nicotiana* and a synthetic preparation against adults and immatures of *B. argentifolii* in laboratory bioassays and also demonstrated the ability of natural and synthetic sugar esters to reduce whitefly populations in the field significantly.

## Materials and Methods

***Nicotiana* Plant Cultivation.** Plants were grown in replicated field plots (300 plants each entry) under flue-cured tobacco production conditions at the following 3 sites: University of Georgia Coastal Plains Experimental Station, Tifton, GA; the Crop Research Laboratory, Oxford, NC; and the Pee Dee Research and Education Center, Clemson University, Florence, SC. All species were grown at each site, and extracts from different sites were combined.

**Whiteflies and Host Plants.** *Bemisia argentifolii* were cultured in an air-conditioned greenhouse at the Southwest Florida Research and Education Center (SWFREC), Immokalee FL, on potted tomato, *Lycopersicon esculentum* Miller, 'Florida Lanai'; collard, *Brassica oleracea* L. var. *acephala,* 'Georgia LS'; salvia, *Salvia splendens* L.; eggplant, *Solanum melongena* L, 'Black Beauty'; hibiscus, *Hibiscus rosa-sinensis* L.; and sweet potato plants, *Ipomoea batatas* L. (1 per 15-cm pot) using Metro-Mix 300 growing medium (Grace Sierra, Horticultural Products Company, Milpitas, CA). Plants were watered with 0.4% (wt.:vol.) of Stern's Miracle-Gro (an all-purpose water-soluble plant food with N/P/K: 15:30:15) (Stern's Miracle-Gro Products, Port Washington, NY) once per week.

**Sugar Ester Isolates.** Cuticular extracts were obtained by dipping whole, cut-off plants into isopropyl alcohol (1.5 l/kg of plant material) in the field as previously described by Severson et al. (1994). Plants were allowed to regrow and were

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**Table 1. Constituents and their structures of sugar ester isolates tested**

| Sugar ester sources | Sucrose esters | | Glucose esters | |
|---|---|---|---|---|
| | Acyl groups[a] | Acetyl groups[b] | Acyl groups | Acetyl groups |
| *N. amplexicaulis* | 2, 3 | 1′, 6′ | 2, 3 | 1 |
| *N. cavicola* | 4, 3′ | 6, 4′, 6′ | — | — |
| *N. glutinosa* 24 | 2, 3, 4 | 3′ | — | — |
| *N. glutinosa* 24A | 2, 3, 4 | — | | |
| *N. glutinosa* 24B | 2, 3, 4 | 3′ | | |
| *N. gossei* | 2, 3 | 1′, 6′ | | |
| *N. langsdorffii* | 2, 3, 4 | 3′ | | |
| *N. noctiflora* | Unknown | — | | |
| *N. otophora* | 2, 3, 4 | 6 | | |
| *N. otophora* 38A | 2, 3, 4 | 6 | | |
| *N. otophora* 38B | 2, 3, 4 | 6 | | |
| *N. otophora* 38C | 2, 3, 4 | 6 | — | — |
| *N. palmeri* | 2, 3, 4 | — | 2, 3, 4 | — |
| *N. pauciflora* | 2, 3, 4 | 6, 1 | 2, 3, 4 | 6 |
| *N. plumbaginifolia* | 2, 3, 4 | 3′ | — | — |
| *N. simulans* | Unknown | — | — | — |
| *N. trigonophylla* | 2, 3, 4 | 3′ | 2, 3, 4 | — |

Major components of synthetic OTC7SE, OTC8SE, OTC9SE, and OTC10SE were 6-, 6′-, and 1′ monoacyl SE; 6,6′-, 6,1′-, and 1′,6′-diacyl SE; 6,1′,6′-triacyl SE (based on GC/MS data and NMR data).

[a] Glucose carbons are 1–6, fructose carbons are 1′–6′; acyl groups range from propionic to octanoic acids.

[b] Acetyl groups are generally on fructose carbon hydroxyls.

then cut back and dipped into solvent to extract the cuticular components. This procedure was repeated 3 or 4 times. Sugar ester isolates were obtained from the cuticular extracts by a previously described solvent partitioning procedure (Severson et al. 1991, 1994). This scheme was designed to remove aliphatic hydrocarbons and wax esters with a hexane extraction and to remove alkaloids with an aqueous tartaric acid solution, leaving an acetonitrile fraction that contained the purified sugar esters.

Sugar ester isolates were characterized using gas chromatography–mass spectrometry (GC/MS) by converting samples to volatile trimethylsilyl derivatives and separating on SE-54 or DB-5 glass capillary GC columns (Arrendale et al. 1990). Sugar ester isolates in *Nicotiana* spp. and synthetic preparations generally contained glucose and sucrose of different types and proportions (Table 1). The sugar ester isolate of *N. gossei* consisted of 2 major types of glucose esters (2,3 di-acyl-1-acetyl glucose and 2,3-acyl-glucose) and two major types of sucrose esters (2,3 di-acyl-1′-acetyl sucrose and 2,3-di-acyl-1′,6′-di-acetyl sucrose) (Severson et al. 1994). The sugar ester isolate of *N. gossei* has been extensively investigated (Buta et al. 1993), and the 2 sucrose ester compounds have been patented (Pittarelli et al. 1993). The 2 major acyl groups on the sugar esters have been determined to be 5-methylhexanoyl and 5-methylheptanoyl (Pittarelli et al. 1993). Isolates of *N. glutinosa* 24A contained large amounts (85%) of labdanes along with sugar esters (11%), in contrast to the other *N. glutinosa* accession. All other *Nicotiana* isolates contained ≥98% sugar ester and no significant amounts of labdanes.

**Synthetic Sucrose Esters.** Synthetic sugar esters were prepared by reacting sucrose with acid chlorides according to the method recently described by Chortyk et al. (1996). Sucrose esters of heptanoic, octanoic, monanoic, and decanoic acids were prepared. The total reaction product, consisting of nonoacyl sucroses, diacyl sucroses, and triacyl sucroses, was used directly for testing. Heptanoyl sugar ester were labeled OTC7SE, octanoyl SE were labeled OTC8SE, and so on.

**Spray Dilution Preparations.** Aqueous dispersions of sugar ester isolates were prepared for either spray or leaf-dip application as described by Liu and Stansly (1995b). In brief, the natural or synthetic sugar esters were dissolved in 20 times of acetone (wt.:vol.) to make up a 5% stock solution. When used, the concentrated solution was slowly mixed into vigorously stirred water on a magnetic stirring plate (Model 11-498-7SH [Fisher Scientific, Philadelphia, PA] for 2 min, giving a cloudy emulsion. Acetone (1%) water mixtures were used as controls. All experiments were conducted in the laboratory at 25 ± 2°C, 70 ± 5% RH, and illuminated with fluorescent lights (≈40 $\mu$mol· $m^{-2}$ $s^{-1}$ light intensity) set at a photoperiod of 14:10 (L:D) h.

For field application, 23 g of sugar ester isolates were dissolved with 100 ml of acetone, 100 ml of methanol, and 28 ml of Latron CS-7 spray adjuvant (Rohm-Haas, Philadelphia, PA). The sugar ester solution was then poured into rapidly stirred water (7.6 liter) to make a spray dilution of 3 g (AI)/liter (0.3%). Two commercial standards, as follows, were included for comparison: (1) a mixture of a pyrethroid, cyfluthrin (Baythroid 2EC [Bayer, Kansas City, MO] at 49.0 g (AI)/ha (1st 3 weekly sprays) or at 25.5 g (AI)/ha (5 remaining sprays) plus a synthetic organic phosphate, methamidophos (Monitor 4EC [Bayer, Kansas City, MO] at 841.4 g (AI)/ha, and (2) pyriproxyfen (an insect growth regulator, S-71639 [Knack 0.83 EC] [Sumitomo, Osaka, Japan] at 49.36 g (AI)/ha.

**Adult Bioassays.** Yellow sticky polyethylene cards (Olson products, Medina, OH) were used to immobilize whitefly adults. The sticky cards were cut into pieces (4 by 4 cm) with square area (2 by 2 cm) of sticky surface exposed and attached to a bamboo stick (15 cm long). Infested foliage in the greenhouse was gently shaken over the cards to capture 20–50 whiteflies per card.

*Trial 1.* Whitefly-bearing cards were sprayed to runoff with 2 concentrations (0.5 and 1 g (AI)/liter) of 7 sugar ester isolates including *N. gossei,* using a hand-spray pump (Spritzer [Bel-Art Products, Pequannock, NJ]. Cards were air-dried for 1 h and then held in a plastic ice chest (100% RH for 4 h) after treatment. Whiteflies were examined under a stereoscopic microscope and considered dead when no movement was observed after gentle probing with a camel's-hair brush.

**Table 2. Mortality of *B. argentifolii* adults treated with *Nicotiana* SE isolates applied with a hand pump to runoff (≈100% coverage)**

| Sugar esters | % mortality ± SE | | |
|---|---|---|---|
| | 1.0 g (AI)/liter | 0.5 g (AI)/liter | *F* |
| *N. amplexicaulis* | 94.4 ± 4.7a | 94.4 ± 6.5ab | 0.08 |
| *N. glutinosa* 24 | 96.1 ± 4.0a | 98.1 ± 2.2ab | 0.57 |
| *N. glutinosa* 24A | 94.7 ± 6.3a | 94.2 ± 4.0ab | 0.04 |
| *N. glutinosa* 24B | 95.3 ± 5.3a | 96.4 ± 4.7ab | 0.20 |
| *N. gossei* | 95.5 ± 6.8a | 96.6 ± 4.5ab | 0.01 |
| *N. langsdorffii* | 100.0 ± 0.0a | 93.2 ± 6.4b | 16.57** |
| *N. trigonophylla* | 100.0 ± 0.0a | 100.0 ± 0.0a | 0.00 |
| Water + 1% acetone | 1.4 ± 2.6b | 3.0 ± 3.5c | 0.52 |
| *F* | 59.0** | 44.5** | — |
| LSD | 6.5 | 6.5 | — |

**, $P = 0.01$. Means in the same column followed by different letters differ significantly (SAS Institute 1988).

*Trial* 2. Whitefly-bearing sticky cards were sprayed as above with 0.25, 0.5, 1, and 2 g (AI)/liter *N. gossei* sugar ester or with 2 ml of each solution using the Potter spray tower (Burkard Manufacturing, Rickmansworth, Hertfordshire, England) at 7 kg/cm$^2$ pressure.

**Nymph Leaf-Dip Bioassays.** For all except the 2nd bioassay, young whitefly-free sweet potato leaves were collected and inserted into individual root cubes (3.75 by 3.75 by 3.75 cm) (OASIS Growing Media, [Smithers-Oasis; USA Grower Products, Kent, OH], petiole down. Root cubes with sweet potato leaves were kept in plastic trays and immersed in water (2 cm in depth) into which 1 g/liter of Miracle-Gro was added once per week. Rooted sweet potato leaves maintain their quality and therefore supply a convenient medium for testing effects on nymphs. For the 2nd of 3 experiments, tomato leaves were used as a substrate because whitefly control on tomato was the ultimate objective and was to be used in the field experiment. Leaves (trifoliates) were placed individually into glass vials (petiole down) filled with 20 ml of water. Male and female whiteflies (40–60 per leaf) were introduced onto the sweet potato or tomato leaves in a large cage (60 by 60 by 60 cm, screened). After an oviposition period of 24 h, the newly infested leaves were removed from the large cage, and the whiteflies were extracted using a hand-held vacuum cleaner (AC Insect Vac [Bio-Quip, Gardena, CA]. Egg-bearing leaves were incubated in whitefly-free cages at 25 ± 2°C, 75% RH, and a photoperiod of 14:10 (L:D) h for 10 d when most had developed to 2nd instar. Whitefly-bearing leaves were dipped in appropriate sugar ester concentrations for 5 s, then air-dried for 1 h on paper towels. Treated leaves were incubated in whitefly-free cages (60 by 60 by 60 cm) at 25 ± 2°C, 55–60% RH, and a photoperiod of 14:10 (L:D) h for 3–4 d. An average of 54 ± 14 (mean ± SD) small nymphs per leaf were observed using a stereoscopic dissecting microscope. Nymphs that had dried or detached from the leaf surface were considered dead. The 1st and 2nd experiments were conducted comparing different sugar ester isolates of *Nicotiana,* and a 3rd experiment compared a synthetic sugar ester with a *N. gossei* sugar ester isolate. A randomized complete block design was employed with 8 replicates, and each experiment was repeated 3 times.

**Table 3. Mortality of *B. argentifolii* adults treated with *N. gossei* SE isolate using the Potter spray tower (≈70% coverage)**

| Rate, g (AI)/liter[a] | % mortality ± SE |
|---|---|
| 2.00 | 50.7 ± 5.5a |
| 1.00 | 47.9 ± 4.0a |
| 0.50 | 28.8 ± 3.3b |
| 0.25 | 23.2 ± 3.1b |
| Water + 1% acetone | 7.5 ± 1.2c |
| *F* | 32.5[b] |
| LSD | 9.6 |

[a] 2 ml solution, 0.7 kg/cm$^2$ pressure.

[b] Significant at $P = 0.01$. Mean percentages in the same column followed by different letters differ significantly (SAS Institute 1988).

A 4th bioassay was conducted to evaluate effects of coverage. We treated 2nd-instar nymphs on sweet potato leaves with *N. gossei* sugar ester isolate by either dipping the leaves in 1 g (AI)/liter concentrations (≈100% coverage) or spraying the whitefly-bearing leaves with the Potter spray tower (2 ml solution at 0.7 kg/cm$^2$) (≈70% coverage; Liu and Stansly 1995a). Mortality was examined 4 d after treatment. Three concentrations and the water control were tested for each treatment, with 8 replicates at each concentration.

**Field Trials.** Tomato ('Agriset') seedlings (15–20 cm high) were exposed for 5 d to a greenhouse colony of *B. argentifolii* for infestation with whitefly eggs. Seedlings were planted on 27 February 1995 in sandy soil at SWFREC, 46 cm between in beds (81 cm wide) fumigated with 220 lb methyl bromide–choropicran 67/33 and covered with black polyethylene mulch following standard procedures for southwestern Florida staked tomato production. A randomized complete block design was used with 4 replications, and treatments included 5 sugar ester isolates—the 2 commercial

**Table 4. Toxicity of sugar ester isolates of *Nicotiana* spp. applied as a dip to 2nd-instar nymphs of *B. argentifolii* on sweet potato leaves**

| Sugar ester isolates | % mortality ± SE | | |
|---|---|---|---|
| | 1.0 g (AI)/liter | 0.5 g (AI)/liter | *F* |
| *N. cavicola* | 40.1 ± 9.7e | 44.3 ± 11.4bc | 0.43 |
| *N. gossei* | 96.7 ± 3.5a | 89.6 ± 6.5a | 5.53* |
| *N. noctiflora* | 46.4 ± 13.9cde | 20.5 ± 3.3e | 19.74** |
| *N. otophora* 38 | 53.3 ± 12.9bcd | 28.9 ± 14.7de | 9.33* |
| *N. otophora* 38A | 40.2 ± 15.3de | 22.3 ± 7.5e | 6.48* |
| *N. otophora* 38B | 58.0 ± 11.4bc | 33.6 ± 6.4cd | 20.32** |
| *N. otophora* 38C | 32.2 ± 5.9e | 18.2 ± 9.9e | 8.57* |
| *N. palmeri* | 89.9 ± 12.1a | 63.0 ± 11.3b | 12.20** |
| *N. pauciflora* | 42.9 ± 7.9e | 18.7 ± 8.3e | 23.11** |
| *N. plumbaginifolia* | 58.8 ± 13.6bc | 36.7 ± 14.7bcd | 7.31 |
| *N. simulans* | 52.1 ± 25.9b | 46.7 ± 6.7b | 0.43 |
| Water + 1% acetone | 4.7 ± 2.0f | 4.3 ± 1.9f | 0.08 |
| *F* | 17.5** | 42.7** | — |
| LSD | 14.6 | 10.9 | — |

*, $P = 0.05$; **, $P = 0.01$. Means in the same column followed by different letters differ significantly (SAS Institute 1988).

standards mentioned above and an untreated control. Blocks ran east and west and plots were 7.4 m long and 3 rows (1.8-m centers) wide. Plants were sprayed weekly for 8 wk starting the 4th week after the transplanting (except for pyriproxyfen, which was sprayed every other week at the manufacture's recommendation). Applications were made in the early morning around 0700–0900 hours (March-May, 1995) with a tractor-drawn high-clearance sprayer fitted with 4–8 Albuz yellow hollow cone ceramic nozzles per row (depending on plant height) operating at 14 kg/cm$^2$ pressure and 3.2 km/h (2 mph). Delivery rates were 309 liter/ha (33 gal/acre) with 4 nozzles (first 3 wk), 570 liters/ha (61 gal/acre) with 6 nozzles (4th wk), and 758 liters/ha (81 gal/acre) with 8 nozzles (remaining 4 wk).

A pretreatment sample of whitefly nymphs and pupae was taken on 17 March 1995. Posttreatment samples (8) of whitefly adults, small nymphs (1st and 2nd instars), large nymphs (3rd and 4th instars), pupae, and parasitized pupae were taken weekly thereafter. Whitefly adults from 6 plants in the center row in each plot were sampled by striking a black baking pan (24 by 33 by 2.5 cm) against the vegetation and counting whiteflies trapped in a thin coating of soybean oil (Publix brand) and detergent (Dawn [Procter & Gamble, Cincinnati, OH] mixture (oil–detergent, 30:1 [vol.:vol.]. Whitefly immatures were sampled from 4 randomly selected plants of each of the 3 rows by removing a trifoliate from the 6th node from the top of each plant for a total of 12 trifoliates per plot. All whitefly stages falling within a 0.5-cm$^2$ template placed twice on each side of the midvein of the terminal leaflet of the trifoliate were counted with a stereoscopic microscope, giving 4 cm$^2$ of leaf area per trifoliate.

**Data Analysis.** Percentage mortality (bioassay) of whitefly adults and nymphs were transformed to the arc sine square root [arsine (percentage mortality/100)$^{1/2}$] before analysis of variance (ANOVA) to stabilize error variance (Gomez and Gomez 1984), although untransformed mean percentage mortality (±SE) is reported. Sources of variation for this analysis were insecticides, replicate, repetition, and insecticides × replicate. The error term used to test insecticide effects was the mean square for the insecticide × replicate interaction (Freund et al. 1986). Means were separated using the least significant difference (LSD) test following a significant *F* test (SAS Institute 1988).

**Table 5. Toxicity of sugar ester isolates of *Nicotiana* spp. (1.0 g [AI]/liter) applied as a dip to 2nd-instar nymphs of *B. argentifolii* on tomato leaves**

| Sugar ester isolate | % mortality ± SE |
|---|---|
| *N. amplexicaulis* | 99.0 ± 2.1a |
| *N. glutinosa* 24 | 96.0 ± 3.6a |
| *N. glutinosa* 24B | 97.6 ± 4.0a |
| *N. glutinosa* 24A | 31.2 ± 7.3b |
| *N. gossei* | 98.5 ± 2.5a |
| *N. langsdorffii* | 96.1 ± 4.9a |
| *N. trigonophylla* | 95.0 ± 4.9a |
| Water + 1% acetone | 4.1 ± 2.9c |
| *F* | 239.9** |
| LSD | 4.8 |

**, $P = 0.01$. Means in the same column followed by different letters differ significantly (SAS Institute 1988).

## Results

**Adult Bioassays.** Sugar ester isolates of *N. amplexicaulis, N. glutinosa, N. langsdorffii, N. trigonophylla,* and *N. gossei* induced strong mortality responses in immobilized whitefly adults sprayed to runoff (Table 2). In contrast, mortality response of adult *B. argentifolii* to *N. gossei* sugar ester isolate applied with the Potter spray tower were feeble (Table 3). Rate response was significant ($P < 0.001$), but only between the concentrations of 0.5 and 1 g (AI)/liter. These results indicated that complete coverage of adult whiteflies with these materials was necessary to achieve high levels of adult mortality.

**Table 6. Toxicity of a *N. gossei* sugar ester isolate and a synthetic sugar ester applied as a dip to 2nd-instar nymphs of *B. argentifolii* on sweet potato leaves**

| Rates, g (AI)/liter | % mortality ± SE | | |
|---|---|---|---|
| | *N. gossei* sugar ester | Synthetic SE (OTC8SE) | *F* |
| 1.00 | 95.6 ± 5.2a | 89.5 ± 10.7a | 2.13 |
| 0.50 | 87.1 ± 8.5ab | 80.1 ± 9.0ab | 2.55 |
| 0.25 | 81.5 ± 2.2b | 72.5 ± 12.4a | 2.13 |
| Water + 1% acetone | 4.2 ± 3.2c | 3.2 ± 2.6c | 0.12 |
| *F* | 185.5** | 128.3** | — |
| LSD | 8.7 | 9.7 | — |

**, $P = 0.01$. Means in the same column followed by different letters differ significantly (SAS Institute 1988).

**Table 7. Mortality response of 2nd-instar nymphs of *B. argentifolii* on sweet potato leaves to *N. gossei* sugar ester isolate applied as a leaf dip and with spray in the Potter spray tower**

| Rates, g (AI)/liter | *n* | % mortality ± SE | | |
|---|---|---|---|---|
| | | Dipped | Sprayed | *F* |
| 1.00 | 1,300 | 93.8 ± 0.8a | 52.8 ± 4.6a | 99.9** |
| 0.50 | 1,347 | 87.2 ± 1.5b | 46.3 ± 5.2b | 63.3** |
| 0.25 | 751 | 84.1 ± 1.8b | 35.9 ± 2.8b | 52.1** |
| 0.00 | 921 | 2.0 ± 1.1c | 2.0 ± 0.8c | 0.2 |
| *F* | — | 533.1** | 37.0** | — |
| LSD | — | 3.3 | 12.2 | — |

**, $P = 0.01$. Mean percentages in the same column followed by different letters differ significantly (SAS Institute 1988).
[a] ≈100% coverage.
[b] 2 ml of solution at 0.7 km/cm²; ≈70% coverage.

**Nymph Leaf-Dip Bioassays.** Whitefly nymphs treated with *Nicotiana* sugar ester isolates and the synthetic sugar ester quickly dried and detached from the leaf surface, with dorsal and ventral surfaces of the body compressed together as reported by Neal et al. (1994). Significant differences in mortality response of 2nd-instar *B. argentifolii* to both rates of 11 natural sugar ester isolates of *Nicotiana* species were observed in the 1st test ($P < 0.001$) (Table 4). At the rate of 1 g (AI)/liter, sugar ester isolates of *N. gossei* and *N. palmeri* caused greatest mortality (96.7 and 89.9%, respectively), whereas at the rate of 0.5 g (AI)/liter, the highest mortality (89.6%) was seen with *N. gossei*. Mortality response of nymphs to other materials tested was weak (18.2–58.8%).

Greater than 95% mortality of 2nd-instar nymphs was observed in response to sugar ester isolates at 1 g (AI)/liter of *N. amplexicaulis, N. glutinosa, N. langsdorffii, N. trigonophylla,* and *N. gossei* when tested on tomato leaves (Table 5). The same concentration of sugar ester isolate from *N. glutinosa* 24A caused only 31.2% mortality to 2nd-instar whiteflies, probably because of low (11%) content of sucrose esters. Mortality responses of 2nd-instar nymphs exposed by leafdip to 3 concentrations of *N. gossei* sugar ester isolate and the synthetic sugar ester was statistically indistinguishable (Table 6), but mortalities within rates of each material were significantly different for both synthetic sugar ester and *N. gossei* sugar ester isolates ($P < 0.001$). Mortality of whitefly nymphs were significantly less when leaves were sprayed than when dipped for all 3 rates of *N. gossei* sugar ester isolate (Table 7).

**Field Trial.** Whitefly populations were greater than experienced by local commercial tomatoes that season but were more typical of previous seasons before the widespread use of imidacloprid to control whitefly (Stansly 1996).

*Effects on Immatures.* The mean number of whitefly nymphs sampled before treatments commenced were 1.8 ± 0.4 and not significantly different among replicates ($F = 0.7$, df = 4, 138, $P > 0.05$). Posttreatments differences were most pronounced in larger instars, reflecting accumulated effects over instars. All stages (eggs, small nymphs, large nymphs, and pupae) were significantly less on treated plants compared with the control, except for the synthetic octanoyl sugar ester (OTCSE) and the cyfluthrin–methamidophos mixture against pupae (Table 8). Only these plants receiving these 2 treatments and the control had significantly more pupae than plants treated with pyriproxyfen. Parasitization of whitefly pupae by *Encarsia* spp. and *Eretmocerus* spp. at the end of the field trial averaged 19 ± 4.4% ($N = 165$ pupae) with no significant differences between treatments ($F = 1.09$; df = 7, 35; $P = 0.39$).

*Effects on Adults.* Significantly fewer adults were observed from plants treated with sugar ester isolates compared with untreated controls on all 3 sample dates, corresponding approximately to 3 generations of whiteflies (Table 9). There were no significant differences in results among sugar ester treatments. In comparison, there were no difference between the untreated control and pyriproxyfen in the 1st generation or the cyfluthrin–methamidophos mix in the 2nd and 3rd generations. Numbers of adults in the untreated plots were >3 times than in plots treated with sugar ester isolates at the end of the trial.

## Discussion

The *N. gossei* sugar ester isolate was the most active natural sugar ester extract tested against whitefly nymphs, although some synthetic sucrose esters showed similar activity. The sugar ester isolates of the *N. glutinosa* accessions—*N. glutinosa* 24 and *N. glutinosa* 24B, which contained 55% and 90% sugar ester respectively—were highly toxic to whitefly nymphs. In contrast, the sugar ester isolate of *N. glutinosa* 24A with 11% sugar ester and 89% labdane terpenoids gave a very weak response. Neal et al. (1994) found that sugar ester isolates of *N. gossei, N. benthamiana* Domin, and *N. bigelovii* (Torrey) and 17 *Nicotiana* species were highly active against 2nd- and early 3rd-instar whitefly nymphs. Weak response of 2nd-instar

**Table 8. Populations of immature *B. argentifolii* on tomato foliage in the field after 8 weekly sprays with selected insecticides**

| Sugar esters | No./10 cm² ± SE | | | |
|---|---|---|---|---|
| | Eggs | Small nymphs (1st–2nd) | Large nymphs (3rd–4th) | Pupae |
| *N. trigonophylla* | 1.9 ± 0.8b | 2.7 ± 1.2bc | 0.5 ± 0.3b | 0.3 ± 0.1cd |
| OTC7SE | 0.3 ± 0.2b | 1.3 ± 0.4bc | 0.6 ± 0.3b | 0.7 ± 0.3bcd |
| OTC8SE | 1.4 ± 0.6b | 3.8 ± 1.3bc | 0.8 ± 0.3b | 1.8 ± 0.5abc |
| OTC9SE | 1.0 ± 0.4b | 2.3 ± 0.6bc | 0.2 ± 0.1b | 1.1 ± 0.6bcd |
| OTC10SE | 1.3 ± 1.0b | 2.9 ± 1.0bc | 0.3 ± 0.2b | 0.8 ± 0.4bcd |
| Pyriproxyfen | 0.9 ± 0.6b | 0.6 ± 0.3c | 0.1 ± 0.1b | 0.1 ± 0.1d |
| Cyfluthrin + methamidophos | 8.9 ± 4.8ab | 7.9 ± 1.9b | 1.8 ± 0.8b | 2.1 ± 0.6ab |
| Untreated | 12.3 ± 7.7a | 17.3 ± 7.1a | 7.8 ± 4.3a | 3.5 ± 1.4a |
| *F* | 1.88* | 4.00** | 2.84** | 3.37** |
| LSD | 8.71 | 7.22 | 4.13 | 1.70 |

*, $P = 0.05$; **, $P = 0.01$. Means in the same column followed by different letters differ significantly (LSD; SAS Institute 1988).

nymphs to 98% sugar ester isolates of *N. cavicola, N. simulans, N. pauciflora, N. plumbaginifolia, N. noctiflora,* and *N. otophora* are probably caused by differences in sugar ester structure or composition and remain to be investigated.

Among sugar ester isolates from different species of *Nicotiana,* those from *N. gossei, N. amplexicaulis, N. glutinosa, N. langsdorffii,* and *N. trigonophylla* were highly active when sprayed to runoff against immobilized whitefly adults on yellow sticky cards, although untreated adults could hardly be soaked this way by a field application. Less mortality was seen when adults were sprayed with a Potter spray tower, which gives even but incomplete coverage (Liu and Stansly 1995c); dried residues of *N. gossei* sugar ester isolate were ineffective as toxicants or repellents (Liu and Stansly 1995a,b). Sugar esters of *N. gossei* also were not toxic to eggs of *B. argentifolii* (Liu and Stansly 1995a,b,c). Therefore, the effects of sugar ester sprays observed on adult and egg populations in the field probably results largely from mortality to nymphs. Treatment with pyriproxyfen also reduced the numbers of adults in the 2nd and 3rd generations, in this case, because of suppression of embryogenesis and formation of adults (Ishaaya and Horowitz 1992). Therefore, movement of adults between plots mush have limited.

Buta et al. (1993) and Neal et al. (1987, 1994) also reported that mixtures of sucrose and glucose esters from extracts of *N. gossei* caused >90% mortality against 2nd- and early 3rd-instar nymphs of *T. vaporariorum* and *B. tabaci* (= *B. argentifolii*) as well as the green peach aphid, *Myzus persicae* (Sulzer), and the two-spotted spider mite, *Tetranychus urticae* Koch. They were only weakly toxic to the western flower thrips, *Frankliniella occidentalis* (Pergande), and non-toxic to the Colorado potato beetle, *Leptinotarsa decemlineata* (Say). Concentrations of 0.2 g (AI)/liter of *N. gossei* sugar ester isolates were innocuous to all developmental stages of *Nephaspis oculatus* (Blatchley), and leaf residues did not affect adults of *Encarsia pergandiella* Howard, predator and parasitoid of *B. argentifolii,* respectively (T.-X.L. and P.A.S, unpublished data). The selective toxicity of some natural sugar esters and synthetic sugar esters to a number of plant pests make them potentially attractive biorational alternatives for many management applications.

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**Table 9. Adult *B. argentifolii* sampled in the field with a beat pan from tomato plants sprayed weekly with selected insecticides**

| Sugar esters | No. adults/pan ± SE | | |
|---|---|---|---|
| | 27 March (1st generation) | 21 April (2nd generation) | 17 May (3rd generation) |
| *N. trigonophylla* | 2.0 ± 0.6b | 2.9 ± 0.5b | 44.7 ± 6.6b |
| OTC7SE | 2.6 ± 0.5b | 3.3 ± 0.6b | 35.7 ± 3.6b |
| OTC8SE | 3.2 ± 0.5b | 3.8 ± 0.8ab | 53.0 ± 9.2b |
| OTC9SE | 2.3 ± 0.6b | 3.8 ± 0.6ab | 44.5 ± 8.4b |
| OTC10SE | 3.3 ± 0.6b | 2.8 ± 0.6b | 46.8 ± 13.0b |
| Pyriproxyfen | 5.3 ± 1.0a | 2.2 ± 0.5b | 24.8 ± 3.6b |
| Cyfluthrin + methamidophos | 2.3 ± 0.3b | 5.3 ± 0.9a | 161.0 ± 19.4a |
| Untreated | 6.9 ± 0.9a | 5.8 ± 0.9a | 165.8 ± 21.5a |
| *F* | 6.55** | 2.92** | 19.96** |
| LSD | 1.81 | 1.95 | 33.72 |

**, $P = 0.01$. Means in the same column followed by different letters differ significantly (SAS Institute 1988).

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