Effects of Reduced-Risk Pesticides and Plant Growth Regulators on Rove Beetle (Coleoptera: Staphylinidae) Adults

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ABSTRACT In many regions, pest management of greenhouse crops relies on the use of biological control agents; however, pesticides are also widely used, especially when dealing with multiple arthropod pests and attempting to maintain high esthetic standards. As such, there is interest in using biological control agents in conjunction with chemical control. However, the prospects of combining natural enemies and pesticides are not well known in many systems. The rove beetle, *Atheta coriaria* (Kraatz), is a biological control agent mainly used against fungus gnats (*Bradysia* spp.). This study evaluated the effects of reduced-risk pesticides and plant growth regulators on *A. coriaria* adult survival, development, and prey consumption under laboratory conditions. Rove beetle survival was consistently higher when adults were released 24 h after rather than before applying pesticides. The pesticides acetamiprid, lambda-cyhalothrin, and cyfluthrin were harmful to rove beetle adults, whereas *Beauveria bassiana* (Balsamo) Vuillemin, azadirachtin, and organic oils (cinnamon oils, rosemary oil, thyme oil, and clove oil) were nontoxic to *A. coriaria* adults. Similarly, the plant growth regulators acymidol, paclobutrazol, and uniconazole were not harmful to rove beetle adults. In addition, *B. bassiana*, azadirachtin, kinoprene, organic oils, and the plant growth regulators did not negatively affect *A. coriaria* development. However, *B. bassiana* did negatively affect adult prey consumption. This study demonstrated that *A. coriaria* may not be used when applying the pesticides, acetamiprid, lambda-cyhalothrin, and cyfluthrin, whereas organic oils, *B. bassiana*, azadirachtin, and the plant growth regulators evaluated may be used in conjunction with *A. coriaria* adults. As such, these compounds may be used in combination with *A. coriaria* in greenhouse production systems.

KEY WORDS insecticide, botanical, IGRs, *Beauveria bassiana*, survival

Pest management in greenhouses primarily involves the use of pesticides (Bethke and Cloyd 2009). Studies indicate that conventional pesticides including pyrethroids are relatively harmful to natural enemies in commercial greenhouses (Croft and Whalon 1982, Elzen 1989, Prabhaker et al. 2007). However, problems associated with their use in regulating arthropod pests have led to the introduction of less toxic and more target-specific (reduced-risk) pesticides including plant-derived essential oils, microbial biopesticides, IGRs (IGR), horticultural oils, and insecticidal soaps (Croft 1990, Cloyd 2006, Gradish et al. 2011). These changes in pesticide use may improve the prospect of combining natural enemies with reduced-risk compounds as a pest management strategy in greenhouse production systems (Weinzierl 2009). Changes in the pesticide industry have also resulted in the development of new pesticides with unique modes of action such as neonicotinoids, semicarbazones, and tetramic acids, which are labeled for use against insect and mite pests including fungus gnats (*Bradysia* spp.). However, some neonicotinoids including acetamiprid, clothianidin, dinotefuran, and imidacloprid, have been shown to be harmful to several natural enemies (Naranjo and Akey 2005, Cloyd and Bethke 2011) as well as microbial biopesticides (Donegan and Lighthart 1989) and botanical pesticides (Cloyd et al. 2009a).

The rove beetle, *Atheta coriaria* (Kraatz) is a commercially available biological control agent (BCA) used against fungus gnats (Carney et al. 2002, Jandricic et al. 2006, Warner and Getz 2008). A number of studies have reported the effects of pesticides, including IGR, on rove beetles. For example, Jandricic et al. (2006) showed that bendiocarb and imidacloprid were nontoxic to adult *A. coriaria*, and the IGR cyromazine was harmful to second instar larvae (>80% mortality) when exposed to pesticides applied to the growing medium. However, the IGR diflubenzuron did not negatively harm *A. coriaria*. In a separate study, the neonicotinoids, clothianidin, dinotefuran, and thiamethoxam were toxic to adult *A. coriaria* (Cloyd et al. 2009a), whereas microbial pesticides based on *Bacillus thuringiensis* subsp. *israelensis*, *Metarhizium anisopliae* (Metschn.) Sorokin and spinosad, and botanical insecticides such as azadirachtin were not

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Table 1. Common name, trade name, rates, and company information associated with pesticides used in experiments 1 through 3, and plant growth regulators (PGR) used in experiment 4

Common name (trade name)	Rate (per 100 gal)	Rate (per 70 ml)	Company
Experiment 1			
Acetamiprid (TriStar)	2.66 fl oz[a]	0.014 g	Cleary's, Dayton, NJ
Acetamiprid (TriStar)	5 fl oz	0.028 g	
Kinoprene (Enstar II)	5 fl oz	0.027 ml	Wellmark International, Schaumburg, IL
Organic oils (Zero Tolerance)	6,400 fl oz	35.0 ml	Natural Garden Solutions, Piedmont, CA
Soybean and rosemary oil (Indoor Pharm)	3,200 fl oz	17.5 ml	Pharm Solutions, Port Townsend, WA
Experiment 2			
Beauveria bassiana (BotaniGard ES)	33 fl oz[a]	0.17 ml	BioWorks, Victor, NY
Beauveria bassiana (BotaniGard ES)	200 fl oz	1.08 ml	
Metaflumizone (Alverde)	16 fl oz	0.087 ml	BASF Corp., Research Triangle Park, NC
Lambda-cyhalothrin (CyhaloCap)	5 fl oz	0.026 ml	Whitmire Micro-Gen Research Labs, St Louis, MO
Cyfluthrin (Cy-kick)	16 fl oz[a]	0.086 ml	
Cyfluthrin (Cy-kick)	32 fl oz	0.173 ml	
Azadirachtin (Azatin)	8 fl oz	0.043 ml	OHP, Mainland, PA
Pyriproxyfen (Distance)	2 fl oz	0.010 ml	Valent Corp., Walnut Creek, CA
Cyromazine (Citation)	2.66 oz	0.013 g	Syngenta Crop Protection, Greensboro, NC
Experiment 3			
Azadirachtin (AzaGuard)	8 fl oz	0.044 ml	BioSafe Systems, East Hartford, CT
Azadirachtin (Azatrol)	32 fl oz	0.276 ml	PBI/GORDON, Kansas City, MO
Azadirachtin (Molt-X)	8 fl oz	0.044 ml	BioWorks, Victor, NY
Spirotetramat (Kontos)	1.7 fl oz	0.009 ml	OHP, Mainland, PA
Experiment 4			
Acymidol (A-Rest)	—	9.40 ml[a]	SePRO, Carmel, IN
Acymidol (A-Rest)	—	19.86 ml	
Acymidol (A-Rest)	—	39.72 ml	
Paclobutrazol (Bonzi)	—	0.39 ml[a]	Syngenta Crop Protection, Greensboro, NC
Paclobutrazol (Bonzi)	—	2.58 ml	
Paclobutrazol (Bonzi)	—	4.33 ml	
Uniconazole (Sumagic)	—	3.50 ml[a]	Valent, Walnut Creek, CA
Uniconazole (Sumagic)	—	13.95 ml	
Uniconazole (Sumagic)	—	35.0 ml	

[a] Recommended label rates.

harmful to *A. coriaria* (Cloyd et al. 2009a). Diflubenzuron did not reduce egg-hatch of the rove beetle, *Aleochara bilineata* (Gyllenhal). However, methabenzthiazuron, bromoxynil, and carbaryl significantly decreased survival rate and female egg production (Gordon and Cornect 1986, Samsøe–Petersen 1995). Conversely, the pesticides flonicamid and pymetrozine, and two formulations based on pyrethrins and insecticidal soaps (potassium salts of fatty acids) were not toxic to *A. bilineata* (Jansen et al. 2010, 2011).

Certain plant growth regulators (PGR) are commonly used in greenhouses; however, there is limited information on their effect on natural enemies. In one study, Oetting and Latimer (1995) reported 67% mortality of the thrips predator, *Neoseiulus cucumeris* (Oudemans) when exposed to four times the recommended label rate of the PGR daminozide; however, this may not have been a realistic assessment of the toxic effects of the PGR compared with the recommended label rate. With respect to *A. coriaria*, assessments on survival and effectiveness when used in combination with pesticides are limited (Jandricic et al. 2006, Cloyd et al. 2009a). As such, research on the effects of pesticides, used for fungus gnat management, on *A. coriaria* is warranted. In addition, any effects of pesticides and PGR on the duration of *A. coriaria* life cycle and reproduction have not been quantified. These types of effects are important as they may interfere with the physiology and behavior of beneficial arthropods while influencing life history parameters such as fecundity, longevity, development, and sex ratio (Elzen et al. 1989, Croft 1990, Desneux et al. 2007). Therefore, the objective of this study was to determine the effects of certain pesticides and biopesticides, and PGR on *A. coriaria* adults, based on both mortality and effects associated with development, reproduction, and prey consumption.

Materials and Methods

The effects of selected pesticides and biopesticides, and PGR on the adult rove beetles were determined under laboratory conditions (22–24°C; 40–60% relative humidity [RH]; and a photoperiod of 0:24 [L:D] h). Effects were assessed based on adult survival, as measured by recovery rates of released adults; and any additional effects were determined based on impact on rove beetle development time from egg to adult, and on prey consumption. Common name, trade name, rates, and company information associated with the pesticides and PGR used in this study are presented in Table 1. Assessments involved quantification of rove beetle adult survival after exposure to pesticide treatments for 10 d whereas rove beetle exposure time to the PGR treatments was 96 h. Voucher specimens of *A. coriaria* are deposited as accession number 220 in the Kansas State University Museum of Entomological and Prairie Arthropod Research (Manhattan, KS).

Effects of Pesticides and PGR on *A. coriaria* Adults. The direct effects of the pesticides and PGR on *A. coriaria* adults were determined in four separate experiments with five pesticides used in experiment 1, seven pesticides in experiment 2, and four pesticides in experiment 3; whereas the three PGR at three different application rates were used in experiment 4 (Table 1). Effects were determined after rove beetles were applied to the growing medium (GM) (Sunshine LC1 Professional Growing Mix, Sun Gro Horticulture, Inc., Bellevue, WA) 24 h before, and 24 h after applying the pesticides, whereas the PGR were applied 24 h before releasing the rove beetle adults into 473 ml deli squat containers (Fabri–Kal Corp., Kalamazoo, MI). The experiments were set-up as a randomized complete block design with two blocks (days as blocks) and 10 replications per treatment. The number of treatments for each experiment is presented in Table 1.

The effects of pesticides on rove beetle adults were determined following the procedures described by Cloyd et al. (2009a). Three-hundred milliliters of GM was measured using a 600 ml glass beaker and placed into a 473 ml deli squat container. Modified lids with insect screening (50 × 24 [0.2 × 0.8 mm], Greentek, Edgerton, WI) were used to allow for ventilation. Before preparing the individual pesticide and PGR solutions they were measured using a 1 ml sterile syringe (BD, Franklin Lakes, NJ), and 10, 100, and 500 ml graduated cylinders, except for acetamiprid and cyromazine (solid formulations), which were measured using a balance scale (Denver Instrument, Bohemia, NY). Pesticides and PGR were mixed with water separately using a 600 ml glass beaker to obtain the adequate concentration for each treatment. Subsequently, 70 ml of each pesticide and PGR solution was applied uniformly as a drench to the GM in each deli squat container, and 1.5 g of raw oatmeal (The Quaker Oats Company, Chicago, IL) was placed on the GM surface as a food source for the rove beetle adults. In addition, a deionized water control (70 ml and same food source) was included in all experiments.

Twenty rove beetle adults (males and females of various ages) were randomly collected from a laboratory-reared colony (maintained at Kansas State University, Manhattan, KS) using Sunshine LC1 Professional Growing Mix growing medium (Sun Gro Horticulture, Inc.) containing Canadian sphagnum peat moss (75%), perlite (25%), dolomitic lime, gypsum and wetting agent, and oatmeal as a supplemental food source. Rove beetles were originally obtained from an established colony at the University of Illinois (Urbana, IL) and have undergone over 20 generations in culture.

Colonies were maintained in 7.8 liters Rubbermaid containers (Newell Rubbermaid, Knoxville, TN) and 1.89 liters Gladware plastic containers (The Glad Products Company, Oakland, CA). Substrate preparation was as follows: 1.5 liters (≈500 g) of GM was mixed with 350 ml of water (70 ml water per 300 ml GM) in a 1.89 liters Gladware plastic container. Supplemental food was provided by placing ≈2 g of raw oatmeal onto the GM surface every 4–5 d. To maintain constant moisture, ≈15 ml of water was sprayed daily on the surface of the substrate using a 946 ml plastic spray bottle (The Home Depot, Manhattan, KS). Rove beetle colonies were maintained under ambient laboratory conditions of 22 ± 2°C and 30–50% RH, and a photoperiod of 0:24 (L:D) h.

Rove beetle adults were collected by sieving the GM using #5 and #10 mesh size sieves, recovered into a nine dram plastic vial using an aspirator, and then placed into a container. Initially, the containers were warmed by heat lamps (Commercial Electric, Atlanta, GA) situated ≈90 cm above the containers for 24 h, thus allowing the GM to dry, which facilitated the sieving procedure. After 10 d, rove beetle adults were collected, based on the procedure described previously, and the number of live rove beetle adults were recorded.

Effects of Pesticides and PGR on *A. coriaria* Development and Adult Prey Consumption. The effects of pesticides and PGR were assessed based on *A. coriaria* development time from egg to adult, and prey consumption in two separate experiments with 19 and 17 treatments, with seven replications per treatment, using rove beetle adults obtained from the experiments described above.

Ten rove beetle adults in total (five males and five females) previously exposed to the treatments (pesticides and PGR) were placed on a filter paper disk lining the bottom of a 90 × 10 mm petri dish with ≈3 g of moistened Sunshine LC1 Professional Growing Mix, and 1–2 pieces of raw oatmeal as a supplemental food source. In addition, a piece of moistened cotton was placed in the petri dish to maintain constant moisture. Petri dishes were labeled and then placed separately into a 740 ml plastic container. Subsequently, the plastic containers were maintained for 1 wk in an illuminated incubator (Thermo Electron Corporation, Marietta, OH) at 26 ± 2°C and 50–60% RH, under a photoperiod of 12:12 (L:D) h for egg deposition. Every 24 h, the GM was examined under a dissecting microscope (10 × 22) for the presence of eggs. Rove beetle eggs were collected using a moistened, soft fine camelhair paintbrush and then placed individually on a filter paper disk lining the bottom of a 90 × 10 mm petri dish with ≈3 g of GM and 1–2 pieces of oatmeal as a food source. Petri dishes were placed separately into a 740 ml plastic container and maintained under laboratory conditions (22 ± 2°C; 40–60% RH; and a photoperiod of 0:24 [L:D] h). The GM was examined daily under a dissecting microscope and any fungal growth was removed from the petri dish. For individual rove beetle, time (days) from oviposition to adult emergence was recorded.

The effect of pesticides and PGR on adult *A. coriaria* prey consumption was evaluated in a separate experiment. In total, 20 s (6- to 7-d old) or third (8- to 9-d old) instar fungus gnat *Bradysia* sp. nr. *coprophila* (Lintner) larvae were collected from a fungus gnat-inoculated GM (Sunshine LC1 Professional Growing Mix) sample using a 150 mm disposable flint glass

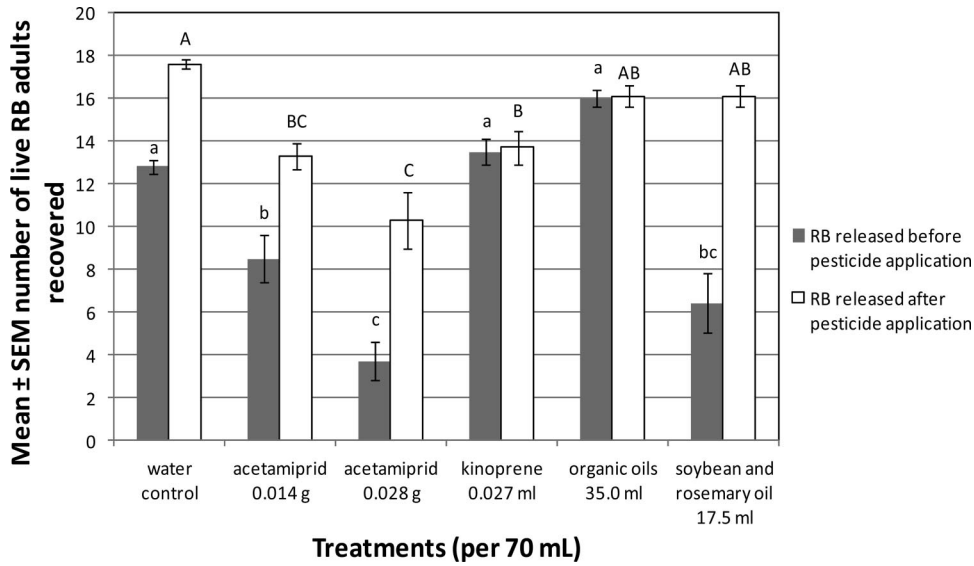

Fig. 1. Rove beetle, *Atheta coriaria* adult recovery rates 10 d after exposure to pesticides used in experiment 1, 24 h before and 24 h after applying the pesticides. Means followed by the same lower case or capitalized letter are not significantly different ($P > 0.05$) as determined by Tukey's mean separation test. Vertical bars represent SEM.

nonsterile Pasteur pipet (Fisher, Pittsburgh, PA), which were then placed into a 50 × 15 mm glass petri dish filled with 10–15 ml of water. Larvae were collected individually using the Pasteur pipet, transferred to the glass petri dish and counted. Subsequently, 1.6 ml of water was poured into a 100 × 15 mm glass petri dish using a 10 ml capacity plastic graduated cylinder. The bottom of the petri dish was lined with 90 mm diameter filter paper (Whatman Int. Ltd., Maidstone, United Kingdom).

For each of the treatments (pesticides, PGR, and water control), 10 treated rove beetle adults, including males and females, were placed into a 473 ml deli squat container with 300 ml of moistened GM and oatmeal as a supplemental food source for ~3 wk to obtain F_1 generation adults, which were used to assess predation. Subsequently, a single F_1 rove beetle adult was placed into the petri dish and the number of fungus gnat larvae consumed out of 20 was determined after 24 h based on the number of head capsules (sclerotized portion of the larval head) in the petri dish. The number of head capsules was counted under a dissecting microscope (10 × 22) and recorded. One control consisted of rove beetle adults only and another consisted of 20 fungus gnat larvae and no rove beetle adults.

Statistical Analysis. Data from all experiments were analyzed using a statistical analysis software program SAS Systems for Windows, version 9.2 (SAS Institute 2002). Data associated with the effects of pesticides and PGR on *A. coriaria* were subjected to an analysis of variance (ANOVA) using the PROC ANOVA procedure (SAS Institute 2002) with the number of live rove beetle adults as the response variable (main effect). Any significant differences among the treatments were determined using a Tukey's least significant means test at a significance level of $\alpha = 0.05$. In addition, data for the effects of the pesticides and PGR on *A. coriaria* development time from egg to adult and prey consumption were subjected to an ANOVA using days from oviposition until adult emergence and number of fungus gnat larval head capsules, respectively, as the response variables (main effects). Any significant differences among the treatments were determined using a Tukey's least significant means test at a significance level of $\alpha = 0.05$.

Results

Effects of Pesticides and PGR on *A. coriaria* Adults. There were significant differences among the treatments for experiment 1 when rove beetle adults were released both before ($F = 28.57$; df = 5, 59; $P \leq 0.0001$) and after ($F = 13.52$; df = 5, 59; $P \leq 0.0001$) applying the pesticides (Fig. 1). The number of rove beetle adults recovered from the acetamiprid treatment at the high rate (0.028 g/70 ml) was 10.3 ± 1.3 (mean ± SEM), which was not significantly different from the recovery rate (13.3 ± 0.6) obtained when acetamiprid was applied at the low rate (0.014 g/70 ml); both were significantly lower than the control (Fig. 1). The number of adult rove beetles recovered was similar for kinoprene, organic oils, soybean and rosemary oil, and the water control (Fig. 1). When rove beetles were released before applying the pesticides, there were no significant differences among the number of rove beetle adults recovered from the kinoprene and organic oil (13.5 ± 0.6 and 16.0 ± 0.4) treatments and the water control (12.8 ± 0.3). The recovery rate associated with acetamiprid at the low rate was similar to the soybean and rosemary oil treatment, whereas the lowest adult

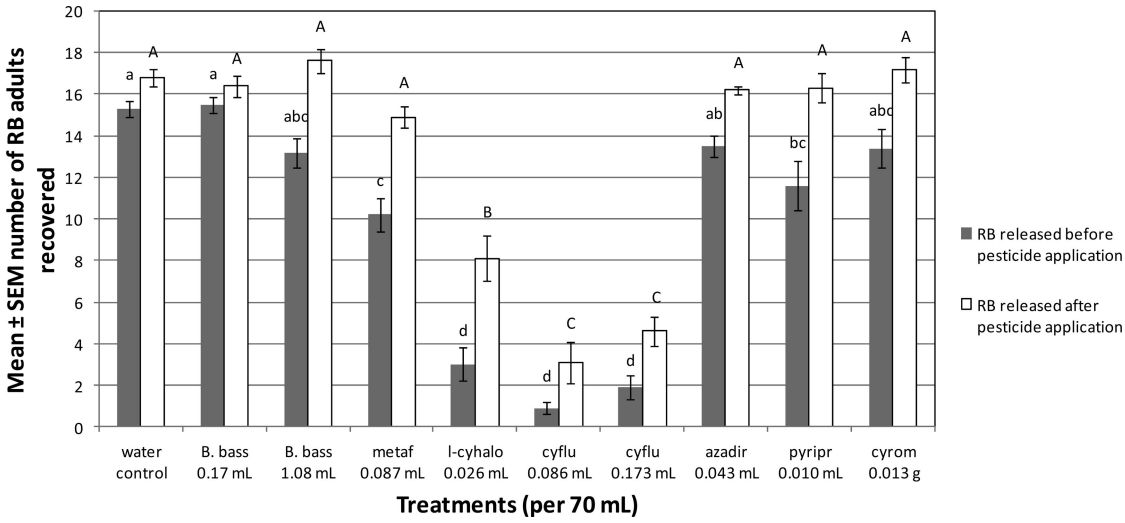

Fig. 2. Rove beetle, *Atheta coriaria* adult recovery rates 10 d after exposure to pesticides used in experiment 2, 24 h before and 24 h after applying the pesticides. Means followed by the same lower case or capitalized letter are not significantly different ($P > 0.05$) as determined by Tukey's mean separation test. Vertical bars represent SEM. Treatment abbreviations are listed in Table 4.

recovery rate was obtained from the high-rate acetaprimid treatment (Fig. 1).

For experiment 2, there were significant differences among the treatments when rove beetle adults were released both before ($F = 64.51$; df = 9, 99; $P \leq 0.0001$) and after ($F = 61.26$; df = 9, 99; $P \leq 0.0001$) applying the pesticides. There were no significant differences in the recovery rates among the treatments, *B. bassiana* (at low and high rates), metaflumizone, azadirachtin, pyriproxyfen, cyromazine, and the water control, when rove beetles were released after applying the pesticides. The lowest recovery rates were associated with cyfluthrin (at both low and high rates), which were significantly lower than lambda-cyhalothrin and the other treatments. When rove beetles was released before application, there were no significant differences among the *B. bassiana* (at both low and high rates), azadirachtin, and cyromazine treatments and the water control. In addition, pyriproxyfen was similar to metaflumizone and both were significantly higher in terms of adult survival than lambda-cyhalothrin and cyfluthrin (at both high and low rates) (Fig. 2).

Overall, when rove beetles were applied to the GM after applying the pesticides, only the pyrethroids, lambda-cyhalothrin, and cyfluthrin (at both high and low rates), were significantly lower in regards to adult survival than the control, whereas when rove beetles were applied to the GM before applying the pesticides, metaflumizone, pyriproxyfen, lambda-cyhalothrin, and cyfluthrin were significantly lower in adult survival than the control (Fig. 2).

Results for experiment 3, in which three azadirachtin products (AzaGuard, BioSafe Systems, East Hartford, CT; Azatrol, PBI/GORDON, Kansas City, MO; and Molt-X, BioWorks, Victor, NY) and spirotetramat were used, are presented in Fig. 3. The highest rove beetle adult recovery rates were associated with Azatrol and the lowest with Molt-X when rove beetles were released into the containers after application (Fig. 3). Similarly, when rove beetles were released into the containers before applying the pesticides, the highest recovery rates were associated with Azatrol and the lowest with spirotetramat (Fig. 3). However, there were no significant differences among the treatments when rove beetles were released either before ($F = 0.55$; df = 4, 24; $P \leq 0.698$) or after ($F = 1.55$; df = 4, 39; $P \leq 0.208$) applying the pesticides (Fig. 3).

There were no significant differences ($F = 0.42$; df = 9, 99; $P \leq 0.924$) associated with the nine PGR treatments (three PGR with three application rates per PGR) for experiment 4 (Fig. 4). Recovery rates for all the treatments were high (>90%) with 18–19 rove beetle adults recovered per treatment (Fig. 4).

Effects of Pesticides and PGR on *A. coriaria* Development and Adult Prey Consumption. There were no significant differences ($F = 1.40$; df = 11, 83; $P \leq 0.193$) among the pesticide treatments in regards to development time from egg to adult (Table 2). Similarly, there were no significant differences ($F = 2.02$; df = 7, 55; $P \leq 0.071$) among the PGR treatments (Table 3). The effects of the pesticides and PGR on rove beetle prey consumption are presented in Fig. 5. There were significant differences in the number of fungus gnat larvae consumed among the treatments ($F = 11.07$; df = 15, 111; $P \leq 0.0001$). The number of fungus gnat larvae consumed in the petri dish was significantly lower for kinoprene (15.0 ± 1.0) than the organic oils and water control (18.3 ± 0.5 and 18.9 ± 0.4) but significantly higher than *B. bassiana* (11.4 ± 0.6) when applied at the high rate. The lowest number of fungus gnat larval head capsules was affiliated with the *B. bassiana* treatments; however, there were no signifi-

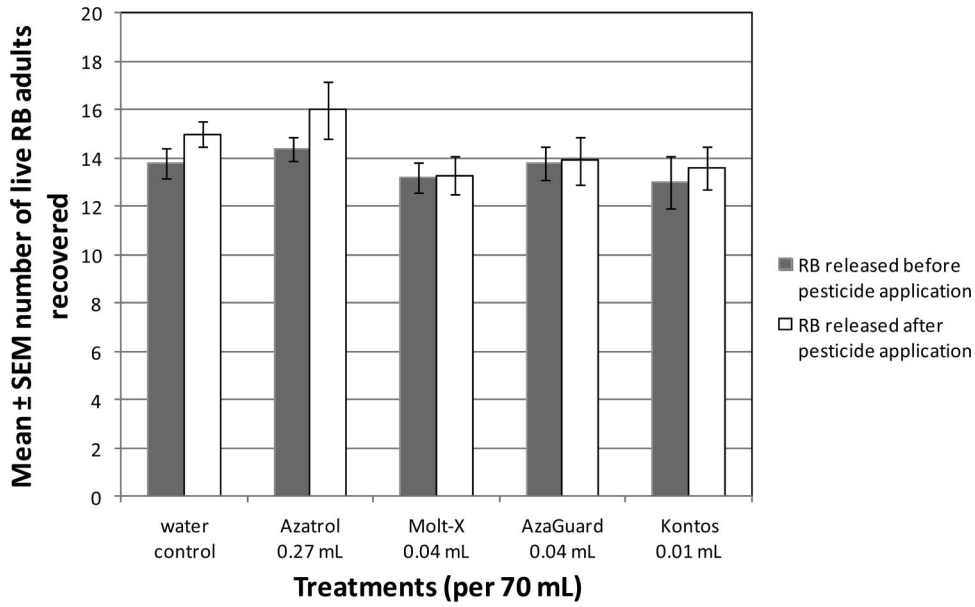

Fig. 3. Rove beetle, *Atheta coriaria* adult recovery rates 10 d after exposure to pesticides used in experiment 3, 24 h before and 24 h after applying the pesticides. None of the treatments associated with rove beetles released either before ($F = 0.55$; df = 4, 24; $P \leq 0.698$) or after ($F = 1.55$; df = 4, 39; $P \leq 0.208$) applying the pesticides were significantly different from each other. Vertical bars represent SEM.

cant differences between low and high rates. The number of head capsules was high (17–18 out of 20) for the organic oil, soybean and rosemary oil, pyriproxyfen, cyromazine, the three azadirachtin-based products (AzaGuard, Azatrol, and Molt-X), and spirotetramat treatments. However, there were no significant differences among the pesticide treatments compared with the control as well as the PGR treatments (Fig. 5).

Discussion

In this study, the pesticides acetamiprid, kinoprene, lambda-cyhalothrin, and cyfluthrin were harmful to *A. coriaria* adults, whereas *B. bassiana*, azadirachtin, organic oils (cinnamon oils, rosemary oil, thyme oil, and clove oil) and the PGR were not harmful. Pesticides labeled for control of fungus gnat larvae, such as organic oils and soybean and rosemary oil, were not toxic when applied at the recommended label rates to the

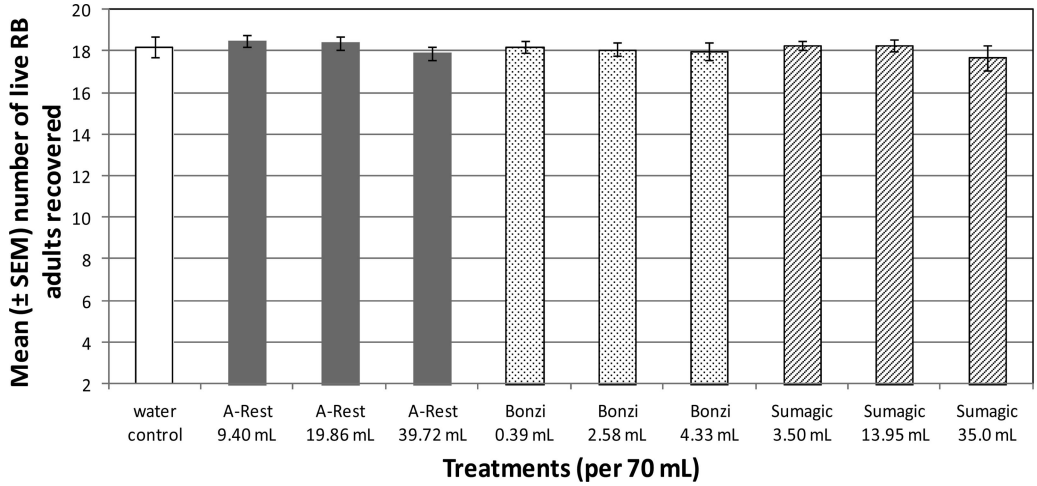

Fig. 4. Rove beetle, *Atheta coriaria* adult recovery rates 96 h after exposure to plant growth regulators (PGR) used in experiment 4, 24 h after applying the PGR. None of the treatments were significantly different ($F = 0.42$; df = 9, 99; $P \leq 0.924$) from each other. Vertical bars represent SEM.

Table 2. Mean (± SEM) *Atheta coriaria* development time (days) from egg to adult in the F_1 generation after exposure of adults to pesticide treatments for 10 d

Treatment (common and trade name)	Rate (per 70 ml)	Development time from egg to adult (days)
Water control	—	21.0 ± 0.3a
Kinoprene (Enstar II)	0.027 ml	23.7 ± 0.6a
Organic oils (Zero Tolerance)	35.0 ml	22.1 ± 1.1a
Soybean and rosemary oils (Indoor Pharm)	17.5 ml	21.7 ± 0.6a
Beauveria bassiana (BotaniGard ES)	0.17 ml[a]	21.7 ± 0.4a
Beauveria bassiana (BotaniGard ES)	1.08 ml	23.1 ± 0.9a
Azadirachtin (Azatin)	0.043 ml	23.4 ± 0.8a
Cyromazine (Citation)	0.013 g	22.7 ± 0.6a
Azadirachtin (AzaGuard)	0.044 ml	22.4 ± 0.7a
Azadirachtin (Azatrol)	0.276 ml	22.3 ± 0.8a
Azadirachtin (Molt-X)	0.044 ml	23.6 ± 0.6a
Spirotetramat (Kontos)	0.009 ml	23.0 ± 0.8a

There were seven replications per treatment.
[a] Recommended label rate.

GM, 24 h before releasing rove beetle adults. However, kinoprene and acetamiprid, when applied at the recommended label rate and at a high rate (0.014 and 0.028 ml/70 ml), were toxic to rove beetle adults. As such, it appears that organic oils and soybean and rosemary oil are not harmful to *A. coriaria*, whereas kinoprene and acetamiprid are. Nonetheless, when the pesticides were applied after releasing rove beetle adults into the containers, soybean and rosemary oil was toxic to rove beetle adults whereas organic oil was not. In fact, lower adult survival rates were obtained for the acetamiprid (at both low and high rates) and soybean and rosemary oil (Fig. 1), which suggests the time that rove beetle adults are released into the containers (whether before or after pesticides are applied) may influence their use with pesticides.

These results are similar to Cloyd et al. (2009b), in which soybean and rosemary oil negatively affected rove beetle survival, when applied at the same rate. It has been shown that soybean and rosemary oil are toxic to the predatory mite, *Amblyseius barkeri* (Hughes) (Momen and Amer 1999). Overall, the organic oil treatment did not negatively harm rove beetle adults when applied at the recommended label rate, whereas soybean and rosemary oil and acetamiprid (at both low and high rates) were toxic to adult rove beetles.

Table 3. Mean (± SEM) *Atheta coriaria* development time (days) from egg to adult in the F_1 generation after exposure of adults to treatments (plant growth regulators) for 96 h

Treatment (common and trade name)	Rate (per 70 ml)	Development time from egg to adult (days)
Water control	—	21.0 ± 0.3a
Acymidol (A-Rest)	9.40 ml[a]	20.6 ± 0.2a
Acymidol (A-Rest)	39.72 ml	21.0 ± 0.0a
Paclobutrazol (Bonzi)	0.39 ml[a]	21.6 ± 0.6a
Paclobutrazol (Bonzi)	2.58 ml	21.0 ± 0.0a
Paclobutrazol (Bonzi)	4.33 ml	22.1 ± 0.6a
Uniconazole (Sumagic)	3.50 ml[a]	22.7 ± 1.0a
Uniconazole (Sumagic)	13.95 ml	22.7 ± 1.2a

There were seven replications per treatment.
[a] Recommended label rate.

Rove beetle adult survival was lower when adults were released before rather than after applying the pesticides except for kinoprene and organic oils where adult survival was similar. It appears that rove beetle adults may have escaped exposure when released after application of soybean and rosemary oil, and when released before applying kinoprene because survival was not significantly different than the water control. This is contrary to what might have been expected; however, in general, a drench application is designed to thoroughly saturate the GM; thus, reducing the potential for rove beetle adults to hide or escape exposure. In addition, although there may have been some effects of the pesticides when rove beetles came into contact with the GM, this may depend on the specific pesticide (contact or IGR) and residual activity. Acetamiprid was less toxic when applied at the recommended label rate than at the high rate when rove beetle adults were released before application, whereas there was no difference in toxicity when rove beetles were released after application.

The pyrethroids, lambda-cyhalothrin, and cyfluthrin (applied at low and high rates) were harmful to rove beetle adults regardless of the time of release into the containers. *B. bassiana* (applied at low and high rates), azadirachtin, and cyromazine may be applied without harming rove beetle adults whereas metaflumizone and pyriproxyfen were toxic to rove beetle adults when applied after release into the containers. However, when rove beetles were released after applying the pesticides, both metaflumizone and pyriproxyfen did not negatively affect rove beetles survival, which suggests that rove beetles may have avoided exposure to the pesticides. Metaflumizone has been shown to not negatively harm predators such as *Orius insidiosus* (Say) and *Amblyseius swirskii* (Athias–Henriot) (Gradish et al. 2011), whereas pyriproxyfen exhibits no toxic effects on *Chrysoperla carnea* (Stephens) (Medina et al. 2003), *Stratiolaelaps scimitus* (Womersley) (Cabrera et al. 2004), and *Cryptolaemus montrouzieri* (Mulsant) (Cloyd and Dickinson 2006). Although rove beetle survival was similar for metaflumizone and pyriproxyfen, these pesticides were less deleterious to rove beetle adults than both lambda-cyhalothrin and cyfluthrin when applied at low and high rates. Furthermore, *B. bassiana* when applied at low and high rates, azadirachtin and pyriproxyfen were not harmful to *A. coriaria.* However, cyromazine was similar to metaflumizone and pyriproxyfen in terms of toxicity when applied after rove beetles were released into the containers.

Although lambda-cyhalothrin was less harmful to rove beetles than cyfluthrin (at low and high rates) when released after applying the pesticides, both were equally harmful when rove beetles was released before application. Furthermore, cyfluthrin was harmful to rove beetle adults regardless of the application rate, with no differences in rove beetle adult survival. Over-

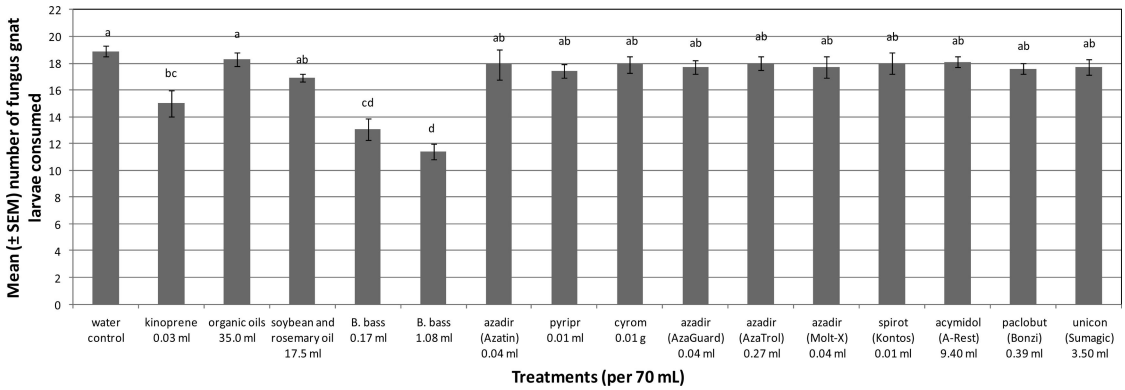

Fig. 5. Rove beetle, *Atheta coriaria* adult prey (fungus gnat larvae) consumption in petri dishes 24 h after exposure of pesticide treated adults to 20 fungus gnat, *Bradysia* sp. nr. *coprophila* larvae. Means followed by the same letter among columns are not significantly different ($P > 0.05$) as determined by Tukey's mean separation test. Vertical bars represent SEM. Treatment abbreviations are listed in Table 4.

all, rove beetle adult survival in experiment 2 was lower when releases were made before rather than after applying the pesticides. *B. bassiana* (at the recommended label rate and high rate), azadirachtin, and cyromazine are not harmful to *A. coriaria.* As such, these pesticides can be applied without compromising biological control programs against fungus gnats when using *A. coriaria.* However, reduced numbers of fungus gnat larvae because of pesticide applications could affect availability of fungus gnat larvae as a food source, which may influence rove beetle adult survival. Moreover, further evaluations, when rove beetle is released before application, are required before using metaflumizone and pyriproxyfen in combination with *A. coriaria.* The findings of the current study corroborate those of Jandricic et al. (2006) in which cyromazine was not harmful to *A. coriaria* adults. Similarly, cyromazine was not toxic to the parasitoid *Chrysocharis parksi* (Crawford) (Parrella et al. 1983) and diflubenzuron exhibited no negative effects to the rove beetle, *Aleochara bilineata* (Gordon and Cornect 1986), whereas kinoprene negatively affected survival of the parasitoid *Opius dimidiatis* (Ashmead) (Poe 1974). As such, the effect of IGR may vary depending on the active ingredient and natural enemy type.

The azadirachtin-based products evaluated (AzaGuard, Azatrol, and Molt-X) and spirotetramat were not harmful to rove beetle adults regardless of the time of release into the containers (before or after applying the pesticides), which suggests these pesticides may be used with *A. coriaria.* These results are similar and elaborate on the findings of Cloyd et al. (2009a) when using azadirachtin, in which adult *A. coriaria* survival was not affected by the active ingredient. However, the toxic effects of azadirachtin on natural enemies may vary depending on the species. For example, azadirachtin has been shown to be harmful to *C. carnea* larvae (Medina et al. 2003) and moderately toxic to *Trichogramma cacoeciae* (Marchall) adults (Saber et al. 2004), whereas azadirachtin was not toxic to *Leptomastix dactylopii* (Howard) (Rothwangl et al. 2004). Based on the short residual toxicity exhibited by azadirachtin, releases made shortly after pesticide application were recommended to avoid harmful effects to *Macrolophus caliginosus* (Wagner) (Tedeschi et al. 2001). In addition, there were no toxic effects on *A. coriaria* associated with the three PGR; acymidol, paclobutrazol, and uniconazole when applied at the recommended label rate or higher rates, which suggests that these PGR are not harmful to *A. coriaria* adults. This is similar to the findings of Oetting and Latimer (1995) in which four PGR including acymidol and paclobutrazol exhibited no harmful effects to the predators' *N. cucumeris* and *Orius insidiosus* (Say).

A. coriaria development time from egg to adult was not affected by any of the pesticides evaluated. Although two of the pesticides used exhibited toxicity to *A. coriaria* adults (kinoprene and soybean and rosemary oil) it appears that these did not arrest larval development or exhibit significant effects on duration of development time from egg to adult in the F_1 generation. Therefore, these pesticides may be applied without affecting predator:prey synchronization (meaning that predacious stages coincide with susceptible development stage of the prey in time), which is an index of natural enemy effectiveness (Bigler 1989, Fournet et al. 2000). Similarly, Peleg (1983) found that methoprene, an IGR similar to kinoprene, did not inhibit larval development of *Chilocorus bi-*

Table 4. Treatments (pesticides and plant growth regulators) and abbreviations associated with Figures 2 and 5

Treatment	Treatment abbreviation
Beauveria bassiana	B. bass
Metaflumizone	Metaf
Lambda-cyhalothrin	l-cyhalo
Cyfluthrin	Cyflu
Azadirachtin	Azadir
Pyriproxyfen	Pyripr
Cyromazine	Cyrom
Spirotetramat	Spirot
Paclobutrazol	Paclobut
Uniconazole	Unicon

pustulatus L. although pupation was negatively affected. Additionally, rove beetle adults exposed to acetamiprid, metaflumizone, pyriproxyfen, lambda-cyhalothrin, and cyfluthrin did not produce offspring or the F_1 rove beetles died before completing development. Whether these pesticides inhibited egg hatch or larval or pupal development was difficult to determine when using GM as a substrate, which suggests that a different technique may be appropriate. Furthermore, the PGR, acymidol, paclobutrazol, and uniconazole did not affect *A. coriaria* development when applied at the recommended label rate or higher rates. These results are important because there is minimal information available associated with the effects of reduced-risk pesticides or PGR on the development of soil-dwelling predators.

A. coriaria consumption of fungus gnat larvae was affected by kinoprene and *B. bassiana* at low and high rates, whereas organic oils, soybean and rosemary oil, azadirachtin, pyriproxyfen, cyromazine, and spirotetramat did not negatively influence prey consumption. Prey consumption (of fungus gnat larvae) was not inhibited by any of the azadirachtin-based products evaluated (AzaGuard, Azatrol, and Molt-X), which coincides with Cloyd et al. (2009a). In addition, the PGR acymidol, paclobutrazol, and uniconazole were not toxic to *A. coriaria* in terms of inhibiting fungus gnat larval consumption when applied at the recommended labeled rates.

Based on the number of rove beetle larvae after 21 d of exposure to the pesticides, *B. bassiana*, azadirachtin, cyromazine, kinoprene, organic oils, soybean and rosemary oil, and the PGR did not negatively affect *A. coriaria* reproduction whereas metaflumizone, lambda-cyhalothrin, cyfluthrin, pyriproxyfen, and acetamiprid inhibited rove beetle female reproduction (Echegaray 2012). In addition, exposure to organic oils increased female rove beetle egg production, which may be caused by hermetic effects (Cohen 2006) or "insecticide hormoligosis," which is not an uncommon phenomenon in natural enemies exposed to pesticides including organic oils (Lale 1991, Cloyd 2003, Guedes et al. 2009). However, further studies should include the number of eggs laid per individual female and those that hatch to assess actual female fecundity. Interestingly, females exposed to lambda-cyhalothrin and metaflumizone that did not produce offspring in treated GM, laid eggs and produced offspring, after they were transferred to untreated GM (Echegaray 2012).

In summary, acetamiprid (at both low and high rates), lambda-cyhalothrin, and cyfluthrin (at both low and high rates) were harmful to *A. coriaria* whereas *B. bassiana* (at both low and high rates), azadirachtin, spirotetramat, cyromazine, and the PGR acymidol, paclobutrazol, and uniconazole did not affect rove beetle survival. Furthermore, there were no toxic effects of the pesticides on *A. coriaria* development from egg to adult except for acetamiprid, metaflumizone, pyriproxyfen, lambda-cyhalothrin, and cyfluthrin, which inhibited the production of F_1 rove beetle adults. In addition, none of the PGR treatments negatively affected rove beetle development. However, kinoprene and *B. bassiana* (at low and high rates) exhibited a negative effect on rove beetle prey consumption (fungus gnat larvae).

Results from this study demonstrate that certain reduced-risk pesticides can be applied against fungus gnat populations without affecting *A. coriaria* performance as a biological control agent whereas pyrethroids are toxic to rove beetle adults regardless of the release time. Although the pesticides and PGR evaluated did not affect *A. coriaria* development time, prey consumption was influenced by *B. bassiana* and kinoprene. Further studies are warranted to investigate the effect of pesticides under greenhouse conditions, because pesticides that are harmful in laboratory experiments may not be so in caged experiments, as noted by Rothwangl et al. (2004) for kinoprene on the parasitoid *L. dactylopii*.

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