Evaluation of Persistence of Selected Miticides Against the Twospotted Spider Mite, *Tetranychus urticae*

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Abstract. Twospotted spider mite, *Tetranychus urticae*, is a major arthropod pest in greenhouses. Greenhouse producers typically use miticides to control twospotted spider mite (TSM) populations. This study, which involved two replicated experiments, was designed to assess the persistence or longevity and efficacy of translaminar miticides with the active ingredient (a.i.) etoxazole, chlorfenapyr, abamectin, and spiromesifen by applying these miticides to either butterfly bush (*Buddleia davidii*) or marigold (*Tagetes erecta*) plants, depending on the experiment, and then artificially infesting the plants with TSM. Based on percent mortality and number of live and dead TSM, several miticides provided adequate control of TSM even after having been applied to the test plants 14 days before being artificially infested with TSM. This suggests that these miticides have extended residual activity. The etoxazole 10 to 12 μm and etoxazole water-dispersible formulations provided control (greater than 85% mortality) of TSM over the course of Expt. 1 with four or less live TSM recovered from treated plants across the three evaluation times (21, 28, and 42 days). Spiromesifen, in Expt. 2, was significantly more effective against both the nymph (89% to 99.2%) and adult (37.3% to 87.9%) stages of the TSM than the other miticides and killed more nymphs (165 to 227) than the other treatments. In general, none of the miticides provided consistent or adequate control of TSM adults across all three evaluation times (49, 56, and 70 days).

Twospotted spider mite, *Tetranychus urticae* (Acari: Tetranychidae), is a major arthropod pest of greenhouses, feeding on over 300 plant species (Jeppson et al., 1975; van de Vrie, 1985). Twospotted spider mite (TSM) feeds within leaf cells, damaging the spongy mesophyll, palisade parenchyma, and chloroplasts, which reduces chlorophyll and moisture content and the plant's ability to photosynthesize. This leads to the expression of characteristic symptoms such as leaf bleaching, yellow stippling, and bronzing of leaves (Lal and Mukharji, 1979; Sances et al., 1979, 1982; Tomczyk and van de Vrie, 1982; van der Geest, 1985).

The primary means of maintaining TSM populations below damaging levels, in greenhouses, is the use of commercially available miticides with active ingredients (a.i.) that either have contact or translaminar activity (Brodsgaard and Albajes, 1999; Nauen et al.,

2003; van Leeuwen et al., 2004). Miticides with contact activity include acequinocyl, fenbutatin-oxide, clofentezine, hexythiazox, pyridaben, bifenazate, and fenpyroximate (Jacobson et al., 1999). Miticides, in general, provide minimal residual activity once spray residues have dried so repeat applications may be required (Brodsgaard and Albajes, 1999). However, a number of miticides have translaminar properties, which means that the material penetrates the leaf cuticle and the a.i. resides within the leaf tissue, including the spongy mesophyll and palisade parenchyma cells, providing a reservoir of a.i. This provides extended residual activity against TSM even after surface residues have dried (Cloyd, 2003). Twospotted spider mites feeding on the leaves, even after spray residues have dissipated, may ingest a lethal concentration of the a.i. This may lead to a decrease in the number of miticide applications, thus reducing worker exposure. However, miticides with extended residual activity such as translaminar miticides may increase the potential for resistance developing in TSM populations (Clark et al., 1994). Miticides registered for use in greenhouses that have translaminar activity include abamectin (Avid; Syngenta Professional Products, Greensboro, NC), chlorfenapyr (Pylon; OHP, Inc., Mainland,

PA), spiromesifen (Judo; OHP, Inc.), and etoxazole (TetraSan; Valent U.S.A. Corporation, Walnut Creek, CA).

The persistence or longevity and efficacy of translaminar miticides are important so as to provide long-term protection against the TSM under greenhouse conditions. As such, we decided to determine the residual activity, based on efficacy, of currently available selected miticides, some with translaminar attributes, in controlling the TSM.

Materials and Methods

Two replicated experiments were conducted to determine the persistence or longevity of selected miticides after test plants had been treated before being artificially infested with TSM. Expt. 1 determined miticide efficacy on the nymphs and adults, which were pooled in the final analysis because we only evaluated miticides with two distinct modes of action, whereas Expt. 2 assessed miticide efficacy against both the nymph and adult life stages because we evaluated miticides with five different modes of action.

Expt. 1: Effect of different miticide formulations on control of twospotted spider mite. Twenty-five 'Nanho Purple' butterfly bush (*Buddleia davidii*) plants were obtained from a local nursery with no prior treatment of pesticides (insecticides, miticides, and/or fungicides). The plants were transplanted into 1.9-L containers filled with a growing medium consisting of 50% to 60% composted pine bark, 20% to 30% Canadian sphagnum peatmoss, 5% to 15% medium-grade horticultural vermiculite, and 5% to 15% horticultural perlite. Plants were fertilized after planting with ≈ 5 g of 14N–11.6P–6.1K Osmocote® (Scotts-Sierra Horticultural Products Company, Marysville, OH) granular fertilizer. All plants were grown on a wire-mesh, raised bench (12 $\times$ 3 m) and arranged in a completely randomized design. There were a total of five treatments with five replications per treatment. The treatments and rates used are presented in Table 1. It should be noted that three formulations of etoxazole [5WD (water-dispersible), 7 to 8 μm , and 10 to 12 μm] were evaluated in the experiment.

Plants were determined to be free of TSM before application of the treatments by visual inspection. The butterfly bush plants were ≈ 48 cm tall when the appropriate treatments were applied using a backpack sprayer (40 psi, flat-fan nozzle, 8002 nozzle size, CO₂ propellant in water). The application volume was 935 L·ha⁻¹. All portions of the test plants were thoroughly saturated with the spray solution; however, this did not lead to any significant runoff. Only one application was made and each plant was equivalent to one replicate. Fourteen d after application, each plant was labeled by placing cotton string around branches in five locations of each plant that had been treated with the designated miticide. We did not label new growth, which was greater than 5.8 cm in length, that

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Table 1. Miticide, formulations, and recommended label rates used to assess effects on the twospotted spider mite, *Tetranychus urticae*, under greenhouse conditions for Expt. 1.

Miticide ^z			
Common name	Formulation ^y	Label rate	Rate used in Expt.
Etoazole	5 WD	8.0 oz/100 gal	1.2 g·L ⁻¹
Etoazole	7–8 µm	8.0 oz/100 gal	1.2 g·L ⁻¹
Etoazole	10–12 µm	8.0 oz/100 gal	1.2 g·L ⁻¹
Chlorfenapyr	SC	4.0 fl oz/100 gal	0.62 mL·L ⁻¹
Untreated control	—	—	—

^zEtoazole (TetraSan; Valent U.S.A. Corporation, Walnut Creek, CA); chlorfenapyr (Pylon; OHP, Inc., Mainland, PA).

^yFormulation designations: WD = water-dispersible; SC = soluble concentrate.

had emerged after application of the treatments. Five to six infested soybean, *Glycine max*, leaves, each containing 10 to 15 TSM (larvae, nymphs, and adults), were placed by hand onto the plants, in the labeled locations, so that a localized concentration of TSM would be initially established. We did not observe any reduction in the survival of TSM when transferred from soybean to either butterfly bush or marigold (Expt. 2 described subsequently).

The temperature inside the greenhouse during the experiment was 30 °C (day) and 22 °C (night). Relative humidity levels ranged from 40% to 80%. The test plants received natural lighting for the duration of the experiment. Plants were hand-watered; overhead irrigation was not performed to avoid washing off any TSM from the test plants. The containers were monitored regularly to ensure that TSM were not migrating among the test plants, which were spaced at least 30 cm apart.

Plants were sampled and counts taken 7, 14, and 28 d after having been artificially infested with TSM or 21, 28, and 42 d after the plants had been treated with the designated miticides. One randomly selected leaf was excised from each of the five labeled locations on each plant, which had greater than 30 leaves, for a total of five leaves excised per plant (replicate). A different set of five leaves was used for each assessment period to avoid double-counting previously killed or dead TSM. Actual counts were recorded on the number of live and dead TSM (nymphs and adults) per leaf. It should be noted that dead TSM were observed to adhere to the leaf surface and did not drop off the plant.

Expt. 2: Effect of miticides with contact and translaminar activity on control of twospotted spider mite. Thirty ‘Antiqua Gold’ marigold (*Tagetes erecta*) plants obtained from Eason Horticultural Resources (Fort Wright, KY) were transplanted into 0.94-L containers filled with a growing medium consisting of 35% peatmoss, 45% aged pine bark, 15% aged rice hulls, 5% composted hardwood, and a supplemental fertilizer (Osmocote at 167.4 oz·m⁻³). No pesticides (insecticides, miticides, and/or fungicides) had been applied to the test plants. One plant was equivalent to one replicate. There were a total of six treatments with five replications per treatment. The treatments and rates used are presented in Table 2.

Plants were determined to be free of TSM before application of the treatments by visual inspection. Approximately nine to 12 recently expanded leaves of each plant were labeled by placing a cotton string around a branch before applying the treatments. The test plants were ≈13 cm tall when the treatments were applied with a backpack sprayer (40 psi, flat-fan nozzle, 8002 nozzle size, CO₂ propellant in water). The application volume was 935 L·ha⁻¹. All portions of the test plants were thoroughly saturated with the spray solution, which did not result in any significant runoff. The test plants were then arranged in a completely randomized design on a wire-mesh, raised bench (12 × 3 m). The temperature inside the greenhouse during the experiment was 30 °C (day) and 22 °C (night) with a relative humidity between 50% and 80%. Test plants received natural lighting for the duration of the experiment. Plants were hand-watered; overhead irrigation was not performed so as to avoid washing off any

TSM from the test plants. The containers were monitored regularly to ensure that TSM were not migrating among the test plants, which were spaced at least 30 cm apart.

All the test plants were artificially infested with TSM 21 d after the treatments had been applied by placing leaf sections from infested cotton *Gossypium* spp. plants onto the labeled branches of each test plant. Leaves were randomly selected from the cotton plants and cut from the stem. Each leaf section contained between 10 to 15 TSM with all life stages present: egg, larva, nymph, and adult. Cotton plants are used to rear TSM in our colonies.

Test plants were evaluated 28, 35, and 49 d after having been artificially infested with TSM or 49, 56, and 70 d after the test plants had been treated with the designated miticides. One randomly selected leaf was excised from each of the five labeled locations on the respective plant for a total of five leaves excised per plant (replicate). A different set of five leaves was used for each assessment period so as to avoid double-counting previously killed or dead TSM. Actual counts were recorded on the number of live and dead TSM nymphs and adults per leaf.

Data analysis

Expt. 1: Effect of different miticide formulations on control of twospotted spider mite. Data were corrected for control mortality (Abbott, 1925) to calculate a measure of mortality as our response variable in the experiment using the following formula:

$$X-Y/X*100 = \text{percent mite control} \\ (\text{mortality}) \quad (1)$$

where X = percent live mites in untreated control, Y = percent live mites on treated plant, and X-Y = percent mites killed by the designated treatment.

The number of days postmiticide application constituted a repeated measure in an analysis of variance model in which miticide and days posttreatment were the main effects in a factorial treatment structure. The repeated measures were on the individual plants with the leaves as sample units. Percent mortality for each treatment was calculated by dividing the number of dead TSM (nymphs and adults pooled) by the total number of TSM recovered per plant (replicate). We analyzed the data using the Proc Mixed procedure in SAS (Littell et al., 2006) with Kenward-Rogers correction to the denominator degree of freedom for correlated errors, and we used a spatial power transformation as the covariance matrix structure for the repeated measures because days were not equally spaced (21, 28, and 42). If the F test for any effect was significant at the 0.05 level, we used a Fisher's protected least significant difference procedure to compare the respective means. The data were inverse transformed back to the original scale (percentages) for the purposes of reporting them in tables and for discussion.

Table 2. Miticide, formulations, and recommended label rates used to assess effects on the twospotted spider mite, *Tetranychus urticae*, under greenhouse conditions for Expt. 2.

Miticide ^z			
Common name	Formulation ^y	Label rate	Rate used in Expt.
Etoazole	5 WG	16.0 oz/100 gal	1.19 g·L ⁻¹
Acequinocyl	15 SC	12.8 fl oz/100 gal	1.0 mL·L ⁻¹
Abamectin	0.15 EC	4.0 fl oz/100 gal	0.31 mL·L ⁻¹
Chlorfenapyr	SC	2.6 fl oz/100 gal	0.20 mL·L ⁻¹
Spiromesifen	4 SC	2.0 fl oz/100 gal	0.15 mL·L ⁻¹
Water control	—	—	—

^zEtoazole (TetraSan; Valent U.S.A. Corporation, Walnut Creek, CA); acequinocyl (Shuttle; Arysta Life Science, San Francisco, CA); abamectin (Avid; Syngenta Professional Products, Greensboro, NC); chlorfenapyr (Pylon; OHP, Inc., Mainland, PA); and spiromesifen (Judo; OHP, Inc.).

^yFormulation designations: WG = wettable granules; SC = soluble concentrate; EC = emulsifiable concentrate.

Expt. 2: Effect of miticides with contact and translaminar activity on control of twospotted spider mite. Data were corrected for control mortality (Abbott, 1925) to calculate a measure of mortality as our response variable in the experiment using the following formula:

$$X-Y/X*100 = \text{percent mite control (mortality) (2)}$$

where X = percent live mites in water control, Y = percent live mites on treated plant, and X-Y = percent mites killed by the designated treatment.

The number of days postmiticide application constituted a repeated measure in an analysis of variance model in which miticide and days posttreatment were the main effects in a factorial treatment structure. The repeated measures were on the individual plants with the leaves as sample units. Percent mortality for each treatment was calculated by dividing the number of dead TSM nymphs and adults by the total number of TSM recovered per plant (replicate). We analyzed the data using the Proc Mixed procedure in SAS (Littell et al., 2006) with Kenward-Rogers correction to the denominator degree of freedom for correlated errors and we used an autoregressive covariance matrix structure with repeated measures because the more complicated spatial power structure did not improve the fit of the model because the repeated measures were not equally spaced (49, 56, and 70). If the F test for any effect was significant at the 0.05 level, we used a Fisher's protected least significant difference procedure to compare the respective means. The data were inverse transformed back to the original scale (percentages) for the purposes of reporting them in tables and for discussion.

Results

Expt. 1: Effect of different miticide formulations on control of twospotted spider mite. Only the treatment ($P \leq 0.0001$) and day ($P = 0.020$) main effects were significant; the interaction term, treatment*day, was not significant ($P = 0.105$) so we pooled the data associated with the evaluation times (21, 28, and 42 d) to obtain an overall percent mortality for each treatment. The estimated mean percent TSM mortality is presented in Table 3 along with

the number of live and dead TSM (nymphs and adults pooled) for each treatment and evaluation time. All the miticides had higher TSM mortalities (based on percent) than the untreated control (Table 3). Both the etoxazole 10 to 12 μm and etoxazole WD formulations had the highest percent TSM mortalities (greater than 85%) and fewest number of live TSM (four or less) recovered from the treated plants across all three evaluation times (Table 3). The etoxazole 7 to 8 μm formulation had an extremely high number of both live and dead TSM across all three evaluation times compared with the other treatments (Table 3), which likely influenced the level of control associated with percent mortality (56.7%).

Expt. 2: Effect of miticides with contact and translaminar activity on control of twospotted spider mite. For TSM nymphs, the treatment ($P \leq 0.0001$) and day ($P \leq 0.0001$) main effects were significant; however, the interaction term, treatment*day, was also significant ($P \leq 0.0001$). The estimated mean percent TSM nymphal mortality for each treatment corresponding to each evaluation time is presented in Table 4 as well as the number of live and dead TSM nymphs associated with each treatment and evaluation time. Both spiromesifen and etoxazole were significantly higher than the other treatments, across all three evaluation times, always providing greater than 80% TSM nymphal mortality (Table 4). Spiromesifen, however, had a significantly higher TSM nymphal mortality than etoxazole 70 d after treatment. Spiromesifen provided the most consistent and effective control of TSM nymphs compared with the other treatments with 89% to 99.2% mortality across all three evaluation times (Table 4). The TSM nymphal mortality rate for etoxazole ranged from 80.9% to 96.9% across all three evaluation times, whereas the other miticides failed to provide long-term control of TSM nymphs (Table 4). Acequinocyl resulted in 93% mortality initially (Day 49) but declined to 18% at 70 d posttreatment, which is likely associated with plants treated with acequinocyl having the highest number of live TSM nymphs ($n = 197$) at 70 d compared with the other treatments (Table 4).

Similarly, for TSM adults, the treatment ($P \leq 0.0001$) and day ($P = 0.003$) main effects were significant; however, the inter-

action term, treatment*day, was also significant ($P = 0.0033$). The estimated mean percent TSM adult mortality for each treatment corresponding to each evaluation time is presented in Table 4 as well as the number of live and dead TSM adults associated with each treatment and evaluation time. Plants treated with spiromesifen had significantly higher percent adult TSM mortalities (61.8% and 87.9%, respectively) than the other miticide treatments at 49 and 56 d posttreatment (Table 4). In addition, the fewest number of live ($n = 3$) and dead ($n = 11$) TSM adults were recovered from plants treated with spiromesifen (Table 4). However, spiromesifen was not significantly different from etoxazole, chlorfenapyr, or abamectin at 70 d and by that time, it ranked fourth out of the five miticide treatments with a mortality rate of 37.3%. Furthermore, and at that point, spiromesifen only significantly exceeded acequinocyl and the water control in effectiveness. None of the miticides evaluated provided consistent or long-term control of TSM adults with less than 60% mortality 70 d posttreatment (Table 4). Acequinocyl was not significantly more effective than the water control treatment at any day posttreatment.

Discussion

Because no pesticides (insecticides, miticides, and/or fungicides) had been applied to the test plants (in both experiments), any effects on TSM were likely the result of TSM being killed by the designated treatments. This also reduced the possibility of any active residues negatively affecting reproduction of TSM females. We evaluated three different formulations of the a.i. etoxazole because, although the composition of the etoxazole formulations was similar, the milling of the particle size was different. The initial formulation of etoxazole (5 WD) contains a high percentage of clay filler. The milling process reduces the particle size of both the clay and etoxazole technical grade together. However, the clay filler is difficult to mill down to small particle sizes, so we wanted to determine if particle size influenced efficacy of the a.i. in providing control of TSM. In Expt. 1, based on percent mortality of TSM (nymphs and adults) and number of live and dead TSM, the etoxazole 10 to 12 μm and 5 WD formulations were

Table 3. Mean twospotted spider mite (TSM), *Tetranychus urticae*, mortality (%) for all treatments in Expt. 1 pooled across all three evaluation times (21, 28, and 42 d), and the number of live (L) and dead (D) TSM for each evaluation time.^a

Treatments ^b	Formulation ^c	Mortality (%)	21 d ^w		28 d		42 d	
			L	D	L	D	L	D
Etoxazole	10–12 μm	94.5 a ^x	4	41	2	13	0	33
Etoxazole	7–8 μm	56.7 b	155	128	122	65	8	125
Etoxazole	5 WD	87.8 a	2	21	0	24	1	8
Chlorfenapyr	SC	69.2 b	11	16	5	15	0	24
Untreated control	—	0.0 c	87	0	26	2	56	0

^aThe nymph and adult life stages were pooled together to obtain the data presented.

^bRefer to Table 1 for information associated with the treatments.

^cFormulation designations: WD = water-dispersible; SC = soluble concentrate.

^wday = days after treatment.

^xMeans not followed by a common letter are significantly different ($P \leq 0.05$) as determined by Fisher's protected least significant difference test.

Table 4. Mean twospotted spider mite, *Tetranychus urticae*, mortality (%) for all treatments across the three evaluation times (49, 56, and 70 d) for Expt. 2, and the number of live (L) and dead (D) twospotted spider mite nymphs and adults for each evaluation time.

		Mortality (%)			49 d		56 d		70 d	
Treatments ^z	Formulation ^y	Day ^x 49	Day 56	Day 70	L	D	L	D	L	D
Nymphs										
Spiromesifen	4 SC	89.0 a ^w	99.2 a	98.8 a	28	227	0	182	1	165
Etoxazole	5 WG	82.0 a	96.9 a	80.9 b	3	16	0	41	1	10
Chlorfenapyr	SC	55.3 b	55.2 b	29.3 c	54	67	20	25	75	31
Acequinocyl	15 SC	93.0 a	42.4 b	18.3 c	0	19	34	24	197	44
Abamectin	0.15 EC	51.3 b	56.9 b	15.7 c	10	11	20	24	48	10
Water control	—	3.3 c	12.1 c	1.1 d	52	1	46	7	323	4
Adults										
Spiromesifen	4 SC	61.8 a	87.9 a	37.3 a	3	6	1	11	3	1
Etoxazole	5 WG	26.6 b	17.4 b	55.9 a	13	5	12	2	2	4
Chlorfenapyr	SC	14.9 bcd	19.5 b	49.9 a	23	4	30	8	7	6
Acequinocyl	15 SC	8.3 cd	9.9 bc	4.7 b	52	5	43	5	49	2
Abamectin	0.15 EC	8.2 cd	21.7 b	56.0 a	55	5	25	7	7	9
Water control	—	3.0 d	2.0 c	2.4 b	78	2	62	0	76	1

^zRefer to Table 2 for information associated with the treatments.

^yFormulation designations: SC = soluble concentrate; WG = wettable granules; EC = emulsifiable concentrate.

^xDay = days after treatment.

^wMeans not followed by a common letter are significantly different ($P \leq 0.05$) as determined by Fisher's protected least significant difference test.

most effective in preventing the buildup of TSM populations. However, by 42 d, based on the number of live and dead TSM, all the treatments killed a high proportion (89% to 100%) of TSM. Plants initially treated with the etoxazole 7 to 8 μ m formulation had an excessive number (155 live and 128 dead) of TSM on 21 d. However, by 42 d, the etoxazole 7 to 8 μ m formulation treatment was similar in effectiveness to the other two etoxazole formulations based on the number of live and dead TSM (Table 3). It is possible that the smaller particle sizes may have reduced penetration of a lethal concentration of the a.i. into the leaf tissues, which would have delayed any translaminar effect, thus allowing the TSM population to build up.

The reason why the interaction term (treatment*day) was significant in Expt. 2 may be the result of the number of dead TSM nymphs associated with the spiromesifen treatment and low number of live and dead TSM adults recovered from plants treated with spiromesifen across all three evaluation times (Table 4). Several of the miticides provided control of TSM even after having been applied to plants 14 d before artificial infestation of TSM. This suggests that these miticides may have extended residual activity. In our study, we did not use the new growth that had developed after infesting the plants with TSM because we were uncertain that the a.i. would be present in the new leaves at a lethal concentration. In fact, the chlorfenapyr label indicates that the a.i. may be diluted in new expanding leaves compared with concentrations of a.i. in the leaf tissues after application (Vance Publishing Corporation, 2007). However, after artificial infestation, TSM could have moved onto new growth that had a lower concentration of a.i. than the leaves initially treated. As a result, the miticides may have had a minimal negative effect on the TSM population.

Based on our results, both etoxazole and spiromesifen were significantly more effective on TSM nymphs compared with the other miticide treatments in regard to percent

mortality and number of nymphs killed (Table 4). Etoxazole is a mite growth regulator that functions as a chitin synthesis inhibitor. It has activity on eggs, larvae, and nymphs, but not adults (Nauen and Smagghe, 2006), which was evident in the results obtained in Expt. 2.

Although both abamectin and chlorfenapyr have translaminar activity, they failed to provide control of either TSM nymphs or adults. This was interesting because abamectin, in particular, penetrates foliage within several hours after application and has been shown to provide residual control of both the immature (larvae and nymphs) and adult stages of TSM (Lasota and Dybas, 1991; Putter et al., 1981). On cotton plants, for example, abamectin has provided between 85% and 96% control of TSM up to 49 d posttreatment. However, residual activity may be influenced by plant species and leaf age (Lasota and Dybas, 1991). Furthermore, abamectin is susceptible to ultraviolet degradation (Wislocki et al., 1989), although it is unlikely this was responsible for inadequate control of both TSM nymphs and adults in Expt. 2. At this point, it is not clear why abamectin failed to control TSM in our study, although it is possible that the TSM population in our colony, which has been in culture for over 1 year, may have evolved resistance to abamectin. In fact, abamectin has been ineffective in several previously conducted miticide efficacy trials against TSM (R.A. Cloyd, unpublished data). Moreover, TSM populations throughout the United States are less susceptible to abamectin since it was introduced in the 1980s (Zhang, 2003) with studies documenting that certain TSM populations have developed resistance to abamectin under both laboratory and field conditions (Campos et al., 1995; Clark et al., 1994; Price et al., 2002; Stumpf and Nauen, 2002). Similarly, although chlorfenapyr is a newer miticide and is active on all life stages of TSM (Dekeyser, 2005), studies have demonstrated that populations of TSM are resistant to this a.i. (Herron and Rophail,

2003; Uesugi et al., 2002; van Leeuwen et al., 2004). Furthermore, it is possible that the results obtained were a consequence of the effect of plant type (butterfly bush versus marigold).

Acequinocyl has contact activity only and is supposedly active on all TSM life stages, including eggs (Thomson, 2001); however, it does not have translaminar properties, which was evident based on the low percent mortality of TSM nymphs and adults 56 d (42.4% and 9.9%) and 70 d (18.3% and 4.7%) after the plants had been treated. This also was apparent based on the number of live TSM nymphs (34 and 197) and adults (43 and 49) at 56 d and 70 d, respectively. As such, this miticide may not be the appropriate choice for long-term control of TSM unless more frequent applications are conducted.

Spiromesifen resulted in 87.9% TSM adult mortality 56 d after treatment and then declined to 37% at 70 d after treatment. It is interesting to note that plants treated with spiromesifen had four instances (one on 49 d, two on 56 d, and on 70 d) in which no TSM were recovered per plant. Etoxazole was the only other treatment that had one instance (49 d) of no TSM being recovered. Twospotted spider mites may not have established on plants treated with spiromesifen because translaminar activity was more pronounced than the other treatments. Furthermore, spiromesifen reduces the fecundity of TSM females by negatively affecting the ovaries (Nauen et al., 2003), which would result in an eventual decline in TSM over time. Spiromesifen is more active on the immature stages (larvae and nymphs) than adults (Dekeyser, 2005; Nauen et al., 2002, 2003), which may be associated with a different adult feeding behavior, compared with the immature stages. For example, young adult females spend more time moving than feeding, whereas immatures tend to be stationary (Bancroft and Margolies, 1996). This may have affected the amount of a.i. ingested from plant tissues. It has been suggested that miticide applications may influence or alter

the dispersion of TSM, thus biasing estimates of TSM populations (Trumble, 1985). In our evaluations, there was no indication that TSM distribution in the plant canopy was impacted by the treatments (R.A. Cloyd, unpublished data).

In our study, we hand-watered the test plants so as to avoid washing off any TSM and miticide residues from the foliage. However, under typical nursery production systems, plants are routinely overhead-irrigated, which may not only wash off TSM feeding on the upper leaf surface but also any residues after applying a translaminar miticide. This may reduce persistence of the material, thus influencing long-term control of TSM populations.

In conclusion, we have demonstrated that translaminar miticides may vary in efficacy against the TSM depending on the life stages (nymph or adult) present. Spiromesifen, in general, was the most effective translaminar miticide against both the nymphs and adults of TSM compared with the other miticides evaluated, although several formulations of etoxazole also provided adequate control of TSM. The persistence and efficacy of translaminar miticides is important to greenhouse growers to protect crops from damage caused by TSM and reduce the frequency of applications needed. However, there are potential negative implications of miticides with extended residual activity such as the development of resistance by TSM populations. As such, this should be taken into consideration before using translaminar miticides.

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