Evaluation of Reduced-Risk Insecticides for Armored Scales (Hemiptera: Diaspididae) Infesting Ornamental Plants[1]

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ABSTRACT Armored scale insects (Hemiptera: Diaspididae) are economically important pests of ornamental trees and shrubs in nurseries and landscapes. The cycad aulacaspis scale, *Aulacaspis yasumatsui* Takagi, and the tea scale, *Fiorinia theae* Green, are economically important armored scale pests of cycads, *Cycas* spp., and camellia, *Camellia* spp., respectively, in the southeastern United States. Our objective was to evaluate fungal, botanical, and chemical insecticides that were applied as foliar sprays or drenches when the motile crawler stages were active. In tests with *A. yasumatsui* over two years, products based on a mineral oil (SuffOil-X®), azadirachtin (Molt-X®), an entomopathogenic fungus (BotaniGard®-ES), and an azadirachtin/fungus combination applied three times, significantly reduced the number of scales on cycads, *Cycas revoluta* Thunb., over 3–4 months, but were less effective overall compared with the insecticidal standard dinotefuran (Safari®). In tests with *F. theae*, spinetoram + sulfoxaflor (GF-2860), cyantraniliprole (Mainspring®), pyriproxifen (Distance®), buprofezin (Talus®), horticultural oil (SuffOil-X), and dinotefuran (Safari) applied between one and three times, significantly reduced scale numbers (adults and large nymphs) on established foliage (older leaves) of Japanese camellia, *Camellia japonica* L., compared with controls within five months. The apparent slow activity (decline) in numbers of armored scales on old foliage was influenced by the difficulty of differentiating between live and dead insects that remained attached to leaf surfaces for some time after death. Monitoring infestations spreading to new foliage later in the season is a more reliable method to estimate the efficacy of insecticides against this group of pests.

KEY WORDS Cycad aulacaspis scale, tea scale, *Aulacaspis yasumatsui*, biorational insecticide, sago palm, camellia, *Cycas*

Among the scale insects (Coccoidea), the armored scale (Hemiptera: Diaspididae) are the most diverse, with over 2650 species in 418 genera currently recognized (Morales et al. 2015). Diaspidids include some of the most widespread and economically significant pests of woody plants, including many species that are invasive and highly polyphagous (Miller et al. 2005). The removal of plant nutrients by scale insects does not generally cause immediate mortality, but often

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causes plant stress and aesthetic damage. Long-term feeding may result in branch dieback, and potentially death if not managed (Miller & Davidson 2005, Camacho & Chong 2015). Armored scales cause regulatory difficulties in interstate shipment of plants, since they are difficult to detect and identify (Millar et al. 2012).

In the southeastern United States, armored scales infest most types of woody and herbaceous ornamental plants grown in nurseries and landscapes. A case in point is that since it arrived in Florida in 1996, the cycad aulacaspis scale, *Aulacaspis yasumatsui* Takagi, has become a significant pest on popular ornamental cycads, especially *Cycas* spp. (Cycadaceae). This insect has resulted in the removal of thousands of plants from the landscape, and has spread to other regions (Howard et al. 1999, Germain & Hodges 2007). By themselves, natural enemies appeared to be ineffective at providing satisfactory control of *A. yasumatsui* (Wiese et al. 2005, Cave 2006). The tea scale, *Fiorinia theae* Green, is another invasive armored scale from Asia (Green 1900) that was introduced in the southeastern United States and elsewhere. In these regions, *F. theae* infests many different plants, but is most commonly associated as a pest of camellias and hollies (Miller et al. 2005).

Chemical control is the primary management approach reported for scale insects infesting ornamental nursery plants in the southeastern United States (Fulcher et al. 2012, LuBude et al. 2012). An obstacle to using contact insecticides for armored scales is a shell (scale) composed of wax and exuviae that protects the insect. Traditional contact insecticides, including pyrethroids or horticultural soaps and oils, are most effective against the first instar motile ‘crawler’ stages, which lack the waxy cover. However, repeated applications of these products are often necessary because crawlers may emerge over several weeks or months (Raupp et al. 2001). Currently, several systemic insecticides, particularly the neonicotinoids, are used for management of scale insects. The ability of neonicotinoids, such as dinotefuran, to be applied as soil drench/injection, trunk spray/injection, or as a granular broadcast, makes them the preferred management tool against scale insects on large trees and shrubs in urban landscapes where spray drift is undesirable (Camacho & Chong 2015). Although neonicotinoids have benefits of greater flexibility and residual activity, along with other insecticides they should be used carefully due to potential impacts on pollinators (Godfray et al. 2015) and the possibility to induce secondary pests due to their negative impacts on beneficial arthropods (Szczepaniec et al. 2011, 2013).

Reduced-risk insecticides with low impacts on natural enemies and pollinators (EPA 2016) provide alternative management tools for control of scale insects. Entomopathogenic fungi are potential candidates because some have been shown to be able to penetrate and germinate through armored scale covers under natural conditions (Marcelino et al. 2009). Several newer reduced-risk insecticides have not been widely tested against armored scales. Here we report on field tests conducted over two years in which entomopathogenic fungi and other reduced-risk insecticides were tested against established populations of *A. yasumatsui* and *F. theae* infesting containerized ornamental plants under nursery conditions.

Materials and Methods

Cycad aulacaspis scale: Plants and insects. One hundred three-year-old sago palms, *Cycas revoluta* Thunb., were obtained from a local nursery and transplanted into 26.5 L (7 gal) containers filled with growing medium consisting of 55% pine bark, 35% NuPeat (equal parts composted yard waste, hardwood bark and Florida Sedge peat), and 10% coarse sand (amended with 0.68 kg/m^2 micronutrients and 2.3 kg/m^3 dolomite limestone) (Florida Potting Soil, Inc. Apopka, FL). Plants were maintained on a nursery pad (22 ×13 m) and held for at least six months to allow any insecticide residues to dissipate. Plants were fertilized with slow-release Osmocote® Plus 15-9-12 (The Scotts Company, Marysville, OH) at the rate of 104 g/container every three months and were hand watered (about 10 liters water/plant as needed).

Infestations of *A. yasumatsui* were established on sago palms in 2013 by placing sections of infested fronds on top of the plants. The infested fronds were collected from natural infestations in the surrounding region when crawler activity was detected. Plants were first used in tests the following year, when scale populations had established on most fronds of test plants.

Cycad aulacaspis scale: Insecticide treatments. The following products and rates were tested against *A. yasumatsui* on sago palms: *Beauveria bassiana* Strain GHA (BotaniGard® ES containing 2.1×10^{13} spores/liter, Laverlam International Corp., Butte, MT) at 2.5 ml/L, azadirachtin 3% v/v (Molt-X®, BioWorks Inc., Victor, NY) at 0.8 ml/L, mineral oil (SuffOil-X® EC, BioWorks, Inc.) at 20 ml/L, and dinotefuran (Safari®- 20 SG, Valent USA, Inc., Walnut Creek, CA) as an insecticidal standard at 0.3 g/L.

The first experiment was conducted from July to November 2014. A randomized complete block design with 1.5 m spacing between plants was used to assign five treatments (four insecticides plus a control) with five replications. Treatments were applied as foliar sprays to the upper and lower sides of each frond and the main trunk, when crawlers were observed emerging from underneath females. Treatments were applied using a CO_2-pressurized sprayer of 10 L capacity (R&D Sprayers, Opelousas, LA). Fitted with a hollow cone nozzle and operating at 206 kPa, the sprayer was calibrated to apply a volume application rate of 1870 L/ha. The surfactant CapSil® (Aquatrols, Paulsboro, NJ) was used at 1mL/L (6 fl oz/100 gal) in all treatments, except for BotaniGard, which already contained an emulsifying wetting agent. Control plants were treated with water plus CapSil only. The first treatments were applied on 19 July 2014, and they were repeated at 10 and 40 days after first treatment (DAT), except for Safari that was only applied at 10 DAT.

A second experiment was conducted from June to October 2015 using different plants. The same treatments and experimental design as in 2014 were tested, with the addition of a combination treatment of BotaniGard plus Molt-X (with each at one-half the previous rate). The goal was to assess the compatibility, and look for potential additive or synergistic interactions between entomopathogenic fungi with azadirachtin, which has been previously observed (Mohan et al. 2007, Islam et al. 2010, Hernández et al. 2012). The first treatments were applied on 26 June 2015 and repeated at 10 and 40 DAT, except for Safari.

Cycad aulacaspis scale: Data collection. Large nymphs and adult *A. yasumatsui* (excluding crawlers) were sampled from fronds pretreatment and at 2–3 week intervals for 3–4 months. The proportion of fronds that were visibly infested was noted *in situ*. To estimate the scale density, a single pinnae (leaflet) mid-way up the frond was randomly selected and removed from six different fronds from each sago plant. Adult females and immature scales were counted at 20X under a dissecting microscope. The number of live scales was estimated by excluding old dead dried scales noted under the cover. New fronds were examined later in the season as they became available and data analyzed separately to determine if the scale infestation was spreading to new growth via crawler movement. Any scales with small exit holes (i.e., characteristic of parasitoid emergence) were noted. The presence of visual phytotoxicity was noted.

Environmental conditions monitored from a nearby weather station (http://fawn.ifas.ufl.edu/) remained generally hot and sunny, with average daily maximum and minimum values ranging from 20.3–32.1°C and 59–95% RH in 2014, and 22.4–33.3°C and 71-95% RH in 2015. There were frequent afternoon showers during the summer, with 45 cm rainfall in 2014 and 58 cm in 2015; however insecticides were not applied within 24 hours of rain.

Tea scale: Plants and insects. Seventy three-year-old Japanese camellia plants, *Camellia japonica* L. (Theaceae), partially infested with *F. theae* were obtained from a local nursery in March 2014 and transplanted into 18.9-L containers using the specialty potting mix described above. Plants were maintained in a shadehouse (12 × 12 m). The shade cover was applied in June, when sunlight intensity at solar noon reached about 1,000 W/m^2. Plants were fertilized with Osmocote® Plus 15-9-12 at 73 g/container every three months. Plants were fitted with microjet irrigation (spray stakes) fitted to a central control unit that delivered up to four liters water/plant/day depending on need. To increase scale populations for tests, cut fronds containing crawlers were moved between plants in 2014 to increase and standardize infestation levels. The study was conducted the following year (2015), when scale was established on 60–70% of the leaves.

Tea scale: Insecticide treatments. We evaluated foliar and drench insecticide treatments (based on IR-4 protocol #14-006) against *F. theae* infesting Japanese camellia in containers under shadehouse conditions from March through August 2015. The foliar treatments were spinetoram + sulfoxaflor (GF-2860 40WG, Dow AgroSciences, Indianapolis, IN) applied twice at three rates (0.15, 0.21, and 0.26 g/L; i.e., 2.0, 2.75, and 3.5 oz/100 gallon), two insect growth regulators [pyriproxifen (Distance®, Valent USA) applied once at 0.94 ml/L (12 fl. oz/100 gal), and buprofezin (Talus® 70DF, SePRO, Carmel, IN) applied twice at 1.05 g/L (14 oz/100 gal)], a mineral oil (SuffOil-X, BioWorks Inc.) applied three times at 2% v/v. Drench treatments were cyantraniliprole (Mainspring® 200 SC, Syngenta US, Greensboro, NC) applied once at 0.94 ml/L (12 fl.oz/100 gal) or twice at 0.63 ml/L (8 fl.oz/100 gal), and dinotefuran (Safari- 20SG, Valent USA) applied once at 1.8 g/L (24 oz/100 gal).

The experimental design was a randomized complete block design with 10 treatments and six replicate plants at 1-m spacing within blocks. Foliar treatments were applied to drip on both sides of the leaves with a CO_2 sprayer (R&D Sprayers) set at 206 kPa, with a hollow-cone nozzle delivering 1870 L/ha (200 gallons/A). The wetting agent CapSil was added to foliar treatments excluding SuffOil-X at 1ml/L (6 fl oz/100 gal). Control plants were treated twice with water plus CapSil to account for any effect of the surfactant. Drenches were applied in 1.2 L/container for Mainspring or 0.6 L/container for Safari. Treatments were first applied in the spring (13 March 2015) when crawler activity was detected and continued through 10 April 2015 when spring crawler activity had declined. The partial windbreak provided by the shadehouse walls reduced the risk of crawlers blowing to adjacent plants.

Tea scale: Data collection. Tea scale (adult female, settled nymphs and male tests) were sampled from five randomly selected leaves per plant prior to treatments (12 March 2015) and at 7, 14, 21, 35, 76, and 150 DAT. Leaves were examined *in situ* with a 10X hand lens. Leaves from new seasonal growth (5 leaves/plant) were included as they became available to determine if the infestation was spreading to new growth via movement of crawlers. The proportion of leaves infested was determined using the following scale: 0 = no infestation, 1 ≤ 10% leaf infestation, 2 = 11–30%, 3 = 31–50%, 4 = 51–70%, 5 = ≥ 71% leaf infestation. Natural enemy activity was noted while sampling and when examining scales in the laboratory for the presence of parasitoid exit holes. Visual evidence for any phytotoxicity was assessed. Environmental conditions during the test period (daily maximum and minimum values) ranged from 20–32°C and 56–92% RH and with 56 cm rainfall; however insecticides were not applied within 24 h of rain.

Data analyses. Data were subjected to analysis of variance (ANOVA) for treatment effects with means separately by Tukey's HSD test at $P < 0.05$. In 2015, means for *A. yasumatsui* tests were separated via Fisher's LSD tests to account for a higher variability among replicates. If necessary, all count data were transformed via ln (n+1) and proportional data via arcsine prior to analysis. Treatment effects on the infestation index collected for the *F. theae* scale test were compared with Chi-square values (2-sided) based on a cross tabulation of treatment and infestation scale. Analyses were performed with Statistical Analysis System v.9.2 (SAS 2008).

Results

Cycad aulacaspis scale. In 2014, the number of *A. yasumatsui* on insecticide-treated plants declined significantly when compared with controls (Table 1). Overall, dinotefuran performed best, reducing scale by 92% at 30 DAT, and populations remained low through the end of the study. All insecticides reduced scale density by 53 DAT and achieved greater than 90% reduction (*B. bassiana* treatments were slightly less effective with approximately 80% reduction in scale density) by the end of the study. However, the proportion of mature (established) fronds that remained visibly infested with scale remained high (at least 76%) throughout the study in all treatments because most scales did not readily slough off after death (Table 2). Only dinotefuran reduced the proportion of infested mature fronds by 53 DAT. A more distinct difference among insecticide treatments was observed in the number of new scale on newly emerging fronds (seasonal growth). The proportion of new fronds that became infested after 88 DAT remained low in the mineral oil, azadirachtin, and dinotefuran treatments (Table 3). The same trend was not observed in the *B. bassiana* treatments, in which new fronds became infested at a similar rate to control plants.

In 2015, *A. yasumatsui* densities were higher overall, probably due to infestations having become established on plants, including the trunk and roots, in the previous year. All insecticide treatments again provided significant control. Dinotefuran and mineral oil provided the best control overall, with greater than 99% reduction in density of live scale on both mature (Table 4) and new fronds (Table 5) by 94 DAT. Declines in scale among treatments were observed between 30 and 45 DAT. Infestation on new fronds (seasonal growth) due to crawler

Table 1. Mean number of cycad aulacaspis scale (CAS) on sago palms at various days after treatment (DAT) with foliar insecticides in 2014.

Treatment	Rate/liter	Application (DAT)	Mean no. live CAS per pinna[a,b]						
			Pre	16 DAT	30 DAT	53 DAT	67 DAT	88 DAT	114 DAT
Control (water/surfactant)	n/a	0, 10, 40	10.3a	8.7a	12.3a	7.1a	9.5a	8.4a	8.5a
Mineral oil	20 ml	0, 10, 40	7.0a	3.0a	5.5ab	0.7c	1.1b	0.3bc	0.4bc
B. bassiana GHA	2.5 ml	0, 10, 40	5.2a	4.4a	3.8bc	2.2bc	1.1b	1.7b	1.8b
Azadirachtin 3%	0.8 ml	0, 10, 40	12.2a	7.5a	8.3ab	4.2ab	1.6b	0.6bc	0.5bc
Dinotefuran	0.3 g	0, 10	5.2a	2.8a	1.0c	2.2bc	0.3b	0.2c	0.2c

[a] Means within columns followed by different letter are different ($P < 0.05$, Tukey's HSD test).

[b] CAS comprised adult females, settled nymphs (excluding crawlers) and male pupae.

Table 2. Mean percent of mature sago palm fronds infested with cycad aulacaspis scale (CAS) at various days after treatment (DAT) with foliar insecticides in 2014.

Treatment	Rate/liter	Application (DAT)	Mean % CAS-infested fronds[a,b]						
			Pre	16 DAT	30 DAT	53 DAT	67 DAT	88 DAT	114 DAT
Control (water/surfactant)	n/a	0, 10, 40	100a	94a	100a	100a	100a	100a	100a
Mineral oil	20 ml	0, 10, 40	94a	86a	96a	100a	100a	98ab	98ab
B. bassiana GHA	2.5 ml	0, 10, 40	100a	82a	100a	100a	100a	100a	100a
Azadirachtin 3%	0.8 ml	0, 10, 40	86a	92a	70a	100a	100a	84ab	84ab
Dinotefuran	0.3 g	0, 10	92a	76a	96a	90b	84b	76b	76b

[a] Means within columns followed by different letter are different ($P < 0.05$, Tukey's HSD test).

[b] Infestation measured on fronds that were sprayed by first application

Table 3. Mean percent new sago palm fronds infested with cycad aulacaspis scale (CAS) at various days after treatment (DAT) with foliar insecticides in 2014.

Treatment	Rate/liter	Application (DAT)	Mean % CAS-infested fronds[a,b]						
			Pre	16 DAT	30 DAT	53 DAT	67 DAT	88 DAT	114 DAT
Control (water/surfactant)	n/a	0, 10, 40	n/a	n/a	17a	18a	28a	54a	56a
Mineral oil	20 ml	0, 10, 40	n/a	n/a	15a	25a	18a	5b	3b
B. bassiana GHA	2.5 ml	0, 10, 40	n/a	n/a	18a	12a	16a	54a	54a
Azadirachtin 3%	0.8 ml	0, 10, 40	n/a	n/a	0a	0a	5a	8b	8b
Dinotefuran	0.3 g	0, 10	n/a	n/a	10a	0a	0a	2b	2b

[a] Means within columns followed by different letter are different ($P < 0.05$, Tukey's HSD test).

[b] Infestation measured on seasonal growth occurring post first application.

Table 4. Mean number of cycad aulacaspis scale (CAS) on mature sago palm fronds at various days after treatment (DAT) with foliar insecticides in 2015.

Treatment	Rate/liter	Application (DAT)	Mean no. live CAS per pinna[a,b]						
			Pre	16 DAT	30 DAT	45 DAT	63 DAT	80 DAT	94 DAT
Control (water/surfactant)	n/a	0, 12, 45	8.9a	11.8a	23.0a	73.5a	111.2a	134.2a	178.4 a
Mineral oil	20 ml	0, 12, 45	8.3a	1.0a	1.2b	1.8bc	2.5bc	3.0c	0.8cd
B. bassiana GHA	2.5 ml	0, 12, 45	10.8a	6.7a	1.8b	3.5bc	7.6bc	7.0b	8.5bc
Azadirachtin 3%	0.8 ml	0, 12, 45	6.7a	2.7a	5.1ab	7.1b	11.9b	10.2b	22.0b
B. bassiana / azadirachtin	½ rate	0, 12, 45	8.0a	1.8a	2.6ab	2.0bc	7.8b	7.0b	22.5b
Dinotefuran	0.3 g	0, 12	13.2a	2.9a	0.2b	0.0c	0.0c	0.0c	0.0d

[a] Means within columns followed by different letter are different ($P < 0.05$, Fishers LSD test).

[b] CAS comprised adult females, large nymphs (excluding crawlers) and male pupae.

Table 5. Mean number of cycad aulacaspis scale (CAS) on new sago palm fronds (seasonal growth) at various days after treatment (DAT) with foliar insecticides in 2015.

Treatment	Rate/liter	Application (DAT)	Mean no. live CAS per pinna[a,b]						
			Pre	16 DAT	30 DAT	45 DAT	63 DAT	80 DAT	94 DAT
Control (water/surfactant)	n/a	0, 12, 45	0.3a	0.2a	1.2a	6.3a	21.7a	21.7a	102.4a
Mineral oil	20 ml	0, 12, 45	0.6a	0a	0a	0b	0b	0b	0.1c
B. bassiana GHA	2.5 ml	0, 12, 45	0.1a	0.1a	0.1a	0.1b	4.0ab	4.0ab	6.5bc
Azadirachtin 3%	0.8 ml	0, 12, 45	1.1a	0.4a	1.4a	2.2ab	9.9ab	7.4ab	11.6b
B. bassiana/azadirachtin	½ rate	0, 12, 45	0a	0.4a	0a	0b	2.9ab	2.3ab	6.5bc
Dinotefuran	0.3 g	0, 12	0a	1.3a	0.1a	0b	0b	0b	0c

[a] Means within columns followed by different letter are different ($P < 0.05$, Fishers LSD test).

[b] CAS comprised adult females, large nymphs (excluding crawlers) and male pupae.

activity increased dramatically in control plants to more than 100 scale/pinna by 94 DAT (Table 5). The proportion of new fronds becoming infested increased to 86% in control plants, and also increased among *B. bassiana*, azadirachtin, and their combination treatment (relative to mineral oil and dinotefuran), starting at 63 DAT (Table 6). In this study, the vast majority (over 99%) of established fronds remained infested with at least some residual scale. This was again due to the scale remaining attached for several months after death.

No natural enemies were noted in 2014, but in 2015 we observed approximately 1% of recovered scales on our tests plants containing exit holes indicative of parasitism. Parasitized scales were recovered in all treatments except dinotefuran, although data was insufficient for formal comparisons. Phytotoxic effects to foliage were not observed from any treatments.

Tea scale. All tested insecticides significantly reduced scale numbers (adults and settled nymphs) on established foliage (mature leaves) compared with the control plants at 150 DAT (Table 7). Fewer tea scales on old leaves were observed from two of the spinetoram + sulfoxaflor treatments (0.15 and 0.21 g rates) at 76 DAT, but there were no significant reduction among treatments before this time. This apparent slow activity (decline) may have been influenced by older scales remaining attached to leaf surfaces after death (we did not differentiate between live and dead scales). There was also some natural leaf drop at 76 DAT, possibly due to high temperatures which reduced scale numbers in all treatments, although they increased again in the control treatment by 150 DAT.

Reduced scale numbers were also observed on seasonal growth (new leaves) of plants treated with spinetoram + sulfoxaflor, pyriproxifen, mineral oil, and dinotefuran-treated plants at 35 DAT, and all treatments at 76 and 150 DAT (Table 8). This finding indicates that treatments reduced scale reproduction during the spring. The increased numbers in control plants at 76 DAT and again at 150 DAT likely indicated activity of the second and third (or more) generations of tea scale, respectively. For example, the mean density of scales on new leaves at 150 DAT was greater than 47 scales per leaf on control plants, in comparison to less than 7.5 on treated plants. There were no differences among spinetoram + sulfoxaflor treatments (3 rates) or cyantraniliprole treatments (2 rates).

The proportion of infested leaves increased significantly later in the season in control relative to insecticide treatment plants (Table 9). Smaller infestations (less than 10% leaves infested) were observed at 150 DAT in all treatments except cyantraniliprole. No phytotoxic effects to foliage were observed from insecticide treatments. Parasitoid activity was not observed.

Discussion

Relative to their widespread diversity, distribution, and economic significance (Morales et al. 2015), the management of armored scales is poorly studied. We evaluated reduced-risk insecticides against two species of armored scales infesting ornamental plants. In tests with *A. yasumatsui*, three applications of products, which included a mineral oil, azadirachtin, entomopathogenic fungus, and an azadirachtin/fungus combination, significantly reduced the number of scales on cycads over 3–4 months, but were less effective overall compared with the standard systemic insecticide dinotefuran. In tests with *F. theae*, several reduced-risk insecticides performed similarly to dinotefuran and all of them

Table 6. Mean percent new sago palms fronds infested with cycad aulacaspis scale (CAS) at various days after treatment (DAT) with foliar insecticides in 2015.

Treatment	Rate/liter	Application (DAT)	% CAS-infested fronds[a,b]						
			Pre	16 DAT	30 DAT	45 DAT	63 DAT	80 DAT	94 DAT
Control (water/surfactant)	n/a	0, 12, 45	33a	33a	48a	78a	74a	78a	86a
Mineral oil	20 ml	0, 12, 45	14a	16a	8a	20b	0c	0b	4b
B. bassiana GHA	2.5 ml	0, 12, 45	3a	8a	22a	24b	42abc	44ab	50ab
Azadirachtin 3%	0.8 ml	0, 12, 45	30a	44a	58a	66a	62a	58a	64a
B. bassiana/azadirachtin	½ rate	0, 12, 45	10a	5a	8a	8b	56ab	50a	64a
Dinotefuran	0.3 g	0, 12	5a	43a	20a	20b	10bc	4b	0b

[a] Means within columns followed by different letter are different ($P < 0.05$, Fishers LSD test).

[b] Infestation measured on seasonal growth occurring post first application treatment.

Table 7. Mean number of tea scale on mature leaves of Japanese camellia at various days after treatment (DAT) with foliar and drench insecticides in 2015.

			# tea scale per leaf [a,b]						
Treatment	Rate/liter	Application (DAT)	Pre	7 DAT	14 DAT	21 DAT	35 DAT	76 DAT	150 DAT
Control (water/surfactant)	n/a	0, 14	75.9	89.3	66.7	44.8	44.9	8.9 abc	49.2 a
Spinetoram + sulfoxaflor	0.15 g	0, 14	71.8	64.9	64.9	58.6	28.8	0.3 d	2.0 cd
Spinetoram + sulfoxaflor	0.21 g	0, 14	63.7	44.9	37.5	19.6	21.8	0.3 d	0.1 d
Spinetoram + sulfoxaflor	0.26 g	0, 14	67.3	47.8	60.1	35.0	28.4	3.4 abcd	0.3 d
Cyantraniliprole[c]	0.94 mL	0	71.0	93.8	61.7	38.6	36.3	16.9 a	13.3 b
Cyantraniliprole[c]	0.63 mL	0, 28	68.7	65.5	48.9	42.6	31.8	15.4 ab	9.6 bc
Pyriproxifen	0.94 mL	0, 21	71.0	53.8	60.8	33.9	38.2	3.1 abcd	0.3 d
Buprofezin	1.05 g/L	0, 14	68.4	71.2	72.9	43.6	38.5	14.7 abc	1.5 cd
Mineral oil	20 ml	0, 14, 28	67.7	47.6	57	20.6	20.2	1.8 cd	0 d
Dinotefuran[c]	1.8 g/L	0	70.3	62.5	79.8	24.1	27.1	2.6 bcd	0 d

[a] Column means followed by different letters (where present) are different ($P < 0.05$, Tukey's HSD).

[b] Tea scale comprised adult females, large nymphs (excluding crawlers) and male pupae.

[c] Applied as a drench.

Table 8. Mean number of tea scale on new (seasonal) leaves of Japanese camellia at various days after treatment (DAT) with foliar and drench insecticides in 2015.

			# tea scale per leaf[a,b]						
Treatment	Rate/liter	Application (DAT)	Pre	7 DAT	14 DAT	21 DAT	35 DAT	76 DAT	150 DAT
Control (water/surfactant)	n/a	0, 14	n/a	n/a	2.0	0.9	0.8 a	21.3 a	47.6 a
Spinetoram + sulfoxaflor	0.15 g	0, 14	n/a	n/a	0.0	0.0	0.0 b	0.1 b	0.2 c
Spinetoram + sulfoxaflor	0.21 g	0, 14	n/a	n/a	0.0	0.0	0.0 b	0.0 b	0.1 c
Spinetoram + sulfoxaflor	0.26 g	0, 14	n/a	n/a	0.0	0.0	0.0 b	0.0 b	0.3 c
Cyantraniliprole[c]	0.94 ml	0	n/a	n/a	0.0	0.0	1.0 a	0.1 b	5.0 b
Cyantraniliprole[c]	0.63 ml	0, 28	n/a	n/a	0.0	0.0	0.2 ab	0.4 b	7.4 b
Pyriproxifen	0.94 ml	0, 21	n/a	n/a	0.0	0.0	0.0 b	0.0 b	0.3 c
Buprofezin	1.05 g/L	0, 14	n/a	n/a	0.0	0.7	0.2 ab	0.0 b	3.5 b
Mineral oil	20 ml	0, 14, 28	n/a	n/a	0.0	0.0	0.0b	0.0 b	0.0 c
Dinotefuran[c]	1.8 g/L	0	n/a	n/a	0.1	0.2	0.0 b	0.0 b	0.0 c

[a] No new growth before 14 DAT; column means followed by different letters (where present) are different ($P < 0.05$, Tukey's HSD).

[b] Tea scale comprised adult females, large nymphs (excluding crawlers) and male pupae.

[c] Applied as a drench.

Table 9. Relative infestation of tea scale on Japanese camellia at various days after treatment (DAT) with insecticides.

Treatment	Rate/liter	Application (DAT)	Infestation index (0–5)[a,b]						
			Pre	7 DAT	14 DAT	21 DAT	35 DAT	76 DAT	150 DAT
Control (water/surfactant)		0, 14	2.3	2.3	2.3	1.7	1.8	1.0	2.5
Spinetoram + sulfoxaflor	0.15 g	0, 14	2.2	2.0	1.8	1.7	1.3	0.8	0.5
Spinetoram + sulfoxaflor	0.21 g	0, 14	2.0	1.8	1.8	1.3	1.2	1.0	0.2
Spinetoram + sulfoxaflor	0.26 g	0, 14	2.2	1.7	1.8	1.5	1.3	1.0	0.2
Cyantraniliprole[c]	0.94 ml	0	2.7	2.7	2.3	1.7	1.5	1.2	2.0
Cyantraniliprole[c]	0.63 ml	0, 28	2.5	2.5	2.2	1.7	1.3	1.0	1.3
Pyriproxifen	0.94 ml	0, 21	2.7	2.2	2.0	1.8	1.3	0.8	0.1
Buprofezin	1.05 g/L	0, 14	2.5	2.8	2.5	1.8	1.5	1.2	0.8
Mineral oil	20 ml	0, 14, 28	2.7	2.0	1.7	1.3	1.3	0.5	0.0
Dinotefuran[c]	1.8 g/L	0	2.5	2.5	2.2	1.3	1.3	0.8	0.0
Pearson Chi-Square (df=27)			0.98	0.93	0.43	0.80	0.69	0.26	<0.0001

[a] Data based on average of 6 plants rated on a 5-point scale where 0 = no infestation, 1 = ≤ 10% leaves infested, 2 = 11-30%, 3 = 31-50%, 4 =51-70%, 5 = ≥71% of leaves infested.

[b] Chi-square values (2-sided tests) based on cross tabulation among treatment and infestation scale.

[c] Applied as a drench.

provided significant control within five months. In both cases, however, the most effective control of these armored scales was observed on the new seasonal growth. We noted that once settled, these insects tend to persist on established foliage for some time after death, thus potentially masking the mortality effects in the treated generation for some time. We suggest that monitoring movement of infestations to new foliage (or new plants) is a useful method to establish the efficacy of insecticides against this pest group, since only live scales would be present.

Our treatments were applied when the motile first instars were active. These 'crawlers' and, to some extent, recently settled nymphs lack the waxy covering that accumulates as they grow (Miller & Davidson 2005, Frank 2012). Therefore, scale insects become progressively more difficult to control with contact insecticides as they mature. The tea scale is also a pupillarial form of armored scale in which the adult female develops inside the cast skin of the last nymphal instar, which provides additional protection from contact insecticides. In addition, because settled armored scales are immobile, they do not come into contact with insecticide residue on foliage and branches (Raupp et al. 2001). In tests with *A. yasumatsui*, better control might have been achieved had applications started earlier in the season against the first (spring) generation. This scale is also notoriously hard to control since it infests all parts of the cycad including the fronds, cones, stems, and even roots (Howard et al. 1999). Thus, fronds on sago palms can become re-infested weeks or even months after insecticides have been applied. Monitoring scale populations through routine inspection, or using forecasting methods such as degree-days or plant phenological indicators, can help determine when crawlers are active and can be best managed (Hodges & Braman 2004).

Entomopathogenic fungi have not been widely tested as mycoinsecticides against scale insects. In our tests, three applications of *B. bassiana* GHA equivalent to 5.5×10^7 spores/ml reduced *A. yasumatsui* populations on sago palms by about 80% in 2014 and 90% 2015, although this did not prevent later re-infestation of new fronds. Castillo et al. (2011) tested a commercial blastospore formulation of another fungus, *Isaria fumosorosea* Wize (Hypocreales: Cordycipitaceae) against first instar *A. yasumatsui* under laboratory conditions. These authors reported 73–84% infection at 5.4×10^7 blastospores/mL, depending on temperature. We did not observe a synergistic interaction between the fungus and azadirachtin. It has been hypothesized that an increased inter-molt period for larvae caused by the growth regulating mode of action of azadirachtin may provide better opportunity for the fungal conidia to contact and penetrate the insect cuticle (Akbar et al. 2005). In our study, it is not clear what contribution of control was achieved through fungal infection or from the side-effects of emulsifiers in the ES formulation.

In tests with *F. theae*, several reduced-risk insecticides performed well, and eliminated or almost eliminated the scale infestation by 150 DAT. Among them, spinetoram + sulfoxaflor is a new insecticide combination currently labelled as XXpire^{TM} WG (Dow AgroSciences, Indianapolis, IN) that is registered for chewing and sucking insects in nurseries, greenhouses, and commercial landscapes. Spinetoram, derived by chemically modifying naturally-occurring spinosyns, is a Group 5 MOA insecticide-like spinosad, whereas sulfoxaflor belongs to a newer chemical class of sulfoximines (Dow AgroSciences 2014). Two insect growth regulators (IGR), pyriproxifen (a juvenile hormone mimic) and buprofezin (a chitin inhibitor) both provided significant control on new and old foliage within 76 and 150 DAT, respectively. We note that control of *F. theae* on mature leaves may have been achieved at an earlier date, due to dead scales potentially being counted. These materials have been reported effective or somewhat effective in tests against *A. yasumatsui* (Emshousen et al. 2004) and other species of armored scale (Grafton-Cardwell et al. 2006, Frank 2012, Buzzetti et al. 2015, Salahuddin et al. 2015).

The use of reduced-risk insecticides (EPA 2016) will help conserve natural enemies that reduce further outbreaks of scale insects. For example, several parasitic wasps native to the United States, including *Aphytis diaspidis* Howard and *Aspidiotiphagus* spp. (both Hymenoptera: Aphelinidae), have been reported parasitizing tea scales in Florida and Georgia (Cooper & Oetting 1987). In Florida, *Coccobius fulvus* Compere & Annecke (Hymenoptera: Aphelinidae), which parasitizes female scales, and *Arrhenophagus chionaspidis* Aurivillius (Hymenoptera: Encyrtidae), which parasitizes male scales, were imported from Asia and released against *A. yasumatsui* (Cave 2006).

Sixteen species of predatory lady beetles (Coccinellidae) have been recovered from scale-infested cycads in south Florida; however, these natural enemies do not provide adequate control by themselves and need to be supplemented with insecticides as part of an IPM program (Wiese et al. 2005, Cave 2006). Frank (2012) showed that reduced-risk insecticides (insect growth regulators [IGRs], neonicotinoids, spirotetramat) provided season-long control of euonymus scale, *Unaspis euonymi* Comstock (Hemiptera: Diaspididae), with reduced impact on natural enemies, such as *Encarsia* spp. (Hymenoptera: Aphelinidae) and *Cybocephalus* spp. (Coleoptera: Cybocephalidae), compared with several conventional, broad-spectrum insecticides. Preserving these natural enemies though use of less disruptive insecticides might offer advantages to managing scale insects in nurseries and urban landscapes in cases where natural enemies are abundant.

For logistical reasons, commercial landscape companies often prefer insecticides that are effective with a single application, and thus may favor drenches which also avoid issues with drift and potential phytotoxicity. In the case of scales, such as *A. yasumatsui*, drenches may also help control populations on the underground plant parts and petioles of the trunk. In our tests, some materials (i.e., sulfoxaflor, cyantraniliprole, and dinotefuran) had systemic properties. Several factors may influence the effectiveness of systemic insecticides to control scale insects. Plant health, water solubility, location of the scale insect on the plant and feeding activity, and other environmental influences, will influence whether a lethal dosage of insecticide is acquired. Armored scales feed on parenchymal cells or vascular bundle tissue through a stylet bundle (Juárez-Hernández et al. 2014). This intracellular method of feeding may make armored scales relatively less susceptible to systemic insecticides that preferentially accumulate in the phloem, relative to soft scales, aphids and other pests that phloem feed.

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