Compatibility of Acaricide Residues with *Phytoseiulus persimilis* and Their Effects on *Tetranychus urticae*

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Abstract. The twospotted spider mite, *Tetranychus urticae* Koch, is a serious pest of many nursery crops. Regular acaricide applications are required to maintain acceptable population levels of this pest. *Phytoseiulus persimilis* Athias-Henriot is a commercially available predator used to control *T. urticae* populations. The effects of acaricide residues were tested on *P. persimilis* and *T. urticae* using a leaf disk system. Both species were exposed to residues for 24 hours 1, 3, 7, and 14 days after acaricide application. Abamectin, Gowan 1725, hexythiazox, horticultural oil, neem oil, pyridaben, and spionosyn residues caused no mortality to *P. persimilis* 1, 3, 7, or 14 days after application. Chlorfenapyr was harmful to both species at all times after application. Bifenthrin residue was toxic to *P. persimilis* at all times after application, but was only harmful to *T. urticae* up to one week after application. *Tetranychus urticae* mortality from Gowan 1725, horticultural oil, and neem oil residues was significantly greater than the control 24 hours after application, but not thereafter. *Tetranychus urticae* mortality from hexythiazox and spinosad residues was not significantly greater than the control. Proper pesticide selection may create favorable conditions for release of *P. persimilis* and reduce acaricide dependency.

The twospotted spider mite, *Tetranychus urticae* Koch, is a serious pest of many greenhouse plants, nursery-grown ornamentals, and field crops. Twospotted spider mite damage may include webbing, fine stippling, leaf yellowing, leaf drop, and even plant death (Helle and Sabelis, 1985). Species in its host range include numerous herbaceous and woody landscape plants such as rose, ivy, and winged euonymus (Johnson and Lyon, 1991). Female *T. urticae* can develop from egg to adult in ≈ 6.5 d at 30 °C (Sabelis, 1981), and females can lay as many as 60 eggs in 5 d (Helle and Sabelis, 1985). The expense of new acaricides and the loss of production time associated with pesticide applications has made frequent acaricide applications costly. Development of resistance by *T. urticae* to numerous acaricides has caused difficulties in controlling outbreaks (Carbonaro et al., 1986). These conditions have raised interest by growers to introduce predatory phytoseiid

mites to manage twospotted spider mites to reduce their need for acaricide applications (Sabelis, 1981).

Phytoseiulus persimilis Athias-Henriot can be effective as one of many tools of an integrated pest management program for *T. urticae*. Trials conducted in Florida, which used *Phytoseiulus persimilis* to control twospotted spider mite on Crotons and Areca palms, reduced the number of acaricide applications by 87% to 92% in Croton, and 100% in Areca palms (Cashion et al. 1994). Releases of *P. persimilis* in interiorscapes to suppress mite populations have performed with varying degrees of success (Lindquist, 1981). Despite successful suppression of *T. urticae*, limitations to the effectiveness of *P. persimilis* arise under certain conditions in which their fecundity may be reduced. The optimum conditions for rapid population development of *P. persimilis* is a temperature of 27 °C and relative humidity (RH) of 60% to 85% (Stenseth, 1979). A temperature of 27 °C with RH <40% reduces the reproductive rate of *P. persimilis* by increasing egg mortality (Stenseth, 1979). This is a significant disadvantage because most greenhouses have temperatures and humidity levels that are outside these optima for part of the day. Another limitation to *P. persimilis* effectiveness is related to *T. urticae* density. As *T. urticae* density increases, *P. persimilis* predation becomes less likely to provide adequate suppression (Helle and Sabelis, 1985). Trumble and Morse (1993) demonstrated that suppression was achieved by releasing *P. persimilis* before *T. urticae* reach threshold levels that warrant chemical treatment. After threshold levels are surpassed, predator re-

lease combined with compatible acaricides is more effective than using chemical or biological control tactics alone.

To combine *P. persimilis* with acaricide applications, chemical residues must be non-toxic to the predators. The effects of chemical classes on *P. persimilis* from most harmful to least harmful are organophosphates, pyrethroids, organochlorines, and carbamates (Pratt and Croft, 2000). However, the effects of individual products and formulations can vary greatly. Our objective was to determine the toxicity of residues of 10 new or commonly used acaricides to *P. persimilis* 1, 3, 7, and 14 d after application. In addition, residual toxicity to *T. urticae* was recorded.

Materials and Methods

Twospotted spider mite colonies were maintained on lima beans (*Phaseolus lunatus*) at 30 °C and 14:10 (L:D) photoperiod. The colony originated from an infested rose plant that was purchased at a local nursery. Rearing cages were 20 × 40 × 30-cm Plexiglas boxes with an open top, fitted with thrips-proof screening. A ring of double-sided sticky tape on the outside rim and petroleum jelly on the inside rim prevented mite escape and contamination of colonies.

Acaricides were mixed with tap water at recommended rates and applied with a hand sprayer to whole bean plants under a fume hood (Table 1). Control plants were left unsprayed. Plants were left in the fume hood 30–45 min until leaf surfaces dried. Treated plants were placed under high intensity discharge (HID) lights with 250 fc, 14:10 (L:D) photoperiod without overhead watering. Twenty leaf disks, each with a surface area of ≈ 10 cm², were cut from plants of each treatment 1, 3, 7, and 14 d after application.

Survival tests were conducted on treated and control leaves using a modified Huffaker cell system (Huffaker, 1948; Lester et al., 1999; Munger, 1942). The cells were made from three 7.6 × 7.6 × 0.6 cm Plexiglas pieces bolted together like a sandwich. A 4.5-cm diameter hole in the middle piece of Plexiglas created a small chamber in which the assay was performed.

Phytoseiulus persimilis adults were obtained from Koppert Biological (Ann Arbor, Mich.). After arrival, predators were brushed into a container of bean leaves infested with *T. urticae*. The predators were allowed to feed on prey for 18–24 h before testing. One *P. persimilis* adult was placed on the leaf disk in each modified Huffaker cell with two *T. urticae* adults to provide food for the predators. Cells were closed immediately after mite introduction. The total number of mites that died in all cells in each treatment was recorded after 24 h. Temperatures averaged 28 °C with a range of 25.2 to 32.5 °C during the test period. For each material tested, mite mortality was compared on 20 nontreated leaf disks and 20 treated leaf disks for each time period. Data were analyzed by contingency table ($\alpha = 0.05$). Two-week-old resi-

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Table 2. Common and trade names, and application rates of acaricides tested

Common name	Trade name + formulation	Manufacturer	Mix rate
Abamectin	Avid 0.15 EC	Novartis, Greensboro, N.C.	4 oz/100 gal
Bifenthrin	Talstar GH 0.67F	FMC, Philadelphia, Pa.	40 oz/100 gal
Chlorfenapyr	Pylon 2SC	American Cyanamid, Parsippany, N.J.	5.2 oz/100 gal
Gowan 1725	Gowan 1725 0.1% EC	Gowan, Yuma, Ariz.	20 oz/100 gal
Hexythiazox	Hexygon 50 WP	Gowan, Yuma, Ariz.	1.5 oz/100 gal
Horticultural oil	Sunspray Ultra-Fine	Sun Company, Philadelphia, Pa.	250 oz/100 gal
Neem oil	Triact 70 EC	Thermotriology Corporation, Columbia, Md.	250 oz/100 gal
Pyridaben	Sanmite 75 WP	BASF Corp., Research Triangle Park, N.C.	4 oz/100 gal
Spinosad	Conserve SC	Dow AgroSciences, Indianapolis, Ind.	600 mL/100 gal

dues were not tested when mortality from residues was not significantly greater than controls for 1-week-old residues.

Results

The duration of acaricide residue toxicity varied among the compounds tested. Mortality of *P. persimilis* from exposure to residues of bifenthrin and chlorfenapyr was significantly greater than observed on the controls 1, 3, 7, and 14 d after application. *Phytoseiulus persimilis* mortality on leaf disks treated with abamectin, Gowan 1725, hexythiazox, horticultural oil, neem oil, pyridaben and spinosad was not significantly greater than on untreated leaf disks at any time after application (Fig. 1A–D).

The response of *T. urticae* to residue exposures was more variable than that of *P. persimilis*. *Tetranychus urticae* mortality from chlorfenapyr residues was significantly greater than the control 1, 3, 7, and 14 d after application. Even after 2 weeks, chlorfenapyr residues caused 55% mortality to adult *T. urticae* compared to 6% mortality in the control. *Tetranychus urticae* mortality from bifenthrin and abamectin residues was not significantly greater than the control 1 d after application. However, *T. urticae* mortality for both bifenthrin and abamectin residues was significantly greater than the control 3, 7, and 14 d after application. *Tetranychus urticae* mortality caused by Gowan 1725, horticultural oil, and neem oil residues was significantly greater than the control 24 h after application but not

at the other times tested. *Tetranychus urticae* mortality from hexythiazox and spinosad residues was not significantly greater than the control at any time tested (Fig. 2A–D).

Discussion

Our objective was to determine an aspect of compatibility between selected acaricides and release of predatory mites for management of *T. urticae*. For our purposes, a compatible acaricide can be defined as a product that has a residue that does not kill *P. persimilis*. The level of compatibility will usually depend, at least partly, on the post application interval. We measured toxicity of acaricide residues to commercially available *P. persimilis*. We did not consider sublethal

Fig. 1. Residue toxicity to *Phytoseiulus persimilis* (A) 1 d after application, (B) 3 d after application, (C) 7 d after application, and (D) 14 d after application. ***Indicates significant difference ($\alpha = 0.05$) between treatments and control.

effects, which can occur from acaricide residues (Oomen et al., 1991).

Exposure to abamectin, Gowan 1725, hexythiazox, horticultural oil, neem oil, pyridaben, and spinosad residues at typical rates did not cause *P. persimilis* mortality 24 hours after application. However, abamectin residue did result in significant mortality to adult *T. urticae* 3, 7, and 14 d after application. Several other studies have found that exposure to abamectin residues does not have a significant effect on *P. persimilis* survival (Oomen et al., 1991; Shipp et al., 1999; Zhang and Sanderson, 1990). Abamectin causes significant mortality and reduction in the mobility and fecundity of *T. urticae* (Zhang and Sanderson, 1990). Even after 2 weeks, in our experiments abamectin residue killed *T. urticae* adults. Residual activity of abamectin is likely to decrease more quickly in outdoor environments than indoor environments (Wright et al., 1984). Fourteen-day-old residues from abamectin applications of 3 ppm on cotton grown in greenhouses resulted in 97% mortality after 72 h of exposure (Wright et al., 1984). Trials conducted with plants given the same treatment in field conditions caused 47% mortality with the same exposure (Wright et al., 1984). In our experiments, 14-day-old abamectin residues from applications of 6.25

ppm, with 24 h of exposure resulted in 45% *T. urticae* mortality compared to 6% mortality on untreated leaf disks in the control.

Abamectin residues can have sublethal effects on *P. persimilis*. Eight days of exposure beginning 1 h after 4 ppm abamectin applications reduced *P. persimilis* egg laying by as much as 50% (Zhang and Sanderson, 1990). Exposure of *P. persimilis* to abamectin residues does not decrease egg hatch rate, but feeding on *T. urticae* intoxicated with abamectin can reduce egg production (Zhang and Sanderson, 1990). Despite its sublethal effects on *P. persimilis*, abamectin may be a good candidate for IPM programs because of its high toxicity to *T. urticae* and its relatively low impact on *P. persimilis*.

Mortality of *P. persimilis* caused by Gowan 1725 and hexythiazox residues 1 d after application was not significantly greater than the control. Our results were consistent with other studies of hexythiazox on *P. persimilis* (Oomen et al., 1991). However, a duration of hexythiazox exposure which is longer than ours may have a negative impact on *P. persimilis*. Residues of Gowan 1725 and hexythiazox may not provide acceptable suppression of adult *T. urticae* in some situations. Gowan 1725 has a chemical structure that is similar to abamectin, but its residues were not

effective against adult *T. urticae*. Although hexythiazox has a low toxicity to adult female *T. urticae*, it still may suppress mite populations by reducing *T. urticae* egg production (Chapman and Marris, 1986). Hexythiazox residues have been shown to have ovicidal effects on *Panonychus ulmi* 30 d after application (Pree et al., 1992). Unlike hexythiazox, Gowan 1725 residue has a short period of adulticidal activity on *T. urticae* under laboratory conditions.

Neem products and paraffinic horticultural oils may be a useful part of IPM programs, however their short residual toxicity may not suppress large populations. We found these products to be compatible with *P. persimilis* because they are active for only a short period. Residues from these products did cause mortality to *T. urticae* 24 h after application, but no mortality thereafter. All neem products may not be equally compatible with *P. persimilis*. Direct application of a neem formulation containing 80% neem oil at a rate of 3% was highly toxic to *P. persimilis* and only moderately toxic to *T. urticae* (Papaioannou-Souliotis et al., 2000). We applied a formulation of 70% neem oil at a rate of 1.4%. Although the residues had low toxicity to *P. persimilis*, topical applications may be harmful. Horticultural oil can control *T. urticae* eggs and mobile

Fig 2. Residue toxicity to *Tetranychus urticae* (A) 1 day after application, (B) 3 d after application, (C) 7 d after application, and (D) 14 d after application. ***Indicates significant difference ($\alpha = 0.05$) between treatments and control.

stages (Haitas, 1997) and also reduces female fecundity (Osman, 1997).

Spinosad and pyridaben residues did not cause direct harm to *P. persimilis* or *T. urticae*. Pratt and Croft (2000) also found that spinosad does not have a highly toxic effect on *P. persimilis*. Formulations of spinosad containing 11.6% spinosad A and D, can cause 100% mortality when applied directly to mites at 400 ppm (DeAmicis et al., 1997). Our application rate was 181 ppm and residues were allowed to dry before exposing mites. This application rate did not suppress *T. urticae* populations under laboratory conditions (Cote, unpublished data). We recorded 28% and 30% mortality after 24 h of exposure to 1- and 3-day-old pyridaben residue, respectively. Shipp et al. (1999) found pyridaben to cause *P. persimilis* mortality as high as 71% 4 d after application with 48 h of exposure under laboratory conditions.

Bifenthrin and chlorfenapyr were toxic to *P. persimilis* up to 2 weeks after treatment, but this prolonged period of residual activity may be useful for controlling high-density populations of *T. urticae*. Chlorfenapyr provided excellent control of *T. urticae* infestations without short-term population resurgence (Allen and Kharboutli, 1999; Cote, unpublished data). This is the first published account of the effects of chlorfenapyr residues on *P. persimilis*. Our results with bifenthrin are consistent with other studies (Oomen et al., 1991; Pratt and Croft, 2000).

Acaricides tested in this study varied greatly in their toxicity to *P. persimilis* and *T. urticae* adults. *Phytoseiulus persimilis* releases alone are unlikely to prevent *T. urticae* populations from reaching economic injury levels on ornamental crops (Helle and Sabelis, 1985). Selective use of acaricides may create a favorable situation for release of *P. persimilis* by reducing *T. urticae* to manageable levels, providing that other environmental conditions are suitable. While treatment with acaricides that have long residual toxicity may be required to suppress high-density spider mite populations, their use may promote spider mite resistance. Acaricides that have short residual toxicities can be used in combination with predators to reduce large populations of spider mites, but the timing of application and predator release is critical (Osborne and Pettitt, 1985). Applica-

tions of insecticidal soap 3 d after release of *P. persimilis* did not adversely affect predator populations and provided enhanced suppression of spider mite populations (Osborne and Pettitt, 1985). Biological control may be enhanced through careful selection of acaricides and releasing predators into the crop once residues are no longer toxic to them.

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