The Implementation of Systemic Insecticides and Increased Irrigation against Gall Wasp and Scale Insect Pests Attacking Ficus Trees in Hawaii

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The implementation of systemic insecticides and increased irrigation against gall wasp and scale insect pests attacking *Ficus* trees in Hawaii

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Abstract

Chinese banyan, *Ficus microcarpa* (Rosales: Moraceae), and weeping banyan, *F. benjamina* (Rosales: Moraceae), are commonly planted landscape trees throughout the Hawaiian Islands. They are popular landscape trees due to their large canopy, incremental leaf drop, and minimal need for management. The unintentional introduction of invasive species including a stem gall wasp, *Josephiella* sp. (Hymenoptera: Agaonidae), a leaf gall wasp, *Josephiella microcarpae* Beardsley and Rasplus (Hymenoptera: Agaonidae), and the lobate lac scale *Paratachardina pseudolobata* Kondo and Gullan (Hemiptera: Kerriidae); are causing negative impacts on rural and urban landscape banyan trees throughout Oahu. The deleterious impact of feeding between these 3 pests can cause moderate to severe branch dieback, canopy reduction, early leaf drop, with severe infestations causing the death or removal of landscape trees. In 2 separate studies, the use of systemic insecticides applied via soil drench or trunk injection with or without amended irrigation was examined to determine if there was a reduction of these pests over 24 mos. In the first study, emamectin benzoate was applied to *F. microcarpa* targeting *Josephiella* spp. gall wasps and a second concurrent study assessed the impact of imidacloprid on *P. pseudolobata* infestations of *F. benjamina*. The results of these trials indicated that effective treatments can be utilized as a management tactic for reducing infestations of these invasive pests in the urban landscape ecosystems of Oahu.

Key Words: lobate lac scale; gall wasps; integrated pest management; ornamental horticulture; ornamental entomology; landscape pests

Resumen

El banyan chino, *Ficus microcarpa*, y el banyan llorón, *F. benjamina*, son árboles de paisaje comúnmente plantados en las islas hawaianas. Son árboles de paisaje populares debido a su gran dosel, caída de hojas incremental y necesidad mínima de manejo. La introducción no intencional de especies invasoras, incluida una avispa de las agallas, *Josephiella* sp. (Hymenoptera: Agaonidae), una avispa de las agallas de la hoja, *Josephiella microcarpae* Beardsley y Rasplus (Hymenoptera: Agaonidae), y la escama lobada laca *Paratachardina pseudolobata* Kondo y Gullan (Hemiptera: Kerriidae); están causando impactos negativos en los árboles de higuera de Bengala del paisaje rural y urbano en todo Oahu. El impacto nocivo de la alimentación entre estas tres plagas puede causar muerte regresiva de ramas de moderada a severa, reducción del dosel, caída temprana de hojas, con infestaciones severas que causan la muerte o la eliminación de árboles de paisaje. En dos estudios separados, se examinó el uso de insecticidas sistémicos aplicados mediante empapado del suelo o inyección en el tronco con o sin riego modificado para determinar si hubo una reducción de estas plagas durante 24 meses. En el primero estudio, se aplicó benzoato de emamectina a *F. microcarpa* contra *Josephiella* spp. avispas de las agallas y un segundo estudio simultáneo evaluó el impacto de imidacloprid en las infestaciones de *P. pseudolobata* de *F. benjamina*. Los resultados de estos ensayos indicaron que se pueden utilizar tratamientos efectivos como una táctica de manejo para reducir las infestaciones de estas plagas invasoras en los ecosistemas del paisaje urbano de Oahu.

Palabras Clave: escama lobulada lac; avispas de las agallas; manejo integrado de plagas; horticultura ornamental; entomología ornamental; plagas del paisaje

The Hawaiian Islands have a variety of introduced *Ficus* trees that provide ecological and economic benefits to the urban landscapes. Ornamental landscape trees reduce storm water runoff, energy consumption, air pollutants, and improve aesthetic appeal for residents and tourists (Vargas et al. 2007). Chinese banyan, *F. microcarpae* are characteristic landscape trees in Honolulu and are favored for their large canopy and aerial roots. Weeping banyan, *F. benjamina* is frequently planted throughout the residential landscape.

The lobate lac scale, *Paratachardina pseudolobata* Kondo and Gullan (Hemiptera: Kerriidae), has been found on *F. microcarpa, F. benjamina,* and 111 urban host species since its introduction to Oahu in 2012 (Bhandari & Cheng 2018). Statewide surveys have led to its detection in an open environment on Maui and limited detection in enclosed environments on Hawaii Island and Kauai (Howard et al. 2014). *Paratachardina psuedolobata* is a parthenogenetic species, with mature females appearing as characteristic maroon colored and X-shaped (2 × 2 mm) shellac (Cheng et al. 2018). The crawler stage exits the shellac and disperses to new branches to complete its lifecycle. Crawler dispersal can occur with wind currents, human transport, or with animal assistance, easily spreading them to a new location. Heavy infestations of *P. psuedolobata*

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results in a black sooty mold, branch dieback, thinning foliage, and in severe infestations there can be host plant mortality (Howard et al. 2014).

An invasive leaf gall wasp, *Josephiella microcarpae* Beardsley and Rasplus (Hymenoptera: Agaonidae), was detected on Oahu in 1989, leaving characteristic galls on *F. microcarpa* leaves (Beardsley & Rasplus 2001). The females are 2.2 mm long, and the males are 1.1 mm, and both are dark brown in appearance. This species is assumed to be native to Southeast Asia and was found in California and the Canary Islands in 1997 (Caldwell 2012). Since then, its range has expanded to Florida. *Ficus microcarpa* has another agaonid gall pest, *Josephiella* sp., which was discovered in 2012 causing stem galls on new shoots (Bhandari & Cheng 2016). The estimated life cycle takes 3 to 4 mos for *J. microcarpae* and an estimated 5 to 6 mos for *Josephiella* sp. (Kellar 2018). The stem gall wasp (*Josephiella* sp.) is still being described and is more damaging than *J. microcarpae*. Although leaf galls can lead to early leaf drop and poor shade coverage, stem galls can have more severe impacts on tree health. Infestations result in cell proliferation throughout the vascular tissue of the stem, leading to branch dieback, and thinning canopy coverage (Mani 1966). As a result, some heavily infected *F. microcarpa* were cut down in Oahu's urban areas Such as at the University of Hawaii at Manoa campus, impacting the aesthetic value of the campus and incurring costs associated with tree removal (University of Hawaii at Manoa, personal communications).

Systemic insecticides are an effective method to manage pests in urban landscapes and have been implemented on multiple occasions on Oahu (Bhandari & Cheng 2016, 2018; Suckling et al. 2019). Multiple low-risk insecticides have been tested such as acephate, imidacloprid, and emamectin benzoate. Systemic insecticides generally use less active ingredient when applied, reducing exposure to non-target organisms. Irrigation can increase chemical uptake and efficiency for systemic insecticides (Doccola et al. 2009).

Two separate studies were set up to test the efficacy of different systemic insecticides and available application methods. The efficacy of irrigation and chemical injections on *Josephiella* sp. and *J. microcarpae* were observed for 24 mos on *F. microcarpa*. A concurrent study was set up to evaluate *P. psuedolobata* infestations on *F. benjamina*, testing the effects of soil drench and injection of systemic insecticides with and without irrigation. It is hypothesized that irrigation and chemical combination will reduce infestations. With all 3 of these pests attacking *F. microcarpa* trees around Oahu, the goal of these studies is to provide management strategies for mitigating infestations and improving long term tree health.

Material and Methods

JOSEPHIELLA SPP. CONTROL EXPERIMENTAL DESIGN AND DATA COLLECTION

Twigs from *F. microcarpa* trees on the University of Hawaii at Manoa campus (21.2970 °N, 157.8170 °W) in Honolulu, Hawaii were collected in Oct 2016 to determine initial *J. microcarpae* and *Josephiella* sp. presence. The trees used were approximately 55 yrs old. Twenty *F. microcarpa* were selected with similar infestation ratings within this group, with replicates of 5 trees per treatment. Each group had trees that were randomly assigned a treatment (injection alone, injection with irrigation, irrigation alone, and an untreated control). A TREE I.V. system (Arbojet, Woburn, Massachusetts, USA) was used to apply emamectin benzoate according to label rates based on the tree diameter at breast height (DBH). The label rate for emamectin benzoate (4%) was 10 mL per 2.54 cm DBH. As there are multiple generations a year of each insect pest, the application start date was not timed for specific emergence of pests. The select trees that received the irrigation treatment with or without insecticidal application were watered with an extra 38 liters per month in addition to natural rainwater. The remaining *Ficus microcarpa* trees in this study did not have additional irrigation outside of rainfall.

The treatments were applied in Oct 2016 and monthly observations started Nov 2016. The trial concluded 24 mos after treatment (i.e. Oct 2018). The samples were conducted by randomly cutting 3 new terminal shoots from each tree approximately 40–50 cm long using a tree pruner (ATSS PSPL30NC, American Tree Service Supply, Greenville, Rhode Island, USA). Each sample included a visual evaluation of the average *Josephiella* sp. stem gall infestation level (1–5 scale, 1 = no infestation on branch, 2 = up to 24% branch coverage, 3 = 25–49% branch coverage, 4 = 50–74% branch coverage, and 5 = 75% or greater branch coverage with stem gall wasp infestation signs). Another rating system evaluated the average *J. microcarpae* infestation with a percent rating of the total number of leaves infested (1 = no leaves infested, 2 = 1–24% of the leaves infested, 3 = 25–49%, 4 = 50–74%, 5 = 75% or greater). The measurements for the 3 samples were averaged.

PARATACHARDINA PSEUDOLOBATA CONTROL EXPERIMENTAL DESIGN AND DATA COLLECTION

Twigs of adult *F. benjamina* trees were collected from a golf course 3 miles away (21.2776 °N, 157.8191 °W) from the University of Hawaii at Manoa campus in Honolulu, Hawaii to determine initial *P. pseudolobata* presence. The trees on the golf course are approximately 40 yrs old. The experiment used 18 trees from the golf course. These 18 *F. benjamina* trees were similar in infestation ratings, and each replicate of 3 trees had comparable starting conditions for each treatment. The trees in each group were then randomly assigned a treatment (injection alone, injection plus irrigation, soil drench alone, soil drench plus irrigation, irrigation alone, and an untreated control). A TREE I.V. system (Arborjet, Woburn, Massachusetts, USA) was used for the imidacloprid (5%) injections of respective trees at 8 mL per 2.54 cm DBH for each tree. The imidacloprid soil drench treatments were applied at label rates with approximately 4 liters of water at the base of each tree. The same amount of active ingredient was applied between injection and drench treatments. The select trees that received the irrigation treatment with or without insecticidal application were watered with an extra 38 liters per month in addition to natural rainwater. The other *Ficus benjamina* trees in this study did not have any irrigation besides rainfall.

The data collection began 1 mo after treatment (i.e. Nov 2016) and concluded in Oct 2018. Each measurement was conducted by randomly cutting 3 new branches from each tree that were approximately 40–50 cm in length. This was done with a tree pruner (ATSS PSPL30NC, American Tree Service Supply, Greenville, Rhode Island, USA). The measurement evaluated the infestation level of *P. psuedolobata* (1–5 scale, 1 = no infestation or no living individuals, 2 = presence of crawlers or live scales, 3 = increased live scales and crawlers, 4 = moderate coverage of live scale density, 5 = heavy infestation where almost the entire branch is covered). The juvenile *P. pseudolobata* crawlers were all visibly alive, and up to 10 adults were randomly pressed with a fingernail because the shellac remains on the branch even after the adult is dead. If pressed adults excreted hemolymph, they were considered alive, otherwise they would be considered dead for the rating for that specific month of measurement. The samples were evaluated the day they were cut from the trees.

STATISTICAL ANALYSIS

The statistical analysis was conducted using RStudio (version 1.1.463). Twenty trees with 5 trees per replicate (3 branches averaged for each replicate) were evaluated for the *Josephiella* spp. trials, and 18 trees with 3 replicates (3 branches averaged for each replicate) were collected for the *P. pseudolobata* trial. The Kruskal-Wallis test was conducted to evaluate differences in treatments at individual months. If there was statistical significance (P≤0.05), Dunn's method was used to determine the differences between treatments.

Results

It was hypothesized that increased irrigation should improve the uptake of systemic insecticides and decrease infestation levels below a potentially detrimental infestation level of 4 to 5. The efficacy of the treatments was evaluated through the infestation ratings of each target insect. In the trial evaluating various treatments as control methods for *Josephiella* gall wasps, there were visible trends with the treatments. For the stem gall wasp infestation rating of *Josephiella* sp., there was visual evidence indicating a difference in infestation between months 7 to 17 post-treatment where emamectin benzoate (EB-D), ememactin benzoate with irrigation (EB-W), and irrigation (W) trees had a lower *Josephiella* sp. infestation than the control trees (C) (Fig. 1). There was a reduction in infestation levels in trees treated with insecticide in months 10, 12, and 17 post-treatment. This was attributed to the EB-D treatment, which had lower gall ratings on a visual basis and was statistically significant for these months (Dunn's method, month 10; X^2 = 8.3472; df = 3, P = 0.03936, month 12; X^2 = 8.2023, df = 3, P = 0.04201, month 17; X^2 = 7.9399, df = 3, P = 0.04727).

For the *J. microcarpae* gall ratings there was visual evidence between months 9 to 17 post-treatment indicating that there were higher leaf gall ratings in the control trees, in comparison to the other treatments (Fig. 2). There was only statistical significance between the treatments for month 8 post-treatment, in which EB-D and the irrigation treatment had a lower gall rating compared to the control (X^2 = 11.176, df = 3, P = 0.01081).

Imidacloprid was effective at controlling *P. pseudolobata* infestations through both soil drench and injection of *F. benjamina* trees. There was a steady decline in *P. pseudolobata* infestation with all chemical treatment types, visible in the first few months following the application with statistical significance between treatments in month 15 post-treatment (Fig. 3, X^2 = 13.366, df = 5, P = 0.0202). In month 15 post-treatment both imidacloprid injections with and without irrigation were more efficacious than the other treatments.

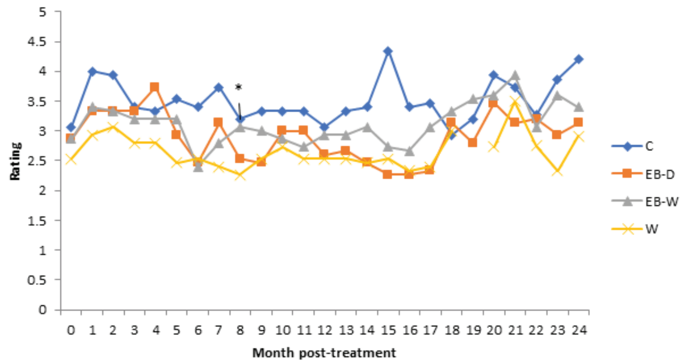

Fig. 2. *Josephiella microcarpae* infestation rating (1–5 rating scale, 1 showing no infestation, increasing up to a 5 showing heavy infestation). C = Control, EB-D = Emamectin benzoate with no irrigation, EB-W = Emamectin benzoate with irrigation, W = Irrigation alone. * represents P < 0.05 within the specified month post-treatment (Kruskal-Wallis test).

Discussion

The inadvertent introduction of invasive arthropods has increased in the last century, as globalization enables the transportation of invasive species to new areas (Suckling et al. 2019). Many of these species become easily established in their new habitats, negatively impacting the native ecosystems. The Hawaiian Islands have had detrimental impacts caused by many invasive insect introductions such as the erythrina gall wasp, *Quadrastichus erythrinae* Kim (Hymenoptera: Eulophidae), which was devastating urban and rural endemic wiliwili trees, until it was mitigated using systemic insecticides (Doccola et al. 2009). This was eventually controlled through the release of a biological control agent.

Hawaii's landscape *Ficus* trees are widespread throughout the urban landscape of Oahu (Vargas et al. 2007). Previous studies on *F. microcarpa* and *F. benjamina* have evaluated the efficiency of various systemic insecticides on the invasive *Josephiella* spp. gall wasps and *P. pseudolobata* (Bhandari & Cheng 2016, 2018). Imidacloprid and emamectin benzoate were tested against *Josephiella* spp. wasps with results indicating that both chemicals had some effect on the *J. microcarpae* infestation for 18 mos after treatment (Bhandari & Cheng

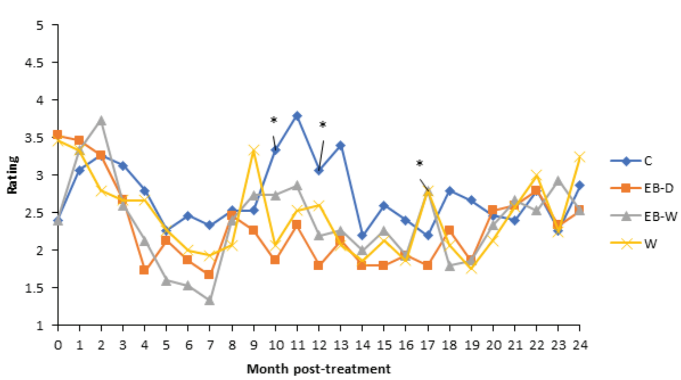

Fig. 1. *Josephiella* sp. infestation rating (1–5 rating scale, 1 showing no infestation, increasing up to a 5 showing heavy infestation). C = Control, EB-D = Emamectin benzoate with no irrigation, EB-W = Emamectin benzoate with irrigation, W = Irrigation alone. * represents P < 0.05 within the specified month post-treatment (Kruskal-Wallis test).

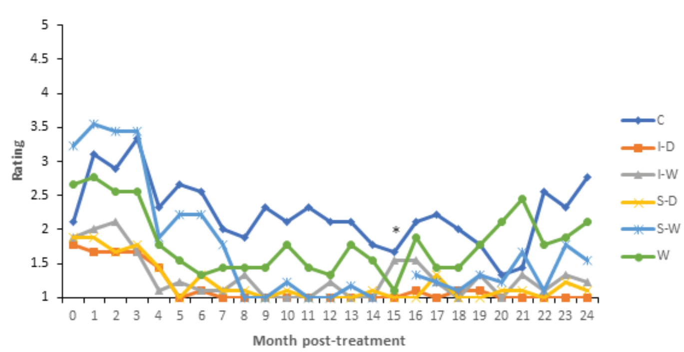

Fig. 3. *Paratachardina psuedolobata* infestation level (1–5 rating scale with a 1 showing no infestation or living individuals, increasing up to a 5 indicating a heavy infestation). C = Control, I-D = Imidacloprid injection with no irrigation, I-W = Imidacloprid injection with irrigation, S-D = Imidacloprid soil drench with no irrigation, S-W = Imidacloprid soil drench with irrigation, W = Irrigation alone. * represents P < 0.05 within the specified month post-treatment (Kruskal-Wallis test).

2016). These chemicals were complemented with and without phosphorous acid amendment to enhance natural plant defenses, but this had negligible effects. Emamectin benzoate was efficient for 14 mos after treatment against *Josephiella* sp. This study took a different approach through additive irrigation with these systemic insecticides to reduce pest infestations and potentially increase chemical uptake after application. Efficiency of emamectin benzoate was evident with and without irrigation for gall wasp reduction during the trials. The delay in treatment effect can likely be attributed to the time it took for new growth to emerge on the trees that had decreased gall wasp infestations. The irrigation without emamectin benzoate treatment yielded decreased infestation ratings during many months of the trial, suggesting that improved water and nutrient uptake through additional irrigation could have contributed to the reduction in infestation levels. This could be confirmed in a future study with greater replication.

Another study was conducted to evaluate mitigation methods against *P. psuedolobata* infestations on Oahu that indicated imidacloprid injections were curative for 20 mos after treatment on *F. benjamina* and prevented infestations on *F. microcarpa* for 22 mos after treatment (Bhandari & Cheng 2018). This included a survey that indicated an expansion of *P. pseudolobata* onto 111 host species in Oahu's urban areas. Our study yielded similar results with imidacloprid applications applied through soil drench and trunk injection with or without additive irrigation. Increased irrigation on its own did not influence the infestation levels of *P. pseudolobata* compared with the chemical treatments. There was no resurgence of *P. pseudolobata* infestations, indicating long term prevention is feasible through the application of imidacloprid and that increased irrigation without chemical treatment will not decrease infestation levels. The results indicated that chemical treatment of *F. benjamina* trees infested with *P. pseudolobata* has a beneficial impact on reducing or eliminating infestation levels.

Chinese and weeping banyan trees are already threatened by the pests addressed in this manuscript, but there are other pests of concern that could negatively impact the use of these landscape trees. In Nov 2022, a new psyllid pest, *Macrohomotoma gladiata* Kuwayama (Hemiptera: Psyllidae) that causes branch dieback and covers the branches in white wax secretions was found on Oahu on *F. microcarpa* trees (Matsunaga 2022). The rapid spread, lack of natural enemies, and branch dieback caused by this pest may further impact the future of these trees in the urban landscape. *Ficus benjamina* trees are not impacted by these pests, but are vulnerable to the whitefly, *Singhiella simplex* Singh (Hemiptera: Aleyrodidae), which has spread around the world defoliating *Ficus* hedges (Ahmed et al. 2022). If *S. simplex* were to be established in Hawaii, it could devastate the ornamental *F. benjamina* trees throughout the state.

Our studies were limited due to a small sample size of available banyan trees. As there appears to be high variability in the data collected then it would be beneficial to repeat the study with a larger sample size, and then it might be possible to better understand the differences between the treatments. Nonetheless, the results indicated that curative imidacloprid application can treat *P. pseudolobata* infestations on target *F. benjamina* trees. Further research on an effective pesticide rotation is recommended to maintain the health of these trees in landscape settings. This research could provide an effective management plan for heavily infested trees on Oahu, and potentially for other areas with similar infestations. *Ficus microcarpa* trees face infection from all 3 of these pests, and chemical mitigation is a strategy that can help maintain landscape trees. These treatments may be effective against other *Ficus* pests, which could be explored in future studies. The application of emamectin benzoate and increased irrigation can potentially mitigate *Josephiella* spp. gall wasps. Mitigation of these 3 *Ficus* pests with systemic insecticides is a useful tactic in an integrated pest management program, but the evaluation of potential biological control agents should be considered, along with enhanced biosecurity protocols to prevent the entry of more pests than can severely alter the urban landscape in Hawaii.

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