Toxicity of Synthetic Sucrose Esters Against the Tobacco Aphid (Homoptera: Aphididae)[1]

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Abstract Four synthetic sucrose esters were evaluated in the laboratory and field to determine their insecticidal activity on the tobacco aphid, *Myzus nicotianae* Blackman. Synthetic sucrose esters provided moderate to good insecticidal activity against tobacco aphids in laboratory evaluations. Octanoyl sucrose esters were most toxic, and decanoyl sucrose esters were least toxic to aphids. Only the octanoyl sucrose esters at a 2 mg/ml rate were as toxic to aphids as the natural sugar esters from *Nicotiana gossei* Domin. They were also the most effective synthetic sucrose esters against aphids when a CO_2 hand-held sprayer was used. All of the synthetic sucrose esters demonstrated significantly higher aphid mortality at a rate of 2 mg/ml than at 1 mg/ml. Heptanoyl and octanoyl sucrose esters provided significantly higher aphid control under wet conditions than under dry conditions in the laboratory. Results from field tests were inconsistent. Field evaluations conducted in 1995 showed that the four synthetic sucrose esters were moderately toxic at a rate of 4 mg/ml using a CO_2 hand-held sprayer and low to moderately toxic using a high clearance sprayer. The addition of a surfactant (Volpo G-31, Silwet L-77 or Volpo G-31 plus Silwet L-77) significantly improved the efficacy of octanoyl sucrose esters when a CO_2 hand-held sprayer was used. Relatively low aphid control was obtained with octanoyl sucrose esters in the field even though two surfactants were added when a high clearance sprayer was used at rates of 840 L/ha and 1400 L/ha.

Key Words sucrose esters, sugar esters, tobacco, toxicity, aphids, *Myzus nicotianae, Nicotiana gossei*

A mixture of sugar esters including two sucrose esters (2,3-di-O-acyl-6′-O-acetylsucrose, and 2,3,-di-O-acyl-1′,6′-diacetylsucrose) and two glucose esters (1-O-acetyl-2,3-di-O-acylglucose, and 2,3-di-O-acylglucose), extracted from *Nicotiana gossei* Domin, have shown toxicity against the tobacco aphid, *Myzus nicotianae* Blackman (Severson et al. 1991). Insecticidal activity of synthetic sucrose esters against tobacco aphid and sweet potato whitefly, *Bemisia tabaci* (Gennadius), was reported recently (Chortyk et al. 1996). However, information on the toxicity of synthetic sucrose esters to the tobacco aphid is limited. This study was conducted to evaluate the toxicity of four types of synthetic sucrose esters against tobacco aphids in the laboratory and the field.

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Materials and Methods

Tobacco aphids. Aphids used in this study were the red color form of the tobacco aphid. Apterous adults and immatures were tested together. The aphids used in the laboratory tests were collected from a tobacco field at the Clemson University Pee Dee Research and Education Center (PDREC) in Florence, SC. Natural infestations of aphids were evaluated on field tobacco plants ('Coker 371') for field studies.

Sucrose esters and other chemicals. Four synthetic analogs of natural sucrose esters from *N. gossei* were synthesized by the methods described by Chortyk et al. (1996). The synthetic sucrose esters included heptanoyl sucrose esters, octanoyl sucrose esters, nonanoyl sucrose esters, and decanoyl sucrose esters. Each of the four synthetic sucrose esters was a mixture of 6-, 6′-, or 1′-monoacyl sucroses, 6,6′-, 6,1′-, or 1′,6′-diacyl sucroses, and 6, 1′, 6′-triacyl sucroses. *Nicotiana gossei* sugar esters which included two sucrose esters and two glucose esters as described above were used for comparison. Sugar esters were dissolved in methanol (1g [AI]: 10.9 ml) to make stock solutions that were then formulated in distilled water (for laboratory tests) and tap water (for field tests) to the desired concentrations immediately before application. Acephate (Orthene® 75 S, Valent U.S.A. Co., Walnut Creek, CA) was dissolved in water to make a 0.23 (AI)% concentration. Volpo® G-31(Croda Inc., Parsippany, NJ) was used as a humectant to maintain moisture after application. Silwet® L-77 (OSi Specialties Inc., Sistersville, WV) was used as a wetting agent. Concentrations (v:v) of surfactants in this study were based on the formulated products, no attempt was made to purify the surfactants before use.

Laboratory experiments. Tobacco leaves infested with at least 100 aphids per leaf were collected from a nearby tobacco field immediately before treatment. Treatments were applied to each tobacco leaf or leaf section using a hobby type air brush (General Electric, Fort Wayne, IN) at a pressure of ≈1.06 kg/cm^2. Both sides of each leaf or leaf section were sprayed by passing the sprayer over each leaf surface five times to provide thorough coverage at a distance of approximately 12 cm from the leaf surface, achieving an application rate of ≈39 µl/cm^2. Treated leaves were placed in Petri dishes (9 cm diam) with wet filter paper immediately after application for wet replicates, or treated leaves were dried under an electric fan for about 30 min, and then placed in the Petri dishes with dry filter paper for dry replicates. Petri dishes with lids were then maintained in an environmental chamber (Sherer-Gillett Co., Marshall, MI) at a temperature of 25 ± 2°C, room humidity (30 to 50% RH), and a photoperiod of 16:8 (L:D) h. Each Petri dish containing a treated leaf or leaf section was considered a replicate, and each treatment was replicated 4 times. Aphid mortality was determined 24 h after treatment with the aid of a microscope. Aphids were considered dead if no movement was detected when they were probed gently with a camel hair brush. All aphids (adults and immatures) within a Petri dish were counted. Number of aphids in each replication varied from 100 to 200.

Field experiments. Field experiments were conducted from June to September 1995 and June to July 1996. The tobacco was transplanted in late May. Rows were 1.22 m apart, and plants were 55.9 cm apart in rows. Tillam® (6-E, Zeneca Inc., Wilmington, DE) was applied as a preplant broadcast incorporated treatment at 6.3 L/ha, and Prowl® (3.3 EC, American Cyanamid Co., Wayne, NJ) was applied at last cultivation (layby) at 1.4 L/ha for weed control. Granular fertilizer (6:6:18 [N:P:K]) and sodium nitrate (16% N) were sidedressed after transplanting at 756 kg/ha and 336 kg/ha, respectively.

Experimental plots were marked off in the field in a randomized complete block design using 4 replicates. Each plot was 7.6 m long and 1.22 m wide, containing 10 plants, and was considered a replicate. Plots in a row were separated by 4 untreated plants.

1995 Tests. An average of 0.035 L of sucrose ester solution (513 L/ha) and 0.025 L of acephate solution (374 L/ha as recommended by the South Carolina Agricultural Chemicals Handbook) were applied to both sides of the 4 top leaves per plant using a CO_2 hand-held sprayer (R & D Sprayers Inc., Opolousas, LA) with one full cone nozzle (TG-2, Spraying System Co., Wheaton, IL) at a working pressure of 2.8 kg/cm^2. A spray volume of 1869 L/ha solution was applied with a high clearance sprayer using five full cone nozzles (D2-35) per row at a working pressure of 5.6 kg/cm^2. The nozzle arrangement on the high clearance sprayer consisted of a center nozzle over the top and two drop nozzles on each side of each row of plants. The center nozzle sprayed straight down, while the upper nozzle on each side was angled downward at 45°, and the lower nozzle on each side was angled upward at 45°. Temperature and relative humidity at the time of application were 32°C and 55% using a CO_2 sprayer, and 31°C and 55% using a high clearance sprayer, respectively. Temperature and relative humidity were recorded with a thermohygrometer (Brooklyn Thermometer Company Inc., Farmingdale, NY). Aphid mortality was checked 24 h after application. Four upper leaves (10 to 15 cm long) were randomly collected from each treated plot and four untreated plots and taken to the laboratory. The number of live and dead aphids was counted on each leaf to determine aphid mortality. Only the first 100 aphids were counted on a tobacco leaf.

1996 Tests. An average of 0.060 L of sucrose ester solution (880 L/ha) was applied per plant using the CO_2 hand-held sprayer as described above. Spray volumes of 840 L/ha and 1400 L/ha were applied with a high clearance sprayer using either five hollow (840 L/ha) or full cone (1400 L/ha) nozzles per row at a working pressure of 5.6 kg/cm^2. The nozzle arrangement on the high clearance sprayer consisted of a center nozzle and four top nozzles at each end of a horizontal right angle cross. The center nozzle sprayed straight down, while the remaining nozzles were angled downward at 45°. Temperature and relative humidity at the time of application were 34°C and 42% using a CO_2 sprayer, 36°C and 53% (840 L/ha), and 35°C and 42% (1,400 L/ha) using a high clearance sprayer, respectively. Procedures for determination of aphid mortality were the same as described above.

Statistical analysis. Abbott's (1925) formula was used if mortality in the control was >5% (Busvine 1971). All percentage data were transformed by arcsine before analysis. Analysis of variance procedures (ANOVA, MEANS, SAS 6.10, SAS Institute 1990) were used to conduct analysis of variance among treatments and blocks, and to compute means and standard errors of dependent variables. Waller-Duncan K-ratio T test (ANOVA, Waller Option, SAS Institute 1990) was used to compare means among treatments (α = 0.05). All data presented were untransformed.

Results

Laboratory experiments. All synthetic sucrose esters were toxic to aphids under the test conditions in this study (Table 1). At a rate of 1 mg/ml, aphid mortality from synthetic sucrose esters and *N. gossei* sugar esters ranged from 20 to 96% under wet filter paper conditions and 16 to 68% under dry filter paper conditions, respectively. At a rate of 2 mg/ml, aphid mortality ranged from 67 to 98% under wet filter paper

Table 1. Toxicity of synthetic sucrose esters to tobacco aphids in the laboratory using a leaf spray technique

	Mean % aphid mortality after 24 h (± SEM)*	
	Sugar ester concentration	
Sugar esters	1 mg/ml	2 mg/ml
	Wet Filter Paper**	
Heptanoyl sucrose esters	53 ± 15.1 c, bc	84 ± 5.5 bc, d
Octanoyl sucrose esters	82 ± 4.5 e, d	95 ± 5.0 d, e
Nonanoyl sucrose esters	42 ± 9.5 bc, b	84 ± 9.8 c, d
Decanoyl sucrose esters	20 ± 9.5 a, a	67 ± 13.2 a, c
N. gossei sugar esters	96 ± 4.5 f, e	98 ± 4.3 d, e
	Dry Filter Paper†	
Heptanoyl sucrose esters	41 ± 6.8 bc, b	64 ± 11.8 a, c
Octanoyl sucrose esters	36 ± 15.2 b, b	82 ± 5.7 bc, d
Nonanoyl sucrose esters	36 ± 7.1 b, b	70 ± 11.8 ab, d
Decanoyl sucrose esters	16 ± 2.4 a, a	57 ± 6.9 a, c
N. gossei sugar esters	68 ± 5.6 d, c	79 ± 13.8 bc, d

* Means followed by the same letter are not significantly different within a column (letters before comma) or within a filter paper condition (letters after comma) (α = 0.05, Waller-Duncan K-ratio T-test, SAS Institute 1990).

** Wet filter paper: treated leaves were immediately placed in Petri dishes with moist filter paper after application.

† Dry filter paper: treated leaves were dried under an electric fan for about 30 min after application, then, placed in Petri dishes with dry filter paper.

conditions, and 57 to 82% under dry filter paper conditions. Toxicity was related to the type and rate of the sucrose esters, as well as the moisture condition in Petri dishes. There were significant differences in the efficacy of the sucrose esters at a rate of 1 mg/ml using wet filter paper (F = 41.46; df = 4, 15; P < 0.0001), 1 mg/ml using dry filter paper (F = 19.28; df = 4, 15; P < 0.0001), 2 mg/ml using wet filter paper (F = 8.63; df = 4, 15; P < 0.0001), and 2 mg/ml using dry filter paper (F = 4.09; df = 4, 15; P < 0.019) (Table 1).

Nicotiana gossei sugar esters provided the highest toxicity, at 1 mg/ml, under both wet and dry conditions (Table 1). Toxicity of synthetic octanoyl sucrose esters to tobacco aphids was the highest of the four synthetic sucrose esters at a rate of 1 mg/ml using wet filter paper, and at a rate of 2 mg/ml using dry filter paper. All sucrose esters demonstrated low aphid mortality at a rate of 1 mg/ml using dry filter paper. It appeared that synthetic decanoyl sucrose esters were the least toxic to aphids among the four synthetic sucrose esters (Table 1).

Aphid toxicity for all four synthetic sucrose esters was significantly higher at a rate of 2 mg/ml than at the 1 mg/ml rate under both wet and dry conditions (α = 0.05). Aphid mortality for *N. gossei* sugar esters was significantly higher at a rate of 2 mg/ml than at the 1 mg/ml rate using dry filter paper, but not significantly different under wet filter paper conditions (Table 1).

Nicotiana gossei sugar esters provided significantly higher aphid control under wet conditions than under dry conditions using a 1 mg/ml ($F = 34.14$) or 2 mg/ml ($F = 8.59$) concentration (Table 1). Synthetic heptanoyl sucrose esters and octanoyl sucrose esters also provided significantly higher control under wet conditions than under dry conditions at both concentrations. Synthetic nonanoyl sucrose esters provided significantly higher aphid control under wet conditions than under dry conditions at a concentration of 2 mg/ml (Table 1).

Field experiments, 1995. Aphid mortality was significantly different among the field treatments using a CO_2 hand-held sprayer ($F = 7.45$; df = 5, 18; $P < 0.006$), and a high clearance sprayer ($F = 6.62$; df = 4, 15; $P < 0.0028$) (Table 2). In the test using a CO_2 hand-held sprayer, aphid toxicity for synthetic octanoyl sucrose esters and decanoyl sucrose esters was not significantly different although the numerical value of aphid mortality for synthetic octanoyl sucrose esters was higher than the rest of the synthetic sucrose esters. Synthetic heptanoyl sucrose esters provided the lowest insecticidal activity to tobacco aphids (Table 2). Aphid toxicity from synthetic octanoyl sucrose esters and *N. gossei* sugar esters at a rate of 4 mg/ml and a spray volume of 513 L/ha was not significantly different (Table 2).

In the test using a high clearance sprayer, synthetic octanoyl sucrose esters provided significantly higher aphid mortality than the other synthetic sucrose esters. Aphid mortality for synthetic heptanoyl sucrose esters, nonanoyl sucrose esters, and decanoyl sucrose esters was not significantly different from each other (Table 2). Toxicity of synthetic octanoyl sucrose esters at a rate of 4 mg/ml and a spray volume of 1869 L/ha, and acephate at a rate of 0.23% and a spray volume of 374 L/ha was not significantly different (Table 2).

Field experiments, 1996. Insecticidal activity among the treatments of synthetic octanoyl sucrose esters only and synthetic octanoyl sucrose esters with surfactants

Table 2. Field evaluation of synthetic sucrose esters against the tobacco aphid using a CO_2 hand-held sprayer and high clearance sprayer, 1995

Treatments	Mean % aphid mortality after 24 h (± SEM)*	
	CO_2 hand sprayer	High clearance sprayer
4 mg/ml Heptanoyl sucrose esters	59 ± 10.2 ab	41 ± 17.2 a
4 mg/ml Octanoyl sucrose esters	82 ± 7.8 cd	83 ± 12.2 cde
4 mg/ml Nonanoyl sucrose esters	72 ± 9.6 bcd	58 ± 24.7 ab
4 mg/ml Decanoyl sucrose esters	66 ± 18.4 bc	44 ± 23.0 a
4 mg/ml *N. gossei* sugar esters	87 ± 5.4 de	
0.23% Acephate	97 ± 4.3 f	93 ± 7.2 ef

* Means followed by the same letter in entire table (separation by column was done, result was the same as that by entire table) are not significantly different (α = 0.05, Waller-Duncan K-ratio T-test, SAS Institute 1990).

using a CO_2 hand-held sprayer was significantly different ($F = 17.08$; df = 5, 18; $P < 0.0001$) (Table 3). Toxicity of synthetic octanoyl sucrose esters was not significantly improved by the addition of 0.1% Silwet L-77. Addition of 2% Volpo G-31 significantly enhanced the efficacy of synthetic octanoyl sucrose esters (Table 3). Aphid mortality from synthetic octanoyl sucrose esters and the addition of either 0.25% Volpo G-31 and 0.1% Silwet L-77, 1% Volpo G-31 and 0.1% Silwet L-77, or 2% Volpo G-31 and 0.1% Silwet L-77 was significantly higher than that for synthetic octanoyl sucrose esters alone or for synthetic octanoyl sucrose esters with 2% Volpo G-31 or 0.1% Silwet L-77.

Relatively low aphid control from 3 mg/ml rates of sucrose ester treatments was observed in field tests using a high clearance sprayer even though surfactants were used (Table 4). There was no difference in aphid mortality with the addition of 1% Volpo G-31 and 0.1% Silwet L-77 at a spray volume of 840 L/ha ($F = 0.89$; df = 4, 15; $P = 0.4956$) or 1400 L/ha ($F = 1.52$; df = 4, 15; $P = 0.2473$). Aphid mortality for the various treatments at a spray volume of 1400 L/ha was higher than that for corresponding treatments at 840 L/ha although the difference in mortality between the two spray volumes was not statistically different (Table 4).

Discussion

Four synthetic sucrose esters demonstrated moderate-to-good aphid control in laboratory tests. However, field evaluation results were inconsistent. Relative humidity and leaf surface moisture affected the efficacy of certain synthetic sucrose esters as they did for *N. gossei* sugar esters (Xia and Johnson, 1997). This may be the reason for the variation in aphid mortality from field applications. Spray coverage and application volume are important factors affecting control results from sucrose esters. Laboratory sprays and field applications using a CO_2 hand-held sprayer resulted in better droplet coverage and higher spray volume than the high clearance sprayer. Consequently, aphid mortality was higher in the tests using a CO_2 hand-held sprayer than a high clearance sprayer.

Table 3. Toxicity of synthetic octanoyl sucrose esters (4 mg/ml) with surfactants to the tobacco aphid in the field using a single nozzle CO_2 hand-held sprayer, 1996

Treatments	Mean % aphid mortality after 24 h (± SEM)*
Octanoyl sucrose esters	17 ± 13.4 a
Octanoyl sucrose esters + 0.1% L-77**	31 ± 15.8 ab
Octanoyl sucrose esters + 2% G-31**	49 ± 19.6 b
Octanoyl sucrose esters + 1% G-31 + 0.1% L-77	77 ± 18.2 c
Octanoyl sucrose esters + 2% G-31 + 0.1% L-77	87 ± 8.4 c
Octanoyl sucrose esters + 0.25% G-31 + 0.1% L-77	89 ± 10.0 c

* Means followed by the same letter are not significantly different ($\alpha = 0.05$, Waller-Duncan K-ratio T-test, SAS Institute 1990).

** L-77 = Silwet L-77; G-31 = Volpo G-31.

Table 4. Toxicity of synthetic sucrose esters (3 mg/ml) with surfactants Volpo G-31 (G-31) and Silwet L-77 (L-77) to tobacco aphids in the field using a high clearance sprayer, 1996

Treatments	Mean % aphid mortality after 24 h (± SEM)*	
	840 L/ha	1400 L/ha
Heptanoyl sucrose esters + 1% G-31 + 0.1% L-77	11 ± 14.5 a	29 ± 11.8 abc
Octanoyl sucrose esters + 1% G-31 + 0.1% L-77	22 ± 8.5 abc	38 ± 25.7 bc
Nonanoyl sucrose esters + 1% G-31 + 0.1% L-77	18 ± 22.9 ab	21 ± 14.9 abc
Decanoyl sucrose esters + 1% G-31 + 0.1% L-77	12 ± 3.1 ab	33 ± 15.6 bc
N. gossei sugar esters + 1% G-31 + 0.1% L-77	26 ± 12.8 abc	48 ± 9.0 c

* Means followed by the same letter in entire table (separation by column was done, result was the same as that by entire table) are not significantly different (α = 0.05, Waller-Duncan K-ratio T-test, SAS Institute 1990).

This study, and our previous research (Xia and Johnson, 1997, Xia et al. 1997), suggest that three major problems should be solved before synthetic sucrose esters or sugar esters can be used to control aphids. These problems are (1) relatively low efficacy in a field environment, (2) direct contact required for toxicity, and (3) reliance on leaf surface moisture and high relative humidity. We might be able to solve the first problem by designing new structures of sucrose esters (Plummer 1992). It is also possible to overcome the third problem by the addition of humectants or surfactants in field applications (Xia et al. 1997). Whether or not we are able to solve the second problem depends on the mode of action of sucrose esters. If sucrose esters function by disrupting cuticle structure (Puterka and Severson 1995), there may be very little we can do to change the required contact toxicity of sucrose esters. However, if sucrose esters affect the insect's nervous system like most insecticides, we may be able to make sucrose esters become systemic by changing the polarity of the molecules. Therefore, further research should be focused on the mode of action of sucrose esters to aphids and other insect pests.

One of the major efforts that leads to the development of lead compounds into commercial insecticides is understanding the relationship between biological activity and chemical structures. This research has provided some information on the structure-activity relationships of sucrose esters. The synthetic octanoyl sucrose esters were the most effective sucrose esters. Therefore, it is necessary to study the insecticidal activity of different isomers of octanoyl sucrose esters. Also, studies are needed to clarify the effects of different structures of acyl groups on the insecticidal activity of a sucrose ester molecule.

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