Curative and Preventive Control of *Aceria aloinis* (Acari: Eriophyidae) in Southern California

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ABSTRACT The aloe mite, *Aceria aloinis* Keifer, causes physiological and morphological alterations in species of *Aloe* L. We conducted three trials to evaluate the potential of various miticides for curative and preventive control of damage caused by *A. aloinis*. In the first trial, the efficacy of nine miticides against aloe mite damage was assessed without the removal of infected tissue in *Aloe reitziiae* Reynolds. Although significant reductions in the number of mites and eggs were found due to the treatments, miticide application did not reduce the amount of plant area damaged or damage severity. Once the plants are infected, the irreversible damage by aloe mite progresses. The second trial analyzed the effects of seven miticides on aloe mite damage on *Aloe* 'Goliath' plants in which the damaged tissue was removed. Reduced damage severity and mite number was observed in all treated plants. To determine if aloe mite damage could be prevented, the effects of six miticides with and without surfactant were tested on uninfected plants of *Aloe spinosissima* A. Berger in a third trial. Except for chlorfenapyr and fenazaquin, all treatments reduced plant damaged area, damage severity, and the number of mites 60 wk following three miticide applications. The severity index in the second and third trials suggested that all treated plants would be marketable. Our study demonstrated that there were miticides that were effective by contact (carbaryl), translaminar (spiromesifen), and systemic (spirotetramat) action, which can be used to cure and to prevent aloe mite plant damage alone or in combination with cultural practices.

KEY WORDS aloe mite, mite management, miticide, translaminar, systemic

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More than three thousand species of eriophyid mites have been described, and most of them are host specific (Brodsgaard and Albajes 1999). *Aceria aloinis* Keifer, also called aloe mite, aloe gall mite, or aloe wart mite (Green 2008), feeds almost exclusively on *Aloe* spp. (Xanthorrhoeaceae), although it has also been reported on closely related plants such as *Gasteria* spp. and *Haworthia* spp. (Smith Meyer 1996, Deinhart 2011). Eriophyid mites feed on plant epidermal cells, causing morphological and physiological alterations (Brodsgaard and Albajes 1999, Graham 2004), sometimes referred to as aloe cancer (Kelly 2011), as they are tumor-like growths on leaves and inflorescences (Smith Meyer 1996, Deinhart 2011).

Aloe plants have traditionally been grown and harvested for aloe gel, which is used for its medicinal value. However, the demand for exotic ornamental aloe species has been increasing (Grace 2011), and the incidence of aloe mite damage in ornamental plant production has been increasing as well, especially in the more sensitive varieties (Personal observation LEV). Although aloes are tolerant to most insect pests, a wide array of these plants are affected by *A. aloinis*. The typical control method for aloe producers has been to destroy and discard infected plants (Faría 2002, Green 2008). This approach has been effective in commercial plantations for aloe gel, but the aloe mite causes severe damage to all sizes of potted ornamental aloes, rendering plants aesthetically unappealing and nonsaleable.

Effective management methods against aloe mites in ornamental plant production have not been explored using the relatively new set of miticides available on the market (Stamps and Osborne 2009). The objectives of this study were 1) to analyze the efficacy of various miticides for curative control of aloe mite on infected plants without removal of damaged tissue, 2) to determine the efficacy of several miticides to control aloe mite on infected plants and prevent reinfection after the removal of damaged tissues, and 3) to test miticides as preventive applications.

Materials and Methods

To analyze the curative and preventive effects of different miticides to control aloe mite damage, three trials were established at the Center for Applied Horticultural Research (CfAHR) located in

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Table 1. Characteristics of the miticides tested against *A. aloinis*

Active ingredient	Manufacturer	Mode of action (IRAC classification[a])	Dosage (100 liter^{-1})
Abamectin[b]	Syngenta Crop Protection, Inc., Greensboro, NC	Chloride channel activator, contact and translaminar (6)	31.2 ml
Bifenthrin	FMC Corporation, Philadelphia, PA	Sodium channel modulator, contact and residual (3A)	339.8 ml
Carbaryl[b]	Bayer CropScience Inc., Calgary, AB, Canada	Acetylcholine esterase inhibitor, contact (1A)	125.0 ml
Chlorfenapyr[b]	OHP Inc., Mainland, PA	Uncoupler of oxidative phosphorylation, translaminar (13)	40.6 ml
Etoxazole	Valent U.S.A. Corporation, Dublin, CA	Mite growth inhibitor, translaminar (10B)	119.8 g
Fenazaquin[b]	Gowan Company, Yuma, AZ	Contact (21A)	187.5 ml
Fenpropathrin	Valent U.S.A. Corporation, Dublin, CA	Sodium channel modulator, contact and stomach (3A)	125.0 ml
Fenpyroximate[b]	SePRO Corporation, Carmel, IN	METI, contact (21A)	187.5 g
Hexythiazox	Gowan Company, Yuma, AZ	Mite growth inhibitor, contact (10A)	15.6 g
Insecticidal soap	Gowan Company, Yuma, AZ	Contact	2000 ml
Milbemectin	Gowan Company, Yuma, AZ	Chloride channel activator, contact (6)	125.0 ml
Pyridaben	Gowan Company, Yuma, AZ	METI, contact (21A)	30 g
Spiromesifen[b]	OHP Inc., Mainland, PA	Inhibitors of acetyl CoA carboxylase, translaminar (23)	31.2 ml
Spirotetramat[b]	OHP Inc., Mainland, PA	Inhibitors of acetyl CoA carboxylase, systemic (23)	26.5 ml

[a] Insecticide Resistance Action Committee's mode of action classification (IRAC 2012).
[b] Labeled for use against eriophyid mites in ornamental plant production.

Vista, CA (33° 11′8.2″ N, 118° 49′16.66″ W). The characteristics of the miticides used in these trials are described in Table 1.

Curative Control of *A. aloinis* Without Removal of Infected Plant Tissue. The efficacy of nine miticides against *A. aloinis* was assessed on plants of *Aloe reitziiae* Reynolds variety *reitziiae* damaged by aloe mites. Seventy infested plants were obtained from a cooperating grower and transported to CfAHR. They were growing in 16.1-cm (2.37-liter) plastic containers (Pöppelmann Plastics USA LLC, Claremont, NC) filled with soilless substrate (Sunshine Mix # 4, Sun Gro Horticulture, Bellevue, WA) and were divided in groups of seven plants. Before treatment application, two plants per group were destructively sampled to confirm the presence of live *A. aloinis* (Table 2). The remaining five replicate plants per group received a single application of each miticide treatment (≈57 ml per plant) using a 5.7-liter portable pump sprayer (Solo Newport News, VA). The untreated controls received only water. After treatment application, plants were distributed at random in an outdoor nursery environment and were watered as needed. No additional fertilizer was required. Mean and standard deviation for daily temperature, relative humidity (RH), and total precipitation between 11 November 2009 and 4 January 2010 were 12.1 ± 0.3°C, 62.4 ± 9.3%, and 2.03 mm, respectively.

Table 2. Mean (± SE) of damaged area, damage severity rating, number of live mites, and number of eggs of *A. aloinis* on plants of *A. reitziiae* prior to treatment and 54 DAT with water (control) or with nine selected miticides

Treatment	Before treatment[a]				54 DAT[b]			
	Damaged area[c]	Damage severity[d]	No. of mites	No. of eggs	Damaged area[c]	Damage severity[d]	No. of mites	No. of eggs
Control	42.4 ± 13.4	2.8 ± 0.6	22.5 ± 8.5	22.5 ± 3.5	79.8 ± 26.3	4.0 ± 0.6	16.7 ± 5.8a	4.3 ± 1.9bc
Bifenthrin	12.9 ± 4.0	1.6 ± 0.6	24.5 ± 2.0	4.0 ± 2.0	101.1 ± 68.8	5.0 ± 0.0	3.3 ± 1.7bcde	0.0 ± 0.0d
Chlorfenapyr	6.9 ± 2.0	1.6 ± 0.4	13.0 ± 4.0	6.0 ± 4.0	48.2 ± 16.7	2.0 ± 0.6	14.7 ± 6.7abcd	17.3 ± 4.9a
Etoxazole	78.4 ± 23.2	2.8 ± 0.4	22.0 ± 2.5	5.5 ± 2.5	121.8 ± 44.7	3.7 ± 0.7	4.3 ± 3.8de	2.7 ± 2.2bcd
Fenpropathrin	23.7 ± 3.0	1.8 ± 0.6	18.0 ± 4.0	7.0 ± 4.0	52.4 ± 4.7	3.0 ± 0.6	2.3 ± 1.2e	1.0 ± 1.0cd
Hexythiazox	31.3 ± 12.2	2.4 ± 0.4	9.5 ± 1.0	1.0 ± 1.0	108.9 ± 29.5	3.3 ± 0.3	14.7 ± 5.0abc	18.7 ± 6.4a
Milbemectin	19.3 ± 4.8	1.4 ± 0.4	37.5 ± 2.5	14.5 ± 2.5	44.7 ± 9.9	2.7 ± 0.9	4.7 ± 4.2cde	3.7 ± 2.0bc
Pyridaben	47.1 ± 24.2	3.0 ± 0.9	16.0 ± 7.5	9.5 ± 7.5	93.9 ± 34.2	4.0 ± 0.6	15.0 ± 3.8ab	7.0 ± 2.6ab
Spiromesifen	15.8 ± 4.9	1.6 ± 0.2	17.5 ± 5.5	8.5 ± 5.5	34.8 ± 10.8	3.3 ± 0.7	0.0 ± 0.0e	0.0 ± 0.0d
Spirotetramat	25.7 ± 16.7	3.2 ± 0.7	23.0 ± 4.5	4.5 ± 4.5	31.8 ± 14.5	2.7 ± 0.9	3.3 ± 2.8e	0.0 ± 0.0d
P value	0.05	0.11	0.64	0.33	0.42	0.23	0.009	<0.0001

Within each column, means followed by the same letters are not significantly different at $P < 0.05$ as determined by Fisher's Protected Least Significant Difference.
[a] Before treatment data based on destructively sampling two plants per group.
[b] 54 DAT data based on destructively sampling five plants per treatment.
[c] The area (A) with visible aloe mite damage was calculated by measuring the length (L) and width (W) at the widest point of all lesions present in each plant using the formula: Area (cm^2) = L × W.
[d] Scale of damage severity rating: "1," no damage; "2," plants with small streaks of discoloration in a 2- to 10-cm^2 area; "3," obvious deformation without galls and a 10- to 50-cm^2 area of discoloration; "4," 50- to 100-cm^2 area of discoloration, and severe deformation with galls; "5," severe damage and the presence of >100 cm^2 of the plant discolored, deformed in cancerous-like growth, or both.

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To better describe the damage caused by *A. aloinis* on experimental plants, a damage severity rating was developed on a scale of 1–5. A damage severity rating of "1" indicated no damage; "2" was designated if the plants only contained small streaks of discoloration in a 2- to 10-cm^2 area, suggesting the presence of aloe mites; "3" indicated obvious deformation without evidence of galls, and a 10- to 50-cm^2 area of discoloration; a rating of "4" was designated when a 50- to 100-cm^2 area of discoloration was found, in addition to severe deformation with the presence of galls; and "5" indicated severe damage and the presence of >100 cm^2 of the plant discolored, deformed in cancerous-like growth, or both. In ornamental production, a rating of 2 or greater would mean the plant would be destroyed and discarded.

Fifty-four days after treatment application, all plants were destructively sampled to determine damage severity, the area damaged, and the number of mites and eggs. The area (A) with visible aloe mite damage was calculated by measuring the length (L) and width (W) at the widest point of all lesions present in each plant using the formula: A (cm^2) = L × W.

To sample for mites and mite eggs, plants were decapitated and the whole rosette was transported to the lab. Leaves were separated with care to recover full leaves with the corresponding sheaths attached and were examined under a stereomicroscope (Stereozoom 4, Bausch & Lomb, Rochester, NY). All leaves were examined until a leaf with mites was identified. The number of mites and mite eggs were counted in a 17.7-mm^2 area marked by a cork borer on one leaf per plant.

Curative Control of *A. aloinis* With Removal of Infected Plant Tissue. The efficacy of seven miticides against *A. aloinis* was assessed in plants of *Aloe* 'Goliath' with visible recent aloe mite damage which were growing in 7.57-liter pots. Aloe plants were divided in groups of seven plants per treatment. Before treatment application, damaged leaves were removed with care, pulling out the whole leaf, and cutting out as much as the sheath as possible. The average number of leaves per plant ranged from 8.1 ± 0.3–11.7 ± 4.8, and the number of damaged leaves removed by scalpel per plant ranged from 3.9 ± 0.3–7.3 ± 2.7. All damaged leaves were brought back to the laboratory and observed under a stereomicroscope to verify the presence of live *A. aloinis.*

Miticides were applied to each group of seven replicate plants on 12 January 2012 (80 ml per plant). Abamectin, fenazaquin, fenpyroximate, and spirotetramat were applied with a surfactant (0.7 ml $liter^{-1}$ of CapSil [Aquatrols, Paulsboro, NJ]). Carbaryl, spiromesifen, and the insecticidal soap were applied without a surfactant. There were two groups of untreated controls that only received water or surfactant.

Following preparation and treatment application, all plants were distributed at random in a climate-controlled greenhouse set at 23.89–18.3°C day–night temperature, and were watered as needed for the duration of the experiment. Additional fertilizer was not required.

Plants were checked for damage symptoms once a week and the number of days it took to observe damage was recorded. When damage was present, one leaf with damage symptoms was taken to determine the number of mites using a stereomicroscope.

Six months after treatment, the growth index [GI = (H + (D1+D2)/2)/2] of all plants was calculated based on the height (H), taken from the surface of the substrate to the tallest leaf, and the diameter (D) taken in two directions at the widest point (D1) and perpendicular to the widest point (D2).

The severity of damage was assessed on scale from 1 to 5 and the damaged area per plant was measured as indicated above. When damage was present, all leaves in each plant were inspected until mites were found and all the mites in that leaf were counted. If there was no evidence of damage, only two leaves from the central part of the rosette were sampled to confirm the lack of mites. The total number of leaves per plant was counted at the end of the trial as well, and from the total we determined the number of new leaves produced over the length of the trial.

Preventive Control of *A. aloinis.* The efficacy of six miticides with and without surfactant to prevent aloe mite damage was assessed in *Aloe spinosissima* A. Berger. Healthy cuttings of this plant were rooted in 6.25-cm-diameter containers filled with Sunshine mix # 4 (Sun Gro Horticulture, Bellevue, WA). They were fertilized once a month with 150 mg/liter of Peters Excel 15% N 5% P_2O_2 15% K_2O Cal-Mag Special (Everris, North Charleston, SC), and kept in a climate-controlled greenhouse (18.3–23.8°C night–day). Once roots developed, all plants were transferred to an outdoor area and were divided in groups of 16 plants per treatment. The uninoculated control was kept in the greenhouse to avoid mite colonization by wind dispersal.

Treatment applications were made to each group of 16 plants with a hand pressurized 5.7-liter sprayer (Solo Newport News) on 13 April 2011, 22 September 2011, and on 9 January 2012 (increasing from 6.26 ml per plant at the first application to 31.25 ml at the third application for complete coverage). After treatment application, aloe plants were placed in trays (pot holders, Dillen Products, Middlefield, OH) ≈30 cm apart and organized in a completely randomized design. They were indirectly inoculated with *A. aloinis* by placing several infected plants in proximity to but not touching the healthy ones. Mean and standard deviation for daily temperature and RH, between April 2011 and May 2012, were 16.4 ± 12°C and 52.2 ± 28.6%, respectively.

All plants were inspected once a week for signs of aloe mite infection beginning 9 September 2011. Sixty weeks after treatment, they were taken to the lab to determine damage severity, amount of area damaged, and the number of live mites in one leaf per plant.

Data Analysis. The effects of the different pesticides on the number of live mites and eggs per leaf, plant area damaged and damage severity, number of leaves per plant and growth index, were analyzed by analysis of variance (JMP Version 9.0, SAS Institute

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Table 3. Mean (± SE) damage severity, number of live *A. aloinis*, plant height, growth index, and number of new leaves produced on *Aloe* 'Goliath' 6 mo after treatment with selected miticides

Treatment	Damage severity[b]	No. of mites	Height (cm)	GI[c]	No. of new leaves[d]
Control	3.9 ± 0.4a	29.3 ± 11.9a	20.1 ± 3.0de	20.2 ± 2.9bc	2.6 ± 0.6e
Control[a]	3.3 ± 0.8ab	29.6 ± 12.9ab	19.3 ± 2.8de	20.9 ± 2.7bc	3.6 ± 1.1de
Abamectin[a]	1.6 ± 0.2de	1.9 ± 1.9cd	26.7 ± 3.2bcd	26.5 ± 3.7ab	4.9 ± 1.0bcde
Carbaryl	1.0 ± 0.0e	0.0 ± 0.0d	35.4 ± 1.4a	34.0 ± 2.5a	7.6 ± 1.2ab
Fenazaquin[a]	2.2 ± 0.8bc	10.4 ± 6.3bc	22.3 ± 3.2cde	20.9 ± 2.6bc	4.3 ± 1.2cde
Fenpyroximate[a]	1.9 ± 0.9cd	3.9 ± 3.2cd	18.5 ± 4.0e	18.3 ± 3.3c	4.1 ± 0.6cde
Insecticidal soap	1.5 ± 0.3de	0.3 ± 0.3d	21.5 ± 2.3cde	20.3 ± 2.0bc	8.7 ± 1.3a
Spiromesifen	1.0 ± 0.0e	0.0 ± 0.0d	29.4 ± 1.7abc	27.7 ± 2.2ab	6.0 ± 0.6abcd
Spirotetramat[a]	1.0 ± 0.0e	0.0 ± 0.0d	34.2 ± 3.1ab	32.0 ± 2.7a	6.9 ± 1.7abc

All plants used in the trial were infested with aloe mites, but infested leaves were removed prior to miticide applications.

Data represent the Mean ± SE of seven replicates per treatment. Within each column, means followed by the same letters are not significantly different at $P \leq 0.05$ as determined by Fisher's Protected Least Significant Difference.

[a] CapSil (Aquatrols, Paulsboro, NJ) was added at 0.7 ml liter^{-1} as a surfactant.

[b] Scale of damage severity rating: "1," no damage; "2," plants with small streaks of discoloration in a 2- to 10-cm^2 area; "3," obvious deformation without galls and a 10- to 50-cm^2 area of discoloration; "4," 50- to 100-cm^2 area of discoloration, and severe deformation with galls; "5," severe damage and the presence of >100 cm^2 of the plant discolored, deformed in cancerous-like growth, or both.

[c] The growth index (GI) was calculated based on the height (H), taken from the surface of the substrate to the tallest leaf, and the diameter (D), taken in two directions, at the widest point and perpendicular to the widest point, using the formula: GI = [H + (D1+D2)/2]/2.

[d] The number of new leaves is the difference between the number of leaves left on the plant following the removal of infected leaves at the beginning of the trial and the total number of leaves at the end of the trial.

Inc., Cary, NC). Logarithmic transformation was applied when needed to satisfy assumptions of normality and homogeneity of variance. Means were compared using the Fisher Protected Least Significant Difference ($P < 0.05$).

Data generated from only water-treated plants ($N = 16$) in the preventive treatment trial were used to correlate the number of live mites and the amount of area damaged (JMP Version 9.0, SAS Institute Inc.).

Results

Curative Control of *A. aloinis* Without Removal of Infected Plant Tissue. Before treatment application, there were no statistically significant differences in the area damaged ($P = 0.05$), the damage severity ($P = 0.11$), the number of live mites ($P = 0.64$), and the number of eggs ($P = 0.33$) on aloe experimental plants (Table 2). Fifty-four days after treatment (DAT) application, aloe plants treated with bifenthrin, etoxazole, fenpropathrin, milbemectin, spiromesifen, and spirotetramat, had significantly lower number of live mites ($F = 3.53$; df = 9, 20; $P = 0.0089$) and with bifenthrin, spiromesifen, and spirotetramat had a significantly lower number of eggs ($F = 8.18$; df = 9, 20; $P < 0.0001$) than untreated plants. Chlorfenapyr, hexythiazox, and pyridaben appeared to be ineffective because there were no significant differences between the number of live mites found in the plants treated with these miticides and the number observed in the untreated plants. No significant differences were found between the number of eggs of *A. aloinis* in plants treated with pyridaben and the controls, but plants treated with chlorfenapyr and hexythiazox had greater number of mite eggs than untreated plants (Table 2).

Miticide application had no effect on the amount of plant area damage ($P = 0.42$) or damage severity ($P = 0.23$). Plant area damaged and damage severity increased numerically in all treatments 54 DAT. No treatment held the damage rating below 2.0, and they would not be marketable.

Curative Control of *A. aloinis* With Removal of Infected Plant Tissue. Symptoms of damage in some of the treated plants began ≈75–85 DAT. Those treated with insecticidal soap (81 ± 2.9 d), fenazaquin + surfactant (98.5 ± 10.5 d) and fenpyroximate + surfactant (85 ± 4.1 d) began to show symptoms of damage significantly later ($F = 6.97$; df = 5, 20; $P = 0.0006$) than untreated plants (77 ± 1.4 d). Plants in all treatments except those treated with surfactant alone had less damage severity ($F = 8.30$; df = 8, 53; $P < 0.0001$) and lower number of mites ($F = 6.57$; df = 8, 53; $P < 0.0001$) than the untreated controls six months after treatment (MAT) application (Table 3). Plants treated with carbaryl, spiromesifen, and spirotetramat + surfactant did not show damage symptoms nor presence of live mites six MAT. Additionally, they were also taller ($F = 5.08$; df = 8, 53; $P = 0.0001$), had greater growth index ($F = 4.24$; df = 8, 53; $P = 0.0006$, except in the spiromesifen-treated plants), and a greater number of new leaves ($F = 3.33$; df = 8, 53; $P = 0.0037$) than the untreated controls. Plants treated with insecticidal soap also had a very low number of live mites, severity of damage, and a significantly greater number of new leaves than the controls, but the height and GI of the plants were statistically equal to the controls (Table 3).

Preventive Control of *A. aloinis*. Noninoculated control plants were damage and mite free throughout the trial (60 wk) following three applications of miticides with and without surfactant (Table 4). All treated plants had statistically equal damage area, damage severity, and number of live mites compared with the noninoculated controls except those treated with fenazaquin alone. All treated plants except those treated with fenazaquin alone had smaller damage area than inoculated control plants ($F = 2.79$; df = 15,

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Table 4. Mean (± SE) damaged area, damage severity rating, and number of live mites of *A. aloinis* on plants of *Aloe spinosissima* 60 wk after treatment with selected miticides

Treatment	Damaged area[a]	Damage severity[b]	No. of mites
Inoculated control	8.40 ± 3.90a	2.1 ± 0.4a	2.8 ± 1.5a
Inoculated control[c]	3.40 ± 1.70ab	1.6 ± 0.3abc	1.9 ± 0.9ab
Noninoculated control	0.00 ± 0.00c	1.0 ± 0.0d	0.0 ± 0.0c
Noninoculated control[c]	0.00 ± 0.00c	1.0 ± 0.0d	0.0 ± 0.0c
Carbaryl	0.29 ± 0.20bc	1.2 ± 0.1cd	0.0 ± 0.0c
Carbaryl[c]	0.48 ± 0.30bc	1.2 ± 0.1cd	0.0 ± 0.0c
Chlorfenapyr	2.06 ± 1.90bc	1.5 ± 0.3abcd	1.1 ± 0.8abc
Chlorfenapyr[c]	0.71 ± 0.60bc	1.2 ± 0.1cd	0.0 ± 0.0bc
Fenazaquin	22.20 ± 11.50a	1.9 ± 0.4ab	2.3 ± 1.7ab
Fenazaquin[c]	0.00 ± 0.00c	1.0 ± 0.0d	0.0 ± 0.0c
Fenpyroximate	0.00 ± 0.00c	1.1 ± 0.1cd	0.0 ± 0.0c
Fenpyroximate[c]	0.04 ± 0.04c	1.1 ± 0.1cd	0.0 ± 0.0c
Spiromesifen	1.56 ± 1.60bc	1.2 ± 0.2cd	0.0 ± 0.0c
Spiromesifen[c]	0.66 ± 0.51bc	1.3 ± 0.1bcd	0.0 ± 0.0c
Spirotetramat	0.75 ± 0.50bc	1.3 ± 0.2abcd	0.0 ± 0.0c
Spirotetramat[c]	0.04 ± 0.04c	1.1 ± 0.1cd	0.0 ± 0.0c

Plants received three applications during the length of the trial ≈100 d apart.

Data represent the Mean ± SE of 16 replicates per treatment. Within each column, means followed by the same letters are not significantly different at $P \leq 0.05$ as determined by Fisher's Protected Least Significant Difference.

[a] The area (A) with visible aloe mite damage was calculated by measuring the length (L) and width (W) at the widest point of all lesions present in each plant using the formula: Area (cm^2) = L × W.

[b] Scale of damage severity rating: "1," no damage; "2," plants with small streaks of discoloration in a 2- to 10-cm^2 area; "3," obvious deformation without galls and a 10- to 50-cm^2 area of discoloration; "4," 50- to 100-cm^2 area of discoloration, and severe deformation with galls; "5," severe damage and the presence of >100 cm^2 of the plant discolored, deformed in cancerous-like growth, or both.

[c] CapSil (Aquatrols, Paulsboro, NJ) was added at 0.7 ml $liter^{-1}$ as a surfactant.

240; $P = 0.0005$). However, only plants treated with fenazaquin + surfactant, fenpyroximate with and without a surfactant, and spirotetramat + surfactant had smaller damaged areas than inoculated, surfactant-treated plants. All treated plants except those treated with chlorfenapyr, fenazaquin, and spirotetramat had less damage severity than inoculated control plants ($F = 2.29$; df = 15, 240; $P = 0.0046$). However, only plants treated with fenazaquin + surfactant had less damage severity than inoculated, surfactant-treated plants. All treated plants in this trial attained a severity rating below 2.0 and would be marketable. Regardless, all treated plants except those treated with chlorfenapyr or fenazaquin had fewer live mites than inoculated control plants ($F = 3.26$; df = 15, 240; $P < 0.0001$). All plants except those treated with chlorfenapyr, chlorfenapyr + surfactant, and fenazaquin had fewer live mites than inoculated, surfactant-treated plants. The addition of a surfactant to fenazaquin significantly improved performance compared with the use of fenazaquin alone (Table 4).

There was a positive correlation between the number of mites and damaged area ($r^2 = 0.75$; $P < 0.0001$; Fig. 1).

Discussion

The objective of this study was to evaluate the potential of various miticides for curative and preventive control of aloe mite damage in slow-growing ornamental aloes. Aloes are succulent plants with thick waxy cuticles and Crassulacean Acid Metabolism (Kelly 2011), and it is known that the morphological and physiological characteristics of the plants influence the persistence and efficacy of pesticides (Edwards 1975). Our results showed that there are effective miticides and cultural methods that can be used alone or in combination for aloe mite control on a succulent plant like aloe. We found miticides with different modes of action and that are translaminar or

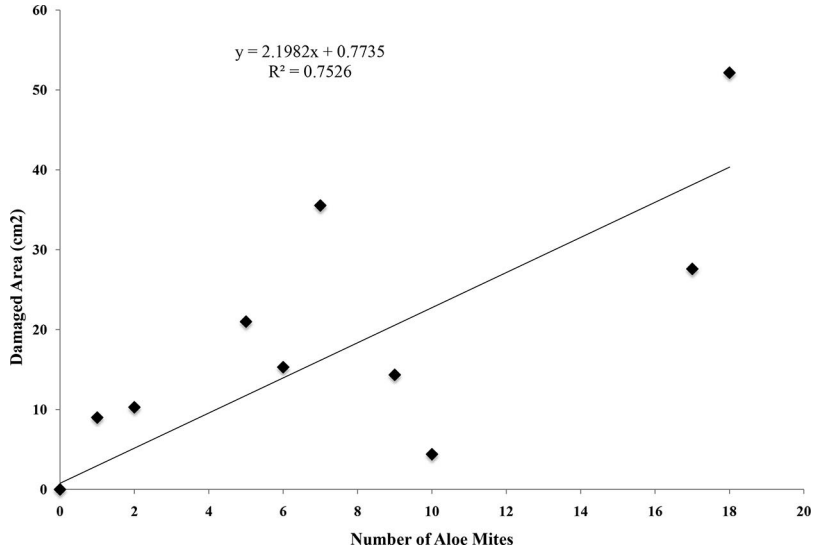

Fig. 1. Relationship between number of aloe mites per plant and the amount of plant area damaged using data generated from 16 replicates of water-treated controls in the preventive trial.

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systemic or that work on contact that can be used to cure or to prevent aloe mite damage, but similar to other commodities, different products have different efficacies due to the plant type, growing conditions, or gall or erinea formation. Additionally, our study suggested that the addition of a surfactant did not improve efficacy of the miticides with the exception of one product, fenazaquin.

In addition to aloe mite's small size, which makes it difficult to detect mite infestations until the plant has been disfigured, eriophyid mites are challenging to control because they induce the formation of protective plant structures (e.g., galls, blisters, erinea) that impede the direct contact of pesticides. Additionally, aloe mites prefer to occupy young plant tissues, at the point of insertion between leaves and stems, further complicating pesticide coverage. Control of infected plants was possible, as long as the damaged tissues with mites were removed before the miticide application. Treatment with miticides without removal of infected tissues and mites was not effective, as indicated by the increases in the area of plant damaged and damage severity, even when the mites were killed or reduced. In contrast, treatment with carbaryl, spiromesifen, and spirotetramat retarded the evidence of damage symptoms and prevented reinfection of the plants in which the damaged tissue was removed. Therefore, a preventive program is preferred, as once the plants are infected the irreversible damage by aloe mite progresses. Indeed, most of the preventive applications (three applications in a year's span) kept the treated plants free of aloe mite for over a year with the exception of chlorfenapyr and fenazaquin. All aloes treated preventively had a damage rating that indicated they would be marketable. Carbaryl, fenpyroximate, spiromesifen, and spirotetramat were effective as a cleanup with infected tissue removal and as a preventive application.

Some products are not labeled for eriophyid mite control but proved to be efficacious in our trials. Bifenthrin, etoxazole, fenpropathrin, milbemectin, and insecticidal soap, reduced the number of live mites and eggs compared with the untreated controls. However, other studies have found that bifenthrin and fenpropathrin provide initial eriophyid mite control, but mite population resurgence occurs due to the toxicity of these chemicals on the natural enemies of the host plants' mites (Ashihara et al. 2004, Van Leeuwen et al. 2010). These chemicals were not tested in the preventive trial, so further studies are needed to determine whether these products are also effective to prevent aloe mite infection.

Pyridaben is considered to be a safer product to beneficial insects, has lower mammalian toxicity, and shorter environmental persistence than other chemicals (Dekeyser 2005). This chemical was not effective for aloe mite control in our study, but was effective in reducing blueberry bud eriophyid mite survival (Isaacs et al. 2004). Similarly, hexythiazox was ineffective in our study and ineffective in reducing the number of mites per leaf in the New Mexico Olive tree (Grasswitz 2012), *Aceria schlechtendali* (Nal.) (Pfeiffer et al. 1989), and *Eriophyes pyri* (Pagenstecher) (Reidl and Shearer 1988), but one study using hexythiazox demonstrated mortality of *Aceria litchii* (Keifer) (Azevedo et al. 2013).

Several studies have also shown that eriophyid mites are susceptible to a wide variety of insecticides, acaricides, and fungicides (Childers et al. 1996, Isaacs et al. 2004, Van Leeuwen et al. 2010, Azevedo et al. 2013), but these studies are on plant types and commodities that are vastly different than an ornamental succulent like aloe. For instance, abamectin provided 100% control of the blueberry bud mite, *Acalitus vaccinii* (Keifer) (Isaacs et al. 2004), the litchi erineum mite, *A. litchii* (Azevedo et al. 2013), and of an undescribed species of *Aceria* that affects New Mexico Olive tree (Grasswitz 2012). Carbaryl has also been shown to be effective against other gall eriophyids such as *Aculops fuchsiae* (Keifer) (Koehler et al. 1985), and *A. litchii* (Azevedo et al. 2013). Fenazaquin and milbemectin were effective to control *Aceria* spp. in New Mexico olive tree (Grasswitz 2012), and fenpyroximate caused high mortality of *A. litchii* (Azevedo et al. 2013).

We demonstrated effective mite control and effective damage prevention or management methods for aloe mite damage reduction in ornamental aloes that can take years to bring to market. The common practice is to throw infected plants away to avoid infecting the mass production of aloe or because it is too costly to try to rehabilitate the plants due to the investment in water, labor, and care of potted aloes. Therefore, we have provided ornamental growers with management options that will reduce or eliminate the need for destroying infected plants, and growing a viable crop when aloe mite is present and a threat. However, some of our results may also be applicable in other crops where aesthetics are not as important. Curative treatments may be particularly valuable for germplasm preservation.

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