Toxicity of 6 Miticides to the Asian Citrus Psyllid, *Diaphorina citri* (Hemiptera: Livididae)

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Abstract

The Asian citrus psyllid (ACP), *Diaphorina citri* Kuwayama (Hemiptera: Livididae), is an important pest of citrus. Research into strategies to control ACP is ongoing at many facilities, including at the USDA-ARS U.S. Horticultural Research Laboratory (USHRL) in Fort Pierce, Florida. The USHRL maintains colonies of ACP, but their survival is often threatened by mites which render host plants unsuitable for ACP. Our objective was to identify miticides/insecticides that could be used to control mite outbreaks with minimal or no adverse affect on ACP. We tested the following 6 miticides in greenhouse trials for their toxicity to each life stage of ACP and also investigated sublethal effects on development and oviposition of ACP: bifenazate (Acramite 50 WS), spiromidoclofen (Envidor 2 SC), dicofol (Kelthane MF), pyridaben (Nexter), petroleum oil, and chlorfenapyr (Pylon). The miticides differed in their toxicity when applied directly to ACP. Bifenazate was the only miticide that was not toxic to any life stage of ACP, whereas pyridaben and chlorfenapyr, which are also labeled as insecticides, were toxic to all life stages of ACP. Petroleum oil and dicofol killed adult and nymphal ACP, but were nontoxic to eggs. Spiromidoclofen was nontoxic to adults, but reduced nymphal survivorship and killed eggs. The duration of residual activity against adult ACP also was widely variable: dicofol residues were only toxic for up to 10 days, whereas chlorfenapyr residues were still toxic after 36 days. We recommend using dicofol, pyridaben, petroleum oil, and chlorfenapyr to maintain clean plants prior to colonization by ACP and then rotating bifenazate and spiromidoclofen, if maintaining adult ACP, or bifenazate, dicofol, and petroleum oil, if maintaining eggs. Bifenazate is the only product safe for maintaining nymphal ACP. Our results are useful for research facilities that wish to maintain colonies of ACP and control mites and may be useful for citrus growers and researchers that wish to kill ACP and mites with a single treatment.

Key Words: bifenazate, chlorfenapyr, dicofol, petroleum oil, pyridaben, spiromidoclofen

Resumen

El psílido asiático de los cítricos (PAC), *Diaphorina citri* Kuwayama (Hemiptera: Livididae), es una plaga importante de los cítricos. Se están realizando investigaciones sobre las estrategias para el control de PAC en muchas instalaciones, incluyendo el Laboratorio de Investigación de Horticultura (USHRL) de USDA-ARS en Fort Pierce, Florida. El USHRL mantiene colonias de PAC, pero su supervivencia está amenazada frecuentemente por los ácaros que hacen las plantas hospedantes no aptas para el PAC. Nuestro objetivo fue identificar los acaricidas / insecticidas que podrían ser utilizados para controlar las infestaciones de ácaros sin o con mínimos efectos adversos sobre los PAC. Hemos probado los siguientes 6 acaricidas en ensayos de invernadero por su toxicidad hacia cada estadio de los PAC y también se investigó los efectos subletales sobre el desarrollo y la oviposición de PAC: bifenazato (Acaramite® 50 WS), espiromidoclofen (Envidor® 2 SC), dicofol (Kelthane® MF), piridaben (Nexter®), aceite de petróleo, y clorfenapir (Pylon®). Los acaricidas varían en su toxicidad cuando fueron aplicados directamente a los PAC. Bifenazato fue el único acaricida que no era tóxico para cualquier estadio de los PAC, mientras que piridaben y clorfenapir, que también son registrados como insecticidas, fueron tóxicos para todos los estados de PAC. El aceite de petróleo y dicofol mató los adultos y las ninñas de PAC, pero no fueron tóxicos para los huevos. La duración de la actividad residual contra los adultos de PAC también fue muy variable: los residuos de dicofol sólo fueron tóxicos para un máximo de 10 días, mientras que los residuos de clorfenapir fueron tóxicos después de 36 días. Recomendamos el uso de dicofol, piridaben, aceite de petróleo, y clorfenapir para mantener limpias las plantas antes de la colonización por los PAC y luego alternando el uso de bifenazato y espiromidoclofen para mantener los adultos de PAC, o bifenazato, dicofol, y aceite de petróleo para mantener los huevos. El bifenazato es el único producto seguro para mantener las ninñas de PAC. Nuestros resultados son útiles para las instalaciones de investigación que desean mantener colonias de PAC y control de los ácaros y puede ser útil para los productores de cítricos y los investigadores que desean matar los PAC y ácaros con un solo tratamiento.

Palabras Clave: bifenazato, clorfenapir, dicofol, aceite de petróleo, piridaben, espiromidoclofen
Mortality of Adults Sprayed with Miticide

We collected 70 female ACP that had been adults for less than 24 h to standardize their age and minimize the probability that they had mated (Wenninger & Hall 2007). On each of 35 ‘Duncan’ grapefruit (Citrus paradisi Macf.) trees, one female ACP was caged on the abaxial side of a leaf and a second female was caged on the adaxial side of a second leaf with clip cages. Clip cages were round plastic tubes (21 × 27 mm) attached to aluminum clips and had a top opening covered by screen. ACP acclimated to plants for 48 h in a greenhouse, which averaged ~30 °C, ~56% relative humidity (RH), and 14 hr photoperiod, before we sprayed them with miticides.

The highest concentrations of 6 miticides/insecticides (hereafter “miticides”), bifenazate (Aramite 50 WS), spirodiclofen (Envidor 2 SC), dicofol (Kelthane MF), pyridaben (Nexter), petroleum oil, and chlorfenapyr (Pylon) (Table 1) were prepared separately in 180 mL Nalgene aerosol spray bottles (#2430-0200, Fisher Scientific, Pittsburgh, PA) by mixing the miticides with 100 mL of tap water. The amount of product per 100 mL of tap water was calculated from the labeled rate per 100 gal of water. These miticides were selected because they are labeled for, and commonly used in, greenhouses, have a relatively short restricted entry interval (12 h), and some are labeled specifically for mites and not insects, such as bifenazate, spirodiclofen, and dicofol (Table 1). Plants were separated into 7 groups of 5 plants each and all ACP within a group (n = 10 ACP per group) were sprayed with a single miticide or tap water (control). We sprayed ACP through the mesh top of the clip cages until the entire leaf surface was wet using the aforementioned aerosol
spray bottle. Each adult ACP was checked daily until their death to determine whether these miticides reduced the lifespan of adults. This experiment was repeated in its entirety with novel plants and ACP, but using moderate concentrations of the miticides mixed with 100 mL of tap water (Table 1). The moderate concentration for each product was calculated by halving the highest concentration to find the lowest concentration, and then using the midpoint between the high and low concentration as the moderate concentration.

We used separate negative binomial models (PROC GENMOD, SAS Institute, 2011) to test for differences in adult lifespan among high and moderate applications of the miticides. The side of the leaf on which ACP were caged was included in the original statistical model, but was removed because it did not influence longevity of ACP. The LSMEANS statement was then used to estimate separation between pairs of means (SAS Institute 2011; Sokal and Rohlf 1995). The final number of ACP used for statistical analyses of this experiment, and the following experiments, was sometimes reduced because individuals escaped.

Sublethal Effects of Miticides on Oviposition

We sprayed 10 flushing ‘Ridge pineapple’ (C. sinensis L. Osbeck) seedlings each with tap water or the highest labeled concentration of bifenazate or spiromidol (N = 30) until thoroughly wet and allowed them to dry for 2 h in a greenhouse. We used these 2 miticides for this experiment because the other miticides were toxic to adults (see Results). We separated 60 female and 30 male ACP into 30 groups, each consisting of 2 females and one male. We chose ACP that had been adults for approximately 6 days to ensure that they had reached reproductive maturity (Wenninger & Hall 2007). Each group of 3 adults was briefly anesthetized with CO2, placed onto filter paper in a Petri dish, and sprayed with miticide or tap water using an aerosol spray bottle. Each group was then transferred using a small brush moistened with tap water to a seedling that had been sprayed with the same treatment. We enclosed plants with plastic cylinders (37 × 255 mm) that had one top opening and 4 circular side openings (25 mm diameter) that were covered with screen. The open bottom of each cylinder was pressed into the Cone-tainer (Stuewe and Sons, Corvalis OR) to prevent adult ACP from escaping. The plants were placed in an environmental chamber operating at ~26.8 °C, 89% relative humidity, and 14 h daily illumination. The number of eggs on each plant was counted 6 days after inoculation under a dissection microscope. We did not repeat this experiment with moderate concentrations of the miticides because high concentrations did not reduce oviposition (see Results).
We used a negative binomial model (PROC GENMOD, SAS Institute, 2011) to test for differences in the number of eggs laid among treatments. The number of adults surviving at the end of the 6-day oviposition period was included as a covariate because the number of eggs laid can be correlated with the number of adults on a plant (MLR, unpublished data). The LSMEANS statement was then used to estimate separation between pairs of means (SAS Institute 2011; Sokal & Rohlf 1995).

Residual Activity of Miticides against Adult ACP

One hundred ‘Valencia’ sweet orange (C. sinensis) trees approximately 70-105 cm tall were separated into 5 groups of 20 trees each in a greenhouse. One group each was sprayed with tap water or the highest labeled concentration of a miticide that kills adult ACP when sprayed directly: dicrofolf, pyridaben, petroleum oil, and chlorfenapyr. Bifenazate and spiropidolofen were not used because they do not kill adults (see Results). Plants dried for one day and then half the plants in each treatment were watered from above the leaf canopy and the other half were watered below the leaf canopy to test whether rinsing the plants with water removes chemical residues. We then used clip cages to cage 80 adult, virgin ACP of mixed gender on the leaves of 16 plants of each treatment (5 ACP per plant and 8 cages per watering regime). We used the watering regime previously described on each day following application of tap water or miticide, but did not water above leaves that had ACP caged on them. Percent mortality of ACP was determined 72 h after confining them to plants. New ACP were transferred to new leaves on the plants 4, 7, 11, 15, 22, 29, and 36 days following application of miticides and mortality was checked 72 h after each transfer. Plants were removed from the experiment when the miticide with which they were sprayed no longer caused higher mortality to ACP than the control.

We tested whether percent mortality of ACP was influenced on each transfer date by the miticide treatment, watering regime, and interaction of miticide and watering regime by using separate non-parametric repeated measures analyses: the F-approximation of the Friedman test (Ipe 1987) and the associated Rank Sum multiple comparison test (PROC GLMMIX, SAS Institute 2011).

Mortality of Nymphs Sprayed with Miticide

Toxicity of miticides to nymphs was investigated using leaf disks embedded on agar. We excised mature leaves from young ‘Ridge pineapple’ trees maintained in a greenhouse and cut 30 circular disks from these leaves using a 2.34 cm diameter copper pipe with sharpened edges. Each leaf disk, adaxial side up, was embedded on agar (7 g / 500 ml water) in a small Petri dish (suspension culture dish, 35 mm × 10 mm, non-treated polystyrene, #430588, Corning Inc., Corning, NY) following the methods of Hall et al. (2010) and Hall & Richardson (2012). 5 nymphs in the fifth instar were transferred from a flush shoot to a filter paper disk using a small brush moistened with tap water. Nymphs on 10 disks each (N = 30 disks, 150 ACP) were misted until wet with tap water or the highest labeled concentrations of bifenazate or spiropidolofen. We used bifenazate and spiropidolofen for this experiment because the other miticides are toxic to adults and nymphs are usually as, or more, susceptible to insecticides than adults (Hall & Richardson 2012). We then transferred the nymphs to the leaf disks, capped the Petri dish with the lid, and secured the lid using laboratory sealing film (#6600 1026, Whatman International Ltd, Maidstone, England) to prevent nymphs from escaping. Nymphs were not sprayed directly on leaf disks to prevent drowning in the chemical or water droplets. The Petri dishes were placed on a tray in an environmental chamber operating at ~24 °C, 89% relative humidity, and 14 h daily illumination. The water associated with the agar generally maintains relative humidity in the Petri dishes at 98 to 100% (DGH, unpublished data). The percentage of dead ACP in each Petri dish was calculated after 48 h. We did not repeat this experiment with moderate concentrations of the miticides because high concentrations did not kill nymphs (see Results).

We tested whether percent mortality of ACP differed among miticide treatments using the F-approximation of the Friedman test and the associated Rank Sum multiple comparison test (PROC GLMMIX, SAS Institute 2011).

Number of ACP Reaching Adulthood when Sprayed with Miticide during the Nymphal Stage

We caged 18 flushing ‘Duncan’ grapefruit trees individually in bugdorms (MegaView Science Co., Ltd., Taichung, Taiwan) in a greenhouse that averaged ~27 °C, ~71% relative humidity, and ~13 h 40 minutes of daily illumination. We released 20 adult ACP into each cage, with no regard to gender. Adult ACP were removed from the cages after 3 days and then 5 days after removal of the adults we sprayed 6 plants each with tap water or a moderate concentration of bifenazate or spiropidolofen when nymphal ACP were in the third or fourth instar. No attempt was made to determine the initial number of nymphs on each plant because handling the plants and nymphs causes high mortality of nymphs. The initial date nymphs developed into adults in each cage was noted in order to test whether miticides prolonged development of ACP. All ACP that survived to adulthood also were collected, counted, and sexed.
We compared date of adult emergence and abundance of male, female, and total ACP among miticide treatments using separate negative binomial models (PROC GENMOD, SAS Institute, 2011). The number of flush shoots in each cage was included as a covariate because the number of eggs laid on a plant is often correlated with the number of flush shoots (MLR, unpublished data). The LSMEANS statement was then used to estimate separation between pairs of means (SAS Institute 2011; Sokal & Rohlf 1995).

Number of ACP Reaching Adulthood when Sprayed with Miticide during the Egg Stage

We caged 21 flushing ‘Duncan’ grapefruit trees individually in bugdorms in a greenhouse that averaged ~27°C, ~71% relative humidity, and ~13 h 40 minutes of daily illumination. We released 20 adult ACP into each cage. After 3 days we removed adult ACP from the cages and sprayed 3 plants each with the highest labeled concentration of miticide or tap water. The initial date nymphs developed into adults in each cage was noted in order to test whether miticides prolonged development of ACP. All ACP that survived to adulthood also were collected, counted, and sexed. This experiment was repeated in its entirety for a total of 6 replications per treatment. We also repeated this experiment with moderate concentrations of spirodiclofen, pyridaben, and chlorfenapyr because these 3 miticides are toxic at the maximum labeled concentration (see Results) and we wanted to determine if they also were toxic at moderate concentrations.

We compared date of adult emergence and abundance of male, female, and total ACP among miticide treatments using separate negative binomial models and the LSMEANS statement, as discussed for the previous experiment.

**Results**

Mortality of Adults Sprayed with Miticide

The lifespan of adult ACP was influenced by miticide when applied at the high ($\chi^2 = 68.7, df = 6,62, P < 0.001$) or moderate rates ($\chi^2 = 31.7, df = 6,60, P < 0.001$). Dicofol, pyridaben, petroleum oil, and chlorfenapyr shortened the lifespan of ACP compared to the control, whereas bifenazate and spirodiclofen did not (Fig. 1a, b).

Sublethal Effects of Miticides on Oviposition

The number of eggs laid per plant was influenced by the total number of adult ACP remaining on the plants after 6 d, but not the miticide (adults ACP, $\chi^2 = 18.6, df = 1,26, P < 0.001$; miticide, $\chi^2 = 5.1, df = 2,26, P = 0.08$). The mean (± SEM) number of eggs per adult ACP was 116 ± 46 when sprayed with tap water, 93 ± 49 when sprayed with bifenazate, and 90 ± 47 when sprayed with spirodiclofen.

Residual Activity of Miticides against Adult ACP

All the miticides had some residual activity against adult ACP (Tables 2 and 3). Rinsing the plants with tap water had no effect 1 day after application of miticides, and all miticides were toxic to ACP (Tables 2 and 3). Dicofol residues no longer caused higher mortality to ACP than the control by day 4 on plants that were rinsed and day 7 on plants that were not rinsed (Table 3). Pyridaben residues no longer caused higher mortality to ACP than the control on plants that were not rinsed by day 4, but were toxic up to 36 days on plants that were rinsed (Table 3). Petroleum oil residues no longer caused higher mortality to ACP than the control by day 7 on plants that were not rinsed and 22 days on plants that were not rinsed (Table 3). Chlorfenapyr residues only started to decrease in toxicity 29 days after application and mortality of ACP on plants that were not rinsed was still higher than the control after 36 days (Table 3).
Table 2. Results of non-parametric repeated measures analysis that tested differences in percent mortality of *Diaphorina citri* among residues of 4 miticides up to 36 days following application. Half the host plants were rinsed with tap water daily and the other half were not rinsed to test whether this influenced residual activity.

<table>
<thead>
<tr>
<th>Days post-application</th>
<th>Miticide</th>
<th>Rinse</th>
<th>Miticide × Rinse</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$F = 26.7, df = 4, P &lt; 0.001$</td>
<td>$F = 26.7, df = 1, P &lt; 0.001$</td>
<td>$F = 0.8, df = 4, P = 0.53$</td>
</tr>
<tr>
<td>4</td>
<td>$F = 15.8, df = 4, P &lt; 0.001$</td>
<td>$F = 0.53, df = 1, P = 0.47$</td>
<td>$F = 3.65, df = 4, P = 0.009$</td>
</tr>
<tr>
<td>7</td>
<td>$F = 13.8, df = 4, P &lt; 0.001$</td>
<td>$F = 2.46, df = 1, P = 0.12$</td>
<td>$F = 1.65, df = 4, P = 0.20$</td>
</tr>
<tr>
<td>11</td>
<td>$F = 9.11, df = 3, P &lt; 0.001$</td>
<td>$F = 0.00, df = 1, P = 0.98$</td>
<td>$F = 0.00, df = 1, P = 0.98$</td>
</tr>
<tr>
<td>15</td>
<td>$F = 50.4, df = 3, P &lt; 0.001$</td>
<td>$F = 0.56, df = 1, P = 0.46$</td>
<td>$F = 2.88, df = 1, P = 0.10$</td>
</tr>
<tr>
<td>22</td>
<td>$F = 21.1, df = 3, P &lt; 0.001$</td>
<td>$F = 4.18, df = 1, P = 0.05$</td>
<td>$F = 4.18, df = 1, P = 0.05$</td>
</tr>
<tr>
<td>29</td>
<td>$F = 5.03, df = 2, P &lt; 0.001$</td>
<td>$F = 0.17, df = 1, P = 0.69$</td>
<td>$F = 1.13, df = 1, P = 0.29$</td>
</tr>
<tr>
<td>36</td>
<td>$F = 3.68, df = 2, P = 0.04$</td>
<td>$F = 0.04, df = 1, P = 0.85$</td>
<td>NA</td>
</tr>
</tbody>
</table>

Mortality of Nymphs Sprayed with Miticide

Percent mortality (± SEM) of nymphs sprayed with the highest labeled concentration of miticides averaged 16 ± 6.5% for bifenazate and 16 ± 8.3% for spirodiclofen, which was not different than the mortality of nymphs sprayed with tap water (11 ± 6.0%; $F_{2,27} = 0.76, P = 0.46$).

Number of ACP Reaching Adulthood when Sprayed with Miticide During the Nymphal Stage

The number of males, number of females, and total number of ACP reaching adulthood after being sprayed with miticides as nymphs were all similarly influenced by the miticides (females, $\chi^2 = 34.4, df = 2,18, P < 0.001$; males, $\chi^2 = 28.1, df = 2,18, P < 0.001$; total adults, $\chi^2 = 27.6, df = 2,18, P < 0.001$), so only the results for total number of ACP reaching adulthood are discussed. The mean number of ACP surviving to adulthood when sprayed with spirodiclofen was 5.6 ± 1.4, which was significantly lower than the mean for bifenazate (81.0 ± 14.3) and the control (97.4 ± 17.0). However, neither miticide delayed development of ACP ($\chi^2 = 0.27, df = 2,18, P = 0.88$).

Number of ACP Reaching Adulthood when Sprayed with Miticide during the Egg Stage

The number of males, number of females, and total number of ACP developing from eggs sprayed with the highest concentration of miticides were all similarly influenced by the miticides (females, $\chi^2 = 35.6, df = 6,34, P < 0.001$; males, $\chi^2 = 35.5, df = 6,34, P < 0.001$; total adults, $\chi^2 = 35.3, df = 6,34, P < 0.001$), so only the results for total number of ACP reaching adulthood are discussed. Spirodiclofen, pyridaben, and chlorfenapyr reduced the number of ACP surviving to adulthood, whereas bifenazate, dicrof, and petroleum oil did not (Fig. 2).

Discussion

The miticides differed in their toxicity to the 3 life stages of ACP (Table 4). Bifenazate was the only miticide that was not toxic to any life stage of ACP, whereas pyridaben and chlorfenapyr, which are also labeled as insecticides, were toxic to all life stages of ACP. Petroleum oil is labeled for mites and insects and killed adult and nymphal ACP, but was nontoxic to eggs. Dicofol is labeled only for mites, but was highly toxic to adult and nymphal ACP. Spirodiclofen was nontoxic to adults, toxic to eggs, and apparently does not kill nymphs immediately, but reduces the likelihood that they will survive to the adult stage. Spirodiclofen inhibits a key enzyme responsible for synthesis of fatty acid, which is a slower mode of action than other common miticides (Marcic 2012).

The duration of residual activity against adult ACP also was widely variable: dicrof had the shortest residual activity (fewer than 10 days), whereas chlorfenapyr was still toxic after 36 days likely because it is translaminar. Translaminar chemicals typically have good residual activity against foliar-feeding mites and insects (Lasota & Dybas 1991; Cloyd 2003), including TSSM (Abdel-Wali et al. 2012), because they penetrate leaf tissue and form a reservoir of active ingredient inside the leaf. Unlike residues of the other miticides, pyridaben residues were toxic for a longer duration on plants that were rinsed with tap water than on plants that were not rinsed. We are unsure why this occurred, but we speculate that water may have rehydrated the residues.

The miticides did not appear to have sublethal effects on development or oviposition of ACP. Bife-
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...which were not toxic to adult ACP also did not reduce the number of eggs laid by adults. We also did not detect any delay in nymphal development when ACP were sprayed with the miticides during the egg or nymphal stage. However, we only assessed nymphal development when ACP were sprayed with the miticides during the egg stage. The miticides are relatively effective at the USFHC (Faulkner et al., 2012) so the efficacy of the miticides we tested against local populations of TSM would be influenced by factors other than the miticides themselves. Particularly, the ones that prevented most ACP from reaching adulthood. The miticides' effectiveness in preventing nymphal development when sprayed during nymphal stages was highly variable. Miticides that were not effective in preventing nymphal development during nymphal stages were also not effective in preventing nymphal development when sprayed during egg stages.

Table 3. Mean (± SEM) percent mortality of Diaphorina citri caused by residues from 4 miticides up to 36 days following application. New adult virgins D. citri were freshly exposed to plants sprayed with tap water or a miticide on the indicated days post-application and their mortality was noted 72 h later. Half the plants were rinsed (R) with tap water daily and the other half were not rinsed (NR). Treatment residues were no longer evaluated for toxicity after mortality was not significantly higher than the control (tap water).

<table>
<thead>
<tr>
<th>Days post-application</th>
<th>Control R</th>
<th>Control NR</th>
<th>Dicofol R</th>
<th>Dicofol NR</th>
<th>Pyridaben R</th>
<th>Pyridaben NR</th>
<th>Petroleum oil R</th>
<th>Petroleum oil NR</th>
<th>Chlorfenapyr R</th>
<th>Chlorfenapyr NR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>28 (14) c</td>
<td>23 (10) c</td>
<td>88 (8) ab</td>
<td>82 (10) b</td>
<td>100 (0) a</td>
<td>88 (13) ab</td>
<td>80 (9) be</td>
<td>100 (0) a</td>
<td>100 (0) a</td>
<td>100 (0) a</td>
</tr>
<tr>
<td>4</td>
<td>20 (8) e</td>
<td>29 (14) d e</td>
<td>55 (12) cd</td>
<td>83 (13) ab</td>
<td>93 (8) a</td>
<td>84 (12) ab</td>
<td>80 (9) be</td>
<td>100 (0) a</td>
<td>100 (0) a</td>
<td>100 (0) a</td>
</tr>
<tr>
<td>7</td>
<td>40 (16) b</td>
<td>41 (15) b</td>
<td>—</td>
<td>35 (15) b</td>
<td>98 (3) a</td>
<td>—</td>
<td>68 (13) b</td>
<td>95 (5) a</td>
<td>95 (3) a</td>
<td>95 (5) a</td>
</tr>
<tr>
<td>11</td>
<td>63 (13) b</td>
<td>58 (16) b</td>
<td>—</td>
<td>—</td>
<td>98 (3) a</td>
<td>—</td>
<td>96 (4) a</td>
<td>98 (3) a</td>
<td>100 (0) a</td>
<td>100 (0) a</td>
</tr>
<tr>
<td>15</td>
<td>33 (13) b</td>
<td>13 (8) b</td>
<td>—</td>
<td>—</td>
<td>97 (3) a</td>
<td>—</td>
<td>50 (14) b</td>
<td>100 (0) a</td>
<td>100 (0) a</td>
<td>100 (0) a</td>
</tr>
<tr>
<td>22</td>
<td>63 (13) b</td>
<td>30 (9) b</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>80 (11) ab</td>
<td>95 (5) a</td>
<td>—</td>
<td>—</td>
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<tr>
<td>29</td>
<td>68 (11) b</td>
<td>55 (15) b</td>
<td>—</td>
<td>—</td>
<td>97 (3) a</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>36</td>
<td>41 (10) b</td>
<td>40 (11) b</td>
<td>—</td>
<td>—</td>
<td>73 (14) ab</td>
<td>—</td>
<td>50 (15) b</td>
<td>75 (11) a</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

Means within a row followed by different letters are significantly different (means separation test, P < 0.05).

Fig. 2. Mean number (± SEM) of Diaphorina citri reaching adulthood when sprayed with miticides during egg stages with the highest labeled concentration of 6 miticides or tap water (control). Means with different letters are significantly different (means separation test, P < 0.05).
Table 4. Toxicity of direct application of 6 miticides to each life-stage of Diaphorina citri and duration of residual activity against adults.

<table>
<thead>
<tr>
<th>Miticide</th>
<th>Adults</th>
<th>Nymphs</th>
<th>Eggs</th>
<th>Residual duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bifenazate</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>NA</td>
</tr>
<tr>
<td>Spirodiclofen</td>
<td>no</td>
<td>yes/no</td>
<td>yes</td>
<td>NA</td>
</tr>
<tr>
<td>Dicofol</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>3-10 days</td>
</tr>
<tr>
<td>Pyridaben</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>3-35 days</td>
</tr>
<tr>
<td>Petroleum oil</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>6-21 days</td>
</tr>
<tr>
<td>Chlorfenapyr</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>&gt;28 days</td>
</tr>
</tbody>
</table>

(Liburd et al. 2007), but should be used only at the frequency and rate listed on the label so that mite populations do not develop resistance. These miticides also could be combined with other measures to control mites, such as mites that prey on herbivorous mites (Gerson & Weintraub 2012) or insecticidal soaps, which have short residues and are nontoxic to eggs of ACP (Hall & Richardson 2012).

In conclusion, our results are useful for selecting a miticide to prevent or control outbreaks of mites that have little or no activity against ACP. The results are also useful for selecting a miticide that kills ACP and mites in greenhouses or citrus groves. All the miticides, except for chlorfenapyr, are labeled and recommended as part of a pesticide rotation to control mites in citrus groves (Rogers & Dewdney 2012), so citrus producers may be able use them to simultaneously control mites and ACP. However, our ACP were reared in a laboratory environment for over 10 years and may be more susceptible to these miticides than wild ACP. In addition, whereas regular applications of petroleum oil are recommended to control ACP in citrus groves (Stansly et al. 2012), and spirodiclofen and pyridaben have been tested for control of ACP in groves (Qureshi & Stansly 2007; Stansly et al. 2012), the efficacy of the other miticides against ACP in the field needs to be verified.

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References Cited


