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EVALUATION OF NATURAL ENEMIES AND INSECTICIDES FOR CONTROL OF *PSEUDACYSTA PERSEAE* (HEMIPTERA: TINGIDAE) ON AVOCADOS IN SOUTHERN CALIFORNIA

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ABSTRACT

Three natural enemies naturally present in southern California avocado groves were evaluated against different stages of the avocado lace bug, *Pseudacysta perseae* (Heidemann), in the laboratory. The natural enemies tested were adult females of a predatory thrips, *Franklinothrips orizabensis*, second instar green lacewing larvae, *Chrysoperla rufilabris*, and a predaceous mite, *Neoseiulus californicus*. The most promising natural enemy from laboratory and subsequent greenhouse evaluations was *C. rufilabris.* In addition to natural enemies, insecticides were evaluated for *P. perseae* control. The contact impact of less persistent materials on nymphs in the laboratory was assessed. The most effective insecticides based on residual impact studies were carbaryl, imidacloprid, and fenpropathrin, and 2 materials commonly used on avocados in California, abamectin and spinosad, which were ineffective. Among the insecticides evaluated based on contact activity, a pyrethrin mixture was the best treatment followed by petroleum oil and potash soap. The contact insecticides were evaluated for their impact on second instars of *C. rufilabris*. The pyrethrin mixture was less toxic to *C. rufilabris*, and because of its low mammalian toxicity this insecticide may be suitable for use with natural enemy releases for homeowners to manage *P. perseae* populations on backyard avocados.

Key Words: biological control, *Chrysoperla rufilabris*, *Franklinothrips orizabensis*, insecticides, IPM, *Neoseiulus californicus*, *Persea americana*

RESUMEN

La eficiencia de tres enemigos naturales, naturalmente presentes en huertos de aguacate en el sur de California, para el control de diferentes estadios de desarollo (primer instar tardio o segundo instar temprano ninfal, tercer instar ninfal y adultos) de la chinche de encaje del aguacate, *Pseudacysta perseae* (Heidemann), fueron evaluados sobre condiciones de laboratorio y casa de vegetacion. Los enemigos naturales evaluados en laboratorio fueron hembras adultas de trips predadores, *Franklinothrips orizabensis*, larvas del segundo instar de crisopas verdes, *Chrysoperla rufilabris*, y hembras adultas del fitoseido, *Neoseiulus californicus*. El enemigo natural más prometedor evaluado en laboratorio y subsequentemente en casa de vegetacion fue *C. rufilabris*. Además del estudio de enemigos naturales, fueron evaluados insecticidas en laboratorio para el control de *P. perseae*, el cual consistio en la experimentacion del impacto residual de insecticidas persistentes y de contacto de insecticidas menos persistentes en ninfas. Los insecticidas mas efectivos basados en los estudios de impacto residual fueron carbaryl, imidacloprid y fenpropatrin. Abamectin y spinosad, dos productos comunmente usados en aguacate en California, fueron ineficaces. Entre los insecticidas investigados basados en su actividad de contacto, una mezcla de píretrinas fue el mejor tratamiento entre aquellos evaluados seguidos del aceite de petroleo y jabón de potasio. Los insecticidas de contacto tambien fueron evaluados por su impacto sobre el segundo instar larval de *C. rufilabris*. La mezcla de píretrinas fue compatible con el uso de *C. rufilabris* y devido a su baja toxicidad mamífero; este insecticida podria ser adecuado para ser usado en conjunto con liberaciones de enemigos naturales para proprietarios de vivienda con poblaciones significativas de chinche de ancaje del aguacate en aguacates en la propriedad.

Translation provided by the authors.

The avocado lace bug, *Pseudacysta perseae* (Heidemann) (Hemiptera: Tingidae), was first described in 1908 from specimens collected from avocados, *Persea americana* Miller (Lauraceae), in Florida. *Pseudacysta perseae* nymphs and adults feed in dense aggregated colonies on the under-

side of predominantly mature leaves, resulting in development of large necrotic areas (Hoddle et al. 2005a). The exact impact of *P. perseae* on productivity is not known, but fruit yields are likely reduced because of lower photosynthetic rates and defoliation events that result from feeding damage. Until recently, *P. perseae* was considered a pest of sporadic and minor economic importance (Mead & Peña 1991). Population outbreaks of *P. perseae* on avocados have been observed since the mid 1990s in Florida and several countries in the Caribbean, and *P. perseae* has now emerged as a serious foliar pest of avocados in the Caribbean (Peña 2003). The known geographic range for *P. perseae* in the Caribbean includes Jamaica, Puerto Rico, the Dominican Republic, St. Lucia, St. Thomas, St. John, St. Croix, and Cuba (Hoddle, unpublished surveys). It has been recorded from the states of Chiapas, Michoacan, Nayarit, Veracruz, and Yucatan in Mexico, and in Escuintla Guatemala (Hoddle, unpublished surveys). In South America, *P. perseae* is known from Venezuela and French Guyana (Mead & Peña 1991; Medina-Gaud et al. 1991; Abreu 1995; Diaz 2003; Hernandez et al. 2004; Hoddle et al. 2005a; Morales 2005; Sandoval & Cermeli 2005; Streito & Morival 2005).

In the U.S., *P. perseae* has been recorded from the southeastern states of Florida, Georgia, Louisiana, and Texas (Hoddle et al. 2005b). In Sep 2004, *P. perseae* was detected for the first time in California on 2 residential backyard avocado trees in Chula Vista and National City in San Diego County. The trees were heavily infested and exhibiting premature leaf drop because of feeding damage (Bender & Witney 2005; Hoddle et al. 2005b). Subsequent surveys conducted by the San Diego County Department of Agriculture, Weights & Measures and the California Department of Food and Agriculture during 2004-05 (winter) and 2006 (spring and fall) indicated that this pest was restricted to residential areas in southern San Diego County and had not established in commercial avocado orchards in this area or spread beyond San Diego County.

Three natural enemies that are common in commercial avocado groves in southern California are the predatory thrips, *Franklinothrips orizabensis* Johansen (Thysanoptera: Aeolothripidae); the green lacewing, *Chrysoperla rufilabris* (Burmeister) (Neuroptera: Chrysopidae); and the predaceous mite, *Neoseiulus californicus* (McGregor) (Acari: Phytoseiidae) (Yee et al. 2001; Oevering et al. 2003, 2005). These 3 species are commercially available and are used augmentatively by some growers in California for biological control of either avocado thrips, *Scirtothrips perseae* Nakahara (Thysanoptera: Thripidae), or persea mite, *Oligonychus perseae* Tuttle, Baker, and Abatiello (Acari: Tetranychidae) (Kergulen & Hoddle 1999; Hoddle et al. 2000b, 2004; Hoddle & Robinson 2004). It is unknown how readily these 3 natural enemies might attack *P. perseae* and thus, 1 objective of this research was to evaluate the predation activity of these 3 natural enemies against various life stages of *P. perseae*.

Peña (1992) conducted pesticide tests under both laboratory and field conditions to determine the efficacy of several insecticides for controlling nymphs and adults of *P. perseae* in Florida. Under laboratory conditions, chlorpyrifos, permethrin, malathion, and methomyl were effective in killing adult *P. perseae*. Field tests indicated that chlorpyrifos, permethrin, malathion, and methomyl significantly reduced adult *P. perseae* populations. Further studies by Peña et al. (1998) showed that soap salts (M-Pede Insecticide Fungicide, 49% potassium salts of fatty acids, Mycogen Corp., San Diego, CA), citrus oil, and Mycotrol (*Beauveria bassiana* conidia, Laverlam International Corporation, Butte, MT) all significantly reduced *P. perseae* densities compared to levels on untreated control trees.

To build upon this work by Peña (1992) and Peña et al. (1998), the efficacy of an additional 5 residual and 6 contact insecticides registered for home and commercial use in California were tested against *P. perseae*. The compatibility of these insecticides was also tested against *C. rufilabris*, the most promising natural enemy evaluated from the studies reported here. Consequently, the objective of these studies was to identify efficacious natural enemies and insecticides for use against *P. perseae* that could form the foundation for an IPM program for this pest in California.

Materials and Methods

Sources of Natural Enemies

Franklinothrips orizabensis larvae were purchased from Buena Biosystems (Ventura, CA) and were reared at the University of California, Riverside, by procedures established by Hoddle et al. (2000a) until bioassays were performed. *Chrysoperla rufilabris* larvae were obtained from Beneficial Insectary (Redding, CA) and *N. californicus* adults were purchased from Sterling Insectary (Delano, CA). Upon receipt, *C. rufilabris* and *N. californicus* were temporarily stored at 10.0-13.0°C for 24-48 h until used in bioassays.

Pseudacysta perseae Colony

Pseudacysta perseae was reared in 2 greenhouses (24.5 m^3 each) at 25 ± 5°C, 60% RH, and 14:10 (L:D) lighting provided by 10 fluorescents lights in each greenhouse (1.2 m long, 40 Watt, 3,200 lumen output per light; Phillips Homelight Cool White Plus bulb, Philips Lighting Company, Somerset, NJ). They were reared on potted avo-

cado trees, with Bacon variety scions grafted to either Duke 7 or Toro Canyon rootstock that were approximately 1.5 years of age. Avocado trees grown in the greenhouse in 57-L pots were infested with *P. perseae* that had been field collected from 5 different sites around San Diego County, CA.

Natural Enemy Laboratory Bioassays

Franklinothrips orizabensis, *C. rufilabris,* and *N. californicus* used in laboratory bioassays were confined individually in small plastic vials (4.8 × 2.9 cm) with screened mesh lids and held at 25 ± 5°C and 80% RH without food for 24 h prior to use in bioassays. After this starvation interval, natural enemies were transferred to modified Munger cells (Munger 1942; Morse & Brawner 1986), which contained a clean, fully expanded, Hass avocado leaf as the foraging substrate. For the *F. orizabensis* and *C. rufilabris* trials, each Munger cell was inoculated with 1 of 3 lace bug life stages 1 h prior to the introduction of either a single adult female predatory thrips or a single second instar lacewing. The 3 life stages evaluated were 5 late first or early second instars of *P. persea*, 5 third instars, or 5 adults. For studies with *N. californicus*, only eggs and 2 nymphal lace bug stages (early first instars and early second instars) were tested due to the small size of this predator. One adult female *N. californicus* was placed in each Munger cell with 5 early first instars, early second instars or a mass of 14.9 ± 0.7 (SD) eggs. Leaves with eggs were collected from the *P. perseae* colony and were used in the Munger cells. Each treatment was replicated 10 times for each predator and *P. perseae* life stage evaluation, a paired control was set up to measure naturally-occurring mortality, and the control treatment consisted only of the *P. perseae* life stage that was being evaluated.

Munger cells were held at 25 ± 5°C, 80% RH, and 14:10 L:D in a temperature controlled cabinet. After 24 h, the number of dead and live *P. perseae* was recorded. *Pseudacysta perseae* test mortality was corrected for control mortality by Abbott's formula (Abbott 1925) after pooling data for the 10 Munger cell replicates from each natural enemy and prey treatment.

A second study was conducted to evaluate the efficacy of *N. californicus* against *P. perseae* eggs. Fully expanded avocado leaves (variety Bacon) with *P. perseae* eggs were removed from the greenhouse colony, the number of eggs counted, and an average of 34.9 ± 6.8 eggs were set up in each Munger cell. Predatory mites were starved for 24 h and then 1 adult female was transferred to the Munger cell containing the *P. perseae* egg mass. Munger cells with *P. perseae* egg masses and predatory mites were held in a temperature cabinet (25 ± 5°C, 80% RH, 14:10 L:D) and were visually assessed for predation events immediately after the last Munger cell was prepared (60 min after the first cell was set up). Predaceous mite behavioral events were recorded as follows: (1) making contact and investigating the egg mass with the forelegs; (2) feeding on eggs; (3) resting (predator was stationary for >15 s); grooming (predator was engaged in cleaning activities), and (4) searching (predator walked around the experimental arena). Altogether, 20 replicates were completed, at a rate of 5 replicates per day over 4 consecutive days. Predator behaviors were recorded during 60 min of observing each of the 5 Munger cells one at a time for 2 min, and returning to observe each cell every 10 min. Six-observation intervals were produced per cell per day. Observations were pooled and percentages for each behavior of interest were calculated.

Statistical Analyses for Laboratory Natural Enemy Bioassays

SAS Version 8.2 for Windows (SAS Institute Inc., Cary, NC) was used in all analyses, test mortality was corrected for control mortality with Abbott's formula (Abbott 1925), and all tests were performed at the 0.05 level of significance. In the *F. orizabensis* bioassay, Fisher's exact test was used to compare the mortality between medium size nymphs and adults of *P. perseae*. Student's *t*-test was used to compare *P. perseae* mortality between late first or early second instars and third instars in the same bioassay. With the *C. rufilabris* bioassay, a logistic regression model with the Bonferroni adjustment was used to compare *P. perseae* mortality among the 3 lace bug developmental stages. In the *N. californicus* bioassay with the 3 *P. perseae* life stages (eggs, early first instars, and early second instars), proportional mortality inflicted on the life stages was compared with Fisher's exact test. In the test observing *N. californicus* behaviors when exposed to *P. perseae* eggs, a multinomial proportion test was used to compare behaviors but excluded "feeding on eggs" because proportions equal to zero occurred with high frequency (Agresti 2002). Therefore, the comparison of "feeding on eggs" against all other behaviors was performed by Fisher's exact test.

Evaluation of *C. rufilabris* for *P. persea* Control on Small Potted Avocado Trees

The Munger cell bioassays indicated that the most effective commercially available natural enemy evaluated for control of *P. perseae* was the larval stage of *C. rufilabris* (see Results and Discussion). Consequently, this life stage was used in the next tier of evaluation, testing efficacy against *P. perseae* on 20 small potted "Bacon" avocado trees in a greenhouse. Second instars of *C. rufila-*

bris were starved for 24 h prior to use in these trials. Each of the 20 uncaged trees was infested with 10-15 medium-sized *P. perseae,* which were transferred to a single leaf and then left for 1 h to acclimate and commence feeding. Following acclimation, the number of live *P. perseae* nymphs successfully transferred to each leaf was recorded (the pre-count). At this time, 10 randomly selected trees were each inoculated with 3 second instars of *C. rufilabris* with 1 larva placed individually on each of 3 randomly selected leaves on the test plant. The remaining 10 trees served as controls without predators. Uncaged experimental trees were separated so that leaves of adjacent plants did not touch. Two white foam boards (Royal Brites Foam Board with Grid, Office Depot, Delray Beach, FL, size 51 × 76 cm) were placed underneath each tree to collect any *C. rufilabris* larvae and *P. perseae* nymphs that fell from experimental trees. Part of each board was removed so the 2 boards could be joined around the tree trunk and held together with binder clips. Tanglefoot (The Tanglefoot Co., Grand Rapids, MI), a sticky insect barrier, was applied liberally along the edges of the foam boards to prevent the escape of any insects that dropped onto the boards. Predators were left to forage for 48 h. This greenhouse trial was replicated 2 times (Nov 15 and 22, 2006) for a total of 20 predator inoculated trees and 20 control trees.

After 48 h, all leaves were stripped from each experimental tree and the total number of dead and live *P. perseae* nymphs and *C. rufilabris* larvae per tree was recorded. *Pseudacysta perseae* test mortality was corrected with Abbott's formula with control mortality pooled across the 10 control trees and with pooled nymphal mortality data for the 10 trees with lacewing larvae within each trial.

Student's Standardized *t*-test was used to determine if treatment and control mortality were significantly different between replicated greenhouse trials in order to allow us to pool the data for statistical analysis. No statistically significant differences were observed, and Logistic Regression was used to analyze pooled data.

Removed leaves were photocopied and the total leaf area for each experimental tree was determined with a leaf area meter (LI-COR area meter, model LI-3100, LI-COR, Inc., Lincoln, NE). Average leaf area for control and treated avocado trees for each greenhouse trial were compared with Student's Standardized *t*-test. All statistical tests on data from the greenhouse experiment were conducted at the 0.05% level of significance.

Pesticides Used in Bioassays

In the pesticide screening research with *P. perseae,* we evaluated the residual impact of several persistent pesticides and the contact effect of several less persistent and less toxic materials. The pesticides evaluated in the residual impact trial were commercial formulations of the following materials applied at label rates: (1) carbaryl at 8.34 g active ingredient (AI) per L of water (GardenTech—Sevin Concentrate Bug Killer, 22.5% carbaryl (0.237 kg AI per L) TechPac LLC, Lexington, KY); (2) soil-applied imidacloprid at 1.01 g AI per pot mixed with 378.5 mL of water and applied uniformly over the soil surface of each pot (Bayer Advanced Tree and Shrub Insect Control Concentrate, 1.47% (15.28 g AI per L) imidacloprid, Bayer Advanced LLC, Birmingham, AL; the label rate is 29.57 mL per 2.54 cm of trunk circumference; the 10 seedlings used for this treatment had an average trunk circumference of 5.66 ± 0.53 cm (SD); (3) spinosad at 0.375 g AI per L of water (Success 2SC, suspension concentrate), 239.7 g AI per L, Dow AgroSciences LLC, Indianapolis, IN; (4) abamectin at 0.014 g AI per L of water (Agri-Mek 0.15 EC, emulsifiable concentrate), 18.0 g AI per L, Syngenta Crop Protection, Inc., Greensboro, NC); (5) 15% petroleum oil (1.5 mL Loveland 415 spray oil per L of water, Loveland Products Inc., Greeley, CO); and (6) fenpropathrin at 0.479 g AI per L of water (Danitol 2.4EC Spray, emulsifiable concentrate), 287.6 g AI per L, Valent USA Corp., Walnut Creek, CA). In the spinosad and abamectin treatments, petroleum oil was added at a rate of 1% to improve their performance as per manufacturer recommendations. The efficacy of insecticide treatments was compared to water treated control plants.

The contact insecticides evaluated included: (1) 0.156 mL pyrethrins per L of water (PyGanic EC 1.4 II, 1.4% pyrethrins, MGK Corp., Minneapolis, MN); (2) 0.391 mL pyrethrins + potash soap per L of water (SAFER BRAND Yard & Garden Insect Killer II Concentrate, 0.012% pyrethrins and 1.015% potassium salts of fatty acids, Safer Inc., Lilitz, PA); (3) 0.025 mL pyrethrins + rotenone per L of water (Pyrellin E.C., 0.6% pyrethrins + 0.5% rotenone + 0.5% associated resins, Webb Wright Corp., Ft. Myers, FL); (4) 0.078 mL neem oil per L (Green Light Neem Concentrate, 70% clarified hydrophobic extract of neem oil, Green Light Co., San Antonio, TX); (5) 1.5 mL petroleum oil per L of water (Loveland 415 spray oil); and (6) 0.391 mL potash soap per L of water (M-Pede Insecticide Fungicide, 49% potassium salts of fatty acids, Mycogen Corp., San Diego, CA). This second set of insecticides was used at the same rates to test the contact impact on *C. rufilabris.* The efficacy of tested contact insecticides was compared to water treated control plants.

Residual Impact Effect of Insecticides on *P. perseae*

In this trial, each of the foliar insecticides and a water control were sprayed with a hand sprayer (Prime Line Sprayer Model N100-S, B&G Equip-

ment Co., Jackson, GA) to apply ca. 0.7 L of spray to 10 avocado Hass seedlings. Plants were sprayed to runoff and were then left exposed to outside weather conditions. The exception was the imidacloprid treatment, which was applied to the soil after the pesticide was diluted in 3.8 L of water and applied in equal amounts to the 10 experimental avocado seedlings. The plants were 1.0 to 1.5 m tall and soil volume in the pots was approximately of 0.0092 m^3. New flush leaves were trimmed off the seedlings as they appeared so they would not be later confused with treated leaves (i.e., all leaves on the tree at the time of treatment). Leaves were sampled to evaluate *P. perseae* mortality 3, 7, 14, 28, 49, 77, and 112 d after treatment (2 treatments were dropped from evaluation after d 7 as *P. perseae* mortality dropped below 10%). Bioassays were conducted by placing each of 10 treated leaves per treatment into a Munger cell, transferring 10 medium size *P. perseae* nymphs into the cell, and evaluating their mortality after 72 h.

Fisher's exact test was used to analyze pesticide data to test if the proportional mortality between treatments was significantly different. On d 3, six treatments: carbaryl (T2), imidacloprid (T3), spinosad + oil (T4), abamectin + oil (T5), petroleum oil (T6), and fenpropathrin (T7), were subjected to pairwise comparisons and significant differences between treatments comparisons were determined with the Bonferroni adjustment at the 0.05 level of significance.

Contact Impact of Insecticides on *P. perseae* and *C. rufilabris*

Two separate bioassays were performed to determine the contact effect of insecticides, 1 bioassay each with *P. perseae* nymphs and second instar *C. rufilabris*. The insecticides were applied directly to avocado leaves with 10 *P. perseae* nymphs or a single *C. rufilabris* larva with a 118.3-mL fine plastic mist spray bottle (Sally Beauty Supply, Marianna, Denton, TX). Approximately 5.8 mL of spray was applied to the 10 leaves per treatment in aggregate. After each spray, the 10 *P. perseae* or single lacewing larva were transferred to a Munger cell with a clean avocado leaf. Ten or 15 replicate Munger cells were used for the *P. perseae* or lacewing bioassays, respectively (100 *P. perseae* or 15 lacewings in total). Excess *P. perseae* nymphs were placed in the Munger cells for the *C. rufilabris* larva to feed on. Mortality was evaluated 72 h after treatment for both *P. perseae* and *C. rufilabris* bioassays. The *P. perseae* bioassay was conducted once and the *C. rufilabris* bioassay was replicated on 2 dates.

Two analyses were used with *P. perseae* data to determine statistical separation between control mortality and mortality observed with the contact pesticides. Logistic Regression was used to test for significant differences between control mortality and mortality with the pyrethrins + potash soap, petroleum oil, and potash soap treatments (i.e., the 2 treatments resulting in 100% and 0% mortality were excluded). Fisher's exact test was used for testing differences between the pyrethrins + potash soap and pyrethrins + rotenone treatments.

In the *C. rufilabris* bioassay, analyses failed to detect significant differences between the tests done on the 2 bioassay dates and data were pooled with final analyses using a Two Factor Logistic Regression with the Bonferroni Adjustment.

Results and Discussion

Second instar *C. rufilabris* were the most efficacious natural enemy tested in the laboratory and caused the highest mortality of third instars of *P. perseae* (Table 1). The predatory thrips *F. orizabensis* successfully attacked and killed 60% of late first or early second instars of *P. perseae* but had limited impact on third instars and failed to kill adults (Table 1). The least effective natural enemy was the predaceous mite *N. californicus*, and it showed little ability to inflict substantial mortality against any of the *P. perseae* life stages tested (Table 2). A second predatory mite study with *P. perseae* eggs was designed because evaluating the number of unhatched eggs after 24 h in the first study was inconclusive as it was difficult to determine whether or not predators had fed on and killed eggs. The second study indicated lim-

Table 1. Mortality of various life stages of *Pseudacysta perseae* (ALB) after exposure to *Chrysoperla rufilabris* or *Franklinothrips orizabensis*.

Treatment	Corrected % mortality after exposure to *C. rufilabris*[1]	Corrected % mortality after exposure to *F. orizabensis*[1]
Late first or early second ALB instars	60.0 b	60.0 a
Third ALB instars	96.0 a	6.0 b
ALB adults	71.4 b	0.0 b

[1]Means followed by the same letter within a column are not significantly different ($P = 0.05$).

TABLE 2. MORTALITY OF *PSEUDACYSTA PERSEAE* (ALB) NYMPHS AFTER EXPOSURE TO *NEOSEIULUS CALIFORNICUS*.

Treatment	Corrected % mortality[1]
Unhatched eggs	11.3[2]
ALB first stage nymphs	0.0 a
ALB small stage nymphs	1.7 a

[1]Means followed by the same letter are not significantly different ($P \geq 0.05$)

[2]Mortality of eggs was not statistically analyzed with the other treatments because of high control mortality. A second trial was designed for this life stage.

ited predator mite responses to *P. perseae* egg masses with mites observed in the vicinity of eggs only 2.5% of the time and with no observed egg feeding (Fig. 1). Because second instar *C. rufilabris* attacked all *P. perseae* life stages tested, this predator was selected for further evaluation against *P. perseae* on small potted avocado trees in the greenhouse.

In the greenhouse study, the average number of *P. perseae* nymphs artificially infested on the experimental trees (pre-count) was similar on control trees and on those in which 3 green lacewing second instars were released (Table 3). The total leaf area for the first and second replication of the green lacewing treatment showed no significant difference between both leaf area (4,166.6 and 3,608.1 cm^2 for the first and second replicate, respectively) and mortality. Therefore, data were pooled for further analysis. Mortality of third instar *P. perseae* on potted avocado plants was significantly different between control plants lacking *C. rufilabris* and those treated with *C. rufilabris* larvae ($W = 42$; $df = 1$; $P < 0.005$). The combined mortality (dead and missing, Table 3) for third instar *P. perseae* for the lacewing treatment was 14.9, 2.2 times higher than that observed for the control treatments (6.9 dead *P. persea* nymphs).

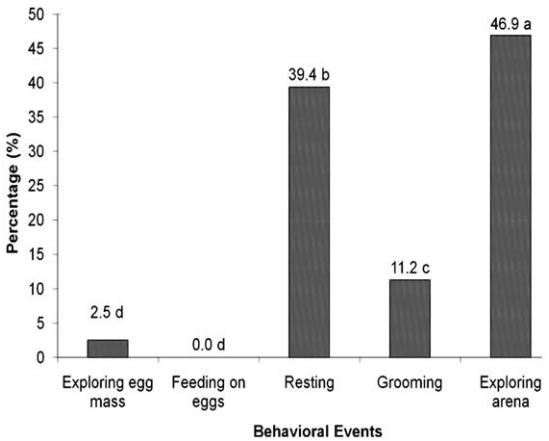

Fig. 1. Behavior of *Neoseiulus californicus* when presented with *Pseudacysta perseae* eggs in the laboratory. Means followed by the same letter are significantly different ($P \geq 0.05$).

Chrysoperla rufilabris has been demonstrated previously as an effective natural enemy against azalea lace bug, *Stephanitis pyrioides* (Scott) (Hemiptera: Tingidae), a serious cosmopolitan pest of ornamental landscape azaleas (Shrewsbury & Smith-Fiola 2000; Stewart et al. 2002). In nursery trials, augmentative releases of *C. rufilabris* onto potted azalea bushes reduced damaging *S. pyrioides* densities by 97%. This level of control was comparable to standard industry insecticide treatments (i.e., acephate) and lacewing larvae could thus be considered a potential control tactic for use within an IPM framework for *S. pyrioides* management (Shrewsbury & Smith-Fiola 2000).

Many homeowners and commercial avocado growers in California are interested in non-chemical control measures for avocado pests, especially the use of natural enemies. Results from laboratory assays and small potted plant trials in the greenhouse indicated that commercially available *C. rufilabris* may have potential for reducing *P. perseae* densities on small avocado trees. However, more comprehensive tests across a variety of tree sizes, pest infestation levels, and climates (i.e., arid interior avocado growing areas of California vs. cooler more humid coastal zones) that approximate more realistic field conditions are needed before recommendations for the use of this predator can be made.

The residual impact of 6 relatively persistent insecticides on *P. perseae* nymphs is shown in Table 4. Carbaryl, imidacloprid, and fenpropathrin were the strongest treatments evaluated. Carbaryl was effective from 3 to 112 d post-treatment. Mortality of *P. perseae* on imidacloprid treated seedlings increased from 75 to 97 to 100% after 1, 2, and 4 weeks post-treatment as the soil-applied material was taken up by the small potted trees. This treatment remained effective through the 112-d post-treatment evaluation. Fenpropathrin was effective early in the trial but mortality of lace bugs declined following the 77-d post-treatment evaluation. Spinosad plus oil and abamectin plus oil were eliminated as candidate treatments after *P. perseae* mortality dropped below 10% with the 7-d post-treatment bioassay. These 2 materials are widely used on California avocados for control of pest thrips and mites, and our results contradict the suggestion by Bender & Witney (2005) that these materials would be effective on avocado lace bug. The reason for lack of activity by spinosad and abamectin is not understood but could be due to the feeding behavior of *P. perseae*, or the mode of action of these pesticides may be ineffective against this pest.

TABLE 3. MORTALITY OF *PSEUDACYSTA PERSEAE* (ALB) NYMPHS ON SMALL POTTED AVOCADO TREES INOCULATED WITH *CHRYSOPERLA RUFILABRIS* LARVAE.

Treatment	Pre-count	Live (L)	Dead (D)	Total (L + D)	Individuals not recovered
ALB on lacewing release seedlings	36.4 ± 0.9	21.5 ± 1.6	4.1 ± 0.8	25.6 ± 1.3	10.8 ± 1.1
Number of green lacewing larvae	3.0 ± 0.0	0.6 ± 0.2	0.0 ± 0.0	0.6 ± 0.2	2.4 ± 0.2
ALB – control seedlings	42.0 ± 1.8	35.1 ± 2.3	1.0 ± 0.3	36.0 ± 2.4	5.9 ± 1.4

TABLE 4. RESIDUAL IMPACT OF PERSISTENT INSECTICIDES ON *PSEUDACYSTA PERSEAE* NYMPHS.

	Corrected % mortality[1]						
	Number of days after treatment						
Treatment	3	7	14	28	49	77	112
Carbaryl	100 a	100 a	100 a	100 a	100 a	100a	100 a
Soil applied imidacloprid	23.0 b	75.0 b	97.1 a	100 a	100 a	100 a	100 a
Fenpropathrin	100 a	100 a	100 a	100 a	100 a	97.5 a	36.3 b
Abamectin + oil	36.0 b	9.9 c	—	—	—	—	—
Spinosad + oil	9.0 c	1.0 d	—	—	—	—	—
Petroleum oil [2]	0.0 d	0.0 d	—	—	—	—	—

[1]Means followed by the same letter within a column are not significantly different ($P \geq 0.05$).

The contact effects of the 6 less persistent and less toxic insecticides on *P. perseae* nymphs and *C. rufilabris* are shown in Table 5. For *P. perseae* nymphs, the pyrethrin mixture was the most effective treatment of those evaluated followed by potash soap, petroleum oil, and pyrethrins + potash soap. The pyrethrins + rotenone and neem oil had little impact on *P. perseae* nymphs. Petroleum oil had no effect as a residual pesticide as shown in our residual impact bioassay, but the contact impact on *P. perseae* was high. The results for the insecticide-predator bioassay showed that the petroleum oil treatment caused the highest *C. rufilabris* mortality. No significant difference was observed among results for contact mortality of *C. rufilabris* with potash soap, pyrethrins + potash soap, pyrethrins, pyrethrins + rotenone, neem oil, and the water control (Table 5).

TABLE 5. ACTIVITY OF CONTACT INSECTICIDES ON *PSEUDACYSTA PERSEAE* AND *CHRYSOPERLA RUFILABRIS* 72 H AFTER TREATMENT.

	Percent mortality[1]	
Treatment	*P. perseae*	*C. rufilabris*
Pyrethrins	100 a	23.3 b
Petroleum oil	74.0 b	70.0 a
Potash soap	73.7 b	26.7 b
Pyrethrins + potash soap	66.1 b	26.7 b
Pyrethrins + rotenone	41.2 c	20.0 b
Neem oil	0.0 d	13.3 b
Water control	—	6.7 b

[1]Means followed by the same letter within a column are not significantly different ($P \geq 0.05$).

In conclusion, experimental results presented here suggest that of the 3 commercially available natural enemies tested against *P. perseae*, the larval stages of *C. rufilabris* were the most efficacious. However, field experiments are needed to confirm the efficacy and cost effectiveness of *C. rufilabris* larvae against *P. perseae*. Of the persistent insecticides evaluated for *P. perseae* control, imidacloprid and carabaryl were the most effective. For the less persistent insecticides, products with pyrethrins were among the most effective evaluated and these showed high compatibility with *C. rufilabris* larvae. Results of work reported here have helped develop the foundation of an IPM program should *P. perseae* emerge as a significant avocado pest in California.

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