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Residual toxicity of acaricides to *Galendromus occidentalis* and *Phytoseiulus persimilis* reproductive potential

F. Javier Sáenz-de-Cabezón Irigaray *, Frank G. Zalom [1], Patricia B. Thompson

Department of Entomology, University of California, Davis, One Shields Avenue, Davis, CA 95616, USA

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Abstract

Understanding the effects of pesticide residues on leaf surfaces through time on phytoseiid mites is important to their successful integration into augmentation and/or conservation programs. The residual toxicities of fenpyroximate (Fujimite®), acequinocyl (Kanemite®), etoxazole (Zeal®), spiromesifen (Oberon®), bifenazate (Acramite®) and abamectin (Agri-mek®) on leaflets to *Galendromus occidentalis* (Nesbitt) and *Phytoseiulus persimilis* Athias-Henriot (Acari:Phytoseiidae) were assessed 3, 6, 10, 14, 17, 24, 30 and 37 days post treatment. Impacts on mortality, fecundity and fertility were determined following 3 days of exposure to each leaf surface residue interval. Percent mortality and total effects (*E*) on adult female reproductive potential thus measured were used to assess each acaricide's persistence. Based on mortality, fenpyroximate was considered slightly (from 5 to 15 days) persistent for both species by IOBC standards, while abamectin was also slightly persistent for *P. persimilis* only. The remaining acaricides would be classified as short lived (less than 5 days) for both species. Persistence classified by considering *E* suggest that fenpyroximate and etoxazole would be the least compatible with *G. occidentalis* and *P. persimilis*. Both were persistent (longer than 30 days). Bifenazate and spiromesifen were slightly persistent to both predators. Acequinocyl was slightly persistent to *G. occidentalis*, but short lived to *P. persimilis*. Abamectin was slightly persistent to *P. persimilis*, but short lived to *G. occidentalis*. Consideration of both direct and side effects of these acaricides will improve pesticide selection, anabling better conditions for Phytoseiid conservation and augmentation.

Keywords: Abamectin; Acequinocyl; Bifenazate; Etoxazole; Fecundity; Fenpyroximate; Fertility; Miticides; Persistence; Phytoseiidae; Predatory mite; Spiromesifen; Sublethal effects

1. Introduction

Integration of a biological control agent into agricultural IPM systems can not be achieved unless the natural enemy can survive the pesticides being used in that crop system (Hoy, 1985). Pesticides are often disruptive to trophic relationships involving these beneficial insects. Consequently plant pest populations may increase to more damaging levels than occurred before treatment (Croft, 1990). Ecological selectivity is achieved by limiting pesticide exposure of a beneficial arthropod in its natural environment while killing its host or prey. Ecological selectivity can be accomplished by manipulation of the pesticide formulation, timing of application, method of application, spatial distribution of treatment, and other means (Croft, 1990). Proper timing is often the most effective and economical method for achieving differential insecticide selectivity on the pest/natural enemy complex (Poehling, 1989). In addition, knowledge of pesticide selectivity to beneficial arthropods is important to its utility in IPM programs, creating better conditions for natural enemies and helping to reduce pesticide applications.

Predatory mites in the family Phytoseiidae are effective as biological control agents in agricultural systems (Hoy et al., 1983). Members of this family, *Galendromus occidentalis* (Nesbitt), the western orchard predator mite, and

* Corresponding author. Fax: +1 530 752 0275.
E-mail addresses: fjsaenzdecabezon@ucdavis.edu (F.J. Sáenz-de-Cabezón Irigaray), fgzalom@ucdavis.edu (F.G. Zalom), pbthompson@ucdavis.edu (P.B. Thompson).
[1] Fax: +1 530 752 1537.

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Phytoseiulus persimilis Athias-Henriot, are widely used in biological control programs throughout California and elsewhere in the world (Gerson et al., 2003). Both are major biocontrol agents of webbing spider mites (especially *Tetranychus* spp.) that infest many deciduous tree fruit crops, strawberries, hops and greenhouse plantings (McMurtry, 1982).

Pesticide toxicity has traditionally been evaluated by considering adult female mortality as the end point, estimating values that measure median lethal concentration (LC_{50}) or median lethal dose (LD_{50}) (Robertson and Worner, 1990; Stark et al., 1997). Because these evaluations focus on a single life stage and generally for a short duration of time (often 1–4 days), the results of these bioassays do not accurately assess the total effects of a pesticide on an exposed population (Stark and Banken, 1999). Evaluation of sublethal effects should be combined with assessment of acute effects to estimate the total effect of a pesticide (Stark et al., 1995).

Several new acaricides have been registered for use in the U.S. since 2000 that represent different modes of action from those commonly used in the previous two decades including propargite, dicofol, and fenbutatin oxide. These new chemicals include etoxazole, spiromesifen, fenpyroximate, bifenazate, and acequinocyl. The mode of action for etoxazole was determined to be chitin biosynthesis inhibition by Nauen and Smagghe (2006), similar to that of benzoylphenylurea insecticides. Spiromesifen is assumed to have a similar mode of action to spirodiclofen which inhibits lipid biosynthesis. Bifenazate is believed to be a γ-amino butyric acid agonist, although there has been no definitive study on the mode of action of this chemical (Dekeyser, 2005). Acequinocyl and fenpyroximate are mitochondrial electron transport inhibitors (METIs) at Complex III and I, respectively. Abamectin whose primary mode of action is to block synaptic transmission, had been registered for many sites prior to the registration of these new chemicals, but its use has increased recently as applications of the older products has declined.

Acute and sublethal effects of these acaricides on *G. ocidentalis* observed through laboratory bioassays conducted by Sáenz-de-Cabezón Irigaray and Zalom (2006, unpublished results) indicated reductions in female reproductive potential after direct contact and leaf surface treatments. Other studies of etoxazole, acequinocyl and bifenazate on *Amblyseius womersleyi* Schicha (Kim and Seo, 2001) and *P. persimilis* (Kim and Yoo, 2002) concluded there was no effect of these chemicals on mortality, fecundity or fertility. Exposure to abamectin residues at "typical" rates was not shown to cause *P. persimilis* mortality 24 h after application (Cote et al., 2002), nor was significant mortality observed under greenhouse conditions (Malezieux et al., 1992; Shipp et al., 2000). *P. persimilis* mortality was observed under laboratory conditions by Oomen et al. (1991) and Shipp et al. (2000). Zhang and Sanderson (1990) reported that abamectin residues produced sublethal effects on *P. persimilis*. Corresponding data for abamectin are not published for *G. occidentalis*. Our study describes the effects of leaf surface residues of selected acaricides to *G. occidentalis* and *P. persimilis* by assessing adult female mortality, fecundity and fertility 3, 6, 10, 14, 17, 24, 30 and 37 days following their application.

2. Materials and methods

2.1. Mites and acaricides tested

Mite colonies were maintained in growth chambers at 24 ± 1 °C, 75–85% RH and 16:8 photoperiod. The phytophagous mites, *Tetranychus urticae* Koch, originally collected from a University of California Davis greenhouse and maintained in our laboratory for 3 years, were reared on cotton seedlings (*Gossypium hirsutum* L.). *G. occidentalis* and *P. persimilis* were reared on detached cotton leaves infested with mixed stages of *T. urticae*. The original sources of our *G. occidentalis* and *P. persimilis* colonies were Sterling Insectary (McFarland, CA) and Biotactics (Riverside, CA), respectively. The active ingredients tested, their trade names, formulations and concentrations applied are listed in Table 1. All of the concentrations are within the range labeled for field use.

2.2. Residual toxicity

2.2.1. Leaf surface treatment

Each chemical evaluated was mixed with distilled water to achieve a solution of the desired concentration. A 100 ml volume of each solution was sprayed onto strawberry (var. Camarosa) plants to run-off using a 200 ml hand trigger sprayer with adjustable nozzle set to mist position (Delta sprayer, Delta Industries, PA). Untreated plants were sprayed with distilled water alone. Five plants were used for each treatment and the control. The plants were grown in 3.8 l plastic pots under field conditions. Drip irrigation and nutrients were applied uniformly to all plants and no pesticides of any kind were used prior to the experimental applications. The plants remained outdoors under field

Table 1
Active ingredient, trade name, formulation and concentration (ppm) of acaricides evaluated

Active ingredient	Trade name	% a.i. and formulation	Concentration (ppm)
Fenpyroximate[a]	Fujimite	5 SC	62.5
Etoxazole[b]	Zeal	72 WP	80.9
Acequinocyl[c]	Kanemite	15 SC	181.5
Bifenazate[d]	Acramite	50 WS	200.7
Spiromesifen[e]	Oberon	23 SC	142.6
Abamectin[f]	Agrimek	15 EC	93.0

[a] Nichino America Inc. (Wilmington, DE).
[b] Valent U.S.A. Corp. (Walnut Creek, CA).
[c] Arysta Lifescience Corp. (San Francisco, CA).
[d] Chemtura Corp. (Middlebury, CT).
[e] Bayer Cropscience Inc. (Research Triangle Park, NC).
[f] Syngenta Crop Protection, Inc. (Greensboro, NC).

conditions following treatment during June 2005. No rainfall occurred during this period, and the plants were not exposed to overhead irrigation or pesticide applications of any kind.

2.2.2. Bioassay units

Each bioassay unit consisted of five 20 mm diameter strawberry leaf disks, cut with a cork borer from three treated and three untreated leaflets removed from the plants. The disks were placed on wet filter paper inside a 90 mm diameter Petri dish. Additional water was then added to create a water barrier to discourage mite movement from the disks. The Petri dish cover had three 6 mm diameter holes to prevent excessive humidity and provide ventilation. Bioassays were conducted at 27 ± 1 °C, 50–60% RH and 16:8 photoperiod.

Bioassays for *G. occidentalis* and *P. persimilis* were conducted in separate sets of bioassay units. Three random age adult predator mite females were placed onto each treated leaf disk with the aid of a fine camel hair brush. A surplus of *T. urticae* active stages and eggs were transferred to each leaf disk daily as food for the predators. Mortality and fecundity (number off eggs laid) were recorded per leaf disc, after three days. Fertility (number of young produced) was determined 6 days after being placed on a disk. There were five replicates (one bioassay unit) of each acaricide treatment and control. These procedures were repeated with treated and untreated leaflets removed from the plants at 3, 6, 10, 14, 17, 24, 30 and 37 days after application.

2.3. Statistical analysis

Mean mortality, and fertility after three days exposure were analyzed by non-parametric Kruskal–Wallis test followed by a Mann Whitney *U* test on all pairs of groups in order to determine differences between treatments. Fecundity was analyzed by ANOVA with means separated by LSD ($p < 0.05$) (SPSS, 2003). Total effects of pesticides (*E*) values were used to measure the persistence of pesticides. *E* values were calculated according to Overmeer and Van Zon (1982) by adjusting fertility corrected values to the reproductive value using the equation:

$$E(\%) = 100\% - (100\% - M) \times R$$

where M = corrected mortality (Abbott, 1925) and R = reproduction per treated female/reproduction per untreated female. Reproduction was defined as the number of eggs per female *x* percentage fertility. Evaluation categories for persistence were assigned according IOBC guidelines (Sterk et al., 1999). Loss of activity was assumed when *E* or mortality <30.

3. Results

Adult female mortality recorded 72 h after exposure to acaricide residues present on leaflets collected at each post treatment interval was greatest for fenpyroximate, resulting in 100% mortality up to 10 days after treatment for both *G. occidentalis* and *P.persimilis* ($H = 34.0$; df = 6; $p < 0.001$ and $H = 34.0$; df = 6; $p < 0.001$, respectively). Etoxazole, abamectin and acequinocyl significantly ($H = 29.2$; df = 6; $p < 0.001$) increased mortality of *G. occidentalis* adult females 3 days after treatment of the strawberry plants. *P. persimilis* adult female mortality was significantly increased for 6 days after treatment with abamectin ($H = 34.0$; df = 6; $p < 0.001$) and 3 days after treatment with acequinocyl ($H = 31.1$; df = 6; $p < 0.001$). No mortality was observed for either pesticide >14 days after treatment (Table 2).

Exposure to fenpyroximate residues significantly ($F = 30.2$; df = 6,28; $p < 0.001$) reduced fecundity of *G. occidentalis* for 37 days after treatment of the strawberry plants (Fig. 1A) for 14 days following acequinocyl treatment ($F = 43.3$; df = 6,28; $p < 0.001$), and for 10 days following treatment with bifenazate, etoxazole and spiromesifen ($F = 22.4$; df = 6,28; $p < 0.001$). Abamectin significantly ($F = 30.3$; df = 6,28; $p < 0.001$) decreased fecundity on only the first observation date (3 days) follow-

Table 2
Percent mortality (mean ± SD) of *G. occidentalis* and *P. persimilis* recorded 72 h after exposure to treated strawberry leaflets removed from treated plants in the field on the indicated days after treatment using the labeled dose of formulated products

Treatment	Mean ± SD % mortality									
	G. occidentalis					*P. persimilis*				
	Days after treatment				IOBC[a]	Days after treatment				IOBC[a]
	3	6	10	>14		3	6	10	>14	
Control	0a	0a	0a	0a	A	0a	0a	0a	0a	A
Bifenazate	0a	0a	0a	0a	A	0a	0a	0a	0a	A
Etoxazole	26.4 ± 6.6b	0a	0a	0a	A	0a	0a	0a	0a	A
Spiromesifen	0a	0a	0a	0a	A	0a	0a	0a	0a	A
Abamectin	33.0 ± 10.4b	0a	0a	0a	A	26.4 ± 12.3b	26.4 ± 12.3b	0a	0a	A
Fenpyroximate	100c	100b	100b	0a	B	100c	100c	100b	0a	B
Acequinocyl	100c	0a	0a	0a	A	100c	0a	0a	0a	A

Within column means (±SD) followed by the same letter do not differ significantly at $p = 0.05$ by LSD.
[a] IOBC categories: A, short lived (<5 d); B, slightly persistent (5–15 d); C, moderately persistent (16–30 d); D, persistent (>30 d).

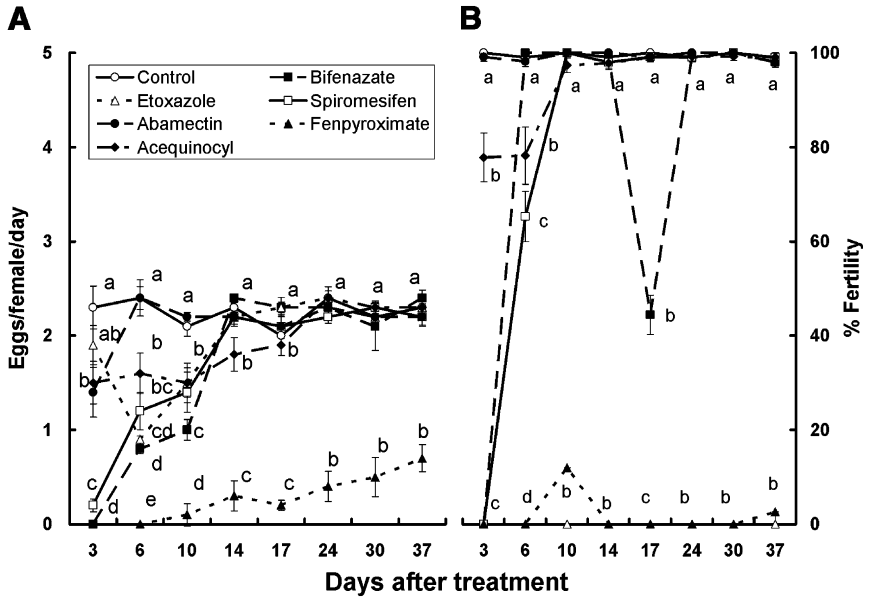

Fig. 1. (A) Mean ± SD *G. occidentalis* fecundity (eggs/female/day) recorded 72 h after exposure to treated strawberry leaflets removed from treated plants in the field on the indicated days after treatment using the labeled concentration of formulated products. Within each time interval, the means followed by the same letter do not differ significantly at $p = 0.05$ by ANOVA and LSD. (B) Mean ± SD *G. occidentalis* fertility after 72 h exposure to treated strawberry leaflets using the labeled concentration of formulated products. Within each time interval, means followed by the same letter do not differ significantly at $p = 0.05$ by the non-parametric Kruskal–Wallis test and by the Mann Whitney *U* test. The vertical lines represent the SEM.

ing treatment. *G. occidentalis* female fertility was strongly decreased ($H = 25.1$; df = 6; $p < 0.001$) following exposure to leaflets treated 37 days earlier with either etoxazole or fenpyroximate (Fig. 1B). A few eggs laid by females exposed on the 10th and 37th days after treatment with fenpyroximate hatched, but none hatched when exposed on the other dates. Spiromesifen and acequinocyl significantly ($H = 32.2$; df = 6; $p < 0.001$) reduced *G. occidentalis* fertility for 6 days after treatment, and bifenazate ($H = 33.6$; df = 6; $p < 0.001$) for 3 days after treatment. Abamectin had no effect on *G. occidentalis* fertility.

Fenpyroximate significantly ($F = 74.6$; df = 6,28; $p < 0.001$) reduced *P. persimilis* fecundity for 24 days after treatment of the strawberry plants (Fig. 2A). Bifenazate,

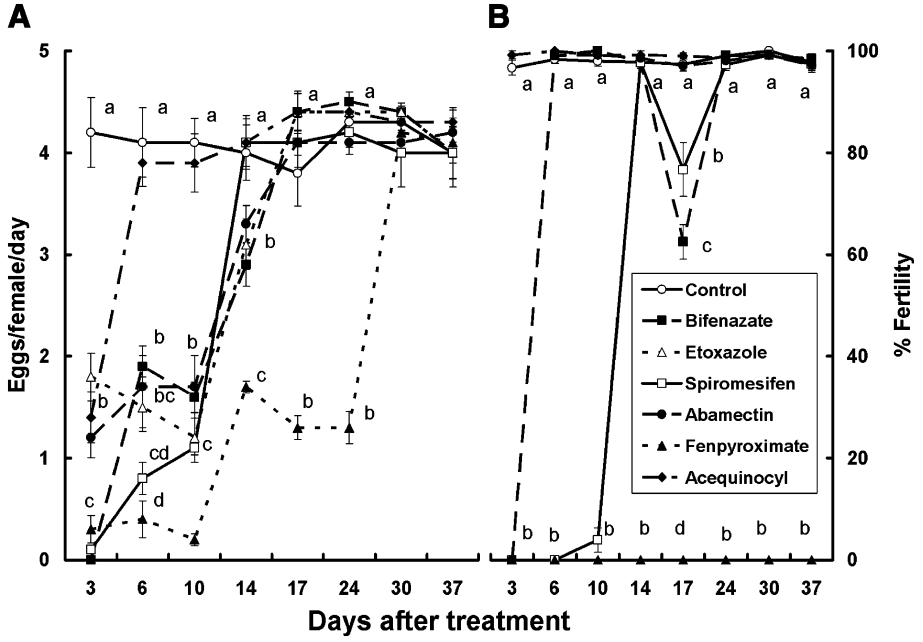

Fig. 2. (A) Mean ± SD *P. persimilis* fecundity (eggs/female/day) recorded 72 h after exposure to treated strawberry leaflets using the labeled concentration of formulated products. Within each time interval, means followed by the same letter do not differ significantly at $p = 0.05$ by ANOVA and LSD. (B) Mean ± SD *P. persimilis* fertility recorded 72 h after exposure to treated strawberry leaflets using the labeled concentration of formulated products. Within each time interval, means followed by the same letter do not differ significantly at $p = 0.05$ by the non-parametric Kruskal–Wallis test and by the Mann Whitney *U* test. The vertical lines represent the SEM.

etoxazole and abamectin significantly ($F = 15.5$; df = 6,28; $p < 0.001$) reduced fecundity for 14 days, while spiromesifen reduced fecundity for 10 days ($F = 48.7$; df = 6,28; $p < 0.001$). Acequinocyl significantly ($F = 50.2$; df = 6,28; $p < 0.001$) reduced fecundity on only the first observation date (3 days) after treatment. *P. persimilis* females did not produce fertile eggs following exposure to treated leaflets for 37 days after application with either etoxazole and fenpyroximate (Fig. 2B). Spiromesifen significantly ($H = 29.7$; df = 6; $p < 0.001$) reduced fertility for 10 days following application, while bifenazate and abamectin reduced fertility ($H = 33.2$; df = 6; $p < 0.001$) for only 3 days. Acequinocyl had no effect on *P. persimilis* fertility.

Total effects of acaricides (E) and IOBC categories for both phytoseiid species are presented on Tables 3 and 4. Total effects of etoxazole and fenpyroximate residues remained at 100 for all 37 days following application for both species and would be considered harmful by IOBC standards. Bifenazate, acequinocyl and spiromesifen total effects on *G. occidentalis* exceeded 30 for 10 days following treatment, while total effects of bifenazate, spiromesifen and abamectin on *P. persimilis* also exceed 30 for 10 days and would be considered slightly persistent by IOBC standards. Total effects of abamectin on *G. occidentalis* exceeded 30 for only 3 days, as did acequinocyl on *P. persimilis*. These acaricides would be considered short lived by IOBC standards for the respective predators.

4. Discussion

Understanding the effects of pesticide residues on leaf surfaces through time on mortality, fecundity and fertility of phytoseiids is important to their successful integration into augmentation programs. The recent introduction of several new acaricides into agricultural crops has made knowledge of the specific residual effects of these chemicals crucial to the continued use of *G. occidentalis* and *P. persimilis* by California's fruit and nut producers.

The persistence of biological activity of different compounds on strawberry leaves under field conditions, assessed by measuring total effect (E) on adult female reproductive potential resulting after 3 days of exposure to residues at different intervals, indicate that fenpyroximate and etoxazole had the greatest effect on both *G. occidentalis* and *P. persimilis* and would be considered persistent by IOBC classification (Sterk et al., 1999). Such data have not been previously reported for fenpyroximate. Sáenz-de-Cabezón Irigaray and Zalom (2006; unpublished results) reported *G. occidentalis* female longevity of less than one day when exposed to 62.5 ppm of fenpyroximate by direct spray contact. Sato et al. (2002) recorded higher tolerance to fenpyroximate in *Neoseiulus californicus* (McGregor) than *T. urticae* (LC_{50} of 69.6 and 24.0 ppm, respectively) when exposing the mites to leaf surfaces with a Potter tower. No mortality was reported when the mites were exposed to residues on strawberry leaves treated in the

Table 3
Total effects (E) of acaricide residues on *G. occidentalis* recorded 72 h after exposure to treated strawberry leaflets removed from treated plants in the field on the indicated days after treatment using the labeled dose of formulated products

Treatment	Days after treatment								IOBC[a]
	3	6	10	14	17	24	30	37	
Bifenazate	100	67	52	0	0	0	0	0	B
Etoxazole	100	100	100	100	100	100	100	100	D
Spiromesifen	100	67	33	0	0	0	0	0	B
Abamectin	60	0	0	0	0	0	0	0	A
Fenpyroximate	100	100	100	100	100	100	100	100	D
Acequinocyl	100	48	30	23	6	0	0	0	B

$E\,(\%) = 100\% - (100\% - M) \times R$.
[a] IOBC categories: A, short lived (<5 d); B, slightly persistent (5–15 d); C, moderately persistent (16–30 d); D, persistent (>30 d).

Table 4
Total effects (E) of acaricide residues on *P. persimilis* recorded 72 h after exposure to treated strawberry leaflets removed from treated plants in the field on the indicated days after treatment using the labeled dose of formulated products

Treatment	Days after treatment								IOBC[a]
	3	6	10	14	17	24	30	37	
Bifenazate	100	54	61	29	26	0	0	0	B
Etoxazole	100	100	100	100	100	100	100	100	D
Spiromesifen	100	100	99	0	12	0	0	0	B
Abamectin	100	70	59	19	3	2	1	2	B
Fenpyroximate	100	100	100	100	100	100	100	100	D
Acequinocyl	100	5	6	0	0	0	0	0	A

$E\,(\%) = 100\% - (100\% - M) \times R$.
[a] IOBC categories: A, short lived (<5 d); B, slightly persistent (5–15 d); C, moderately persistent (16–30 d); D, persistent (>30 d).

field. The results reported in these two studies could be the result of different tolerance to fenpyroximate between species or different methods of exposure. Kim and Yoo (2002) and Kim and Seo (2001) indicated that direct exposure of both *P. persimilis* and *A. womersleyi* to a 25 ppm concentration of etoxazole under laboratory conditions resulted in little mortality of adult females 168 h after treatment and had no effect on their fecundity, but none of the larvae emerging from eggs laid by treated females reached the adult stage. Sáenz-de-Cabezón Irigaray and Zalom (2006; unpublished results) found similar results for fertility and offspring development of *G. occidentalis* and *T. urticae* following treatment of adult females with 24.1 ppm of etoxazole. Aged etoxazole residues were not evaluated in either study. Total effects calculated from our data indicate that bifenazate and spiromesifen are slightly persistent to both *G. occidentalis* and *P. persimilis*, due primarily to reduced fecundity and fertility. This conclusion for bifenazate is somewhat different from that of Dekeyser et al. (1996) who reported bifenazate to be harmless to *G. occidentalis*. Studies on *P. persimilis* and *A. womersleyi* by Kim and Yoo (2002) and Kim and Seo (2001) reported that bifenazate had little effect on mortality, fecundity or fertility of treated females 168 h after treatment. James (2002) observed that bifenazate applied to grapes at the full field rate was moderately toxic to *G. occidentalis*, but less toxic at half and quarter rates. Total effects of spiromesifen on adult female reproductive potential have not been reported. Acequinocyl was slightly persistent to *G. occidentalis* in our study, but short lived to *P. persimilis*. These results are consistent with studies on *P. persimilis* (Kim and Yoo, 2002) and *A. womersleyi* (Kim and Seo, 2001) which indicated that acequinocyl had little effect on mortality, fecundity or fertility of treated females of either species for 168 h following exposure. Abamectin was short lived to *G. occidentalis* in our study, but slightly persistent to *P. persimilis*. This is consistent with the findings of several other authors who reported that exposure to abamectin residues did not have a significant effect on *P. persimilis* mortality (Cote et al., 2002; Malezieux et al., 1992; Shipp et al., 2000). Abamectin residues were shown to produce sublethal effects on *P. persimilis* by Zhang and Sanderson (1990) who found that 8 days of exposure to residues beginning 1 h after a 4 ppm application reduced *P. persimilis* egg laying by as much as 50%. Their study also revealed that exposure of *P. persimilis* to abamectin residues did not decrease egg hatch rate, but feeding on treated *T. urticae* reduced egg production. Studies of abamectin on *Neoseiulus longispinosus* (Evans) conducted by Ibrahim and Yee (2000) indicated differences in reproductive potential between treated and untreated females.

Reduced fertility was the response variable most affected by exposure of *G. occidentalis* and *P. persimilis* to etoxazole residues in our study. Fecundity was also somewhat reduced for 10 days after treatment as mortality increased within 3 days of treatment. Given that the mode of action of etoxazole is similar to that of an insect growth regulator (IGR) (Nauen and Smagghe, 2006), it is not surprising that the low impact on adult mortality, strong ovicidal activity and effects on fertility and juvenile development should be observed. Fecundity reductions due to IGRs have been related to physiological and morphological changes of both male and female arthropods from different orders including Acari (Sharma et al., 1979; Rup and Chopra, 1985; Marco and Viñuela, 1994; Marco et al., 1998; Sáenz-de-Cabezón et al., 2002; Sáenz-de-Cabezón et al., 2006). Fenpyroximate significantly reduced fertility and fecundity of *G. occidentalis and P. persimilis* placed on treated leaves for several weeks after its application. Reduced fecundity was the greatest contributor to the total residual effects of bifenazate, spiromesifen and acequinocyl on *G. occidentalis*, more than either reduced fertility or increased mortality. This observation cannot be explained entirely by the mode of action of these chemicals. so behavior or other mechanisms should also be considered. For example, Sáenz de Cabezón and Zalom (unpublished results) recorded that reduced fecundity of *G. occidentalis* was more severe when females were exposed to fresh leaf surface residues of spiromesifen when the females were exposed by direct contact spray, suggesting a behavioral rather than a physiological cause.

Our results illustrate that evaluating the toxicity of an acaricide to phytoseiids by measuring only female mortality underestimates the true effect of residual exposure. All acaricides but fenpyroximate would be considered IOBC Category A (short lived) products based on female mortality. In fact, a much different conclusion is reached with many of these acaricides when sublethal effects on fecundity and fertility are considered, suggesting that side effects on reproduction may be as lethal as direct effects (Stark and Banken, 1999; Stark and Banks, 2003) on phytoseiid populations present before or introduced following treatment. Selectivity assessment for predatory mites should therefore be done integrating both lethal and sublethal effects.

According to our results, when considering total effects of strawberry leaf surface residues of the six acaricides on *G. occidentalis* and *P. persimilis*, fenpyroximate and etoxazole residues would clearly not be compatible with their augmentative release for at least 5 weeks after treatment. Releases of either predator could be made 2 weeks after treatment with bifenazate or spiromesifen, when total effects fall below 30. *G. occidentalis* releases could be made in as few as 6 days following application of abamectin, and for *P. persimilis* following application of acequinocyl. Knowledge of the total effects of these acaricides temporally should facilitate the integration of biological and chemical controls for spider mites into California's fruit and nut crop systems.

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