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Comparative Efficacies of Acequinocyl (Kanemite™) and Abamectin (Agri-Mek™) against Twospotted Spider Mite on Tomato and Broad Mite on Jalapeño Pepper

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ABSTRACT

Efficacy of a new miticide, acequinocyl (Kanemite™ 15SC; Arysta LifeScience), was determined against the twospotted spider mites, *Tetranychus urticae* Koch (Arachnida: Acarina: Tetranychidae), on tomato in the greenhouse and the broad mite, *Polyphagotarsonemus latus* (Banks) (Arachnida: Acarina: Tarsonemidae), on Jalapeño pepper in the field as compared with the efficacy of abamectin (Agri-Mek™ 0.15EC; Syngenta), a most commonly used miticide-insecticide. In the greenhouse, one application of acequinocyl at 326 g AI/ha (31 fluid oz/acre) or 651 g AI/ha (62 fluid oz /acre) was effective against *T. urticae* on tomato, and the higher rate (651 g AI/ha) performed slightly better than the lower rate (326 g AI/ha). Similarly, in the field, five applications of acequinocyl at 326 g AI/ha (31 fluid oz/acre) or 651 g AI/ha (62 fluid oz/acre) significantly reduced *P. latus* populations on Jalapeño peppers, and the higher rate (651 g AI/ha) performed better than the lower rate (326 g AI/ha). However, acequinocyl was not as effective as abamectin at 15.8 g AI/ha (12 fluid oz/acre) on some sampling dates. Jalapeño pepper plants treated with acequinocyl had slightly less damage than those in the water control. Our conclusions are that acequinocyl is highly efficacious against *T. urticae* on tomato in the greenhouse and relatively efficacious against *P. latus* on Jalapeño pepper in the field with comparable efficacies with abamectin. The factors that may affect the efficacies of those miticides, especially for control of *P. latus* under field conditions, are discussed.

RESUMEN

Eficacia de un miticide nuevo, acequinocyl (Kanemite™ 15SC; Arysta LifeScience), fue determinado contra twospotted los aros de la ara de *Tetranychus urticae* Koch (Arachnida: Acarina: Tetranychidae), en el tomate en el invernadero y el amplio aro de *Polyphagotarsonemus latus* (Banks) (Arachnida: Acarina: Tarsonemidae), en la pimienta de Jalape en el campo con respecto a la eficacia del abamectin (Agri-MekTM 0.15EC; Syngenta), un miticide-insecticida lo m com mente posible usado. En el invernadero, un uso del acequinocyl en 326 g AI/ha (31 oz/acre fl dos) o 651 g AI/ha (62 onzas fl das /acre) era eficaces contra urticae del T. en el tomate, y mejor realizada m alto de la tarifa (651 g AI/ha) el levemente que la tarifa m baja (326 g AI/ha). Semejantemente, en el campo, cinco usos del acequinocyl en 326 g AI/ha (31 oz/acre fl dos) o 651 g AI/ha (oz/acre de 62 l uidos) redujeron perceptiblemente las poblaciones del latus del P. en las pimientas de Jalape , y la tarifa m alta (651 g AI/ha) realizada mejor que la tarifa m baja (326 g AI/ha). Sin embargo, el acequinocyl no era tan eficaz como abamectin en g 15.8 AI/ha (oz/acre de 12 l uidos) algunas fechas del muestreo. Las plantas de la pimienta de Jalape trataron con acequinocyl ten n levemente menos da que os en el control del agua. Nuestras conclusiones son que el acequinocyl es altamente eficaz contra urticae del T. en el tomate en el invernadero y relativamente eficaz contra latus del P. en la pimienta de Jalape en el campo con efficacies comparables con abamectin. Los factores que pueden afectar los efficacies de esos miticides, especialmente para el control del latus del P. bajo campo condicionan, se discuten.

Additional Index Key Words: miticide, acaricide, spider mite, broad mite, vegetable

Acequinocyl, the active ingredient of Kanemite (15SC, Arysta LifeScience Corp., San Francisco, CA), is a novel naphthoquinone derivative which was synthesized in the 1970s for use in control of phytophagous mites (Tsuji 1997, Koura et al. 1998, Kinoshita et al. 1999, Anonymous 2001). This novel chemical has a unique mode of action to phytophagous mites, inhibiting the electron transfer system by binding hydroxyl, and affecting mitochondrial respiration (Tsuji 1997, Koura et al., 1998). It also affects previously unknown targets in mites that influence mite growth and development, offering new opportunities for mite control (Dekeyser 2005).

Acequinocyl has excellent miticidal activity against numerous species of phytophagous mites at all development stages including the egg stage without exhibiting any cross resistance towards other commercial miticides. Acequinocyl has been used widely in vegetable and ornamental IPM programs in Japan to control plant mite species since it was first registered in 1999, and has maintained excellent efficacy without any sign of developing miticide resistance (Koura et al. 1998, Kinoshita et al. 1999). This product is also registered in Korea, Taiwan and other countries (Ahn et al. 2004, Lee et al. 2004). In the US, acequinocyl has been registered by Arysta LifeScience as Kanemite 15SC for tomato, pepper, strawberry, hop, apple, pear and almonds, and as Shutte™ on ornamentals to control multiple mite species, including the twospotted spider mite, *Tetranychus urticae* Koch, the strawberry spider mite, *Tetranychus turkestani* (Ugarov & Nikolski), the citrus red mite, *Panonychus citri* (McGregor), the European red mite, *Panonychus ulmi* (Koch), and the Texas citrus mite, *Eutetranychus banksi* (McGregor) in oranges, grapefruits and lemons, almonds, pistachios, apples, pears and many other field and vegetable crops (Ahn et al. 2004, Gotoh et al. 2004, Lee et al. 2004).

The twospotted spider mite, *T. urticae*, is considered to be one of the most economically important spider mites. This mite has been reported to infest over 200 species of plants, including a number of vegetable crops such as tomatoes, melons, squash, eggplant, cucumber and many others in southern Texas (Capinera 2001). Generally, the spider mites feed on the undersides of leaves. They use their sucking mouthparts to remove sap from plants, causing graying and necrotic spots of the leaves due to mesophyll collapse and yellowing. Leaves of mite infested plants may turn yellow and dry up, and plants may lose vigor and die when infestations are severe, and heavy infestations produce fine webbing which may cover the entire plant.

The broad mite, *Polyphagotarsonemus latus* (Banks) (Arachnida: Acarina: Tarsonemidae), was first described by Banks (1904) as *Tarsonemus latus* from the terminal buds of mango in a greenhouse in Washington, D.C., USA, and it is at present found in Australia, Asia, Africa, Europe, North America, South America, and the Pacific Islands (Denmark 1980). This destructive pest causes terminal leaves and flower buds to become malformed; the damaged leaves turn downward and turn coppery or purplish, and the internodes shorten and the lateral buds break more than normal; the blooms abort and plant growth is stunted when large populations are present, and the toxic saliva of *P. latus* causes twisted, hardened and distorted growth in the terminal of the plant. *P. latus* are usually seen on the newest leaves and small fruit (Denmark 1980, Peña and Bullock 1994, Jovicich et al. 2004).

At present, availability of limited numbers of miticides is of great concern to vegetable growers and consultants because *T. urticae* and *P. latus* are notorious for their ability to develop miticide resistance. New miticides are urgently needed for vegetable growers. The objective of this study was to determine the efficacy of acequinocyl (Kanemite or TM41301, 15SC) on *T. urticae* on tomato in the greenhouse and on *P. latus* on Jalapeño pepper as comparison with the most commonly used miticide-insecticide, abamectin (Agri-Mek) in the field in southern Texas.

MATERIALS AND METHODS

Greenhouse Experiment. Tomato (variety "Heat Master") seedlings (20-25 cm in height) were obtained from a local nursery (Grimsell's in Harlingen, Texas). They were transplanted to 3 gal plastic pots on 12 November 2003. The potting medium was Sunshine Mix #1 with 2% (by volume) Osmocote 18-6-12 fertilizer. The tomato plants were watered as needed, and fertilized every two weeks with calcium nitrate (100 ppm Ca++ solution through drip irrigation). The excess lateral branches of the tomato plants were trimmed off every two weeks, maintaining no more that 4 branches per plant. No other chemicals were used.

Two miticides were used in this study: Kanemite (TM41301, 15SC acequinocyl; Arysta LifeScience North America Corp., San Francisco, CA, USA; formerly Tomen Agro) was used at 326 g AI/ha (31 oz/acre) and 651 g AI/ha (62 oz fluid oz /acre), and Agri-Mek (0.15EC; abamectin; Syngenta, Greensboro, NC) was used at 15.8 g AI/ha (12 fluid oz/acre).

The two miticides were applied on 8 January 2003. They were dispersed in water and applied at a rate of 1,609 l/ha (172 gal/acre) at 344.7 kPa (50 psi) using a CO_2 backpack sprayer. The spray boom had a single hollow cone nozzle (23 core and D2 tip). The nozzle tip was positioned approximately 8 to 10 inches away from the plant and tilted 30° angle upward. While spraying the nozzle is moved up and down the entire height and on 4 sides of the plant. Each plant was between 107-120 cm tall and received spray for 8 s (80 ml). Treatments were replicated four times in a randomized complete block design. Each treatment plot consisted of a single row of ten 11.4-liter (3-gal) pots containing one plant per pot.

Tetranychus urticae populations were evaluated for the different treatments at 1, 2, 3, 4 and 5 weeks after the first application. Two leaves, one from each side of the plant, were collected from the middle of each of the 4 middle plants in each row. A total of 16 leaves were collected from each plot. Numbers of dead and live spider mites, as well as live eggs and immatures were counted from each leaf in the laboratory under a stereomicroscope. For *T. urticae* adults, males and females were counted separately. Phytotoxicity was noted when sampling. Leaf area of each sampled tomato leaflet was estimated by collecting 20 such leaflets and measured using a leaf area meter (LI-Cor 2000). The mean area per leaf was 38.8 cm^2.

At termination on 12 Feb. 2003, foliage damage of the tomato plants in each plot was estimated based on the following categories: 0-no damage, 1-minor (0-20%), 2-minor-moderate damage (21-40%), 3-moderate damage (41-60%), 3-moderate-heavy damage (61-80%), and 5-heavy damage (81-100%).

Field Experiment. The field experiment was conducted against *P. latus* on Jalapeño pepper (Jalapeno M, Peto Seeds Company) at the Research Farm, Texas Agricultural Experiment Station at Weslaco, Texas. There were three miticide treatments, including acequinocyl at 326 g AI/ha (31 oz/acre) and 651 g AI/ha (62 oz fluid oz /acre), and abamectin was used at 15.8 g AI/ha (12 fluid oz/acre). Water was used in untreated control plots.

Jalapeño peppers were transplanted on 21 August 2002. Each experimental plot consisted of two 1 m (40")-rows by 10 m (40') long and with about 40 plants per row. There was a 2 m (5') alley between each plot, and 2 rows of sorghum between the 2-row pepper plots. All plots were arranged in a randomized complete block design with 3 replications for each treatment. Fertilizer (N32 at 112 kg/ha or 100 lb/acre) was applied on 16 August 2002, and herbicide (Prefar 4E at 14 liter/ha or 6 quarts/acre) was applied on 23 August 2002. Rainfalls were recorded at 4.67 cm in August, 13.3 cm in September, 0.7 cm in October, and 6.5 cm in November.

The miticides were applied using a tractor-mounted sprayer with 3 ceramic hollow cone nozzles per row (TX-10, one

40-cm over the plants, 2 on drops) at 689.5 kPa (7.03 kg/cm^2 or 100 psi) at a delivery rate of 280 liter/ha (30 gal/acre) at 2.4 km/h (1.5 mph) driving-speed. The materials were applied on 5 October 2002. The weather conditions were 24.7ºC (76.5ºF) and 22.2ºC (72ºF) for air and soil temperatures, respectively, and wind speed was 3.1 km/h (1.9 mph) SE.

Population density of *P. latus* was evaluated at 1, 2, 3, 4 and 5 weeks after the application on 5, 12, 19, and 26 October and 2 November, respectively. When sampling, 2 leaves, 1 from each canopy side, were collected from the middle of each of 10 pepper plants in each plot, and numbers of *P. latus* (all mites except for eggs) on each leaf were counted in the laboratory under a stereomicroscope. At termination on 5 November 2002, foliage damage of the pepper plants in each plot was estimated as previously described for the greenhouse experiment.

Data Analysis. Percentages of dead *T. urticae* were calculated as: % dead mites = 100 × dead / (dead + live) on tomato leaves. Numbers of all *T. urticae* (live and dead immatures and adults and live eggs) on each of the 10 tomato leaves, numbers of *P. latus* on each of the 20 Jalapeño pepper leaves from each plot among all treatments, and percentage of dead mites were counted and analyzed using analysis of variance (ANOVA), and means were separated using the Fisher's Protected Least Significant Difference test (SAS Institute 2005) at F = 0.05. Foliage damagerankings were also analyzed using ANOVA and means were separated using the LSD test.

RESULTS

Greenhouse Experiment. All three miticide treatments were very effective against T. *urticae* (Table 1 and Fig. 1). Numbers of live *T. urticae* immatures and adults were not significantly different on 8 January, the date of treatment (F = 0.49, df = 3, 57; P = 0.6711). However, one week after the initial treatment, numbers of live immature and adult mites declined significantly, and the plants treated with the three miticides had significantly fewer mites than those with the water control (F = 14.99, df = 3, 57; P < 0.0001). Similar results were observed in the next two sampling dates (22 and 29 January), two and three weeks after the initial miticide application (F = 74.48 and 20.76, df = 3, 57; P < 0.0001). On the last two sampling dates (5 and 12 February), numbers of live *T. urticae* immature and adult mites in the three miticide treatments were significantly less than that in the water control (F = 14.63 and 21.98, df = 3, 57; P < 0.0001), but the treatment of abamectin was significantly less than those in the two acequinocyl treatments.

Table 1. Mean numbers of *T. urticae* on tomato leaves in the greenhouse trial and of *P. latus* on Jalapeño pepper leaves in the field trial.

Miticide	Overall no. of *T. urticae*				Overall no. of
g AI/ha	Live mites	Dead mites	% dead of mites	Live eggs	*P. latus*
Water control	124.3a	12.6c	11.8b	57.7a	11.7a
Acequinocyl, 326	39.2b	36.8b	58.2a	33.8b	7.6b
Acequinocyl, 651	40.5b	36.0b	63.5a	31.9bc	5.2bc
Abamectin, 15.6	45.0b	60.9a	72.4a	24.7c	4.1b
F	14.14	11.27	69.41	3.74	10.06
P	0.0001	0.0001	0.0001	0.0113	0.0001

Means in the same column with the same letter do not differ significantly at P > 0.05 (LSD, SAS Institute 2005).

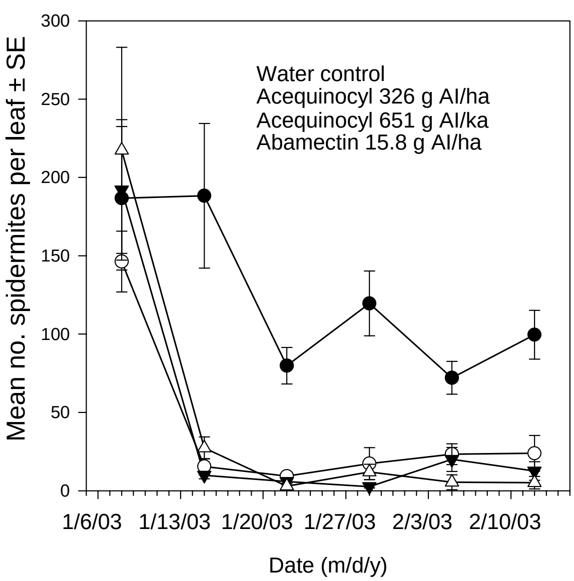

Figure 1. Numbers of live *Tetranychus urticae* (all stage) on tomato leaves in the greenhouse.

Dead *T. urticae* immatures and adults were found one week after the initial application of miticides (Fig. 2). The plants treated with the three miticides had significantly more dead mites than the water control (F = 2.83-7.53, df = 3, 57; P < 0.0001) on the five sampling dates. On the last three sampling dates (29 January and 5 and 12 February), numbers of dead immature and adult mites in the treatment of abamectin was significantly less than those in the two acequinocyl treatments. Of the three miticide treatments, the abamectin treatment had more dead mites than the two acequinocyl treatments (Table 1).

Although the percentages of dead mites are not the exact percent mortalities, there were higher percentages of dead mites on the tomato plants in the three miticide treatments one week after the initial application (Fig. 3), and the same trend occurred on the next four sampling dates (F = 6.27-237.06; df = 3, 57; P < 0.0001) after the initial miticide application. The overall percentages of dead mites among the three miticide treatments were not significantly different (Table 1).

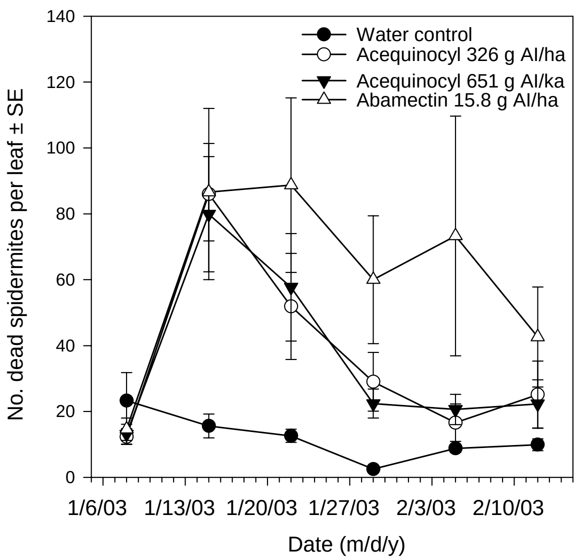

Figure. 2. Number of dead *Tetranychus uricae* on tomato leaves in the greenhouse.

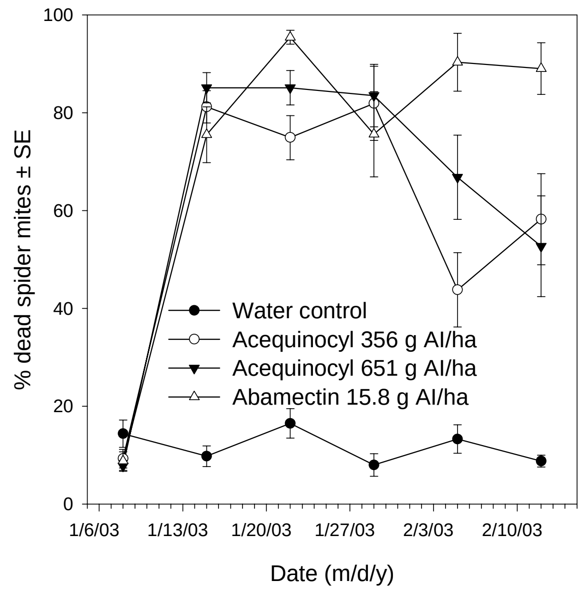

Figure 3. Percentages (%) of dead *Tetranychus urticae* adults and immatures on tomato leaves in the greenhouse.

Numbers of live *T. urticae* eggs on tomato leaves varied greatly among the treatments and over the experiment period (Fig. 4). Significantly more eggs were observed on water control than those on miticide treated leaves (F = 14.63-74.48; df = 3, 57; P < 0.0001). Of the three miticide treatments, the abamectin treatment had less live eggs than the two acequinocyl treatments on the last two sampling dates. However, the overall numbers of live eggs of *T. urticae* were not significantly different among the three miticide treatments (Table 1).

Tomato leaves damaged by *T. urticae* were significantly different among the miticide treatments and water control (F = 25.11; df = 3, 57; P < 0.0001) (Table 2). All leaves of the tomato plants in the water control were completely damaged, and the leaves exhibited graying with necrotic spots and yellowing, and dried up, and the plants lost vigor and were dying. Some plants were covered with fine webbing produced by the spider mites. In contrast, the miticide treated plants were green and vigorous.

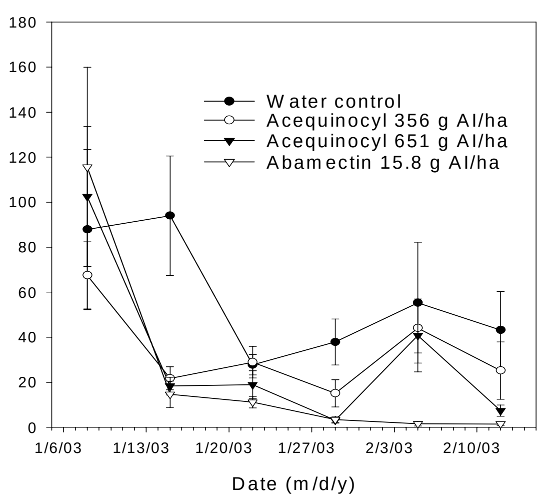

Figure 4. Number of *Tetranychus urticae* eggs on tomato leaves in the greenhouse.

Field Experiment. Generally, numbers of *P. latus* on Jalapeño pepper plants declined after the first miticide application until the end of the experiment on 2 November (Fig. 5). The Jalapeño pepper plants treated with abamectin had the fewest mites, followed by the plants treated with the higher rate (651 g AI/ha or 62 fluid oz/acre) of acequinocyl, and the plants treated with acequinocyl at the lower rate (326 g AI/ha or 31 fluid oz/acre) had similar number of mites as compared with the plants in water control (F = 3.03; df = 3, 57; P = 0.0311). The Jalapeño pepper plants treated with miticides had fewer *P. latus* than those in water control plots on the next four sampling dates (F = 3.62-8.94; df = 3, 57; P = 0.0051-0.0001), and there were no significant difference among the three miticide treatments except the treatments of abamectin and the higher rate of acequinocyl had fewer mites than the lower rate of acequinocyl on 2 November. *P. latus* popultions over the five sampling dates after the first application were

Table 2. Foliage damaged by *T. urticae* on tomato in the greenhouse trial and by *P. latus* on Jalapeño pepper in the field trial.

	Foliage damage, ranking ± SE	
Miticide g AI/ha	By *T. urticae* in the greenhouse	By *P. latus* in the field
Water control	5.0 ± 0.5a	3.7 ± 0.6a
Acequinocyl, 326	2.9 ± 0.2b	3.0 ± 0.4b
Acequinocyl, 651	1.7 ± 0.3c	2.7 ± 0.6bc
Abamectin, 15.6	1.3 ± 0.2c	2.3 ± 0.5c
F	25.11	10.08
P	0.0001	0.0013

Means in the same column with the same letter do not differ significantly at P >0.05 (LSD, SAS Institute 2005).

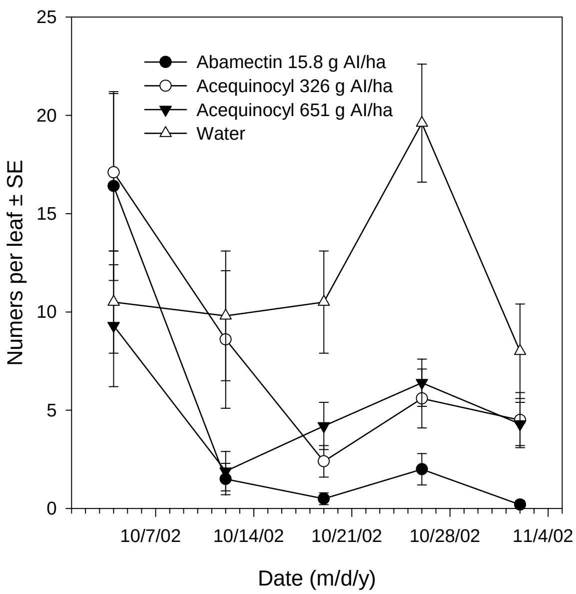

Figure 5. Numbers of *Polyphagolarsonemus latus* adults and numphs on pepper leaves in the field (Weslaco, Fall 2002).

significantly lower than those on the plants in water control (F=10.06; df = 3, 57; $P < 0.0001$), and there were no significant difference among the three miticide treatments (Table 1).

Jalapeño pepper plants damaged by *P. latus* were significantly different among the miticide treatments and water control ($F = 10.08$; df = 3, 57; $P = 0.0013$) (Table 2). Pepper plants in the water control plots showed severe damage. The terminal leaves and flower buds became malformed, and the young damaged leaves turned coppery or purplish. The plant growth was stunted, and the internodes shortened. The toxic saliva of *P. latus* caused twisted, hardened and distorted growth in the terminal of the plant.

DISCUSSION

Our results indicate that acequinocyl was an efficacious miticide against *T. urticae* on tomato under greenhouse conditions, and its efficacy against *T. urticae* on tomato lasted at least five weeks with only one thorough application. We also found that the efficacy of acequinocyl was as good as abamectin with few exceptions. Acequinocyl was also very effective against *P. latus* on Jalapeño pepper under field conditions in southern Texas. Although damage to the acequinocyl treated pepper plants were significantly lower than those sprayed water, the damage was still relatively higher than what the growers expected - a damage ranking of less than 2 on a damage scale of 1 to 5 with 5 for the most severe damage. However, the efficacies of acequinocyl were comparable with those of abamectin under both greenhouse and field conditions, and Acequinocyl could cost much less than abamectin (M. Shigesato, personal communication).

The mode of action of acequinocyl is different from most commonly used miticides. It has been found that the inhibition caused by acequinocyl occurs at the complex III in the mitochondrial electron transfer chain. On the basis of reduction kinetics of cytochromes b and c1, the binding site was shown to be ubiquinol oxidation site (Q0 center) of the complex III (Kinoshita et al. 1999).

Acequinocyl has been tested as an effective miticide against many species of spider mites, including *T. urticae*, *T. kanzawai*, *T. turkestan*, *P. citri*, *P. ulmi*, and *E. banksi*. In the laboratory studies, it has been found that acequinocyl was toxic to *T. kanzawai* eggs (Koura et al., 1998, Kinoshita et al. 1999, Wakasa and Watanabe 1999, Kimura and Ishiguri 2001). The formulation, Kanemite 15% SC, has been is widely used in Japan, Korea and Taiwan and has been recently registered in the US to control plant mite species. However, acequinocyl is not systemic, and it is taken up by the mite primarily by physical contact action and secondarily by feeding on surface residues. Therefore, it is very important that spraying principles are followed to ensure contact to the mites hidden on the undersides of leaves.

Acequinocyl has been considered as a safe miticide to predatory natural enemies, eggs and adult females of *Phytoseiulus persimilis*, adult females and immatures of *Amblyseius womersleyi* Schichathe; predatory thrips, *Scolothrips takahashii* Priesner (Thysanoptera: Thripidae) (Yoo and Kim 2000, Kim and Seo 2001, Mori and Gotoh 2001, Dekeyser 2005). It has been suggested from these results that acequinocyl could be incorporated into the integrated mite management system.

Although acequinocyl is an efficacious miticide, resistance management is critical to prolong its lifespan as an effective miticide. Acequinocyl offers new opportunities for mite control and miticide resistance management because it acts on the mite by inhibiting the electron transfer system by binding hydroxyl, and affecting mitochondrial respiration and previously unknown targets in mites that influence mite growth and development (Koura et al. 1998, Dekeyser 2005). In a laboratory study, Lee et al. (2004) found that the etoxazole R strain of *T. urticae* exhibited cross resistance to acequinocyl and emamectin benzoates in adult females. In contrast, Van Leuuwen et al. (2004) bioassayed a laboratory susceptible strain of *T. urticae* that was selected with chlorfenapyr resulting in a resistant strain with acequinocyl, and they did not find cross-resistance with acequinocyl. Therefore, selection of rotational and alternative miticides or insecticides should be careful to avoid the miticides that may become cross-resistant with the new miticide.

The strategies of resistance management include using cultural practices to avoid water-stress to keep plants healthy and vigorous; applying insecticides only when absolutely essential to avoid serious yield losses to avoid inducing mite outbreaks; using miticides sparingly, but effectively; rotating between different miticides to avoid using the miticides with the same chemistry with the same mode of action in the same fields year after year; always using labeled rates to avoid the use of reduced rates; minimizing pyrethroid insecticide use in areas where miticide resistance is a significant concern, to avoid development of cross-resistance; and using mixtures only where recommended and being aware of possible problems with mixtures. If growers follow the acequinocyl resistance management strategies as outlined above, I expect that acequinocyl will play an important role in mite management on vegetables.

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