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Research Article

Comparative Toxicities of Newer and Conventional Insecticides: Against Four Generalist Predator Species

Nilima Prabhaker,[1] Steven Naranjo,[2] Thomas Perring,[1] and Steven Castle[2,3]

[1]Department of Entomology, University of California, 900 University Avenue, Riverside, CA 92521, [2]USDA-ARS, Arid-Land Agricultural Research Center, 21881 North Cardon Lane, Maricopa, AZ 85138, and [3]Corresponding author, e-mail: steven.castle@ars.usda.gov

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Abstract

Generalist insect predators play an essential role in regulating the populations of *Bemisia tabaci* and other pests in agricultural systems, but may be affected negatively by insecticides applied for pest management. Evaluation of insecticide compatibility with specific predator species can provide a basis for making treatment decisions with the aim of conserving natural enemies. Eleven insecticides representing six modes of action groups were evaluated for toxicity against four predator species and at different developmental stages. Full-concentration series bioassays were conducted on laboratory-reared or insectary-supplied predators using Petri dish and systemic uptake bioassay techniques. Highest toxicities were observed with imidacloprid and clothianidin against first and second instar nymphs of *Geocoris punctipes* (Say) (Hemiptera: Geocoridae). Later instar nymphs were less susceptible to neonicotinoid treatments based on higher LC_{50}s observed with imidacloprid, thiamethoxam, and dinotefuran against third or fourth instar nymphs. The pyrethroid insecticide bifenthrin was highly toxic against adults of *G. punctipes* and *Orius insidiosus* (Say) (Hemiptera: Anthocoridae). Standard concentration/mortality evaluation of nonacute toxicity insecticides, including buprofezin, pyriproxyfen, spirotetramat, and spiromesifen, was inconclusive in terms of generating probit statistics. However, low mortality levels of insects exposed for up to 120 h suggested minimal lethality with the exception of pyriproxyfen that was mildly toxic to *Chrysoperla rufilabris* (Burmeister) (Neuroptera: Chrysopidae).

Key words: *Bemisia tabaci*, *Geocoris punctipes*, *Orius insidiosus*, *Hippodamia convergens*, *Chrysoperla rufilabris*

The explosive outbreaks of *Bemisia tabaci* (Gennadius) (Middle East Asia Minor 1 (MEAM1); Dinsdale et al. 2010) (previous biotype B and *B. argentifolii* Bellows and Perring) that occurred in the southwestern United States in the early 1990s (Culotta 1991; Perring et al. 1991, 1993) are a prime example of an invasive insect expressing its full biotic potential in an optimal environment, but also of inadequate defenses to prevent destructive crop losses. Agriculture in the irrigated desert valleys of the American southwest is recognized by its intensive production and diversity of field and vegetable crops. Pest populations are supported by abundant year-round crop resources that propel population expansion across multiple generations. Outbreak potential is frequently exacerbated by extended production cycles of particular crops such as leafy vegetables (e.g., lettuce and broccoli) and cucurbit crops with planting windows drawn out over many months. Mild winters and a low rainfall environment offer little resistance to insects that are able to tolerate, even exploit, high summertime temperatures that accelerate development and reduce generation time.

In the early 1990s, the capacity of pest management to deal with the initial outbreaks of *B. tabaci* was limited by fewer and less effective chemical modes of action (MoA) that were available at that time compared to a decade later (Nauen and Denholm 2005, Palumbo et al. 2001). Moreover, knowledge of the complex of natural enemies active against *B. tabaci* was lacking, as was information on the compatibility of various insecticide treatments with beneficial insects. The emergency registration in Arizona in 1996 for two insect growth regulator (IGR) insecticides, buprofezin and pyriproxyfen, initiated a series of field studies that examined their effectiveness for

controlling *B. tabaci* and also evaluated the impact of these materials on natural enemy populations (Naranjo et al. 2004, Naranjo and Ellsworth 2009). Both IGR treatments proved to be highly effective at reducing *B. tabaci* populations while conserving natural enemies in comparison to non-IGR treatments. Prior studies of buprofezin and pyriproxyfen conducted in Israel also demonstrated outstanding management capabilities against *B. tabaci*, leading to the adoption of both compounds into Israel's IPM program for *B. tabaci* (Horowitz et al. 1994, 1999; Ishaaya and Horowitz 1995).

Additional insecticides representing novel MoA have been readily adopted into whitefly management programs over the past 25 years as the invasive *B. tabaci* MEAM1 and MED have spread to agricultural production areas throughout the world. Many of these insecticides have a limited activity spectra against a range of pest taxonomies, therefore they often are assumed to be more favorable to beneficial insects in contrast to broader spectrum insecticides. However, recent studies point to lethal and sublethal effects that have occurred in nontarget insects and the need to evaluate the impact on specific beneficial insects that may have important roles in biological control (Desneux et al. 2007, Planes et al. 2013).

Generalist arthropod predators are common residents of many crops and often provide important biological control services (Symondson et al. 2002). *Geocoris punctipes* (Say) (Hemiptera: Geocoridae), *Orius insidiosus* (Say) (Hemiptera: Anthocoridae), *Chrysoperla carnea s.l.* Stephens (Neuroptera: Chryspoidae), and *Hippodamia convergens* Guérin-Méneville (Coleoptera: Coccinellidae) and are among the most abundant and cosmopolitan species of generalist predators in the United States (e.g., Whitcomb and Bell 1964, Ehler 1977, Wilson and Gutierrez 1980). All of them feed on a wide range of small-sized prey including insect eggs, small caterpillars, and whiteflies. In the cotton system, all of these species are frequent predators of *B. tabaci* (Hagler and Naranjo 1994a,b, 2004, 2005) and several may contribute important mortality affecting the population dynamics of this pest (Naranjo and Ellsworth 2005).

The options available for the integrated management of *B. tabaci* and other primary pests have expanded significantly over the past 25 yr, resulting in a progressive decline in crop damage. Insecticides with greater selectivity introduced over this period have made it possible to refine IPM programs and allow the true integration of biological control (Naranjo and Ellsworth 2009). However, there remains the challenge to more broadly characterize the impacts of insecticides on target and nontarget arthropods. The aim of this study was to evaluate the relative toxicities of many of the newer insecticides used over the past 25 yr to select predator species of *B. tabaci*.

Materials and Methods

Insects

G. punctipes and *O. insidiosus* were from long-standing laboratory cultures initially established from collections in cotton and alfalfa fields in Maricopa, AZ in the 1990s and then replenished with wild stock annually thereafter to maintain genetic diversity. Insects were reared in 140 × 22 mm Petri dishes (ca. 100 insects per dish) lined with filter paper and supplied with green beans and eggs of *Ephestia kuehniella* (Zeller) attached to copy paper. Once insects became adults, small cotton balls were placed in each Petri dish as an oviposition substrate for *G. punctipes* while *O. insidiosus* oviposited in the green beans. Cotton balls or green beans containing eggs were transferred to new Petri dishes containing fresh food sources just prior to eclosion. Developing nymphs and adults were the main source of test insects for evaluating the toxicity of 11 commonly used insecticides in cotton and vegetables. The timing of tests was coordinated with the availability of sufficient numbers of reared *G. punctipes* or *O. insidiosus* to carry out bioassays that included a full series of concentrations of one or more insecticides. In the case of *G. punctipes*, this included a series of bioassays on each nymphal instar. The number of rearing dishes was increased to establish synchronized cohorts of *G. punctipes* nymphs by collecting all emerged nymphs in a 24-h period and then isolating them from the main colony in separate rearing dishes. Tests on each instar were carried out when the insects advanced to each successive instar. For all bioassays, insects showing higher activity levels within their rearing dishes were selected for testing to minimize control mortality. Higher levels of control mortality that occurred through handling early instars of *O. insidiosus* precluded testing of its juvenile stages.

Insectary-reared *H. convergens* and *C. rufilabris* (Burmeister) were obtained periodically from a commercial insectary (Rincon Vitova, Ventura, CA) for additional toxicological testing. *Hippodamia convergens* was shipped as 2–3-d-old adults and held in Petri dishes containing thin streaks of honey and *E. kuehniella* eggs after arrival. *Chrysoperla rufilabris* arrived as prehatched larvae held individually in honeycomb cardboard units that each contained ca. 400 larvae. Bioassays were conducted on the day that the *C. rufilabris* larvae arrived from the insectary.

Insecticides

Commercial formulations of 11 insecticides representing six MoA groups were used for toxicological tests against the four predator species. The following insecticides were evaluated: two pyrethroids, bifenthrin (Capture 2EC, FMC Corp., Philadelphia, PA) and fenpropathrin (Danitol 2.4 EC, Valent USA Corp., Walnut Creek, CA); two IGRs, pyriproxyfen (Esteem 0.86 EC, Valent USA Corp.) and buprofezin (Applaud 70 WP, Nichino America, Inc., Wilmington, DE); four neonicotinoids, imidacloprid (Admire Pro, Bayer Crop Science, Kansas City, MO), thiamethoxam (Actara 25 WG, Syngenta, Greensboro, NC), clothianidin (Belay, Valent USA Corp.), and dinotefuran (Safari 20 SG, Valent USA); two insecticides that belong to the tetronic and tetramic acid derivative group, spirotetramat (Movento, Bayer Crop Science, Raleigh, NC) and spiromesifen (Oberon, Bayer Crop Science); and the sulfoximine compound sulfoxaflor (Transform WG, Dow AgroSciences LLC, Indianapolis, IN).

All insecticides were diluted with deionized water on the day of testing to make a series of concentrations. At least five serial concentrations of each insecticide plus a water control were used to obtain dosage mortality data for each predator.

Bioassay Techniques

Mortality responses of the four predators to the various insecticides were recorded in the laboratory using either in a Petri dish (100 × 15 mm) bioassay (Prabhaker et al. 2006) or a systemic uptake bioassay (Prabhaker et al.1997) according to the properties of each insecticide. The four neonicotinoid insecticides are routinely applied to the soil for systemic uptake by plants, or as foliar sprays with both contact and translaminar activity. Therefore, they were tested in both Petri dish and systemic uptake bioassays in this study. Two other insecticides, spirotetramat and sulfoxaflor, are also known for their systemic activity in plants, but they typically are applied as foliar sprays. Thus, the Petri dish technique was used for spirotetramat and sulfoxaflor as well as for spiromesifen, both pyrethroids, and the two IGRs pyriproxyfen and buprofezin. The mortality criterion used for

both types of bioassays was a complete absence of movement by the test subjects.

Petri Dish Bioassay Technique

Agar beds were layered in the base of each Petri dish for the maintenance of cotton test leaves for up to 7 d. Fresh leaf discs 6 cm in diameter were cut from cotton leaves and dipped in each concentration of each insecticide for 60 s. After dipping, the leaf discs were dried on paper towels for 1 h, and then transferred to the Petri dishes and pressed firmly onto the agar bed abaxial side up. Each bioassay included at least five replications of each concentration for each insecticide. For exposure to treated leaves, 10 predators (adults or nymphs) per replicate were placed in each petri dish by using an artisan No. 1 paint brush. For *C. rufilabris*, five third instar larvae were placed in each Petri-dish with five replications per insecticide. With all four predators, a thin streak of honey was smeared on the underside of each petri dish lid to provide food for the insects. Insect mortality was evaluated at 24 and 48 h to determine rapid mortality and at 72, 96, and 120 h post-treatment to determine delayed mortality. The ambient temperature in the laboratory during all experiments ranged between 24 and 27°C under a natural photoperiod.

Bioassay for Systemic Insecticides

The uptake bioassay (Prabhaker et al. 2006) used detached cotton leaves to take up systemic insecticides through the petiole. Appropriate concentrations of each insecticide were prepared on the day of plant exposure and 9.5 ml aliquots of each dilution were placed in aquapiks (www.Floral Supply.com, SYND57-97) that were held in wooden racks. Uptake of insecticide solutions by excised cotton leaves occurred over 24 h under fluorescent lights. Following the uptake period, the excised leaves were transferred to a duplicate set of aquapiks containing only water. Control leaves were placed in water alone. Test subjects of each predator species were attached to the abaxial side of treated leaves using ventilated clip cages (3.8 cm in diameter, 11.34 cm^2 surface area). Ten individuals were placed in each clip cage for each species with the exception of the larger size *C. rufilabris* that had only five insects per cage. A single streak of honey was applied to the organdy screen in each clip cage as a supplemental food source. A minimum of five concentrations plus the untreated controls were used in each test. Exposure times varied by compound according to which exposure provided the most consistent response. Mortality was checked after 24 and 48 h in most cases, but was extended for 120 h in the case of *H. convergens* to attain a mortality response across concentrations. All tests were conducted and maintained at 27 ± 1°C, 22–24% RH, and a photoperiod of 12:12 (L:D) h.

Statistical Analysis

The LC_{50}, 95% fiducial limits (FL), and slopes of the regression lines were estimated by probit analysis using PoloPlus (LeOra Software, 2002–2003). The suitability of the mortality data to the probit model was evaluated by the Chi-square test included in the program output for each test. Differences in LC_{50} values were considered significant between pesticides and insect species if there was no overlap of 95% FL. Because some of the insecticides used in this study have MoA that do not elicit an acute mortality response, probit analysis was unsuitable for evaluating treatment effects for all insecticides. For those tests that produced no acute effect, in some cases even after a 96-h exposure, graphical comparisons were made to contrast one insecticide or predator species with another. Mortalities at each insecticide concentration were corrected to account for control mortality with Abbott's formula (Abbott 1925).

Results and Discussion

The heteropteran predators *O. insidiosus* and *G. punctipes* are commonly found in Arizona field and vegetable crops and are key natural enemies attacking *B. tabaci*. Although they generally are thought of as predators, both species are occasionally omnivorous and may feed on plant tissues (Naranjo and Gibson 1996). This is a potentially important consideration in pest management, especially in situations where systemic insecticide treatments may be used. In the systemic uptake bioassays, imidacloprid was significantly less toxic to *G. punctipes* than to *O. insidiosus* based on a comparison of LC_{50}s (Table 1). Elzen (2001) also found both male and female adults of *G. punctipes* to be less susceptible to imidacloprid compared to *O. insidiosus*. Similarly, further comparisons between these two predators showed that *O. insidiosus* incurred higher mortality than *G. punctipes* when treated with the

Table 1. Probit statistics for eight insecticides representing four modes of action against adults of three generalist predators

Chemical group	Insecticide	Species	Exposure time (h)	*N*	LC_{50} (µg/ml) (95% FL)	Slope ± SE	χ^2 (df)
Neonicotinoid	Imidacloprid	*G. punctipes*	48	251	27.69 (9.77–132.35)	0.431 ± 0.067	8.16 (23)
		O. insidiosus	48	250	2.02 (0.94–4.61)	0.522 ± 0.066	16.04 (23)
	Thiamethoxam	*G. punctipes*	48	300	3.66 (2.16–5.99)	0.752 ± 0.080	15.10 (28)
		O. insidiosus	24	250	1.29 (0.64–2.31)	0.716 ± 0.087	18.58 (23)
	Clothianidin	*O. insidiosus*	48	250	10.13 (4.75–26.26)	0.563 ± 0.072	17.59 (23)
	Dinotefuran	*G. punctipes*	24	250	8.78 (4.74–14.0)	1.310 ± 0.195	20.59 (23)
		H. convergens	120	251	22.49 (11.15–36.45)	1.206 ± 0.273	15.76 (23)
Sulfoxamine	Sulfoxaflor	*O. insidiosus*	48	250	1.32 (0.64–2.58)	0.848 ± 0.105	24.85 (23)
Pyrethroid	Bifenthrin	*G. punctipes*	24	251	0.03 (0.001–0.152)	0.5 ± 0.093	29.68 (23)
		O. insidiosus	24	250	0.77 (0.46–1.22)	1.07 ± 0.115	20.18 (23)
		H. convergens	24	251	2.75 (1.74–4.22)	1.07 ± 0.106	16.01 (23)
	Fenpropathrin	*G. punctipes*	24	250	18.8 (10.82–30.46)	1.09 ± .123	33.45 (23)
Juvenile hormone mimic	Pyriproxyfen	*O. insidiosus*	72	250	103.1 (45.95–752.15)	0.883 ± 0.284	14.19 (23)

Exposure times varied according to the MoA and predator species being tested. Chi-square values were nonsignificant for all tests based on a tabular value ($P = 0.05$) of 35.172 for 23 df and 41.337 for 28 df.

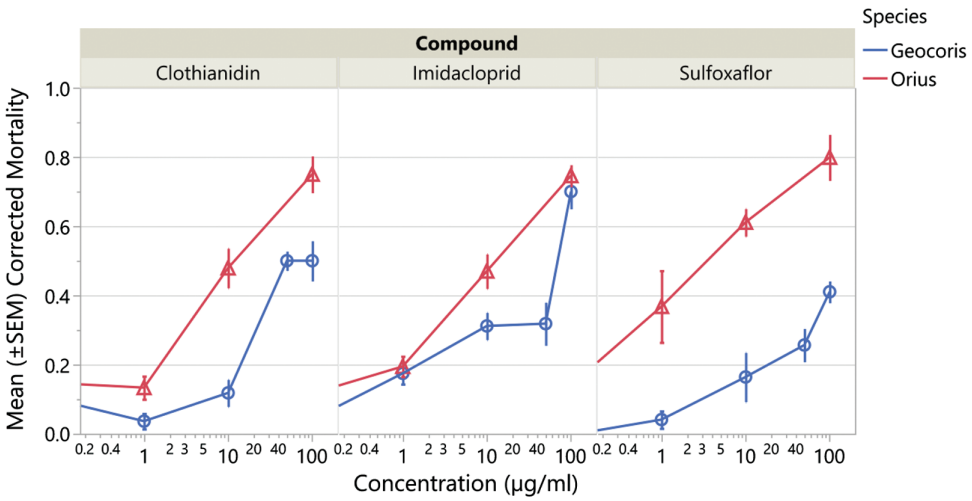

Fig. 1. Mortality comparison between adults of *G. punctipes* and *O. insidiosus* following treatment in separate tests with clothianidin, imidacloprid, or sulfoxaflor.

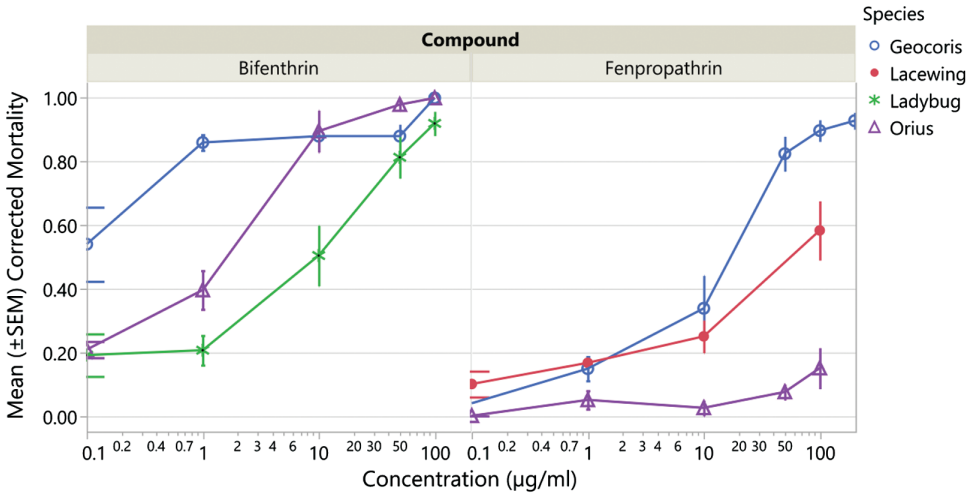

Fig. 2. Relative susceptibilities of *G. punctipes* and *O. insididosus* to bifenthrin and fenpropathrin in Petri dish bioassays. Additional comparisons with *H. convergens* to bifenthrin and *C. rufilabris* to fenpropathrin are included.

neonicotinoid clothianidin or with sulfoxaflor (Fig. 1), a related compound to the neonicotinoids that also targets the nicotinic acetylcholine receptor (Watson et al. 2011). However, the toxicity of sulfoxaflor to *O. insidiosus* (LC_{50} = 1.32) was significantly lower than for clothianidin (LC_{50}=10.13), but not significantly different from either imidacloprid (LC_{50} = 2.02) or thiamethoxam (LC_{50} = 1.29) (Table 1).

Pyrethroid insecticides remain an important component of whitefly control in Arizona crops. Their broad spectrum activity constitutes a serious threat to predators and other beneficial insects active in the crop canopy. Bioassay results from this study indicated high susceptibility to bifenthrin in both *G. punctipes* and *O. insidiosus* (Table 1). However, fenpropathrin (LC_{50} = 18.8) was significantly less toxic to *G. punctipes* than bifenthrin (LC_{50} = 0.03) and also showed much lower toxicity against *O. insidiosus* (Fig. 2). The mortality curve for *H. convergens* indicated lower susceptibility to bifenthrin compared to either *G. punctipes* or *O. insidiosus*, but still substantial mortality at higher concentrations (Fig. 2).

The respective MoA for the IGR compounds pyriproxyfen and buprofezin, or the ketoenol compounds spirotetramat and spiromesifen, do not target the nervous or muscle systems of insects or cause acute toxicity. Evaluation of potential mortality effects is nonetheless appropriate given the variety of sublethal effects reported for some nonacute toxicity insecticides (Delbeke et al. 1997, Desneux et al. 2007, Planes et al. 2013). The only impact on adults observed for either the IGR or ketoenol compounds in our testing was against *O. insidiosus* (Table 1). Treatment with pyriproxyfen caused sufficient mortality at 72 h to yield a high LC_{50} of 103.1 µg/ml. This result suggests a low-level toxicity due to the pyriproxyfen treatment and stands in contrast to an earlier study on *O. laevigatus* (Fieber) that observed no effect after 72 h.

Additional testing of neonicotinoids on the third instar of *C. rufilabris* in the Petri dish bioassay revealed its rather high susceptibility to clothianidin and dinotefuran, but less so to imidacloprid (Table 2). The imidacloprid LC_{50} = 14.88 was significantly higher than LC_{50}s for either clothianidin (LC_{50} = 0.113) or dinotefuran (LC_{50} = 0.38) against *C. rufilabris*. An earlier reading at 24 h in the clothianidin treatment yielded an LC_{50} = 3.21 (Table 2). Mortality curves (Fig. 3) for these three neonicotinoids illustrate the variable toxicities among these three neonicotinoid insecticides. Similar to the neonicotinoids, sulfoxaflor (LC_{50} = 0.43) was highly toxic to *C. rufilabris* (Table 2).

Table 2. Probit results for juveniles of *G. punctipes* and *C. rufilabris* in bioassays with seven insecticides and four MoA

Chemical group	Insecticide	Insecticide	Stage	Exposure time (h)	N	LC_{50} (µg/ml) (95% FL)	Slope ± SE	χ^2 (df)
Neonicotinoid	Imidacloprid	*G. punctipes*	First instar	48	254	0.01 (0.0–0.09)	0.548 ± 0.145	29.69 (23)
		C. rufilabris	Third instar	48	250	14.88 (7.39–29.04)	0.733 ± 0.132	9.68 (23)
	Thiamethoxam	*G. punctipes*	Second instar	48	250	4.14 (1.83–8.24)	0.686 ± 0.099	23.33 (23)
			Fourth instar	48	252	9.08 (3.05–30.69)	0.527 ± 0.081	42.58 (23)
	Dinotefuran	*G. punctipes*	First instar	24	250	2.63 (1.51–4.15)	1.457 ± 0.181	23.69 (23)
			Second instar	24	251	1.83 (1.06–2.80)	1.621 ± 0.239	15.86 (23)
			Third instar	24	250	16.33 (9.35–25.76)	1.131 ± 0.185	8.11 (23)
			Fourth instar	24	250	12.95 (7.59–23.02)	0.762 ± 0.092	22.22 (23)
		C. rufilabris	Third instar	48	125	0.38 (0.15–0.76)	1.036 ± 0.178	11.61 (23)
	Clothianidin	*G. punctipes*	First instar	48	250	0.03 (0.0–0.20)	0.364 ± 0.089	14.80 (23)
			Second instar	48	254	0.07 (0.0–0.55)	0.250 ± 0.081	6.06 (23)
		C. rufilabris	Third instar	48	250	0.113 (0.04–0.26)	0.746 ± 0.125	9.68 (23)
				24	125	3.21 (1.39–8.24)	0.739 ± 0.112	19.02 (23)
Sulfoximine	Sulfoxaflor	*C. rufilabris*	Third instar	48	125	0.43 (0.09–1.51)	0.442 ± 0.091	7.64 (23)
Pyrethroid	Fenpropathrin	*C. rufilabris*	Third instar	48	125	70.5 (13.9–2241.)	0.414 ± 0.098	12.75 (23)
Juvenile hormone mimic	Pyriproxyfen	*C. rufilabris*	Third instar	48	250	39.3 (17.99–103.19)	0.792 ± 0.226	9.32 (23)
		C. rufilabris	Third instar	96	250	3.14 (1.28–5.92)	0.876 ± 0.143	8.14 (23)

Chi-square values were nonsignificant for all but the *G. punctipes* fourth instar thiamethoxam test based on a tabular value ($P = 0.05$) of 35.172 for 23 df.

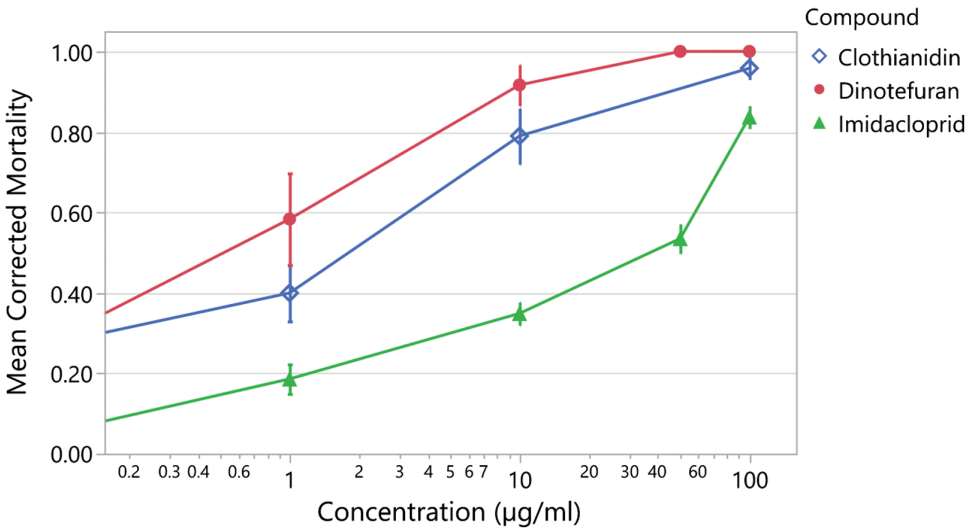

Fig. 3. Relative susceptibility of third instar nymphs of *C. rufilabris* to three neonicotinoid insecticides in systemic uptake bioassays.

A 48-h exposure of third instar *C. rufilabris* to fenpropathrin indicated relatively mild toxicity (LC_{50} = 70.5). In contrast, pyriproxyfen (LC_{50} = 39.3) was more toxic than fenpropathrin at 48 h, with much higher mortality to pyriproxyfen (LC_{50} = 3.14) occurring at 96 h. Exposure of *C. rufilabris* to buprofezin over the same intervals elicited a mild mortality response at the two highest concentrations (Fig. 4). Buprofezin is an inhibitor of chitin biosynthesis that disrupts development of immature hemipterans.

The potential impact of insecticide treatments on predator populations is likely influenced by the demographic makeup of the population at the time of exposure. Relative tolerances to insecticides might be influenced by differences in detoxification capabilities between adults and immatures. Higher susceptibility to insecticides has been observed in immature whiteflies (Prabhaker et al. 1989, Wang et al. 2003), but evaluation of relative susceptibility of hemipterans is generally conducted on adults. In this study, a susceptibility comparison among nymphal instars and the adult stage of *G. punctipes* to four neonicotinoids was conducted. Both imidacloprid and clothianidin were highly toxic to first instar nymphs (Table 2) and to second instar nymphs as well in the case of clothianidin (LC_{50} = 0.07, Table 2). Higher LC_{50}s were observed for second instar nymphs treated with dinotefuran (LC_{50} = 1.83) or thiamethoxam (LC_{50} = 4.14) compared to either imidacloprid or clothianidin. Third (LC_{50} = 16.33) and fourth (LC_{50} = 12.95) instars of *G. punctipes* were significantly less susceptible to dinotefuran as was the fourth instar (LC_{50} = 9.08) to thiamethoxam in comparison to second instars exposed to the same treatments (Table 2). A progressive decline in susceptibility from first to fourth instar was most evident in the clothianidin treatment (Fig. 5). The imidacloprid and thiamethoxam treatments were highly toxic to the first instar of *G. punctipes*, but susceptibility was less in later instars and the adult, most notably between the fourth instar and adult for all three compounds (Fig. 5).

Assessment of the impact of insecticides on pest and beneficial insects requires a multi-prong approach to account for lethal and sublethal effects. Basic toxicological information generated by laboratory testing provides a window into the intrinsic toxicity of an insecticide. However, established dose/mortality procedures that have long been used to compare insecticide toxicities, or to evaluate

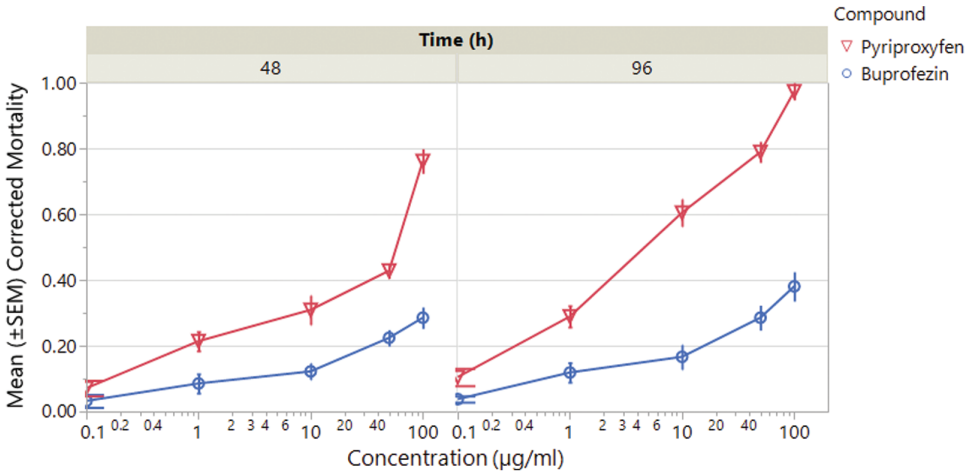

Fig. 4. Comparative mortality curves for *C. rufilabris* treated with pyriproxyfen or buprofezin in Petri dish bioassays and observed at 48 and 96 h.

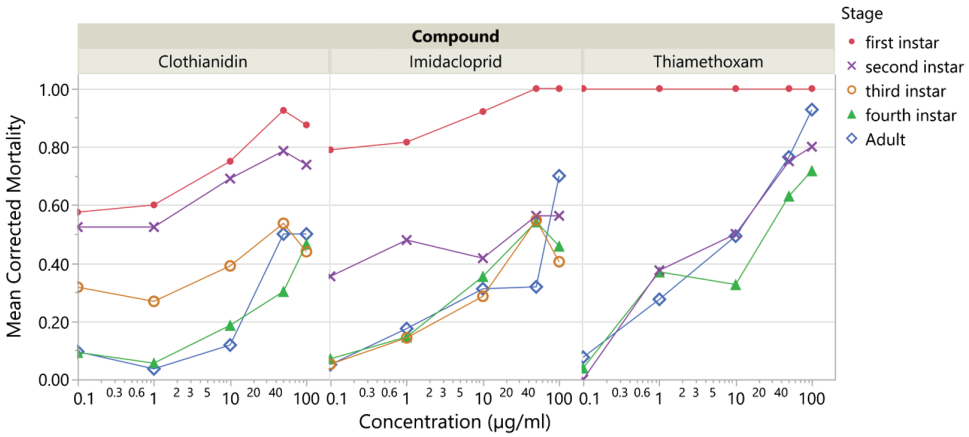

Fig. 5. Relative susceptibility of nymphal instars and adults of *G. punctipes* to three neonicotinoid insecticides in systemic uptake bioassays. No data for third instar in the thiamethoxam panel.

losses of susceptibility due to resistance, are limited in their practicality at evaluating nonacute toxicity insecticides. Nevertheless, the limited number of examples of selective insecticides having lethal impact on nontarget organisms warrants investigating the potential impacts on natural enemies in local agricultural systems.

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