Risk Assessment of Selected Insecticides on *Tamarixia triozae* (Hymenoptera: Eulophidae), a Parasitoid of *Bactericera cockerelli* (Hemiptera: Trizoidae)

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ABSTRACT *Tamarixia triozae* (Burks) (Hymenoptera: Eulophidae) is an important parasitoid of the potato or tomato psyllid, *Bactericera cockerelli* (Sulc) (Hemiptera: Trizoidae), a serious pest of potato (*Solanum tuberosum* L.), tomato (*Solanum lycopersicum* L.), and other solanaceous vegetables in many countries. To produce a marketable crop, insecticides are required when *B. cockerelli* populations reach economically damaging levels. We evaluated 11 commonly used insecticides for their effects on *T. triozae*. Glass-surface residues of spinetoram, imidacloprid-cyfluthrin, abamectin, and tolfenpyrad caused 100% mortality of *T. triozae* in 72 h, and the leaf residue of spinetoram was extremely toxic to *T. triozae* adults; even 15-d-old residues caused 100% mortality. Cyantraniliprole, fenpyroximate, pymetrozine, spirotetramat, spiromesifen, and chenopodium oil did not cause significant mortality in either glass surface or leaf-residue bioassays. Ingestion of spinetoram, abamectin, and imidacloprid+cyfluthrin (Leverage) by the adults resulted in 100% mortality in 12 h, and tolfenpyrad, 75.0% mortality in 12 h; whereas chenopodium oil and pymetrozine showed moderate effects on adult survival. Ingestion of abamectin, imidacloprid-cyfluthrin, and spinetoram killed all adults in the first day of treatment, whereas female adults in the treatment of pymetrozine lived 80.8 d, which was similar to those in the control. Ingestion of abamectin, imidacloprid-cyfluthrin, chenopodium oil, and spinetoram killed all male adults in the first day, whereas ingestion of other insecticides did not cause significant mortality, but reduced percent parasitism. Abamectin, imidacloprid-cyfluthrin, and spinetoram had the most deleterious effects on *T. triozae*, and have the least potential for use in integrated control programs using this parasitoid.

KEY WORDS conservation biological control, potato psyllid, tomato psyllid, toxicity, natural enemy

Potato or tomato psyllid, *Bactericera cockerelli* (Sulc), is a serious pest of potato (*Solanum tuberosum* L.), tomato (*Solanum lycopersicum* L.), and other solanaceous crops in the United States, Mexico, Central America, and more recently in New Zealand (Wallis 1955, Cranshaw 1994, Munyaneza et al. 2007, Hansen et al. 2008, Liefting et al. 2008). Heavily infected plants can be stunted, produce greatly reduced marketable product, and potato seed tubers infected with the bacterium generally will not sprout or generate weak plants (Munyaneza et al. 2008). A variety of chemical insecticides have been used against *B. cockerelli* (e.g., imidacloprid, abamectin, spirotetramat, spiromesifen, dinotefuran, thiamethoxam, and others; Goolsby et al. 2007, Vega-Gutiérrez et al. 2008, Gharalari et al. 2009). Although several of these insecticides are efficacious, the potential for resistance may limit their efficacy and most residues are not effective against adults that transmit *Candidatus* Liberibacter solanacearum (aka *Ca.* Liberibacter psyllarosus) (Butler et al. 2011). Integration of beneficial insects in an integrated pest management (IPM) strategy for control of the psyllid could reduce reliance on insecticides and increase the levels of control.

Tamarixia triozae (Burks 1943) (Hymenoptera: Eulophidae) first was found parasitizing *B. cockerelli* on uncultivated hosts and described as *Tetrastichus* sp. (Romney 1939), which later was redescribed as a new species, *Tetrastichus triozae* (Burks 1943). The new combination, *Tamarixia triozae*, was recorded in Fauna Europaea (http://www.faunaeur.org/full_results.php?id = 7033) without a citation. Later, Johnson (1971) made numerous field observations on this species and found that the pupal mortality of *T. triozae* ranged from 38 to 100%, and he speculated that disease and predation might be the cause. Recently, it has been collected in a wide

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Table 1. Insecticides, active ingredients, concentrations, and manufacturers used for effects on *Tamarixia triozae* in this study

Materials	Active ingredients	Concentrations (g ai/liter)	Manufacturers
Agri-Mek 0.15EC	Abamectin (2%)	11.2	Syngenta, Greensboro, NC
Cyazypyr	Cyantraniliprole (35%)	0.123	Du Pont, Wilmington, DE
FujiMite 5EC	Fenpyroximate (5%)	95.7	Nichino America, Inc., Wilmington, DE
Fulfill	Pymetrozine (50%)	0.19	Syngenta, Greensboro, NC
Leverage 2.7	Imidacloprid (17%) and cyfluthrin (12%)	57.4 ± 39.5	Bayer CropSciences, Research Triangle Park, NC
Movento 240SC	Spirotetramat (22.4%)	96.0[a]	Bayer CropSciences, Research Triangle Park, NC
Oberon 2SC	Spiromesifen	192	Bayer CropSciences, Research Triangle Park, NC
Requiem 25EC	25% of essential oil extract of *Chenopodium ambrosioides* nr. *ambrosiodes*	1.13	AgraQuest, Inc., Davis, CA
Radiant 2SC	Spinetoram	192	Dow AgroSciences Inc., Indianapolis, IN
Rimon 2SC	Novaluron	192	Chemtura Corp., Middlebury, CT
Hachi-Hachi 15EC	Tolfenpyrad (15EC)	239	Nichino America, Inc., Wilmington, DE

[a] Movento + 0.25% Dyn-Amic (vol:vol) (Helena, TN) as required by Bayer CropSciences, Research Triangle Park, NC.

range of environmental conditions from fields and greenhouses in Mexico and United States (Lomeli-Flores and Bueno 2002; Bravo and López 2007; T.-X.L., unpublished data). Bravo and López (2007) observed high levels of parasitism (80%) on *B. cockerelli* by *T. triozae* in fields not using insecticides in southern Mexico (Oaxaca). However, only 5–20% parasitism of *B. cockerelli* by *T. triozae* on potato and tomato were found in south Texas. This low parasitism could be because of multiple factors, such as, lack of alternate hosts, asynchrony of hosts and the parasitoid, and large field size limiting the ability of parasitoid dispersal. However, there is no doubt that application of various insecticides to control *B. cockerelli* negatively affected the survival of *T. triozae* (Yang et al. 2010; T.-X.L., unpublished data). In addition, it has been reported that predators may be the most important natural enemies in this system (Pletsch 1947, MacDonald et al. 2010). Insecticides used for management of target pests often kill the natural enemy populations causing pest resurgence and thus demanding more sprays. It will be only possible to use integrated control measures against *B. cockerelli* if selective and compatible insecticides are chosen.

The objective of this study was to determine the compatibility of insecticides commonly used for management of *B. cockerelli* with a key parasitoid species to maximize the effectiveness of biological control in the potato and tomato cropping systems.

Materials and Methods

Insects and Plants. A laboratory colony of *T. triozae* was established from a population of parasitized *B. cockerelli* nymphs collected on potato and tomato plants from Weslaco and Harlingen, TX, and was identified by J. R. Lomeli-Flores (Entomología y Acarología, Colegio de Postgraduados, Montecillo, Estado de Mexico, Mexico). The colony of *T. triozae* was maintained in an insectary on potted tomato *Lycopersicum esculentum* Mill. variety 'Florida Lanai' at the Vegetable IPM Laboratory at Texas AgriLife Research, TX A&M University System at Weslaco, TX. Voucher specimens of *T. triozae* and *B. cockerelli* were deposited in the Insect Collections of Texas AgriLife Research at Weslaco, TX.

Tomato plants were grown in Metro-Mix 300 growing medium (Grace Sierra, Horticultural, Milpitas, CA) and were fertilized with a slow release fertilizer (N:P:K, 12:8:6) (Diamond R Fertilizer, Winter Garden, FL). All the experiments were conducted at 26 ± 1°C, 60 ± 10% RH, and a photoperiod of 14:10 (L:D) h.

Insecticides and Bioassays. Insecticides, their brand names, concentrations, and manufacturers used in this study are listed in Table 1. Water was used as a control. Concentration for each insecticide used in the bioassay was determined based on the recommended field rate by the manufacturers with a delivery rate of 935 liters hectare^{-1} water. Lethal and sublethal effects of these insecticides on pupae and adults of *T. triozae* were bioassayed. All bioassays were conducted in either plastic petri dishes (9 cm in diameter and 1.5 cm depth) for leaf residue contact and ingestion bioassays or 20-ml glass scintillation vials for contact bioassay.

Toxicity of Direct Applications on Pupae and Subsequent Adult Emergence. All insecticides were used in this bioassay. In each treatment eight pupae of *T. triozae* (2–3 d old), excised from the body, were attached to an indexing card (2.5 by 6.5 cm) by using double-sided sticky tape (2 by 5 cm) and were sprayed with 2 ml of each insecticide solution or water by using a Potter Spray Tower (Burkard Manufacturing, Rickmansworth, Hertfordshire, England) at 7 kg/cm^2 pressure. The treated pupae were allowed to air-dry for approximately 3 h in a fume hood. The cards with the pupae were placed individually in petri dishes. Adult emergence was monitored daily until all adults emerged or the pupae died. There were four replicates per treatment with a total of 32 pupae per treatment.

Contact Toxicity of Residues to Adult Parasitoids. Two trials were conducted to determine the effects of the aged-residues of all insecticides on *T. triozae* over time both on insecticide-treated glass surfaces in glass vials as described by Snodgrass (1996) and on insecticide-treated leaf surfaces as described by Xu et al. (2004) and Haseeb et al. (2004).

In the glass vial bioassay, adult parasitoids were exposed to films of insecticide that had been applied to the inner surfaces of glass vials (20 ml) with a total inner surface of ≈42 cm^2, with an internal diameter of 2.5 cm and a height of 4.7 cm. The insecticide was applied by pipetting 0.5 ml of insecticide solution into each vial. The vials were then continuously rotated on mechanized rollers (Star MFG, Smithville, TN) without supplemental heat to achieve an even layer of insecticide dried on its inner surface. Control vials received 0.5 ml of water and were treated similarly. In all tests, the insecticides were applied to the vials on the same day that the test was performed. In each vial we placed a piece of paper with ≈0.2 μl of honey–water (10% honey) as food for the adults. The vials were stored upright until mortality was determined. Adults were considered dead if they were unable to upright themselves or make any movement when they were prodded with a metal probe. Mortality was determined two and 6 h after treatment and then every 24 h until 120 h. The final results were averaged as the percent of adults dead after 120 h. Each insecticide was tested at least three times with four or more adults per vial for a total of at least 12 adults per insecticide.

In the insecticide-treated leaf residue trial, tomato (variety Florida Lanai) was sown in plastic trays (60 by 35 by 6 cm) in a greenhouse. The seedlings were transplanted into plastic pots (1.5 liters). The tomato plants were each sprayed with one of the insecticides or water until runoff, and placed outside the greenhouse. The plants were watered as needed. Three leaves from each treated plant were removed and a leaf disk of ≈9 cm in diameter from each leaf was cut using a scalpel. The leaf disks were placed individually in the petri dishes. Eight parasitoid adults (not sexed) were introduced into each petri dish. Leaf residues for the insecticides were bioassayed with parasitoid adults 1, 3, 5, 7, 10, and 15 d after the plants were sprayed. Mortality was assessed at 24 and 48 h after the parasitoids were exposed. Each treatment was replicated three times.

Ingestion Toxicity to Adult Parasitoids. All insecticides used in this trial were the same rates as described previously. *T. triozae* adults were fed mixtures of insecticide diluted in 10% honey (vol:vol), with a 10% honey–water solution serving as a control. The feeding arenas were made of large glass petri dishes (1.5 cm in depth and 9 cm in diameter) with a circular hole (1 cm in diameter) on the side of the petri dish. Sixteen droplets (0.2 μl each) of insecticide-honey mixture or honey–water mixture were uniformly dispensed on the bottom of the glass petri dish 0.4–0.6 mm apart. Four pairs of *T. triozae* adults (2–3 d old) were placed into each petri dish, and were allowed to feed on the insecticide–honey or honey–water droplets. Mortality of females and males was recorded separately 24 h after treatment.

To determine effects on parasitism, the petioles of tomato leaves with five leaflets were inserted individually into 20-ml glass vials filled with water. These petioles were fixed using double sticky tape to the center of the bottom of 0.9-liter clear, plastic cups with a 9-cm opening on top screen with nylon organdy and a corked access hole (1.2 cm in diameter) on the side. Forty third- or fourth-instar nymphs of *B. cockerelli* were placed on the leaflets. The surviving females from the feeding trial as described were introduced into each cage for 24 h before they were removed. The nymphs were monitored until pupation of the nymphs or the parasitoids. The parasitoid pupae were monitored until adult emergence or death. Each treatment was replicated four times.

To determine effects on *T. triozae* adult longevity, parasitoid adults were fed on insecticide–honey mixture or honey–water mixture for 24 h. The parasitoids then were removed and maintained in untreated petri dishes in which 10% honey-water solution was provided every third day or as needed. Longevity of the male and female adults was recorded daily until death. Each treatment had four replicates.

Data Analysis. The original percentage of adult emergence, mortality, and persistent toxicities are presented in the tables, but these data were subjected to arcsine transformation before analysis of variance (ANOVA) (one-way ANOVA) with the general linear model (PROC GLM, SAS Institute 2010) except for longevity data that were untransformed. Means were separated with Tukey's Studentized Range Test (honestly significant difference [HSD]) at $P = 0.05$ (SAS Institute 2010). Morality data also were adjusted using Abbott's formula (Abbott 1925). Repeated measurements ANOVA were conducted on percent mortality data of *T. triozae* adults exposed to residues on either glass or leaves.

Results

Contact Toxicity of Residues to Adult Parasitoids. Effects of dry residues of the insecticides on *T. triozae* adults with a glass-vial bioassay varied greatly (Table 2). Of the 11 insecticides, spinetoram resulted in 100% mortality in 6 h, imidacloprid-cyfluthrin caused 100% mortality in 24 h, whereas abamectin and tolfenpyrad gave 100% mortality in 72 h. Cyantraniliprole, fenpyroximate, pymetrozine, spirotetramat, spiromesifen, and chenopodium oil caused no mortality at 24 h, low mortality after 48 h, and only a moderate mortality at 96 h or 120 h. Novaluron had least effects on the adults.

Effects of leaf residues on *T. triozae* adults varied significantly (Table 3). Of the eight insecticides, cyantraniliprole, fenpyroximate, pymetrozine, spirotetramat, spiromesifen, chenopodium oil, novaluron, and tolfenpyrad showed no significant effects after 24 or 48 h of exposure at any age of residue; mortality ranged from 0 to 12.5%. Imidacloprid-cyfluthrin residues produced moderate effects on *T. triozae* adults with 54.2% mortality after exposure to 1-d-old residue, and 45.8% on 7-d-old residue. Ten-day-old residue had no significant impact on adults. In contrast, exposure to leaf residues of spinetoram caused 100% mortality even after aging for 15 d.

Ingestion Toxicity on Adults. *Adult Mortality.* The responses of *T. triozae* to pesticide ingestion varied significantly ($F = 95.18$; df = 11,47; $P < 0.0001$) (Table

Table 2. Contact effects of 11 insecticides on survivals of *Tamarixia triozae* adults after exposed to residues with a glass vial bioassay

Materials	Concentration (g ai/liter)	Mortality, % ± SE[a]						
		2 h	6 h	24 h	48 h	72 h	96 h	120 h
Abamectin	11.2	7.0 ± 2.2cd	38.3 ± 7.4b	86.5 ± 11.4b	90.0 ± 10.0a	100a		
Cyantraniliprole	0.123	0d	1.7 ± 1.7de	1.7 ± 1.7e	11.7 ± 1.7cde	20.0 ± 3.7bcd	21.7 ± 3.1bc	25.0 ± 2.2bc
Fenpyroximate	95.7	0d	0e	0e	13.3 ± 3.3cd	28.3 ± 13.0bc	36.7 ± 13.3ab	48.3 ± 13.5a
Pymetrozine	0.19	0d	0e	6.7 ± 4.9e	18.3 ± 6.5bc	26.7 ± 9.2bc	30.0 ± 8.6ab	31.7 ± 10.1ab
Imidacloprid+Cyfluthrin	57.4 + 39.5	17.0 ± 3.4c	47.8 ± 5.0b	100a				
Spirotetramat	96	0d	3.3 ± 3.3de	6.7 ± 3.3e	13.3 ± 7.6cd	13.3 ± 7.6cde	21.7 ± 8.7bc	33.3 ± 12.8ab
Spiromesifen	192	0d	0e	0e	0e	1.7 ± 1.7e	3.3 ± 3.3d	8.3 ± 8.3cd
Chenopodium oil	1.13	5.0 ± 2.2bc	13.7 ± 4.9cd	23.3 ± 4.2d	30.0 ± 5.2b	31.7 ± 4.8b	43.3 ± 7.1a	51.7 ± 8.7a
Spinetoram	192	80.8 ± 5.5a	100a					
Novaluron	192	1.7 ± 1.7cd	1.7 ± 1.7de	1.7 ± 1.7e	3.3 ± 2.1de	5.0 ± 2.2de	8.3 ± 4.8cd	16.7 ± 9.5bcd
Tolfenpyrad	239	3.3 ± 2.1cd	23.3 ± 10.5c	67.4 ± 8.4c	88.0 ± 4.2a	100a		
Water	0	0d	0e	0e	0e	1.7 ± 1.7e	1.7 ± 1.7d	1.7 ± 1.7d
F		106.3	47.6	82.7	80.2	60.5	47.2	25.8
P		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[a] Means (± SE) within a column followed by the same letter are not significantly different at $P < 0.05$; Tukey's Studentized Range Test (HSD).

4). All adults died 24 h after ingestion of spinetoram, abamectin, and imidacloprid-cyfluthrin, respectively. In contrast, 53 and 75% adults died in the treatment of tolfenpyrad in 12 and 24 h, respectively. However, all adults survived in the treatments of fenpyroximate, and only 3% died in the treatment of spiromesifen. Approximately 22, 25, and 28% of adults died 24 h after ingestion of novaluron, cyantraniliprole, and spirotetramat, respectively, and 41% or 50% of adults died in the treatments of chenopodium oil and pymetrozine, respectively.

Adult Parasitism. Ingestion of insecticides caused negative effects on parasitism ($F = 9.65$; df = 8, 35; $P < 0.0001$) (Table 4). All insecticide treatments reduced parasitism of the surviving females compared with the water control. Of the insecticides, the females fed tolfenpyrad produced significantly less parasitism than all tested pesticides except cyantraniliprole, pymetrozine, and spirotetramat. Of those surviving to pupation, most parasitoids successfully emerged with no significant differences among the treatments ($F = 0.60$; df = 8, 35; $P < 0.7681$).

Adult Longevity. Longevity of female adults varied significantly with the insecticide ingested ($F = 19.45$; df = 11, 47; $P < 0.0001$), and females that survived the first day lived significantly longer than males (Table 5). Both the females and males died one day after ingestion of abamectin, imidacloprid-cyfluthrin, or spinetoram. The females lived 80.8 d after ingestion of pymetrozine, which was similar to that in the water control (83.9 d). Although the females that ingested cyantraniliprole, fenpyroximate, spirotetramat, or tolfenpyrad lived 40–50 d, their lifespans were significantly shorter than those in the water control. The females that ingested chenopodium oil lived ≈2 wk, and those ingesting novaluron lived slightly longer than 23 d.

The *T. triozae* males in control treatments lived only 28.3 d as compared with 83.9 d for the female adults (Table 5). In addition, the responses to pesticides varied as compared with the females. The longevity of *T. triozae* males varied significantly ($F = 4.79$; df = 11,47; $P < 0.0001$). Males that ingested abamectin, imidacloprid-cyfluthrin, chenopodium oil, or spinetoram died on the first day. Those that ingested novaluron lived 13.4 d. The males in the treatments of cyantraniliprole, fenpyroximate, pymetrozine, spirotetramat, spiromesifen, and tolfenpyrad lived from 17.1 d to 31.3 d, which were not significantly different from those in the water control (28.3 d).

Table 3. Leaf residual toxicity of insecticides to adult *Tamarixia triozae* (mortality in 48 h)

Material	Concentration (mg ai/liter)	Mortality (% ± SE)[a] at different residual age (d)					
		1 d	3 d	5 d	7 d	10 d	15 d
Abamectin	11.2	58.3 ± 8.3b	37.5 ± 17.2b	50.0 ± 6.8b	25.0 ± 8.3c	16.7 ± 6.8b	0b
Cyantraniliprole	0.123	0c	0c	0d	0d	0d	0b
Fenpyroximate	95.7	12.5 ± 8.0c	0c	0d	0d	0d	0b
Pymetrozine	0.19	4.2 ± 4.2c	0c	0d	0d	0d	0b
Imidacloprid+Cyfluthrin	57.4 + 39.5	54.2 ± 4.2b	33.3 ± 11.8b	41.7 ± 4.8c	45.8 ± 4.2b	8.3 ± 4.8c	0b
Spirotetramat	96	4.2 ± 4.2c	0c	0d	0d	0d	0b
Spiromesifen	192	0c	0c	0d	0d	0d	0b
Chenopodium oil	1.13	8.3 ± 4.8c	0c	0d	0d	0d	0b
Spinetoram	192	100a	100a	100a	100a	100a	100a
Novaluron	192	12.5 ± 8.0c	12.5 ± 10.5c	0d	0d	0d	0b
Tolfenpyrad	239	4.2 ± 4.2c	0c	4.2 ± 4.2c	4.2 ± 4.2c	8.3 ± 4.8c	0b
Water	0	0c	0c	0d	0d	0d	0b
F		42.6	18.25	138.96	106.73	105.27	
P		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	

[a] Means (± SE) within a column followed by the same letter are not significantly different at $P < 0.05$; Tukey's Studentized Range Test (HSD).

Table 4. Toxicity on adults and parasitism of *Tamarixia triozae* after ingestion of insecticides

Materials	Concentrations (mg ai/liter)	Mortality, % ± SE	Parasitism, % ± SE	Emerged, % ± SE
Abamectin	11.2	100a	–	
Cyantraniliprole	0.123	28.1 ± 6.0d	9.4 ± 1.2bcd	100a
Fenpyroximate	95.7	0e	13.1 ± 4.3bc	87.5 ± 12.5a
Pymetrozine	0.19	40.6 ± 3.1c	9.4 ± 3.6bcd	94.4 ± 5.6a
Imidacloprid+cyfluthrin	57.4 + 39.5	100a	–	–
Spirotetramat	96	25.0 ± 5.1d	5.0 ± 2.7cd	86.7 ± 13.3a
Spiromesifen	192	3.1 ± 3.1e	17.5 ± 2.7b	96.4 ± 3.6a
Chenopodium oil	1.13	50.0 ± 5.1c	13.8 ± 3.0b	100a
Spinetoram	192	100a	–	–
Novaluron	192	21.9 ± 3.1d	13.8 ± 2.4b	100a
Tolfenpyrad	239	75.0 ± 8.8b	0.6 ± 0.6d	100a
Water	–	0e	33.1 ± 3.3a	95.8 ± 4.2a
F		95.18	9.65	0.60
P		<0.0001	<0.0001	0.7681

Means (± SE) within a column followed by the same letter are not significantly different at $P < 0.05$; Tukey's Studentized Range Test (HSD).

Discussion

We found spinetoram, abamectin, and imidacloprid-cyfluthrin were the three most toxic chemicals to *T. triozae* adults in residual and ingestion bioassays. Similar results also have been reported for other parasite species. Williams et al. (2003) found spinetoram was most harmful to hymenopteran parasitoids, but not predators; Hernández et al. (2011a,b) found abamectin was harmful to *Ganaspidium nigrimanus* (Kieffer) and *Neochrysocharis formosa* (Westwood), parasitoids of *Liriomyza* spp. Hall and Nguyen (2010) reported that abamectin killed all adults of *T. radiata*, a parasitoid of the Asian citrus psyllid, *Diaphorina citri* Kuwayama. Our results with Leverage, the combination of imidacloprid and cyfluthrin, was also in agreement with publications reviewed by Cloyd and Bethke (2011) on imidacloprid, and Prabhaker et al. (2007) results with cyfluthrin.

Our data show that pymetrozine and novaluron were not harmful to *T. triozae*. Similar results also have been reported in the literature. Sechser et al. (2002) documented that pymetrozine was harmless to several insect species belonging to different orders. However, pymetrozine had negative effects on larval development and caused male-biased sex ratio of *Aphidius ervi* Haliday (Joseph et al. 2011), and caused increased mortality and shorter longevity than untreated control treatments (Tran et al. 2005). For novaluron, several studies show that it has good selectivity favoring beneficial insects, including *En. formosa* (Ishaaya et al. 2002), *Trichogramma pretiosum* Riley (Bastos et al. 2006), *Diadegma* sp. (Ayalew 2011), and *Ganaspidium nigrimanus* (Kieffer) and *Neochrysocharis formosa* (Westwood) (Hernández et al. 2011b).

Table 5. Effects of ingestions of 11 insecticides on gender longevity of *Tamarixia triozae* adults

Materials	Concentrations (g ai/liter)	Longevity, days ± SE	
		Female	Male
Abamectin	11.2	1.0 ± 0.0e	1.0 ± 0.0c
Cyantraniliprole	0.123	48.7 ± 2.7b	17.1 ± 5.4abc
Fenpyroximate	95.7	40.1 ± 3.9bc	31.3 ± 3.7a
Pymetrozine	0.19	80.8 ± 4.1a	23.6 ± 2.6ab
Imidacloprid+cyfluthrin	57.4 + 39.5	1.0 ± 0.0e	1.0 ± 0.0c
Spirotetramat	96	49.6 ± 5.0b	23.4 ± 3.8ab
Spiromesifen	192	52.0 ± 5.5b	27.9 ± 5.2ab
Chenopodium oil	1.13	14.3 ± 7.4de	1.0 ± 0.0c
Spinetoram	192	1.0 ± 0.0e	1.0 ± 0.0c
Novaluron	192	23.3 ± 7.7cd	13.4 ± 4.8bc
Tolfenpyrad	239	48.0 ± 5.3b	26.4 ± 6.3ab
Water	0	83.9 ± 4.2a	28.3 ± 2.7ab
F		19.45	4.79
P		<0.0001	<0.0001

Means (± SE) within a column followed by the same letter are not significantly different at $P < 0.05$; Tukey's Studentized Range Test (HSD).

Our *Chenopodium* oil results were supported by Hall and Nguyen (2010) who found that *Chenopodium* oil was highly toxic to adult *T. radiata* as a direct spray, but field residues were nontoxic. In addition, this material had negligible effects on the whitefly parasitoid *Encarsia formosa* Gahan under greenhouse conditions (Chiasson et al. 2004).

However, some of our results were not in agreement with those reported in the literature, especially with fenpyroximate and spirotetramat. We found that fenpyroximate was relatively nontoxic to *T. triozae*, but Hall & Nguyen (2010) found that both direct sprays of fenpyroximate and dry residue killed *T. radiata* adults. Similarly, we found that spirotetramat was safe for *T. triozae* adults, but females that ingested this compound produced reduced parasitism. This is in contrast with a report by Hall and Nguyen (2010) that a direct spray of spirotetramat was highly toxic to adult *T. radiata. Tamarixia triozae* and *T. radiata* are sibling species, and we have no explanation that explains why the same insecticide has different effects on the two sibling species.

Methodology to assess insecticide impact on natural enemies may include some combination of topical applications, ingestion studies, exposure to residues, or field studies assessing changes in natural enemy populations in response to insecticide application (Tillman and Mulrooney 2000, Martinson et al. 2001). Each approach provides specific and useful information about insecticide effects on natural enemies. Studies using topical applications of toxins provide information on the gross effects that can be expected when entire fields are treated. Exposure of natural enemies to pesticide residues on

leaves is appropriate for determining the effect of post-application residues on insects not sprayed directly with the insecticide (such as mass releases of beneficials after initial pesticide applications). Our results showed that some insecticides produced different effects when the methodology was varied even within a basic strategy. For example, the glass dry residue of tolfenpyrad was toxic to adult *T. triozae*, whereas the leaf residue had no significant effect. However, by adding ingestion studies we observed that tolfenpyrad caused high levels of adult mortality and as a result the parasitism rate was reduced.

The insecticides cyantraniliprole, pymetrozine, spirotetramat, spiromesifen, and novaluron were harmless based on the classification given by IOBC/WPRS working group on pesticides and nontarget invertebrates because the recommended dose caused <50% mortality under laboratory conditions (Hassan et al. 1985). Thus, *T. triozae* has an excellent potential for integration with these materials.

The variations in the response of the parasitoids to these insecticides may help in management of *B. cockerelli.* The use of insecticides is still necessary within the current agricultural system. Transmission of the Liberibacter pathogen early in the season is more damaging than late-season transmission (Munyaneza et al. 2007, 2008). Thus, use of the most toxic materials early in the season (with the exception of those with very long lived residues) would be useful to reduce pathogen transmission. Later in the season, the releases of commercially available *T. triozae* could follow applications of the less toxic insecticides, and would have the potential to reduce the insecticidal inputs necessary to produce a profitable crop. Currently, reliance solely on pesticides has proven to be economically challenging (Goolsby et al. 2007). Ultimately, such strategies need to be evaluated for cost benefits in a commercial setting (Trumble 1998).The results of present findings on insecticidal effects on adult *T. triozae* showed that the insecticides that consistently appeared to be most IPM-compatible with *T. triozae* at the rates tested were cyantraniliprole, pymetrozine, spiromesifen, and novaluron, which were either nontoxic or short lived. Abamectin, spinetoram, and imidacloprid-cyfluthrin were least compatible with *T. triozae*, and should be used cautiously because they could disrupt natural enemies. Because persistence is a function of dosage, lowering the dosages of certain chemicals may reduce the length of time they significantly affect *T. triozae* activity.

Compared with the insects reared in cages, vials, or dishes, organisms in the field have a chance to survive on noncontaminated parts of the plants. The residues of some insecticides may be reduced when rainfall occurs (Hall and Nguyen 2010). Although this laboratory study should not be extrapolated immediately to the commercial field level, the results illustrate potential negative effects of some insecticides on the parasitoid, and provide a basis from which to select insecticides most compatible with *T. triozae.* In addition to the information from this study, determination of side effects of frequently used pesticides on the commonly encountered predators in the field may also be very important.

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