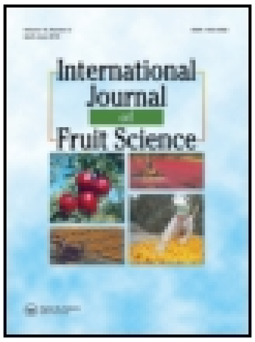

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Efficacy of Insecticides against *Lygus hesperus* Knight (Hemiptera: Miridae) in the California's Central Coast Strawberry

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ABSTRACT

The western tarnished plant bug, *Lygus hesperus* Knight (Hemiptera: Miridae), is an important insect pest of strawberry (*Fragaria ananassa* Duchesne) in the Central Coast of California. Because little is known about efficacy of new insecticides, especially sulfoxaflor and flupyradifurone, against *L. hesperus*, two replicated insecticide experiments were conducted in 2014 and 2015 in commercial strawberry fields naturally infested with *L. hesperus*. The insecticides, sulfoxaflor, flupyradifurone, flonicamid, thiamethoxam fenpropathrin, essential oils (rosemary and peppermint oils), and mineral oil, were compared with untreated check. Higher and lower rates of flupyradifurone and sulfoxaflor were tested. Higher rates of sulfoxaflor and flupyradifurone were effective in suppressing *L. hesperus*. The industry standard, thiamethoxam + fenpropathrin, was effective in 2014 but not in the 2015 experiment. Flonicamid provided a moderate level of efficacy against *L. hesperus* in both years. The number of predacious bugs was significantly lower in the higher rate of flupyradifurone than in other treatments, although the number of spiders was not significantly different among treatments.

KEYWORDS
Integrated pest management; lygus bug; chemical control

Introduction

Western tarnished plant bug, *Lygus hesperus* Knight (Hemiptera: Miridae), is an important insect pest of strawberry (*Fragaria ananassa* Duchesne) (Zalom et al., 2012) in the Central Coast of California. California strawberry, valued at ~US$2.4 billion in 2014, accounts for 86% of the U.S. production (U.S. Department of Agriculture, NASS, 2014). In Monterey County, strawberry was valued at ~US$709 million and was grown in 4473.4 ha (Monterey County Crop Report, 2014), whereas in Santa Cruz County, the value is estimated at ~US$228 million and was planted in 1334.7 ha (Santa Cruz County Crop Report, 2014). *Lygus hesperus* occur during most of the production seasons beginning from February through September and it becomes more problematic during the summer months (May through August).

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Lygus hesperus populations typically develop on several weed hosts surrounding the strawberry fields, such as wild radish (*Raphanus raphanistrum* L.), common groundsel (*Senecio vulgaris* L.), lupines (*Lupinus* spp.), and mustards (*Brassica* spp.) (Zalom et al., 2012). Previously infested second-year strawberry fields are also considered as a source for *L. hesperus* populations. The *L. hesperus* adults move into the strawberry fields and oviposit on the plants. After egg hatch, nymphs molt through five stages before developing into adults. Both nymphs and adults of *L. hesperus* feed on the embryos within the achenes and affect the normal development of tissues surrounding the embryo (Handley and Pollard, 1993). The young fruits (~10 days old) after petal fall are considered most vulnerable to economic injury as the feeding results in unmarketable, deformed, or catfaced fruits (Bolda et al., 2008).

Several tactics have been considered to manage *L. hesperus* in the Central Coast of California, such as tractor-mounted suction devices or vacuums often referred to as "bug-vacs" (Pickel et al., 1995), trap cropping using alfalfa (*Medicago sativa* L.) strips (Swezey et al., 2007), release of braconid wasp *Peristenus relictus* (Ruthe) (Pickett et al., 2009), and reflective mulch (Rhainds et al., 2001). For major strawberry hectarage, where *L. hesperus* is a serious problem, chemical insecticides, primarily pyrethroid, neonicotinoid, and organophosphate insecticides, are extensively used (Zalom et al., 2012). Inadequate *L. hesperus* control has been widely reported after application of organophosphate insecticides, such as dibrom and malathion, is possibly due to development of resistance to these insecticides in certain *L. hesperus* populations. Clearly, new insecticide chemistries with novel modes of action are much needed and will improve management of *L. hesperus* in the Central Coast of California. In California, flupyradifurone and flonicamid are registered on strawberry for *L. hesperus* management, whereas sulfoxaflor is in the path of registration. These insecticides will not only provide additional tools for *L. hesperus* management, but also can be used in rotation with pyrethroid, neonicotinoid, and organophosphate insecticides to delay the development of insecticide resistance. The major objectives of this study were to evaluate: (1) the efficacy of flupyradifurone, flonicamid, and sulfoxaflor against *L. hesperus*, and (2) their effects on beneficial arthropods through field experiments.

Materials and methods

Two experiments, one each in 2014 and 2015, were conducted in commercial strawberry fields in Watsonville, California. In 2014, the entire field was planted with the Albion strawberry cultivar, whereas in 2015 the entire field was planted with the Monterey strawberry cultivar. The strawberry plants were grown under standard management practice. The experiments were initiated when the fields had noticeable *L. hesperus* infestation as detected in preliminary sampling. A randomized complete block design in both years with four and five replications were used in 2014 and 2015, respectively. The treatments were assigned to 132.1-cm bed (with two plant rows per bed) × ten 21.3-m (in 2014) and 19.8-m (in 2015) long plots. The details of the insecticide products and rates tested are listed in Table 1. In 2014, treatments were first broadcast-sprayed on 12 Aug. followed by a second spray on 5 Sept., whereas, in 2015, the first round of treatments was sprayed on 13 June followed by a second spray on 20 June. In both years, insecticides were applied using the same sprayer mounted on a tractor at 140 psi. The water volume used for the applications was 2245.7 L per ha in both years. An adjuvant (Dyne-Amic [99% of methyl esters of C16–C18 fatty acids, polyalkyleneoxide modified polydimethylsiloxane, and alkylphenol ethoxylate]) was added at 0.25% v/v to all of the treatments in both years.

Lygus hesperus adults and nymphs were sampled using a beat-box (Rubbermaid container; 38 × 31× 17 cm [deep]) in the experimental plots. Twenty flowering strawberry plants were randomly sampled per plot and a plant sample consisted of five strikes with the lid of the beat-box. The arthropods collected from 20 plants served as the sample unit. In 2014, plants were sampled a day before application (11 Aug.) then at 3 (15 Aug.), 7 (19 Aug.), and 14 (25 Aug.) days after the first application, then at 2 (5 Sept.), 7 (11 Sept.), and 14 (18 Sept.) days after the second application. In 2015, sampling was done a day before application (12 June) then at 3 (16 June) and 7 (19 June) days after the first application, then 3 (24 June), 7 (26 June), 14 (3 July), 21 (10 July), and 28 (17 July) days after the second application. All of the samples were collected between 14:00 and 17:00 hours. The insect samples were bagged, transported to the University of California Cooperative Extension Entomology laboratory, and stored in the freezer for later evaluation. The beat-box samples were evaluated for all nymphal stages and adults of *L. hesperus*, predaceous bugs (damsel bug [*Nabis* spp.], minute pirate bug [*Orius*

Table 1. Insecticides evaluated for *Lygus hesperus* management in the field experiments in 2014 and 2015.

Class	Insecticide	Formulation	Recommended field rate (product per ha)
Neonicotinoid + Pyrethroid	Thiamethoxam + Fenpropathrin[z,y]	Actara + Danitol 2.4 EC	280.1 g + 1533.9 mL
	Flonicamid[z,y]	Beleaf 50 SG	199.6 g
Sulfoxaflor	Sulfoxaflor[z,y]	Sequoia	170.0 mL (in 2014)
Sulfoxaflor	Sulfoxaflor[z,y]	Sequoia	85.2 mL (in 2015)
Butenolides	Flupyradifurone[y]	Sivanto SL 200	419.9 mL
Butenolides	Flupyradifurone[y]	Sivanto SL 200	1022.6 mL
—	Essential oil[z] (rosemary and peppermint oils)	Ecotek	4674.9 mL
—	Mineral oil[z]	Tritek	16,843.2 mL
—	Essential oil + mineral oil[z]	Ecotek + Tritek	4674.9 mL + 16,843.2 mL

[z]2014 experiment.
[y]2015 experiment.

spp.], bigeyed bug [*Geocoris* spp.]), and spiders. In addition, 100 fruits were randomly sampled from each plot at 28 days after the second insecticide application in both years. Not more than two fruits were collected per plant within the experimental plot. These fruits were evaluated for deformity or catface injury.

Statistical analyses were conducted to determine if the independent variables, such as *L. hesperus* adults and nymphs, predatory bugs, and spiders, had effects with insecticide treatments. All data analyses were conducted in SAS (SAS Institute, 2012). Where applicable, data were tested for normality using the PROC Univariate procedure in SAS and data were transformed to establish homogeneity of variance. The numbers of *L. hesperus* adults and nymphs, predatory bugs, and spiders were log-transformed ($\ln[x+1]$) and these variables were individually subjected to analysis of variance (ANOVA) using the general linear model procedure (PROC GLM) in SAS. The insecticide treatment and replication were factors in the model. Type III sum of squares were used. The proportion of fruits with a deformity was analyzed with ANOVA after arcsine square root transformation. The data were analyzed by sampling date to determine treatment effects as one-way ANOVA. Means were separated using LSD method ($\alpha = 0.05$).

Results

2014 experiment

Pre-application counts of *L. hesperus* adults and nymphs were not significantly different among treatments ($P > 0.05$; Figure 1A and 1B). Number of adult *L. hesperus* captured was similar in all treatments during all sample dates ($P > 0.05$; Figure 1A). The number of nymphs captured in sulfoxaflor, thiamethoxam + fenpropathrin, and flonicamid treatments was numerically lower at 3 and 7 days after the first application (Figure 1B). After 14 days of the first application, the number of nymphs was significantly lower in the sulfoxaflor treatment than other treatments ($F = 4.3$; df = 6, 18; $P = 0.008$). The number of nymphs was numerically lower in thiamethoxam + fenpropathrin and sulfoxaflor treatments at 2 days after the second application relative to other treatments ($P > 0.05$). Seven days after application, the number of nymphs was significantly lower in the thiamethoxam + fenpropathrin and sulfoxaflor treatments than in untreated check and mineral oil treatments ($F = 2.9$; df = 6, 18; $P = 0.039$). Based on fruit evaluation, the number of fruit with “catface” injury was numerically lower in the thiamethoxam + fenpropathrin than in other insecticide treatments ($P > 0.05$) (Table 2).

2015 experiment

Pre-application counts of *L. hesperus* adults and nymphs were not significantly different among treatments (Figure 2A and 2B). After 3 days of the

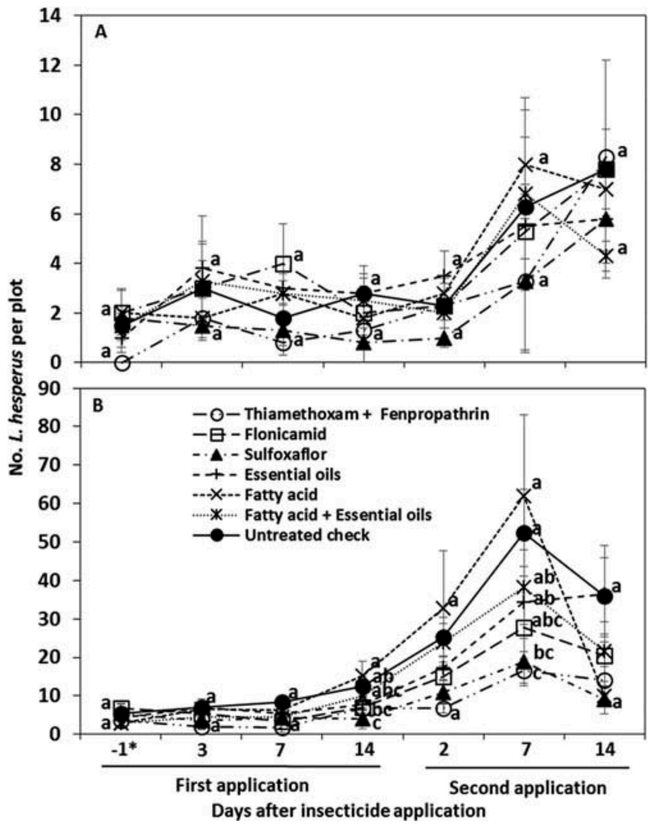

Figure 1. Mean (±SE) number of *L. hesperus* (A) adults, and (B) nymphs collected from various insecticide treatments in 2014 experiment. *Pre-application sample (pre-count) collected a day before first application. Means within sample date with same letters are not significantly different according to ANOVA and LSD test at $P > 0.05$.

Table 2. Mean (±SE) number of unmarketable "catfaced" strawberry fruits treated with various treatments.

Insecticide	2014	2015
Thiamethoxam + Fenpropathrin^{z,y}	9.8 ± 3.9a	18.4 ± 3.9a
Flonicamid^{z,y}	16.5 ± 4.3a	18.6 ± 2.5a
Sulfoxaflor^{z,y}	11.5 ± 2.1a	23.6 ± 3.1a
Flupyradifurone^{y} H^{x}	—	23.3 ± 3.1a
Flupyradifurone^{y} L^{w}	—	17.0 ± 4.2a
Essential oil^{z}	15.5 ± 3.7a	—
Mineral oil^{z}	15.5 ± 3.7a	—
Essential oil + mineral oil^{z}	17.8 ± 3.9a	—
Untreated check	17.3 ± 2.3a	28.2 ± 4.7a

Note. Means within columns followed by the same letter are not significantly different according to ANOVA and LSD test at $P > 0.05$.

^{z}2014 experiment.

^{y}2015 experiment.

^{x}Higher rate per ha.

^{w}Lower rate per ha.

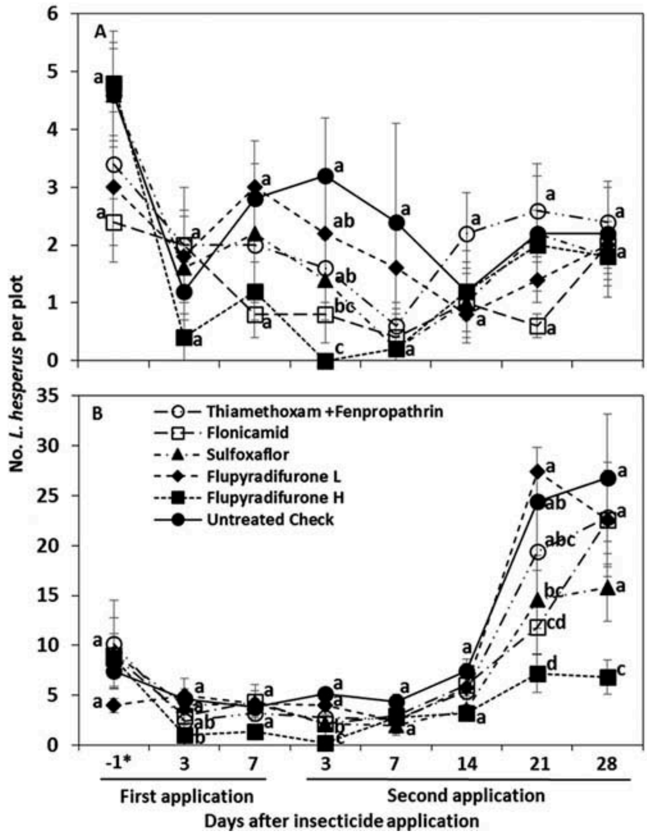

Figure 2. Mean (±SE) number of *L. hesperus* (A) adults, and (B) nymphs collected from various insecticide treatment in 2015 experiment. *Pre-application sample collected a day before first application. Means within sample date with same letters are not significantly different according to ANOVA and LSD test at $P > 0.05$.

first application, the number of *L. hesperus* adults collected in the higher rate of flupyradifurone was numerically lower than in other treatments; however, after 7 days of the first application, there was no significant difference among treatments (Figure 2A). After 3 days of the second application, a significantly lower number of *L. hesperus* adults was captured in the higher rate of flupyradifurone and flonicamid than in other treatments ($F = 5.4$; df = 5, 20; $P = 0.003$). There was no difference in *L. hesperus* adult captures among treatments in any other subsequent sample dates.

The number of nymphs captured was significantly lower in the higher rate of flupyradifurone than in other treatments at 3 days after first application ($F = 2.9$; df = 5, 20; $P = 0.042$; Figure 2B) but there was no difference in nymphal captures observed 4 days later. After 3 days of the second application, the number of nymphs was significantly lower in the higher rate of flupyradifurone, and flonicamid than in the untreated check treatment ($F = 9.6$; df = 5, 20; $P < 0.001$). There was no difference in nymphal captures observed 7 and 14 days after the second application. After 21 days of the second application, the number of nymphs was significantly lower in the higher rate of flupyradifurone than in the lower rate of flupyradifurone, untreated check, and sulfoxaflor (F = 7.9; df = 5, 20; $P < 0.001$). Also, flonicamid treatment had a significantly lower number of nymphs compared with a lower rate of flupyradifurone and untreated check. After 28 days of the second application, the higher rate of flupyradifurone had a significantly lower number of nymphs than in any other treatment (F = 3.9; df = 5, 20; $P < 0.013$). On fruit evaluation, there was no difference in number of fruits with catface injury among the insecticide treatments, although numerically, number of fruit with catface injury was lower in the higher rate of flupyradifurone treatment than in other treatments (Table 2).

The number of predacious bugs was significantly lower in the higher rate of flupyradifurone than in other treatments (Figure 3A). However, number of spiders collected was not significantly different among treatments (Figure 3B).

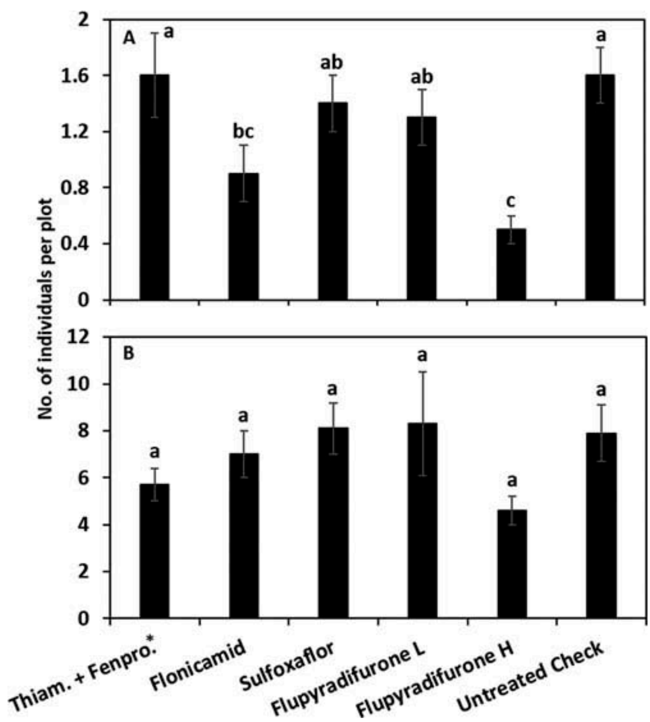

Figure 3. Mean (±SE) number of (A) predaceous bugs, and (B) spiders collected from various insecticide treatments in 2015 experiment. *Thiamethoxam + fenpropathrin. Bars with same letter are not significantly different according to ANOVA and LSD test at $P > 0.05$.

Discussion

A higher rate of sulfoxaflor performed better against *L. hesperus* and when the rate was reduced, it provided inadequate *L. hesperus* suppression. Flupyradifurone (Sivanto) at a higher rate suppressed *L. hesperus*; however, the lower rate did not show any satisfactory efficacy. This suggests that reducing the rate for both sulfoxaflor and flupyradifurone is less likely to provide effective *L. hesperus* control. Both sulfoxaflor and flupyradifurone are in group 4 (Nicotinic acetylcholine receptor [nAChR] competitive modulators) along with neonicotinoid insecticide (IRAC, 2015), which suggest that these insecticides are not recommended to be used in rotation with neonicotinoids for insecticide resistance management. For example, the two neonicotinoid insecticides recommended for *L. hesperus* control are acetamiprid and thiamethoxam (Zalom et al., 2012), and using sulfoxaflor or flupyradifurone in direct rotation should be avoided.

Flonicamid provided moderate *L. hesperus* suppression in both years. It has a distinctly different mode of action (chordotonal organ modulators) from sulfoxaflor and flupyradifurone and is placed in group 29 of IRAC classification (IRAC, 2015). The current University of California recommendation suggests a combination for both neonicotinoid and pyrethroid insecticides in a tank for *L. hesperus* control (Zalom et al., 2012). In this study, combined treatment of thiamethoxam + fenpropathrin was effective against *L. hesperus* in 2014 but did not show any suppression in the 2015 experiment. Although both of the experiments were conducted in the same grower field, it was likely that *L. hesperus* population had developed resistance to the insecticides in IRAC group 3 (pyrethroids) and 4 (neonicotinoids) prior to the initiation of the 2015 experiment. In the 2014 experiment, two organic approved products, the combination of rosemary and peppermint oils, and mineral oil did not provide *L. hesperus* suppression relative to untreated control.

In 2014, the spacing between two applications was 25 days. This suggests that each application and the following evaluation could be regarded as separate experiments. The residual activity of the insecticides on the foliage may not have lasted for 25 days following a single application, although the data do not show an unusual spike in *L. hesperus* adult and nymphal densities 14 days after the first application.

Generalist predaceous bugs, such as bigeyed bug (*Geocoris* spp.), damsel bug (*Nabis* spp.), and minute pirate bug (*Orius tristicolor* White), as well as spiders are common in conventional strawberry fields as they prey on younger nymphs of *L. hesperus* and provide a natural control (Zalom et al., 2012). When prey populations become less available, bigeyed bug can feed on plant parts, such as pods, leaves, seeds, and nectars (Dunbar, 1971; Eubanks and Denno, 1999) and were likely to remain active in the field. In our study, the higher rate of flupyradifurone and flonicamid reduced the predaceous bug densities when compared with other insecticides. Pyrethroids, especially λ-cylahothrin, can be toxic to *Geocoris punctipes* (Say), whereas imidacloprid (neonicotinoid) have a lower risk in cotton (Tillman et al., 2003). The greenhouse and field studies on cotton suggest that insecticides λ-cyhalothrin, abamectin, and spinosad had limited toxic effects on *Orius insidiosus* (Say), whereas imidacloprid and indoxacarb had moderate toxicity (Studebaker and Kring, 2003). In our study, a combined treatment of thiamethoxam + fenpropathrin did not affect predaceous bug densities.

In conclusion, data suggest that higher rates of sulfoxaflor, and flupyradifurone treatments suppressed *L. hesperus* densities. A moderate suppression was evident with flonicamid on *L. hesperus* densities. Future research will continue seeking novel insecticide chemistries for *L. hesperus* management in the Central Coast of California.

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