Assays of Orchard-Applied Insecticides on the Brown Stink Bug (Hemiptera: Pentatomidae) Feeding on Pecan[1]

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Abstract The brown stink bug, *Euschistus servus* (Say) (Hemiptera: Pentatomidae), is an economic pest of pecan, *Carya illinoinensis* (Wangenh.) K. Koch (Juglandaceae), and other agronomic crops across the southeastern United States. The efficacy of many insecticides against *E. servus* attacking pecan is not well documented even though the label for many of these insecticides may indicate one or more stink bug species as targets. Thus, we assayed various insecticides, labeled for application to pecan, to determine efficacy against *E. servus*. Insecticides were applied to pecan limb terminals with nut clusters in orchards in Georgia and Texas during 2009 and 2010. Treated limb terminals were cut from the tree and taken to the laboratory 1, 4, and 7 d after treatment. Treated nuts or limb terminals (i.e., nuts and foliage) were placed individually in cups or cylinder cages, respectively, and adult *E. servus* then placed into these containers. Mortality and moribundity of *E. servus* were recorded at 24, 48, or 72 h in addition to rating feces production at 72 h in some trials. Results consistently indicate that bifenthrin provided greater control of adult *E. servus* for a longer time after application than other products, including the organophosphate chlorpyrifos. Aside from bifenthrin also affecting the feces rating, the only other treatment that reduced feces production compared with untreated nuts was λ-cyhalothrin + thiamethoxam.

Key Words *Carya illinoinensis*, feces rating, insecticide label, residual activity

The brown stink bug, *Euschistus servus* (Say) (Hemiptera: Pentatomidae), is a polyphagous pest of economic concern to numerous row and orchard crops, including pecan, *Carya illinoinensis* (Wangenh.) K. Koch, across much of the southcentral and southeastern United States (Jones and Sullivan 1982, Tedders et al. 1990, Woodside 1946). Pecan, the most valuable native nut crop in North America, is grown commercially in improved-cultivar orchards across the southern United States from the East Coast to the West Coast and is also managed in native stands within its natural range. Pecan fruits are subject to stink bug feeding injury soon after pollination in the spring through harvest in the fall.

Damage to pecan fruit by different pentatomid species is similar (Dutcher and Todd 1983, Yates et al. 1991). Their feeding reduces both kernel quality and yield. Stylet penetration through the shell of developing fruit before the shell hardens causes the kernel to rot, and fruits generally abscise. Stink bugs feeding after the

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kernel reaches dough stage and the shell has hardened leave localized black lesions on the mature kernel, but fruits do not abscise (Demaree 1922, Osburn et al. 1966). Lesions on kernels are bitter and must be separated after harvesting (Demaree 1922, Osburn et al. 1966, Turner 1923). Payne and Wells (1984) reported that 52% of these pentatomid-induced lesions harbored various genera of fungi, including *Penicillium*, *Alternaria*, *Fusarium*, and *Aspergillus*.

Recommendations for stink bug control in orchard crops of the southern United States, especially pecan and peach (*Prunus persica* [L.] Batsch), rely heavily on pyrethroid insecticides (Horton et al. 2010, Hudson et al. 2010). However, *E. servus* is still very difficult to control due to its inherently low susceptibility to many of these insecticides and/or the short residual activity of these materials (Tillman and Mullinix 2004). Other pest pentatomid species, such as *Chinavia hilaris* (Say) and *Nezara viridula* (L.), have proved more susceptible to many of the commonly used pyrethroids (Hopkins et al. 2009, Snodgrass et al. 2005). Management difficulties are often compounded by large numbers of highly mobile *E. servus* adults continuing to move into orchards for multiweek periods of time, especially in late May/early June and then again in late September/early October as nymphs developing on weed and crop hosts mature to adults (Cottrell et al. 2000).

Many insecticide products are available for management of stink bugs; however, their efficacy and residual activity when applied in pecan orchards against *E. servus* generally is not well documented. The objective of this study was to determine the efficacy of some insecticides that are labeled for use in pecan orchards and when that insecticide label also indicates that the product can be used to manage one or more species of stink bugs. Additionally, feces ratings were conducted to assess relative feeding on pecan nuts treated with different products.

Materials and Methods

Study locations. This study was conducted during the summer and fall of 2009 and 2010 in research pecan orchards at the USDA, Agricultural Research Service, Southeastern Fruit and Tree Nut Research Laboratory in Byron, GA, and in a commercial pecan orchard near Caldwell, TX.

Stink bugs. Brown stink bug adults were collected in the field from pheromone-baited pyramidal traps (Cottrell 2001, Cottrell and Horton 2011, Mizell and Tedders 1995) at both locations. Additionally, adults were captured with a sweep net from various host plants at the Texas location. When adults were needed for assays, traps were monitored daily or collected by sweep net. The pheromone used in these traps is an aggregation pheromone, that is, methyl (2,4)-decadienoate, that is attractive to *Euschistus* spp.; nymphs along with adult male and female stink bugs are attracted (Aldrich et al. 1991). Collected adults were taken to the laboratory, housed in plastic containers, and provided green beans (*Phaseolus vulgaris* L.) and ears of field corn (*Zea mays* L.). These adults were maintained under a summer photoperiod of 14:10 h (L:D) and at 25°C for 48 h and then used in an assay, usually within 7 d of being collected from the field.

Insecticides. The insecticides used in this study were labeled for application to commercial pecan orchards in both Georgia and Texas (Tables 1, 2) but also for application to multiple crop species. Each label for each product tested listed certain

Table 1. Insecticides used to treat pecan at Byron, GA, and Caldwell, TX, 2009.

Active Ingredient	Class of Chemistry*	Range of Label Field Rates (935 L^{-1})	Selected Treatment Rate (935 L^{-1})	Formulated Material (L^{-1})	Active Ingredient (g L^{-1})	Pentatomid(s) on Insecticide Label
Bifenthrin**,†	P	0.56–2.24 kg	2.24 kg	2.40 g	0.240	Stink bugs
Thiamethoxam**,†	N	0.14–0.18 kg	0.18 kg	0.19 g	0.075	*Thyanta custator*
λ-Cyhalothrin**	P	187–374 ml	374 ml	0.40 ml	0.048	Stink bug species
Thiamethoxam + λ-cyhalothrin**,†	N + P	365–438 ml	402 ml	0.43 ml	0.061 + .045‡	Stink bug species
Zeta-cypermethrin**,†	P	234–292 ml	292 ml	0.31 ml	0.030	Stink bugs
Chlorpyrifos**,†	O	1.2–4.7 L	4.7 L	5.03 ml	2.41	*Nezara viridula*

* N: neonicotinoid; O: organophosphate; P: pyrethroid.
** Used in Experiments 1 and 2, Byron, GA.
† Used in Experiment 1, Caldwell, TX.
‡ Thiamethoxam + λ-cyhalothrin, respectively.

Table 2. Insecticides and rates used to treat pecan at Byron, GA, and Caldwell, TX, 2010.

Active Ingredient	Class of Chemistry*	Labeled Rates (Ha^{-1})	Treatment Rate ($935\ L^{-1}$)	Formulated Material (L^{-1})	Active Ingredient ($g\ L^{-1}$)	Pentatomid(s) on Insecticide Label
Bifenthrin**,†,‡	P	0.56–2.24 kg	0.56 kg	0.60 g	0.06	Stink bugs
			0.84 kg	0.90 g	0.09	
Imidacloprid + bifenthrin**	N + P	0.82–1.64 L	935 ml	1.0 ml	0.057 + 0.057£	Stink bug species
			1.87 l	2.0 ml	0.114 + 0.114£	
Imidacloprid + bifenthrin‡	N + P	468–935 ml	468 ml	0.5 ml	0.057 + 0.057£	Stink bug species
			935 ml	1.0 ml	0.113 + 0.113£	
Imidacloprid†	N	205–468 ml	468 ml	0.50 ml	0.120	GSB, BSB, SGSB§
Thiamethoxam + λ-cyhalothrin†	N + P	365–438 ml	402 ml	0.430 ml	0.061 + .045¥	Stink bug species

* N: neonicotinoid; P: pyrethroid.
** Used in Experiments 1 and 2, Byron, GA.
† Used in Experiment 1, Caldwell, TX.
‡ Used in Experiment 2, Caldwell, TX.
£ Imidacloprid + bifenthrin, respectively.
§ GSG: *Chinavia hilaris*; BSB: *Euschistus servus*; SGSB: *Nezara viridula*.
¥ Thiamethoxam + λ-cyhalothrin, respectively.

species of Pentatomidae or "stink bug species" as target pests for at least one crop species on the label; the label may or may not have listed one or more species of Pentatomidae as a target pest on pecan (Tables 1, 2). Nonetheless, these products are commonly used on pecan against other pest species listed on the insecticide label and at a time when pecan fruits are susceptible to injury by Pentatomidae (Hudson et al. 2010, Knutson et al. 2010). It is understandable that product users could expect that efficacy against species of Pentatomidae on other crop species should also extend to efficacy against Pentatomidae attacking pecan.

Insecticides assayed in this study included: bifenthrin (Brigade® WSB Insecticide/Miticide; FMC Corporation, Philadelphia, PA); thiamethoxam (Centric® 40WG; Sygenta Crop Protection, Inc., Greensboro, NC); zeta-cypermethrin (Mustang Max™ Insecticide; FMC Corporation); thiamethoxam + λ-cyhalothrin (Endigo® ZC; Syngenta); imidacloprid + bifenthrin (Swagger®; Loveland Products, Inc., Loveland, CO, and Bridgadier® Insecticide: FMC Corporation); chlorpyrifos (Warhawk®; Loveland Products, and Govern® 4E Insecticide; Tenkōz, Inc., Alpharetta, GA); imidacloprid (Macho® 2.0 FL; Albaugh, Inc., Ankeny, IA); λ-cyhalothrin (Karate® Insecticide with Zeon Technology™; Syngenta).

Insecticide assays. Assays using a treated nut placed in a cup and provisioned with a stink bug were conducted at Byron, GA, and Caldwell, TX, during 2009 (Table 1) and 2010 (Table 2). Two replicated experiments were conducted each year (2009 and 2010) at Byron, GA. One replicated experiment was conducted at Caldwell, TX, during 2009 and two replicated experiments were completed in 2010. We used a randomized complete block design (RCBD) each year, always using four (Byron, GA) or three (Caldwell, TX) replicates. Within a replicate, a single treatment was applied to foliage and nut clusters of marked pecan terminals on one tree. Treated nuts were still within the nondehisced (i.e., closed, green) shuck. Multiple terminals (with nut clusters) on a tree were treated to obtain the required number of treated nuts for an assay; assays were conducted 1 and 4 or 1, 4, and 7 d after treatment. When a second experiment was conducted, different trees (without prior insecticide application) were selected to receive treatments. Care was taken to prevent the possibility of drift among trees that received different treatments. During 2009, insecticide treatments were applied on 28 September (Experiment 1) and 8 October (Experiment 2) in Georgia and on 29 September in Texas using rates as indicated in Table 1. During 2010, insecticide treatments were applied on 14 October (Experiment 1) and 21 October (Experiment 2) in Georgia and on 14 August (Experiment 1) and 7 October (Experiment 2) in Texas using rates as indicated in Table 2. Insecticides were prepared in 3.78 L of water equivalent to the typical grower application of 935 L/ha. Treatments were applied to nut clusters on pecan terminals in orchards using a flat fan nozzle on a 3.78-L manual pump sprayer (Hudson® model 30161, Hastings, MN, or Spectracide™ model 27019, Chapin International Inc., Batavia, NY). Applications approached, but did not exceed, runoff and thus were commensurate with grower applications of 935 L/ha to pecan. Again, care was taken such that treated nut clusters on pecan terminals were spaced apart to prevent overspray or drift between adjacent treatments.

At 1, 4, and 7 d after treatment (2009 Experiment 1, GA; 2010 Experiment 1, GA and Experiment 2, TX) and at 1 and 4 d after treatment (2009 Experiment 2, GA and TX; 2010 Experiment 2, GA and Experiment 1, TX), nut clusters were cut from treated pecan terminals and taken to the laboratory. In the laboratory, each treatment (within a replicate) used 10 nuts that were placed singly into lidded cups (266-ml cups [Eco Products®, Boulder, CO] were used in GA and 133-ml cups [VWR International LLC, Radnor, PA] were used in TX) and a single adult brown stink bug was placed in the cup. Thus, 10 insects were used for each treatment in each of the 4 or 3 replicates for the GA or TX locations, respectively. The cups containing a pecan and a stink bug were placed, using a RCBD, in a controlled environment incubator at 25 $\pm$ 1°C and a 14:10 h (L:D) photoperiod. Stink bugs were observed for percentage mortality + moribundity after 24, 48, and 72 h in the cup (2009 and 2010 Experiments 1 and 2, GA) or after 24 and 48 h in the cup (2009, TX; 2010 Experiments 1 and 2, TX). Moribund insects were alive but unable to right themselves when turned over or did not exhibit coordinated movement. In addition, for the studies in GA during 2009 and 2010, after stink bugs had been in cups with nuts for 72 h, the amount of feces produced was rated (0, none; 1, light; 2, heavy) but only if the stink bug was alive at 72 h. This was done for nuts collected from the orchard 1, 4, and 7 d after treatment.

An assay using a treated limb terminal (i.e., foliage, limb, and nut cluster) was conducted in GA during 2009. This assay tested exposure of adult stink bugs to the entire limb terminal, as when stink bugs are in a pecan tree, treated with bifenthrin (0.56, 1.12, 1.40, 1.68, or 2.24 kg a.i./ha) and a nontreated control limb terminal. Treatments were prepared and applied, similarly as before, to nut clusters and foliage of the pecan terminal. Four replicates of each treatment were used. At 1, 4, and 7 d after treatment, terminals were cut from trees and taken to the laboratory. For each terminal, the cut end was placed into a 500-ml Erlenmeyer flask filled with water. The opening of the flask, with the protruding terminal, was wrapped with Parafilm® (Bemis Flexible Packaging, Neenah, WI) to prevent stink bugs from entering the flask. This arrangement of the terminal and flask was then placed into a transparent cylinder cage. The cylinder (height 45 cm, radius 14.5 cm) was made of clear polyester film and was enclosed, top and bottom, using standard white bucket lids (United States Plastic Corp., Lima, OH) that had been vented by cutting a hole in each lid and covering with plastic mesh to prevent stink bugs escaping. Ten adult *E. servus* ($n = 40$ per treatment) were then added to the cylinder and were visually confirmed to have crawled onto the pecan terminal. The cylinders were then left undisturbed at room temperature and a 14:10 h (L:D) photoperiod for 48 h after which the cages were examined and the number of live, moribund, and dead bugs was recorded.

Statistical analyses. The percentages of stink bugs that were nonfeeding, i.e., dead + moribund, at the observation intervals (i.e., 24, 48, and 72 h) were analyzed by location using a univariate repeated-measures analysis of variance (ANOVA) each time pecan fruit were collected (i.e., 1 and 4 or 1, 4, and 7 d after treatment) (SAS Institute 2013). In this model, the effect of treatment was tested with respect to the variation from replicate to replicate and the repeated-measures factor for the "observation intervals" (3 or 2 for GA and 2 for TX) was tested with respect to the variation from the different observation intervals within a replicate. The within-replicate variability was reflected in the residual error. The effect of observation interval used the residual error for the denominator of its *F* statistics. However, the between-replicate variability was not measured by residual error but was captured with the replicate within-treatment effect in the model. The *F* statistic for the between-replicate effect treatment used this nested effect instead of the residual error for its F ratio denominator. For the feces rating, the average score was analyzed using one-way ANOVA. If a treatment did not have any living bugs, a feces rating for that treatment was excluded from analysis. Data collected at 48 h from the pecan terminal assay (1, 4, and 7 d after treatment) were analyzed using one-way ANOVA. For all analyses, if a significant treatment effect was detected ($P < 0.05$), Tukey's Honestly Significant Difference test was used to separate means (SAS Institute 2013).

Results

Cup assays: 2009 and 2010. A significant treatment effect was detected 1 d after treatment during the first experiment conducted in GA ($F = 10.36$; df = 6, 21; $P < 0.0001$). Bifenthrin resulted in a higher percentage of dead + moribund stink bugs than all other treatments except chlorpyrifos (Fig. 1A). Similarly, at both 4 and 7 d after treatment, a significant treatment effect was detected ($F = 25.86$; df = 6, 21; $P < 0.0001$ and $F = 59.42$; df = 6, 21; $P < 0.0001$, respectively) and each time, only bifenthrin resulted in a higher percentage of nonfeeding stink bugs (Fig. 1B, C). Rating for feces was not analyzed for bifenthrin and chlorpyrifos treatments 1 d after treatment or for bifenthrin 4 d after treatment due to very low numbers of stink bugs. For the remaining treatments and control 1 d after treatment, no difference was detected in feces production but statistical significance was approached ($F = 3.14$; df = 4, 12; $P = 0.0553$). At 4 d after treatment, feces production was significantly higher for the control, thiamethoxam, and zeta-cypermethrin than for thiamethoxam + λ-cyhalothrin ($F = 8.95$; df = 5, 15; $P = 0.0004$) (Fig. 2A). The feces rating 7 d after treatment was different among treatments ($F = 22.52$; df = 6, 18; $P < 0.0001$) and was significantly lower for bifenthrin than all other treatments and the control. The rating for thiamethoxam + λ-cyhalothrin was lower than the control, chlorpyrifos, and zeta-cypermethrin (Fig. 2B).

During the second experiment conducted in GA (2009), a significant treatment effect was detected 1 d after treatment ($F = 5.44$; df = 6, 20; $P = 0.0018$) when chlorpyrifos resulted in a higher percentage of nonfeeding stink bugs 1 d after treatment than all other treatments except bifenthrin and the combination treatment of thiamethoxam + λ-cyhalothrin (Fig. 3A). At 4 d after treatment, a significant treatment effect was detected again ($F = 3.13$; df = 6, 20; $P = 0.0249$); however, the only significant difference occurred between bifenthrin and the control treatment (Fig. 3B). The difference in results, 4 d after treatment in the second experiment, from the first experiment is likely because 0.46 and 1.45 cm of rain occurred during the second Experiment 2 and 4 d after treatment, respectively, before pecan nuts were collected for the 4 d after treatment assessment. An assay was not conducted at 7 d after treatment for this second experiment because by that time there had been 5.66 cm of rain since treatment application. Concerning the feces rating 1 d after treatment, bifenthrin and thiamethoxam + λ-cyhalothrin were both significantly lower than the control, and bifenthrin was lower than thiamethoxam ($F = 5.40$; df = 6, 26; $P = 0.0028$) (Fig. 2C). At 4 d after treatment, there were no treatment differences for the feces rating ($F = 1.94$; df = 6, 26; $P = 0.1313$) likely due to rainfall that occurred.

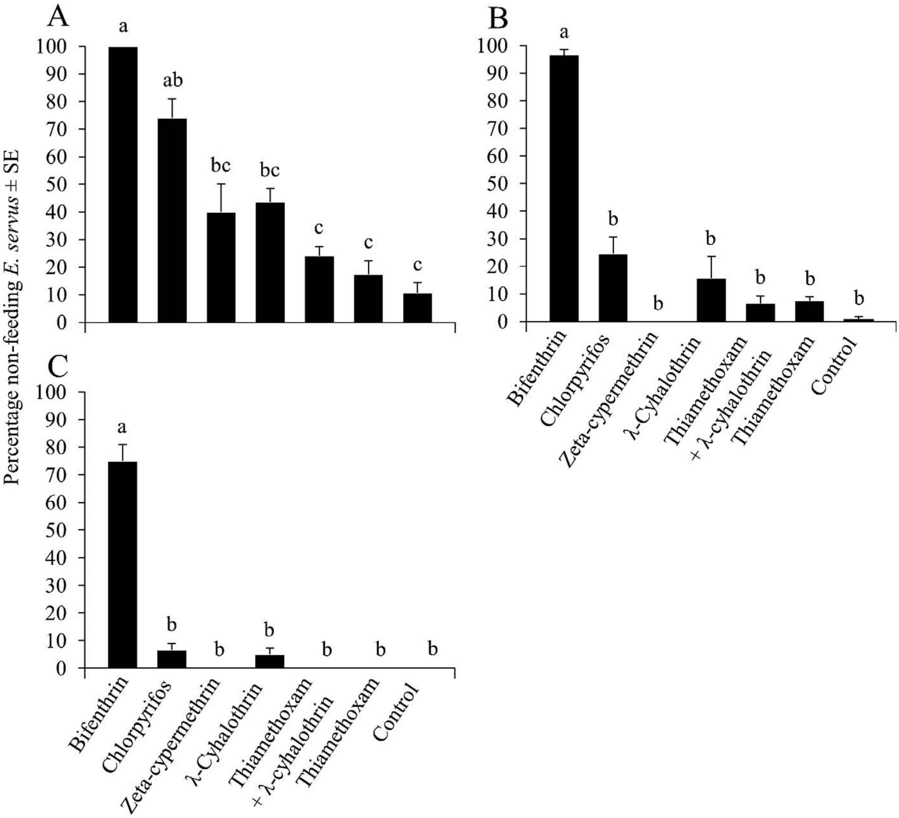

Fig. 1. Percentage of nonfeeding (i.e., dead + moribund) *E. servus* adults (Byron, GA, 2009) when placed singly in a cup with an insecticide-treated or nontreated pecan nut 1, 4, or 7 d after treatment (A, B, and C, respectively). Repeated-measures analysis of variance was performed on nonfeeding *E. servus* as observed at 24, 48, and 72 h after placement of the adult in the cup. Different letters above columns indicate a significant difference between treatments (Tukey's Honestly Significant Difference, $P < 0.05$).

When the experiment was conducted in TX a significant treatment effect was detected 1 d after treatment ($F = 100.43$; df = 5, 12; $P < 0.0001$). Bifenthrin resulted in a higher percentage of nonfeeding stink bugs than all other treatments (Fig. 4A). The chlorpyrifos treatment, although significantly lower than bifenthrin, resulted in a higher percentage of nonfeeding stink bugs than the remaining treatments. At 4 d after treatment, a significant treatment effect was detected ($F = 32.49$; df = 5, 12; $P < 0.0001$) but only bifenthrin resulted in a higher percentage of nonfeeding stink bugs (Fig. 4B).

During the first experiment of 2010 in GA, a significant treatment effect was detected 1, 4, and 7 d after treatment ($F = 20.81$; df = 4, 15; $P < 0.0001$, $F = 12.71$;

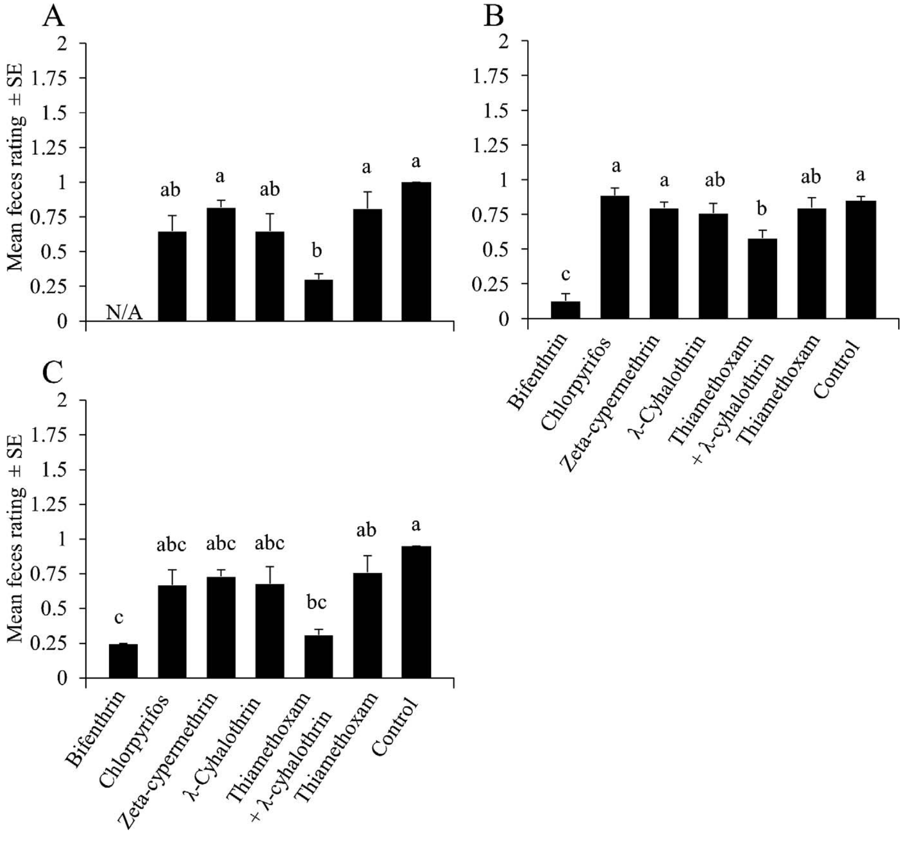

Fig. 2. Mean rating for feces production by adult stink bugs (0, none; 1, light; 2, heavy), after 72 h, when provided a pecan nut treated with an insecticide or a nontreated nut (A) 4 or (B) 7 d after treatment during Trial 1 and (C) 1 d after treatment during Trial 2 at Byron, GA, in 2009. Different letters above columns indicate a significant difference between treatments (Tukey's Honestly Significant Difference, P < 0.05).

df = 4, 15; P = 0.0001, F = 6.17; df = 4, 15; P = 0.0038, respectively). Regardless of how many days after treatment, both rates of the bifenthrin-only product always resulted in a significantly higher percentage of nonfeeding stink bugs compared with the control treatment at 1, 4, and 7 d after treatment (Fig. 5A, B, C). The higher rate of bifenthrin + imidacloprid resulted in a significantly higher percentage of nonfeeding stink bugs, compared with the control at 1 d after treatment but not at 4 or 7 d after treatment; whereas, the low rate of this treatment was never significantly different from the control (Fig. 5A, B, C). Feces ratings were different at 1, 4, and 7 d after treatment with a significantly higher rating for the control than for any of the treatments each time (F = 12.64; df = 4, 12; P = 0.0003, F = 30.88; df = 4, 12; P < 0.0001, F = 11.03; df = 4, 12; P = 0.0005, respectively) (Fig. 6A, B, C).

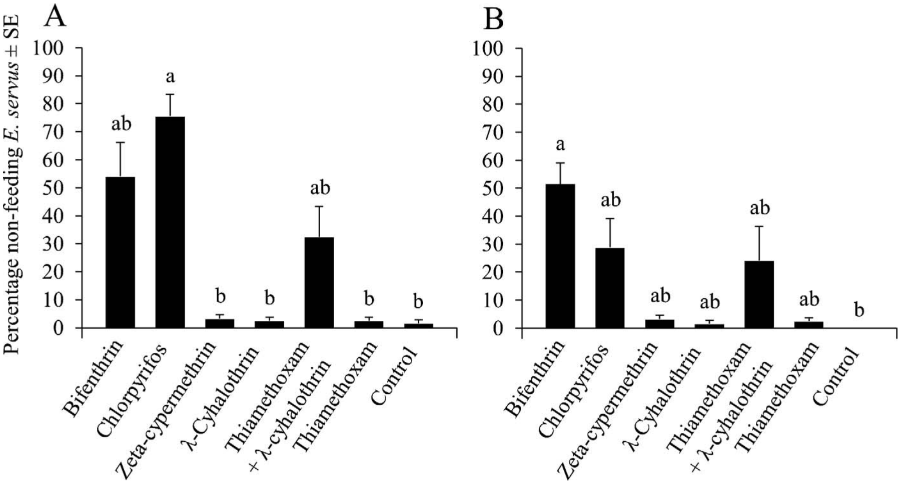

Fig. 3. Percentage of nonfeeding (i.e., dead and moribund) *E. servus* adults (Byron, GA, 2009) when placed singly in a cup with an insecticide-treated or nontreated pecan nut 1 or 4 d after treatment (A and B, respectively). Repeated-measures analysis of variance was performed on nonfeeding *E. servus* as observed at 24 and 48 h after placement of the adult in the cup. Different letters above columns indicate a significant difference between treatments (Tukey's Honestly Significant Difference, $P < 0.05$).

The second experiment during 2010 in GA also detected a significant treatment effect at 1, 4, and 7 d after treatment ($F = 20.69$; df = 4, 15; $P < 0.0001$, $F = 15.61$; df = 4, 15; $P < 0.0001$, $F = 3.30$; df = 4, 15; $P = 0.0395$, respectively). At 1 d after treatment, both rates of both products resulted in a significantly higher percentage of nonfeeding stink bugs compared with the control (Fig. 7A). At 4 d after treatment, both rates of bifenthrin resulted in significantly more nonfeeding stink bugs than the control; whereas, this only occurred with the higher rate of bifenthrin + imidacloprid (Fig. 7B). At 7 d after treatment, only the higher rate of bifenthrin + imidacloprid was significantly higher than the control (Fig. 7C). Feces ratings were different at 1, 4, and 7 d after treatment, with a significantly higher rating for the control than for any of the treatments each time ($F = 12.13$; df = 4, 12; $P = 0.0004$, $F = 78.51$; df = 4, 12; $P < 0.0001$, $F = 9.66$; df = 4, 12; $P = 0.0010$, respectively) (Fig. 8A, B, C).

During the first experiment of 2010 in TX, a significant treatment effect was detected at 1 and 4 d after treatment ($F = 33.13$; df = 4, 10; $P < 0.0001$ and $F = 12.97$; df = 4, 10; $P = 0.0006$, respectively). Both rates of bifenthrin resulted in a significantly higher percentage of nonfeeding stink bugs 1 d after treatment compared with the other treatments. The imidacloprid treatment and the λ-cyhalothrin + thiamethoxam treatments were not different from the control at either 1 or 4 d after treatment (Fig. 9A, B). At 4 d after treatment, the higher rate of the bifenthrin product was significantly different from all other treatments, except the low

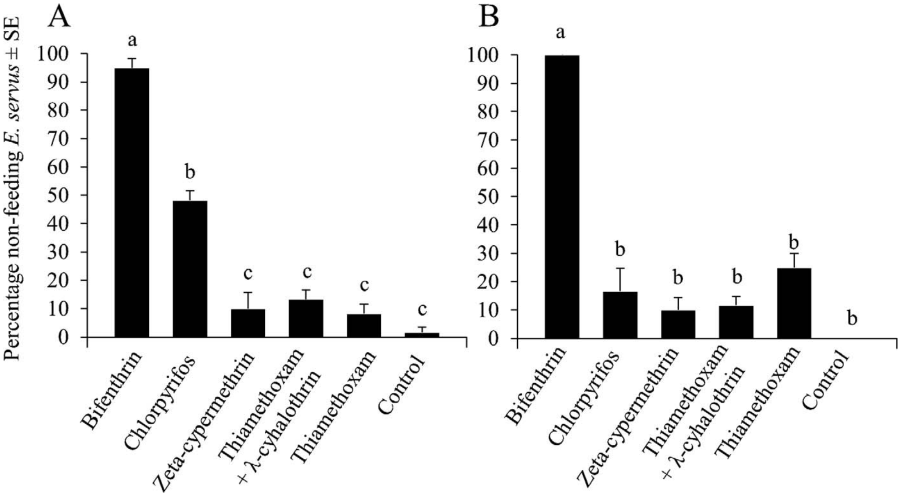

Fig. 4. Percentage of nonfeeding (i.e., dead and moribund) *E. servus* adults (Caldwell, TX, 2009) when placed singly in a cup with an insecticide-treated or nontreated pecan nut 1 or 4 d after treatment (A and B, respectively). Repeated-measures analysis of variance was performed on nonfeeding *E. servus* as observed at 24 and 48 h after placement of the adult in the cup. Different letters above columns indicate a significant difference between treatments (Tukey's Honestly Significant Difference, $P < 0.05$).

rate of bifenthrin, and no other treatment was significantly different from the control (Fig. 9B).

The second experiment during 2010 in TX detected a significant treatment effect at 1, 4, and 7 d after treatment ($F = 187.86$; df = 4, 10; $P < 0.0001$, $F = 548.08$; df = 4, 10; $P < 0.0001$, $F = 51.07$; df = 4, 10; $P < 0.0001$, respectively). At 1 d after treatment, both rates of both insecticides (i.e., bifenthrin and bifenthrin + imidacloprid) resulted in a significantly higher percentage of nonfeeding stink bugs compared with the control (Fig. 10A). At 4 d after treatment, all treatments resulted in significantly more nonfeeding stink bugs than the control (Fig. 10B); only the low rate of bifenthrin + imidacloprid was lower than the other treatments. At 7 d after treatment, both rates of both treatments resulted in a similar and significantly higher percentage of nonfeeding stink bugs than the control (Fig. 10C).

Limb terminal assay. When treatments were applied to the bark, foliage, and nut cluster of an entire branch terminal and caged together with adult stink bugs for 48 h at 1, 4, and 7 d after treatment, a significant treatment effect was detected each time ($F = 13.46$; df = 5, 15; $P < 0.0001$, $F = 14.48$; df = 5, 15; $P < 0.0001$, and $F = 11.43$; df = 5, 15; $P < 0.0001$, respectively). At 1, 4, and 7 d after treatment a higher percentage of nonfeeding stink bugs was found in each treatment rate compared with the control. The only difference among rates was at 4 d after treatment between the lowest and highest bifenthrin rates (Fig. 11A, B, C).

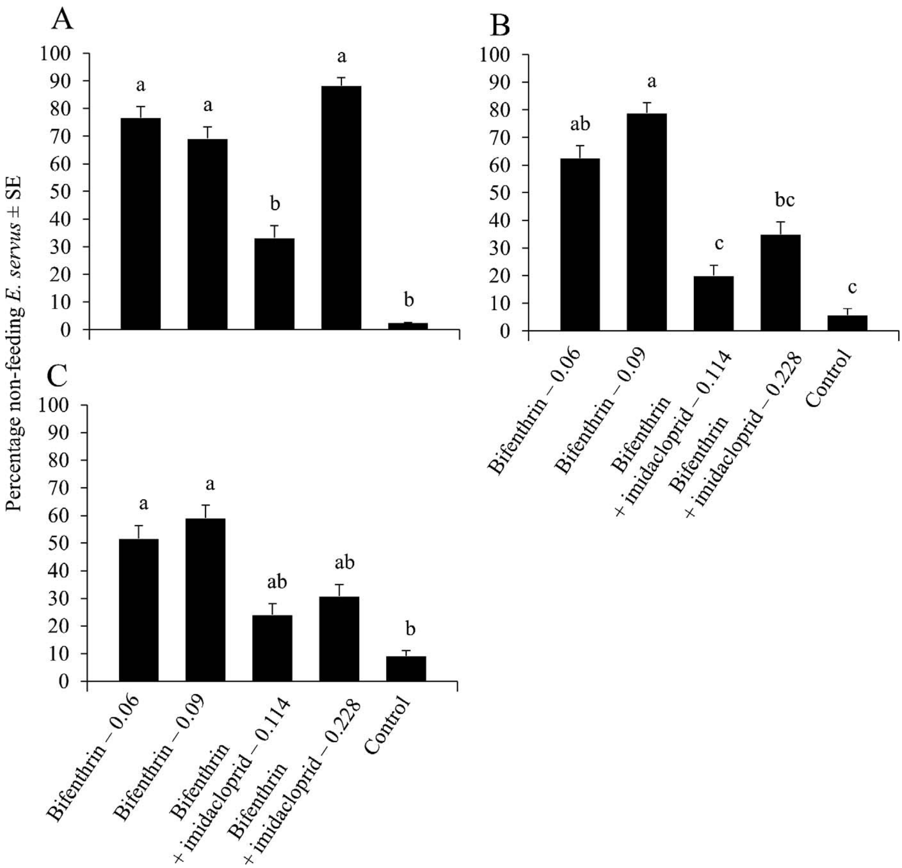

Fig. 5. Percentage of nonfeeding (i.e., dead and moribund) *E. servus* adults (Byron, GA, 2010) when placed singly in a cup with an insecticide-treated or nontreated pecan nut 1, 4, or 7 d after treatment (A, B, and C, respectively). Bifenthrin was applied at 0.6 and 0.9 g product per liter. The bifenthrin + imidacloprid combination product was applied at 1.0 and 2.0 ml product per liter. Repeated-measures analysis of variance was performed on nonfeeding *E. servus* as observed at 24 and 48 h after placement of the adult in the cup. Different letters above columns indicate a significant difference between treatments (Tukey's Honestly Significant Difference, $P < 0.05$).

Discussion

All insecticides used in this study listed one or more Pentatomidae on its label as target pests, but our results demonstrate that the different insecticides, even when used at high rates, do not provide the same outcome against *E. servus* when applied to pecan nut clusters. Thus, producers relying upon management of target

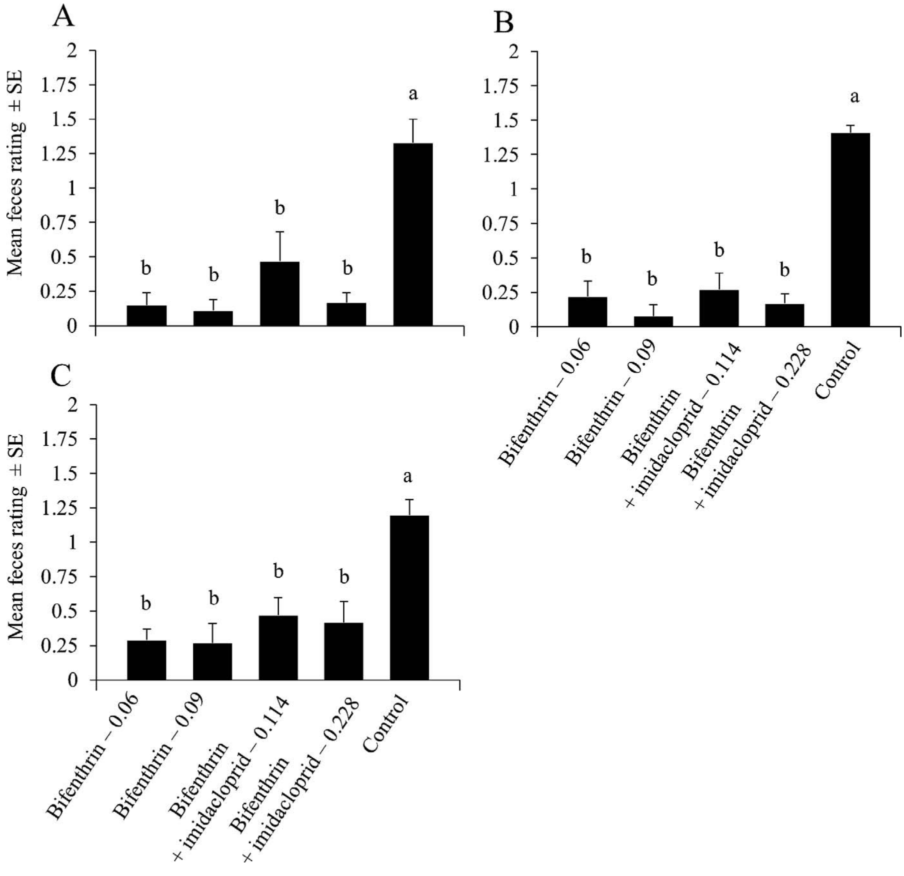

Fig. 6. Mean rating for feces production by adult stink bugs (0, none; 1, light; 2, heavy), after 72 h, when provided a pecan nut treated with two rates of two insecticides or a nontreated nut (A) 1, (B) 4 or (C) 7 days after treatment during Trial 1 at Byron, GA, in 2010. Different letters above columns indicate a significant difference between treatments (Tukey's Honestly Significant Difference, $P < 0.05$).

pests (as listed on an insecticide label) may not always achieve an expected level of control against a particular pest species. In fact, the label for the imidacloprid product specifically listed *E. servus* as a target pest, but the percentage of nonfeeding adults achieved was never different from the control treatment. Even still, when a particular pentatomid species is controlled using a certain rate of an insecticide, that does not guarantee control of another pentatomid species with that same rate. For example, Snodgrass et al. (2005) reported lower susceptibility of *E. servus* than *C. hilaris* and *N. viridula* to certain insecticides. Additionally, the efficacy of an insecticide can vary against the same species attacking different crops as when the combination of λ-cyhalothrin + thiamethoxam provided higher efficacy against *E. servus* attacking peach fruit than when applied to pecan fruit, possibly

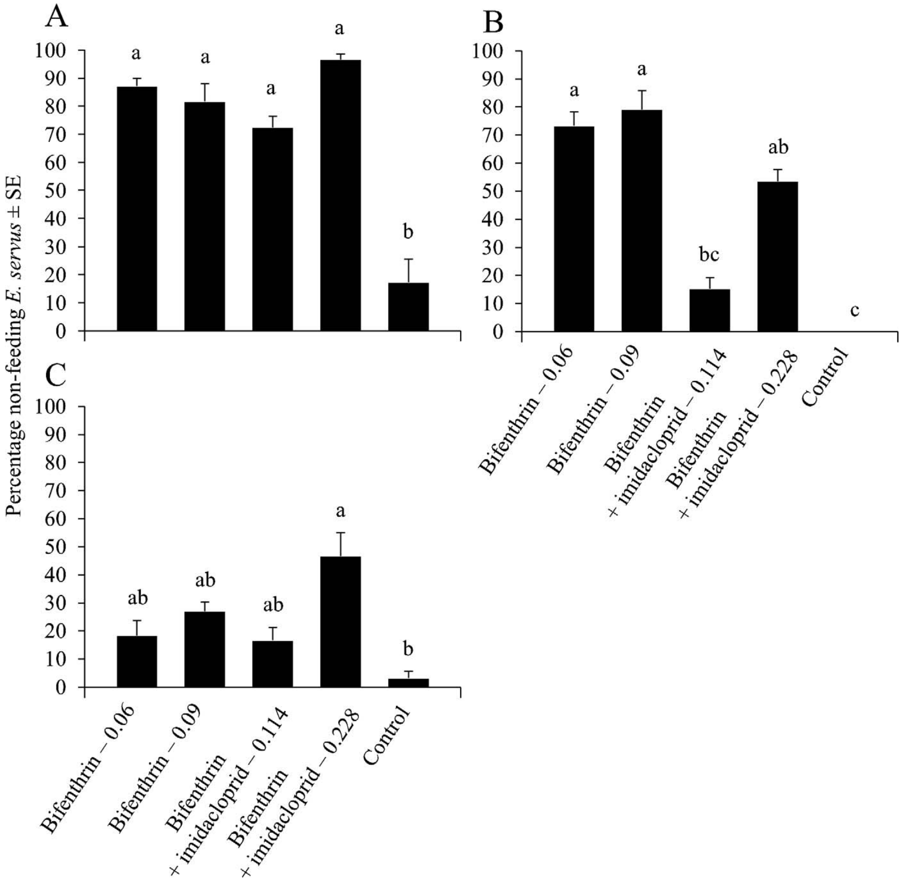

Fig. 7. Percentage of nonfeeding (i.e., dead and moribund) *E. servus* adults (Byron, GA, 2010) when placed singly in a cup with an insecticide-treated or nontreated pecan nut 1, 4, or 7 d after treatment (A, B, and C, respectively). Numbers following treatment names on the *x*-axis represent total grams active ingredient/liter. Repeated-measures analysis of variance was performed on nonfeeding *E. servus* as observed at 24, 48, and 72 h after placement of the adult in the cup. Different letters above columns indicate a significant difference between treatments (Tukey's Honestly Significant Difference, $P < 0.05$).

due to increased feeding on peach as evidenced by greater feces production (T.E.C. unpubl. data).

The literature contains numerous laboratory studies reporting the efficacies of insecticides against *E. servus* (Kamminga et al. 2009a, 2009b; López et al. 2012a, 2012b; Snodgrass et al. 2005; Willrich et al. 2003). Willrich et al. (2003) found that adult brown stink bugs were more susceptible to field rates of bifenthrin than other

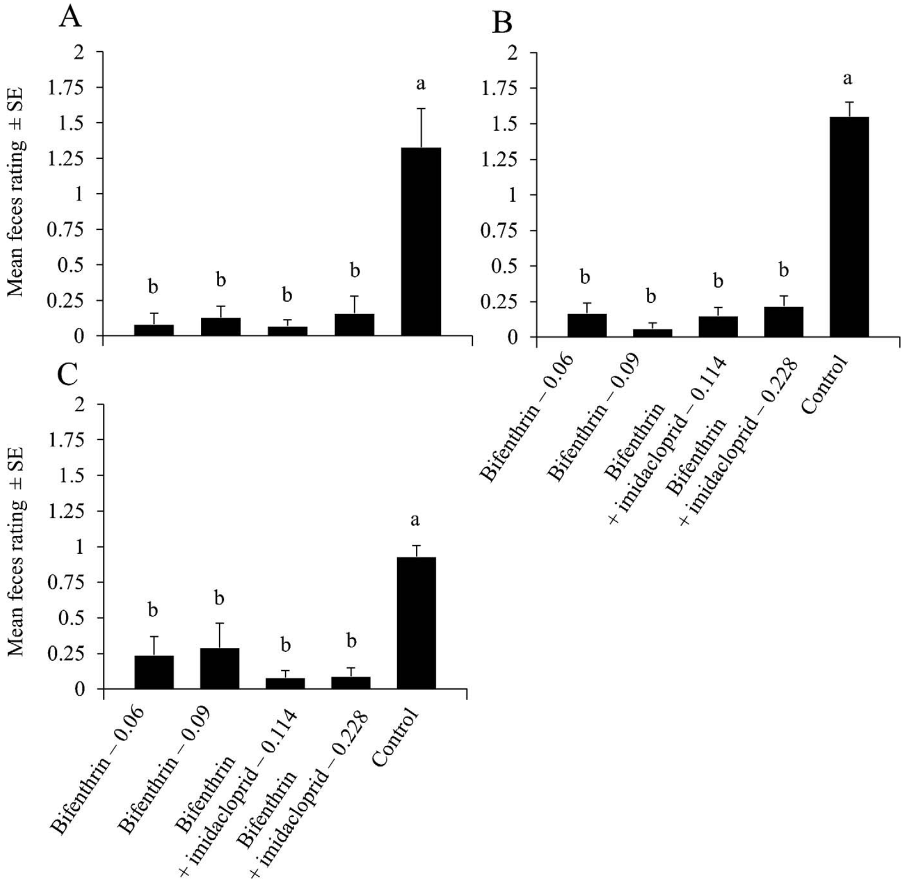

Fig. 8. Mean rating for feces production by adult stink bugs, after 72 h, when provided a pecan nut treated with two rates of two insecticides or a nontreated nut (A) 1, (B) 4, or (C) 7 d after treatment during Trial 2 at Byron, GA, in 2010. Different letters above columns indicate a significant difference between treatments (Tukey's Honestly Significant Difference, $P < 0.05$).

pyrethroid insecticides, and Snodgrass et al. (2005) also found that cyfluthrin was similarly toxic to *E. servus*. In another study, which did not include cyfluthrin, López et al. (2012a) found zeta-cypermethrin and γ-cyhalothrin similarly toxic as bifenthrin to *E. servus*. Additionally, these laboratory studies support the assertion that *E. servus* is less susceptible than *C. hilaris* or *N. viridula* to many insecticides.

In contrast to the laboratory studies, field studies typically do not show such a distinct separation among treatments. Insecticide treatments may increase stink bug mortality compared with the untreated control, but most are not significantly different from each other (Hopkins et al. 2009, Kamminga et al. 2009b, Willrich et al. 2003). For example, Kamminga et al. (2009b) used a green bean pod dip assay in

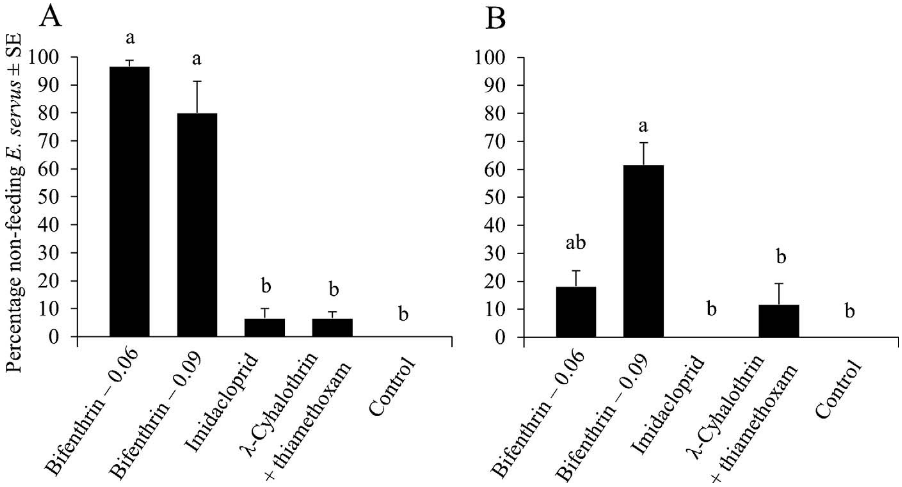

Fig. 9. Percentage of nonfeeding (i.e., dead and moribund) *E. servus* adults (Caldwell, TX, 2010) when placed singly in a cup with an insecticide-treated or nontreated pecan nut 1 or 4 d after treatment (A and B, respectively). Numbers following treatment names on the *x*-axis represent total grams active ingredient per liter. Repeated-measures analysis of variance was performed on nonfeeding *E. servus* as observed at 24 and 48 h after placement of the adult in the cup. Different letters above columns indicate a significant difference between treatments (Tukey's Honestly Significant Difference, $P < 0.05$).

the laboratory and found that the pyrethroids zeta-cypermethrin, λ-cyhalothrin, cyfluthrin, and fenpropathrin were similarly toxic to *E. servus*. When these and other insecticides were applied to soybean (*Glycine max* [L.] Merr.) in the field, most treatments had lower numbers of brown stink bugs than the untreated control, but there was little separation among treatment means up to 7–8 d after application (Kamminga et al. 2009b). Similarly, Hopkins et al. (2009) showed that insecticides applied to cotton (*Gossypium hirsutum* L.) killed more adult *E. servus* than the control, but there was no separation between insecticide treatments.

Field studies that record stink bug abundance in treated plots do not account for the amount of time that adult stink bugs have spent in a plot, nor would dead or moribund stink bugs that have fallen from the host plant normally be sampled. Thus, our study attempted to use the benefits of both field and laboratory settings. Treatments applied in orchard settings were exposed to normal orchard conditions (i.e., application to the surface of pecan fruits and foliage, sunlight, rainfall, and dew) but were then taken to the laboratory where mortality, moribundity, and feces production were examined under constant environmental conditions.

When examining host plant injury, stylet sheaths can be used to determine feeding activity (Bowling 1979, 1980), but Zeilinger et al. (2015) state that numbers of sheaths should not be used to infer food consumption or preference by adult *E.*

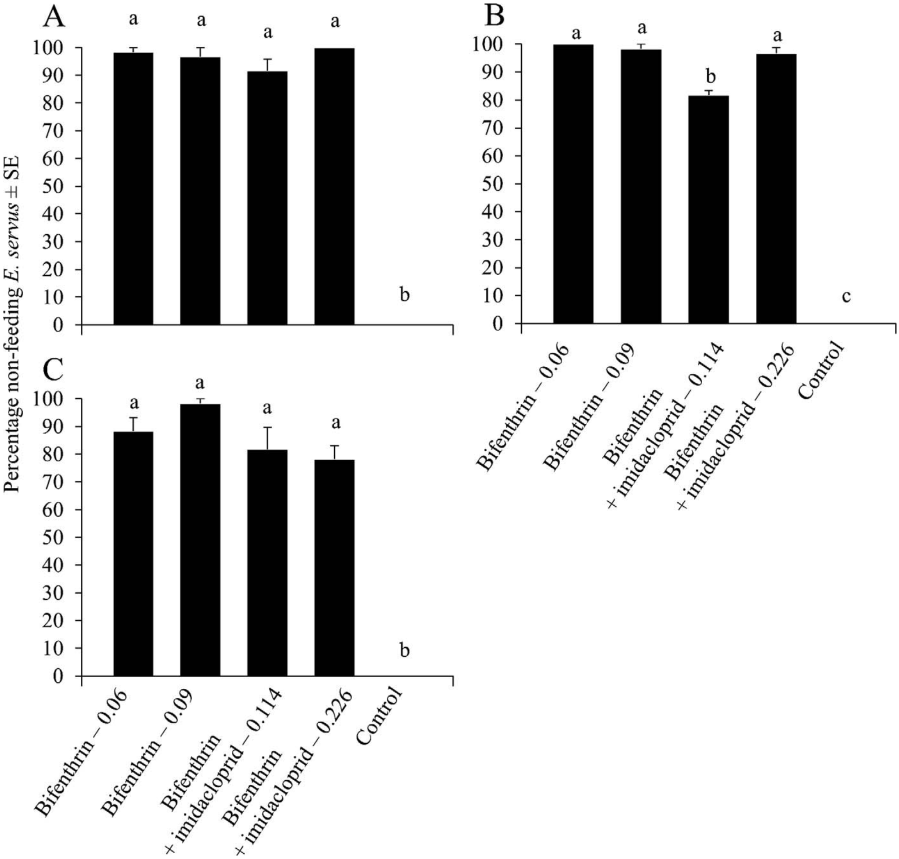

Fig. 10. Percentage of nonfeeding (i.e., dead and moribund) *E. servus* adults (Caldwell, TX, 2010) when placed singly in a cup with an insecticide-treated or nontreated pecan nut 1, 4, or 7 d after treatment (A, B, and C, respectively). Numbers following treatment names on the *x*-axis represent total grams active ingredient per liter. Repeated-measures analysis of variance was performed on nonfeeding *E. servus* as observed at 24, 48, and 72 h after placement of the adult in the cup. Different letters above columns indicate a significant difference between treatments (Tukey's Honestly Significant Difference, $P < 0.05$).

servus; those authors instead used quantity of feces produced as a proxy for food consumption. In our study, rating feces production was useful in that it provided additional information about the different treatments aside from mortality and moribundity. For instance, when the percentage of nonfeeding stink bugs was similar for some treatments, this rating showed that consumption was lower when treated with thiamethoxam + λ-cyhalothrin than many other treatments. This would

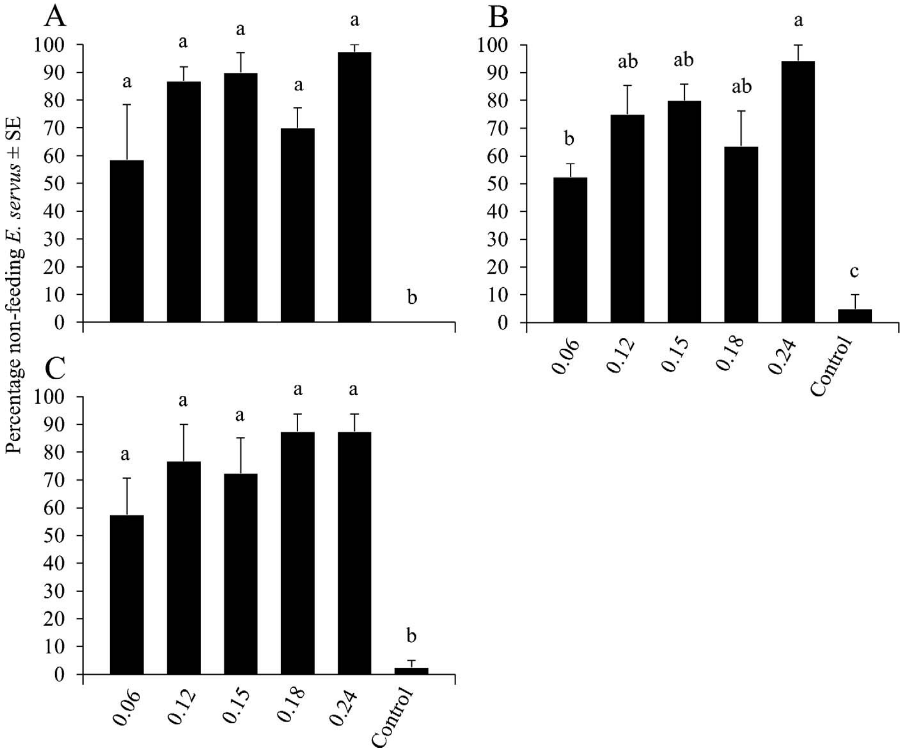

Fig. 11. Percentage of nonfeeding (i.e., dead and moribund) *E. servus* adults (Byron, GA, 2009) when placed in a cylinder cage with a bifenthrin-treated (0.06 to 0.24 g active ingredient/liter) or nontreated limb terminal (i.e., foliage and nuts) after 48 h (A) 1, (B) 4, or (C) 7 d after treatment. Different letters above columns indicate a significant difference between treatments (Tukey's Honestly Significant Difference, $P < 0.05$).

not have been detected otherwise and can be important, especially for other crops, for example, peach, that do not have a bifenthrin label.

Our results, when combining field and laboratory conditions, showed that target pests on labels are not always controlled and that bifenthrin provided overall better control of *E. servus* than other insecticides tested. Although other untested insecticides may perform at a similar level, the information presented here can be used in pecan orchards and likely in other orchard crops with a bifenthrin label for management of *E. servus*.

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References Cited

Aldrich, J.R., M.P. Hoffman, J.P. Kochansky, W.R. Lusby, J.E. Eger and J.A. Payne. 1991. Identification and attractiveness of a major pheromone component for Nearctic *Euschistus* spp. stink bugs (Heteroptera: Pentatomidae). Environ. Entomol. 20: 477–483.

Bowling, C.C. 1979. The stylet sheath as an indicator of feeding activity of the rice stink bug. J. Econ. Entomol. 72: 259–260.

Bowling, C.C. 1980. The stylet sheath as an indicator of feeding activity by the southern green stink bug on soybeans. J. Econ. Entomol. 73: 1–3.

Cottrell, T.E. 2001. Improved trap capture of *Euschistus servus* and *Euschistus tristigmus* (Hemiptera: Pentatomidae) in pecan orchards. Fla. Entomol. 84: 731–732.

Cottrell, T.E. and D.L. Horton. 2011. Trap capture of brown and dusky stink bugs (Hemiptera: Pentatomidae) as affected by pheromone dosage in dispensers and dispenser source. J. Entomol. Sci. 46: 135–147.

Cottrell, T.E., C.E. Yonce and B.W. Wood. 2000. Seasonal occurrence and vertical distribution of *Euschistus servus* (Say) and *Euschistus tristigmus* (Say) (Hemiptera: Pentatomidae) in pecan orchards. J. Entomol. Sci. 35: 421–431.

Demaree, J.B. 1922. Kernel-spot of the pecan and its cause. USDA Bull. 1102.

Dutcher, J.D. and J.W. Todd. 1983. Hemipteran kernel damage of pecan, Pp. 1–11. *In* Payne, J.A. (ed.), Pecan Pest Management—Are We There? Misc. Publ. Entomol. Soc. Am. 13: 1–140.

Hopkins, B.W., A.E. Knutson, J.S. Bernal, M.F. Treacy and C.W. Smith. 2009. Species composition, damage potential, and insecticide susceptibility of stink bugs in cotton in the lower gulf coast region of Texas. Southwest. Entomol. 35: 19–32.

Horton, D.L., P. Brannen, B. Bellinger and D. Ritchie. 2010. Southeastern peach, nectarine and plum pest management and culture guide. Univ. Georgia Coll. Agric. Environ. Sci., Coop. Ext. Serv. Bull. 1171. 60 pp.

Hudson, W., J. Brock, S. Culpepper, W. Mitchem and L. Wells. 2010. Georgia pecan pest management guide. Univ. Georgia Coll. Agric. Environ. Sci., Coop. Ext. Serv. Bull. 841.

Jones, W.A. and M.J. Sullivan. 1982. Seasonal abundance and relative importance of stink bugs in soybean. South Carolina Agric. Exp. Stn. Tech. Bull. 1087.

Kamminga, K.L., D.A. Herbert, Jr., T.P. Kuhar, S. Malone and H. Doughty. 2009a. Toxicity, feeding preference, and repellency associated with selected organic insecticides against *Acrosternum hilare* and *Euschistus servus* (Hemiptera: Pentatomidae). J. Econ. Entomol. 102: 1915–1921.

Kamminga, K.L., D.A. Herbert, Jr., T.P. Kuhar, S. Malone and A. Koppel. 2009b. Efficacy of insecticides against *Acrosternum hilare* and *Euschistus servus* (Hemiptera: Pentatomidae) in Virginia and North Carolina. J. Entomol. Sci. 44: 1–10.

Knutson, A., B. Ree and M. Muegge. 2010. Managing insect and mite pests of commercial pecans in Texas. Texas A&M Agrilife Ext. Serv., E-215. 25 pp.

López, J.D., Jr., M.A. Latheef and B. Ree. 2012a. Toxicity by glass-vial bioassay of selected pyrethroid and organophosphate insecticides to adult brown stink bugs (Hemiptera: Pentatomidae) from central Texas. Southwest. Entomol. 37: 39–46.

López, J.D., Jr., M.A. Latheef, B. Ree and W.C. Hoffman. 2012b. Toxicity to adult brown stink bug (Hemiptera: Pentatomidae) in a glass-vial bioassay of selected insecticide mixtures. Southwest. Entomol. 37: 459–466.

Mizell, R.F. and W.L. Tedders. 1995. A new monitoring method for detection of the stinkbug complex in pecan orchards. Proc. Southeast. Pecan Growers Assoc. 88: 36–40.

Osburn, M.R., W.C. Pierce, A.M. Phillips, J.R. Cole and G.E. Kenknight. 1966. Controlling insects and diseases of pecan. USDA Agric. Handb. 240.

Payne, J.A. and J.M. Wells. 1984. Toxic penicillia isolated from lesions of kernel-spotted pecans. Environ. Entomol. 13: 1609–1612.

Rolston, L.H. and R.L. Kendrick. 1961. Biology of the brown stink bug, *Euschistus servus* Say. J. Kansas Entomol. Soc. 34: 151–157.

SAS Institute. **2013**. JMP® 11 Multivariate Methods. SAS Institute Inc., Cary, NC.

Snodgrass, G.L., J.J. Adamczyk, Jr. and J. Gore. 2005. Toxicity of insecticides in a glass-vial bioassay to adult brown, green, and Southern green stink bugs (Heteroptera: Pentatomidae). J. Econ. Entomol. 98: 177–181.

Tedders, W.L., I.E. Yates and D. Sparks. 1990. Stink bug and coreid bug damage can be detected on pecan shells. Proc. Southeast. Pecan Growers Assoc. 83: 63–70.

Tillman, P.G. and B.G. Mullinix, Jr. 2004. Comparison of susceptibility of pest *Euschistus servus* and predator *Podisus maculiventris* (Heteroptera: Pentatomidae) to selected insecticides. J. Econ. Entomol. 32: 1399–1403.

Turner, W.F. 1923. Kernel spot of pecan caused by the Southern green soldier bug. J. Econ. Entomol. 16: 440–445.

Yates, I.E., W.L. Tedders and D. Sparks. 1991. Diagnostic evidence of damage on pecan shells by stink bugs and coreid bugs. J. Am. Soc. Hortic. Sci. 116: 42–46.

Willrich, M.M., B.R. Leonard and D.R. Cook. 2003. Laboratory and field evaluations of insecticide toxicity to stink bugs (Heteroptera: Pentatomidae). J. Cotton Sci. 7: 156–163.

Woodside, A.M. 1946. Cat-facing and dimpling in peaches. J. Econ. Entomol. 39: 158–161.

Zeilinger, A.R., D.M. Olson, T. Raygoza and D.A. Andow. 2015. Do counts of salivary sheath flanges predict food consumption in herbivorous stink bugs (Hemiptera: Pentatomidae)? Ann. Entomol. Soc. Am. 108: 109–116.