THE RESIDUAL AND DIRECT EFFECTS OF REDUCED-RISK AND CONVENTIONAL MITICIDES ON TWOSPOTTED SPIDER MITES, *TETRANYCHUS URTICAE* (ACARI: TETRANYCHIDAE) AND PREDATORY MITES (ACARI: PHYTOSEIIDAE).

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ABSTRACT

The residual effects of several reduced-risk and conventional miticides were evaluated in strawberries (*Fragaria x ananassa* Duchesne) on the twospotted spider mite (TSSM), *Tetranychus urticae* Koch (Acari: Tetranychidae) and on 2 predatory mites, *Neoseiulus californicus* McGregor and *Phytoseiulus persimilis* Athias-Henriot (Acari: Phytoseiidae). Experiments were conducted in the laboratory and greenhouse. The greenhouse experiments also tested the direct effects of the miticides on TSSM. The efficacy of conventional and reduced-risk miticides was evaluated on strawberry leaf discs and on whole plants for control of TSSM. Furthermore, the residual effects of these miticides were evaluated on whole strawberry plants against selective predatory mites. For TSSM, 5 treatments were evaluated: a conventional miticide; fenbutatin-oxide (Vendex®) and 3 reduced-risk miticides; binfenazate (Acramite 50WP®), activated garlic extract (Repel®), sesame seed and castor oil (Wipeout®), and a water-treated control. For predatory mites, the residual effects of only Acramite® and Vendex® were evaluated. Acramite® was the most effective acaricide in reducing TSSM populations in both the laboratory and greenhouse experiments. Vendex® and Wipeout® were also effective in the laboratory, but did not cause significant reduction of TSSM in the greenhouse. Repel® was the least effective of the 4 pesticides evaluated. Neither Acramite® nor Vendex® had a significant effect on either predatory mite species. However, there appeared to be more predatory mites on the Vendex®-treated plants than on the Acramite®-treated plants. There were significantly more predatory mites of both species on the cue plants, which were inoculated with TSSM versus the non-cue plants, which were not inoculated.

Key Words: predatory mites, twospotted spider mite, miticides

RESUMEN

Los efectos residuales en poblaciones de la 'araña roja', *Tetranychus urticae* Koch (Acari: Tetranichidae) y de los ácaros predadores *Neoseiulus californicus* McGregor y *Phytoseilus persimilis* Athias-Henriot (Acari: Phytoseiidae) causados por varios acaricidas convencionales y de riesgo-reducido fueron evaluados en fresas (*Fragaria x ananassa* Dúchense). Los experimentos fueron realizados en laboratorio e invernadero. Los experimentos en el invernadero evaluaron también el efecto directo de los acaricidas en la 'araña roja'. La eficacia para controlar la 'araña roja' de los acaricidas convencionales y de riesgo-reducido fue evaluada en discos de las hojas y en plantas de fresa, y los efectos residuales de los acaricidas en los ácaros predadores fueron evaluados en plantas completas. Para la 'araña roja' se evaluaron cinco tratamientos: el acaricida convencional fenbutatin-oxido (Vendex®), 3 acaricidas de riesgo-reducido binfenazate (Acaramite 50WP®), extracto de ajo activado (Repel®), aceite de semillas de ajonjolí y ricino (Wipeout ®) y un control tratado con agua. Para los acaros predadores solamente los efectos de Acaramite® y Vendex® fueron evaluados. Acaramite® fue el tratamiento mas efectivo para la 'araña roja' en el laboratorio y el invernadero. Vendex® y Wipeout® fueron también efectivos en el laboratorio, pero no causaron una reducción significativa de 'arañas rojas' en el invernadero. Repel® fue el tratamiento evaluado menos eficaz. Ni Acaramite® ni Vendex® redujeron significativamente las poblaciones de ácaros predadores. Sin embargo, aparentemente hay más ácaros predadores en Vendex® que en Acaramite®. También se encontraron significativamente más ácaros predadores en plantas inoculadas que en plantas no inoculadas.

Translation provided by the authors.

The application of pesticides remains a popular method for controlling arthropod populations in many agroecosystems. If used properly, they can assist in controlling high populations of the twospotted spider mite (TSSM), *Tetranychus urticae* Koch. However, managing TSSM with pesticidal tactics has led to several problems including high cost of production and resistance to key acaricides (Dittrich 1975; Edge & James 1986). TSSM have no documented resistance to mineral oils but inadequate coverage can lead to insufficient control (Amer et al. 2001).

Control of TSSM is warranted in strawberries since they feed voraciously on the leaves causing chlorosis, which may significantly affect yields (Rhodes & Liburd 2006; Sances et al. 1982). Managing soil moisture has been shown to reduce TSSM numbers (White & Liburd 2005). However, evidence is accumulating that more integrated approaches involving the use of reduced-risk acaricides and predatory mites may be a more sustainable approach to managing TSSM (Rhodes et al. 2006). Identifying effective reduced-risk pesticides for control of TSSM and other arthropods is necessary so that more options are available for inclusion in an integrated management program (Myers et al. 2006).

Predatory mites have been used to successfully control TSSM for decades. Two predatory mite species, *Phytoseiulus persimilis* Athias-Henriot and *Neoseiulus californicus* McGregor, recently have been shown to effectively control TSSM in strawberries in Florida (Rhodes & Liburd 2006; Rhodes et al. 2006; Liburd et al. 2003). *Phytoseiulus persimilis,* a specialist predator that feeds exclusively on tetranychid mites (Schausberger & Croft 1999), was imported from Chile and Italy and released in the US (McMurtry et al. 1978). It can effectively reduce TSSM populations. However, once control has been achieved, the low numbers of TSSM could cause this predatory mite to disperse or die (Rhodes & Liburd 2006; Jung & Croft 2001). This may necessitate additional releases if the population of TSSM persists.

Neoseiulus californicus is a generalist predator that prefers tetranychid mites as prey (Rhodes & Liburd 2005; Croft et al. 1998). *Neoseiulus californicus* persists in agricultural fields even if mites are not present because it is capable of surviving on alternative food sources such as other mites, small insects, and even pollen (McMurtry & Croft 1997).

Effective control of TSSM may not be achieved by using a single control tactic (Rhodes & Liburd 2006; Kim & Seo 2001). Combining tactics involving reduced-risk pesticides and selective releases of predatory mites may yield more acceptable control of TSSM while maintaining predatory mite populations in the field (Rhodes et al. 2006; Spollen & Isman 1996; Hoy & Ouyang 1986; Hoy & Cave 1985). Our goal was to determine the direct and residual effects of several miticides on 2 predatory mite species and the twospotted spider mite.

Materials and Methods

Twospotted Spider Mite

Colony. A TSSM colony reared on strawberries (c.v. Sweet Charlie in laboratory experiments and c.v. Festival in greenhouse experiments) was maintained in the laboratory to ensure that only TSSM predisposed to strawberries were used in the experiments. The colony consisted of mite-infested strawberry plants that were kept under 14:10 light:dark regime at a temperature of ~27°C with 65% RH. Plants were watered twice weekly.

Laboratory. Strawberry plants, c.v. Sweet Charlie, were grown in pots with a diameter of 15 cm in the Fruit and Vegetable IPM greenhouse at the University of Florida in Gainesville, Florida. Plants were grown according to standard greenhouse production practices. No pesticides were applied, but plants received fertilizer NPK 10:10:10 once every 6 weeks. Plants were approximately 25 cm in height when leaves were detached. All leaves used were screened for twospotted spider mite and other mites and insects by examining each leaf under a dissecting microscope and removing any mites or insects with a small paintbrush. Leaf squares (2.5 × 2.5 cm) were cut with an utility knife from the center of each strawberry leaf. Each leaf square was placed inside a petri dish on moist cotton. The cotton served to keep leaves turgid for up to 1 week. Water was sprayed onto the cotton with a hand-atomizer (500 mL Dynalon Quick Mist HDPE Sprayer Bottle, Fisher Scientific) to prevent the cotton from drying out. Five treatments including a conventional miticide, 3 reduced-risk miticides, and a water-treated control were evaluated. Miticides were applied to leaf squares before they were placed on the cotton with hand atomizers of the same make and model used to apply the water to the cotton. The conventional miticide was fenbutatin-oxide (Vendex®) (Griffin L.L.C., Valdosta, GA) sprayed at a rate of 2.2 kg/ha (2 lb/acre). The three reduced-risk miticides were bifenazate (Acramite 50WP®) (Crompton Manufacturing Company Inc. Bethany, CT) sprayed at a rate of 1.125 kg/ha (1 lb/acre), activated garlic extract Repel® (UAS of America Inc., Hudson, FL) sprayed at a rate of 2.6 L/ha (1 qt/acre), and sesame seed and castor oil (Wipeout®) (UAS of America Inc., Hudson, FL) sprayed as a 2% solution at a rate of 935.4 L/ ha (100 gal/acre). We assumed a spray volume of 935.4L/ha for each treatment when mixing the solutions. This translated to 0.03 g Acramite® in 84 mL water (3 squirts per leaf square), 0.53 mL Repel® in 84 mL water (3 squirts per leaf square), 0.05g Vendex® in 84 mL water (3 squirts per leaf square) and 2.3 mL Wipeout® in 113 mL water (3 squirts per leaf square). There were twelve replicates per treatment.

Ten TSSM (adults) from a laboratory colony were placed upon each leaf square. Leaf squares were allowed to air dry for 30 min after the application of treatments. TSSM were transferred from infested colony leaves to experimental leaf squares one at a time using an insect pin. The number of living and dead TSSM adults was monitored 6, 12, 24, 48, and 72 h after application of the miticides. The number of eggs laid after a 1 week period was counted to investigate the potential for early reinfestation of TSSM.

Data were analyzed by Analysis of Variance with mean separation by least significant differences (LSD) (SAS 2002). Data were considered significant when the P value ≤ 0.05.

Greenhouse. Strawberry plants, c.v. Festival, were grown with the same methods as the laboratory study. Twenty-five plants approximately 25 cm in height each having 4 mature trifoliates were used for the greenhouse study. All plants used were screened for twospotted spider mites and other mites and insects prior to use by gently but firmly running the thumb and forefinger over the entire surface of each leaflet to kill any mites or insects that might be present.

Experimental design was a randomized complete block design with 5 replicates per treatment. The same 5 treatments as in the laboratory experiment were evaluated.

Two TSSM (adults) from the colony were placed upon each leaflet (24 per plant) by the same methods as in the laboratory experiment. They were allowed to multiply for 1 week. Miticides were applied at the same rates as in the laboratory experiments with a hand-atomizer (500 mL Dynalon Quick Mist HDPE Sprayer Bottle, Fisher Scientific). This translated to 0.03 g Acramite® in 77 mL water (20 squirts per plant), 0.55 mL Repel® in 77 mL water (20 squirts per plant), 0.05 g Vendex® in 77 mL water (20 squirts per plant) and 2 mL Wipeout® in 100 mL water (29 squirts per plant). Each plant was placed approximately 20 cm away from its neighbors. An initial sample of 1 leaflet per plant was taken just before treatment application to obtain an estimate of how large the TSSM population on each plant had grown after 1 week. Leaflets were removed from plants and mites were counted under a dissecting microscope. Plants were then monitored 6, 12, 24, 48 and 72 h as well as 1 week (168 h) after application of the miticides. The number of living TSSM motiles (all life stages excluding eggs) and eggs were recorded. Egg data were collected to investigate the potential for early reinfestation of TSSM.

Data were log + 1 transformed and analyzed by an Analysis of Variance with mean separation by least significant differences (LSD) (SAS 2002). Data were considered significant when the *P* value ≤ 0.05.

Predatory Mites. In order to determine how conventional and reduced-risk miticides affect predatory mites, the conventional miticide Vendex® and the reduced-risk miticide Acramite® were evaluated against *P. persimilis* and *N. californicus*.

Twelve strawberry plants 30 cm in height were selected from the greenhouse and trimmed down to 6 trifoliates per plant. Plants were screened for insects and mites as in the previous experiments. Plants were separated into 2 categories, cue and non-cue, with each category representing 6 plants. Two days before the experiment started, all 6 plants from the cue category were inoculated with 10 adult TSSM with the same methods as discussed in the previous experiments. The 6 plants in the non-cue category were not inoculated prior to the experiment. Inoculated plants are termed "cue" because these plants received TSSM 4 days before the predators were released. Therefore, these plants were more likely to have spider mite webbing and may have released volatiles to attract and maintain a predator colony. The other 6 plants that did not receive these TSSM in advance were referred to as "non-cue".

Predatory mites used in all experiments were obtained from Koppert Biological Systems (Romulus, MI). A representative sample (1 bottle from each species of predatory mite) was observed for at least 15 min to assure that the shipped predatory mites were active and in good condition prior to use. Adult female predatory mites were transferred to the strawberry plants from a petri dish one by one with an insect pin after being chilled briefly.

At the start of the experiment, time zero, 1 of the plants from each of the categories was sprayed with water and these plants were designated as controls 1 and 2, respectively. Predatory mites were released at a rate of 1 predatory mite per 10 TSSM. A total of 100 TSSM and 10 predatory mites were released on the control cue plants. The 10 adult TSSM that were initially released on these plants had increased to an average population of 50 TSSM when the second application of 50 TSSM and predatory mites occurred. A total of 50 TSSM and 5 predatory mites were released on the control non-cue plants. The remaining plants from the cue and non-cue were labeled 6, 12, 24, 48 and 72 h after miticide application. All of the plants were sprayed with 1 of the designated miticide treatments (Vendex® or Acramite®) except for the controls, which were sprayed with water. A standard hand-atomizer (500 mL Dynalon Quick Mist HDPE Sprayer Bottle, Fisher Scientific) was used to apply all of the treatments. Six hours after miticide application, the 6-h plants received the same number of mites as the control plants; that is, for the cue treatment 100 TSSM and 10 predatory mites and for non-cue 50 TSSM and 5 predatory mites. These 6-h plants were monitored for predatory mite motiles and eggs every 24 h for a total of 72 h after the mites were released. The 12-h plants received the same number of mites the 6-h plants received 12 h after miticide application. Each plant followed the same protocol until the 72-h plants were completed. These methods were repeated for both predators with both miticides. The experiment was replicated 3 times.

TABLE 1. EFFECT OF CONVENTIONAL AND REDUCED-RISK MITICIDES ON TWOSPOTTED SPIDER MITE (TSSM) MORTALITY IN THE LABORATORY.

		Mean number of live TSSM adults (±SEM)				
		Hours				
Treatment	Classification	6a	12b	24	48 d	72 e
Acramite	Reduced-risk	6.75 ± 0.99 b	5.42 ± 1.0 5c	4.50 ± 0.93 d	2.25 ± 0.43 c	1.33 ± 0.41 d
Vendex	Conventional	8.33 ± 0.51 a	7.17 + 0.42 ab	6.00 ± 0.56 bc	4.75 ± 0.63 b	2.92 ± 0.54 c
Wipeout	Organic oil	6.83 ± 0.63 b	6.00 + 0.76 bc	4.58 ± 0.66 cd	3.25 ± 0.57 c	3.08 ± 0.56 c
Repel	Repellent	8.92 ± 0.38 a	7.58 ± 0.72 a	6.75 + 0.46 ab	6.17 ± 0.49 ab	5.00±0.51 b
Control		8.75 ± 0.60 a	8.25 + 0.59 a	7.50 + 0.50 a	7.08 ± 0.50 a	6.58 ± 0.40 a

Initially 10 TSSM transferred to each leaf square.
Means within columns followed by the same letter are not significantly different (P = 0.05, LSD Test).
[a]$F = 2.88$; $df = 4,44$; $P = 0.03$ (6 h)
[b]$F = 2.71$; $df = 4,44$; $P = 0.04$ (12 h)
[c]$F = 5.30$; $df = 4,44$; $P \leq 0.01$ (24 h)
[d]$F = 16.60$; $df = 4,44$; $P \leq 0.01$ (48 h)
[e]$F = 19.73$; $df = 4,44$; $P \leq 0.01$ (72 h)

Predatory mites were sampled non-destructively. The number of predatory mites per plant was counted by gently examining each plant leaflet by leaflet under a dissecting microscope.

Data for this experiment were analyzed by repeated measures ANOVA (SAS 2002). For both species, cue and non-cue plants were compared by a Satterthwaite *t*-test for unequal variance. Data were considered significant when the P value ≤ 0.05.

RESULTS

Twospotted Spider Mite

Laboratory. At 6 and 12 h after treatment application, Acramite® and Wipeout® were the only treatments that had significantly fewer TSSM adults compared with the control (Table 1). At 24 h, the Acramite®, Vendex®, and Wipeout® treatments had significantly fewer adult TSSM compared with the control. Also, the Acramite® treatment had significantly fewer adult TSSM compared with the Vendex® treatment. At 48 h, the Acramite®, Vendex®, and Wipeout® treatments again had significantly fewer adult TSSM compared with the control and both the Acramite® and Wipeout® treatments had significantly fewer adult TSSM compared with the Vendex® treatment. At 72 h, all 4 miticide treatments had significantly fewer TSSM adults compared with the control. The Acramite®, Vendex®, and Wipeout® treatments had significantly fewer TSSM adults compared with the Repel® treatment. Also, the Acramite® treatment had significantly fewer TSSM adults compared with the Vendex® and Wipeout® treatments.

After 1 week, there were no eggs present on the Acramite® treated leaves compared with an average of more than 17 eggs on the control leaves (Table 2). Vendex® and Wipeout® were not significantly different from the control. Repel® was totally ineffective in reducing egg production.

Greenhouse. In the greenhouse, there were no significant differences among treatments until 1

TABLE 2. EFFECT OF CONVENTIONAL AND REDUCED-RISK MITICIDES ON EGG PRODUCTION OF TWOSPOTTED SPIDER MITE (TSSM) AFTER 1 WEEK ON THE PLANTS.

		Total mean number TSSM eggs (±SEM)
Treatment	Classification	One Week
Acramite	Reduced-risk	0.00 ± 0.00 c
Vendex	Conventional	11.75 ± 4.47 bc
Wipeout	Organic oil	7.25 ± 4.25 bc
Repel	Repellent	29.00 ± 8.97 a
Control		17.83 ± 5.07 ab

Initially 10 TSSM transferred to each leaf square.
Means followed by the same letter are not significantly different (P = 0.05, LSD Test).
$F = 5.39$; $df = 4,44$; $P = < 0.01$ (one week)

TABLE 3. EFFECT OF SELECTED MITICIDES ON TWOSPOTTED SPIDER MITE (TSSM) MOTILE MORTALITY IN THE GREENHOUSE.

		Mean number of live TSSM motiles per leaflet (±SEM)						
		Hours						
Treatment	Classification	Pre-count[a]	6[b]	12[c]	24[d]	48[e]	72[f]	168[g]
Acramite	Reduced-risk	14.2 ± 4.0	4.2 ± 1.7	7.6 ± 2.7	3.8 ± 1.0	10.0 ± 3.1	9.4 ± 3.5	4.2 ± 15. b
Vendex	Conventional	8.8 ± 5.1	3.6 ± 1.9	6.4 ± 2.7	3.0 ± 1.1	7.0 ± 2.4	7.2 ± 2.6	17.8 ± 4.6 a
Wipeout	Organic oil	8.0 ± 2.0	4.2 ± 2.4	0.8 ± 0.8	4.8 ± 2.9	23.2 ± 8.2	12.8 ± 3.0	25.2 ± 10.8 a
Repel	Repellent	18.8 ± 6.0	7.8 ± 3.9	2.4 ± 1.0	6.4 ± 2.8	20.4 ± 6.5	7.6 ± 2.9	33.4 ± 9.2 a
Control		23.2 ± 5.9	7.4 ± 7.4	10.8 ± 3.0	6.8 ± 2.4	8.0 ± 2.9	18.2 ± 5.3	31.6 ± 8.7 a

Means within columns followed by the same letter are not significantly different (P = 0.05, LSD Test).
[a]$F = 1.20$; $df = 4,20$; $P = 0.34$
[b]$F = 0.33$; $df = 4,20$; $P = 0.85$
[c]$F = 2.43$; $df = 4,20$; $P = 0.08$
[d]$F = 0.36$; $df = 4,20$; $P = 0.84$
[e]$F = 0.98$; $df = 4,20$; $P = 0.44$
[f]$F = 0.91$; $df = 4,20$; $P = 0.48$
[g]$F = 3.82$; $df = 4,20$; $P = 0.02$

week after miticide application for both motiles and eggs (Tables 3 and 4). At 1 week, there were significantly fewer TSSM motiles and eggs on the Acramite® treated plants compared with the control and the other 3 miticide treatments (Tables 3 and 4).

Predatory mites. On the non-cue and cue plants treated with both Vendex® and Acramite® there were no significant differences among treatments (Tables 5-8). However, the 2.9 ± 0.2 *P. persimilis* on the cue plants was significantly more than the 1.3 ± 0.1 on the non-cue plants ($t = 5.72$; $df = 156$; $P < 0.0001$). The same was true on the *N. californicus* cue (3.0 ± 0.3) vs. non-cue (1.5 ± 0.2) plants ($t = 5.02$; $df = 142$; $P < 0.0001$).

DISCUSSION

Results showed that treatments of Acramite® had a higher rate of TSSM mortality when compared with the conventional miticide Vendex®. In the laboratory, leaf squares treated with Acramite® had half as many live TSSM adults compared with Vendex® after 72 h and had no egg production after 1 week. In the greenhouse, both TSSM motile and egg numbers on Acramite® treated plants were significantly lower than the control while TSSM motile and egg numbers on the Vendex® plants were not. It is possible that Acramite® has more residual activity on TSSM compared with Vendex®, which appears to have

TABLE 4. EFFECT OF SELECTED MITICIDES ON TWOSPOTTED SPIDER MITE (TSSM) EGG NUMBERS IN THE GREENHOUSE.

		Mean number of live TSSM motiles per leaflet (±SEM)					
		Hours					
Treatment	Classification	Pre-count[a]	6[b]	12[c]	24[d]	48[e]	72[f]
Acramite	Reduced-risk	54.4 ± 20.5	23.2 ± 11.1	20.2 ± 9.4	17.2 ± 12.1	11.0 ± 5.3	12.6 ± 6.5
Vendex	Conventional	26.6 ± 26.6	18.6 ± 7.6	29.0 ± 14.2	18.4 ± 6.7	20.4 ± 16.3	11.8 ± 4.5
Wipeout	Organic oil	22.6 ± 9.1	19.4 ± 8.2	11.8 ± 7.4	28.2 ± 16.3	39.0 ± 13.7	23.4 ± 9.6
Repel	Repellent	58.0 ± 16.9	11.2 ± 4.9	5.2 ± 3.2	38.0 ± 13.2	32.0 ± 11.6	14.0 ± 10.0
Control		65.4 ± 19.9	7.8 ± 1.9	37.0 ± 12.9	27.2 ± 4.4	11.6 ± 6.3	29.2 ± 11.5

Means within columns followed by the same letter are not significantly different (P = 0.05, LSD Test).
[a]$F = 1.01$; $df = 4,20$; $P = 0.43$
[b]$F = 0.09$; $df = 4,20$; $P = 0.99$
[c]$F = 1.13$; $df = 4,20$; $P = 0.37$
[d]$F = 0.67$; $df = 4,20$; $P = 0.62$
[e]$F = 1.46$; $df = 4,20$; $P = 0.25$
[f]$F = 0.69$; $df = 4,20$; $P = 0.61$
[g]$F = 3.99$; $df = 4,20$; $P = 0.02$

TABLE 5. EFFECTS OF VENDEX ON ADULT FEMALE PREDATORY MITES RELEASED ON NONCUE PLANTS.

	Sampling interval		
Release time	1	2	3
		Phytoseiulus persimilis	
0	4.00 ± 0.57	4.00 ± 0.00	2.33 ± 0.88
6	2.00 ± 1.53	2.00 ± 1.53	2.00 ± 1.53
12	3.00 ± 0.58	2.00 ± 1.00	1.33 ± 0.88
24	1.00 ± 0.57	0.67 ± 0.33	0.67 ± 0.33
48	1.00 ± 0.57	1.33 ± 0.88	0.33 ± 0.33
72	1.67 ± 0.33	1.33 ± 0.88	0.67 ± 0.67
		Neoseiulus californicus	
0	3.00 ± 1.53	2.67 ± 0.88	2.00 ± 0.57
6	2.00 ± 1.00	2.33 ± 0.88	0.67 ± 0.67
12	1.33 ± 0.88	1.00 ± 1.00	1.67 ± 0.88
24	2.33 ± 1.45	2.33 ± 0.67	2.33 ± 0.67
48	1.00 ± 0.57	1.00 ± 1.00	0.33 ± 0.33
72	2.00 ± 0.57	1.00 ± 0.57	1.33 ± 0.88

P. persimilis: $F = 1.62$; $df = 5,12$; $P = 0.2288$
N. californicus: $F = 1.12$; $df = 5,12$; $P = 0.3993$

less activity on motile TSSM allowing them to reproduce.

It is unclear why the density of TSSM took a full week to increase in the control plants. It is possible that spraying the control plants with water slowed their development since TSSM prefer dry conditions (White & Liburd 2005). Alternatively, the greenhouse environment may not have been ideal for quick development.

In both the laboratory and the greenhouse, Wipeout® produced similar mortality results when compared with Vendex®. Both were effective in the laboratory, but not as effective as Acramite. However, neither miticide significantly reduced numbers in the greenhouse experiment. Wipeout® is fine organic horticultural oil, which can be used in mite IPM programs as a tool for resistance management. Until recently, Vendex® has been

TABLE 6. EFFECTS OF ACRAMITE ON ADULT FEMALE PREDATORY MITES RELEASED ON NONCUE PLANTS.

	Sampling interval		
Release time	1	2	3
		Phytoseiulus persimilis	
0	2.00 ± 1.52	1.67 ± 1.20	1.00 ± 0.57
6	1.33 ± 1.33	0.33 ± 0.33	0.33 ± 0.33
12	1.00 ± 0.00	0.67 ± 0.33	0.67 ± 0.67
24	3.00 ± 1.15	1.67 ± 0.88	1.00 ± 0.58
48	1.00 ± 0.58	0.33 ± 0.33	0.00 ± 0.00
72	0.33 ± 0.33	0.67 ± 0.33	0.33 ± 0.33
		Neoseiulus californicus	
0	2.00 ± 1.15	2.67 ± 1.20	2.00 ± 1.53
6	1.33 ± 1.33	1.67 ± 1.67	1.67 ± 1.67
12	1.33 ± 0.67	1.33 ± 0.88	1.00 ± 1.00
24	0.33 ± 0.33	0.67 ± 0.67	0.33 ± 0.33
48	1.33 ± 0.67	0.33 ± 0.33	0.67 ± 0.67
72	1.33 ± 1.33	1.00 ± 1.00	1.00 ± 1.00

P. persimilis: $F = 1.00$; $df = 5,12$; $P = 0.4582$
N. californicus: $F = 0.36$ $df = 5,12$; $P = 0.8629$

TABLE 7. EFFECTS OF VENDEX ON ADULT FEMALE PREDATORY MITES RELEASED ON CUE PLANTS.

	Sampling interval		
Release time	1	2	3
		Phytoseiulus persimilis	
0	3.67 ± 1.86	2.67 ± 1.45	2.33 ± 1.20
6	2.33 ± 0.33	2.67 ± 0.88	2.00 ± 1.15
12	3.33 ± 1.76	3.00 ± 2.08	2.67 ± 1.45
24	3.67 ± 0.33	5.33 ± 0.33	5.00 ± 0.00
48	3.33 ± 0.33	2.33 ± 0.88	2.33 ± 0.88
72	5.33 ± 1.33	4.67 ± 0.88	3.33 ± 0.67
		Neoseiulus californicus	
0	4.33 ± 0.88	3.33 ± 0.88	2.67 ± 1.20
6	4.00 ± 1.73	5.33 ± 1.76	4.00 ± 2.00
12	6.67 ± 1.20	6.67 ± 1.76	5.67 ± 1.76
24	3.00 ± 1.73	2.33 ± 0.88	2.67 ± 0.33
48	1.67 ± 1.20	3.67 ± 1.20	3.33 ± 0.67
72	4.00 ± 1.15	5.33 ± 0.33	3.33 ± 0.67

P. persimilis: $F = 1.02$; $df = 5,12$; $P = 0.4288$
N. californicus: $F = 1.56$ $df = 5,12$; $P = 0.2445$

the key conventional miticide used in strawberries to control TSSM in Florida. However, there have been reports of TSSM resistance to Vendex® (Leeuwen et al. 2005). Also, this miticide affects a broad spectrum of organisms (DuPont™ 2005) and may eliminate beneficial mite species from fields. Vendex® is a restricted use pesticide due to acute human toxicity (it can be fatal if inhaled) and very high toxicity to aquatic organisms. Acramite® and Wipeout® should be considered as alternatives to Vendex®, although further research in the greenhouse and in the field is needed.

Alternatively, neither Vendex® nor Acramite appeared to significantly affect the activity of either *P. persimilis* or *N. californicus* on either non-cue or cue plants. Kim & Yoo (2002), and Ahn et al. (2004) found that both miticides were much more toxic to TSSM than to *P. persimilis*. They

TABLE 8. EFFECTS OF ACRAMITE ON ADULT FEMALE PREDATORY MITES RELEASED ON CUE PLANTS.

	Sampling interval		
Release time	1	2	3
		Phytoseiulus persimilis	
0	4.33 ± 0.88	3.67 ± 1.20	1.33 ± 1.33
6	3.33 ± 2.40	1.67 ± 1.67	1.67 ± 1.20
12	1.67 ± 0.67	2.33 ± 0.88	1.67 ± 0.67
24	5.33 ± 0.88	2.33 ± 1.33	1.67 ± 1.67
48	3.67 ± 0.88	2.00 ± 0.58	0.33 ± 0.33
72	1.00 ± 1.00	0.67 ± 0.67	0.33 ± 0.33
		Neoseiulus californicus	
0	4.00 ± 3.05	2.33 ± 2.33	2.67 ± 1.20
6	1.33 ± 0.88	1.33 ± 0.88	0.33 ± 0.33
12	1.00 ± 0.58	2.00 ± 2.00	1.67 ± 1.67
24	1.00 ± 0.58	2.00 ± 1.00	1.33 ± 0.88
48	1.67 ± 1.67	1.00 ± 1.00	1.33 ± 1.33
72	0.67 ± 0.33	0.67 ± 0.67	1.00 ± 1.00

P. persimilis: $F = 0.78$ $df = 5,12$; $P = 0.5808$
N. californicus: $F = 0.37$ $df = 5,12$; $P = 0.8574$

also noted that neither prey consumption nor the sex ratio of the *P. persimilis* progeny were significantly affected by either miticide. Acramite® has also been shown to have low toxicity towards *N. californicus* (Veire & Tirry 2003). Our findings appear to support this conclusion.

It is interesting to note that there appear to be less predatory mites of both species on the Acramite® treated plants compared with the Vendex® treated plants. It is possible Acramite® may have some toxicity toward predatory mites. Cloyd et al. (2006) found that Acramite® was toxic to *P. persimilis* but not to *N. californicus*. Alternatively, if Acramite® is more toxic to TSSM than Vendex®, as our results show, there may have been lower prey availability on the Acramite® treated plants. Predatory mites on these plants may have attempted to disperse or resorted to cannibalism in order to survive (Schausberger 2003; Schausberger & Croft 2000), resulting in lower recorded numbers. This would be particularly true of *P. persimilis* because of its specialist diet. This is an important topic to research further.

There were significantly more *P. persimilis* and *N. californicus* on cue plants compared with non-cue plants. It is known that some plants release volatiles when being fed upon by spider mites that predatory mites use to locate prey patches (Dicke & Sabelis 1988; Dicke et al. 1998). The presence of these volatiles on the cue plants may have stimulated the predators to remain on these plants to search for prey. In contrast, the lack of these cues from the non-cue plants may have caused the predators to maintain a more general searching behavior and wander off of the plants.

The predator experiment attempted to use a non-traditional technique by using whole plants as opposed to leaf discs in order to simulate field conditions. With leaf discs, 100% coverage of the miticide is always acquired. However, in the field this is not the case and TSSM and predatory mites will often find areas where the miticide is absent and continue to develop. The problem with using whole plants is that the predatory mites are small and there are many places for them to hide. In addition, they tend to leave the plants. This makes finding and counting them extremely difficult and tedious.

Overall, an IPM strategy for the management of TSSM in strawberries seems to be the best option for long-term control and resistance management. Rhodes et al. (2006) found that Acramite® used in combination with either *P. persimilis* or *N. californicus* provided effective control of TSSM in the field. Rotating the use of reduced-risk compounds, such as Acramite® and possibly Wipeout®, combined with the timely release of predatory mites should provide effective control of TSSM populations.

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