Evaluating the Persistence of Pyrethrin and Pyrethroid Insecticides in Coconut Palm (*Cocos nucifera)* Canopies for Coconut Rhinoceros Beetle (*Oryctes rhinoceros*) Management

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Abstract. Canopy application of contact insecticides is emerging as a short-term tool for protecting against coconut rhinoceros beetles (CRB; *Oryctes rhinoceros*) in Hawai'i. Pyrethrin and pyrethroid formulations are primarily labeled for use on ornamental plants, which represent a large portion of Hawai'i's public palms. To provide guidance on the frequency for which insecticides should be applied, we evaluated five products with labeling that allowed applications to coconut palm crowns as ornamentals and/or fruit production in Hawai'i. Burlap was soaked in spot-treatment or minimum-volume per area rates according to product labels, with water as the control. After drying, burlap was used immediately in bioassays or affixed to coconut palm canopies at a research station in Mānoa Valley, O'ahu, exposed to local weather. Sub-samples were collected every four weeks for bioassays, where 4 to 5 g of treated burlap was placed in a perforated 500-mL bottle with four colony-reared adult CRB added (12 total per treatment). After a 24-h exposure, insect health was rated on a 5-point scale (1 = dead, 5 = healthy) via double-blind evaluation. CRB ratings were analyzed using Kruskal-Wallis and Dunn's tests with Bonferroni correction. Burlap treated with synthetic pyrethroids deltamethrin, prallethrin and lambda-cyhalothrin, cypermethrin, and zeta-cypermethrin retained toxicity against CRB for at least 12 weeks. The organic pyrethrins did not retain toxicity. Since many palms in Hawai'i are routinely serviced by arborists and landscapers every 3 to 5 months, a canopy application of the longer-lasting formulations may serve as an immediate management option for protecting palms from CRB.

Key words: coconut palm, coconut rhinoceros beetle (CRB) management, burlap, pyrethrin, pyrethroid, treated article

Coconut rhinoceros beetle (CRB), *Oryctes rhinoceros* (L.), (Coleoptera: Scarabaeidae) is a major pest of coconut (*Cocos nucifera*) and oil (*Elaeis guineensis*) palms, particularly outside of its native range (Gressitt 1953, Manjeri et al. 2014). Adult CRB are sap feeders that will bore into palm canopies at the base of the petiole and feed upon exudates of the soft, nutrient-rich tissues prior to emergence (Gressitt 1953). This feeding damages the emerging fronds, reducing their photosynthetic potential. This feeding can also result in death of the host through the introduction of secondary infections, damage to the meristem, or reducing the

structural integrity of the trunk which can result in the canopy being toppled during wind events (Hinckley 1973). Native to Asia, CRB has invaded much of the tropical Pacific through the 1900s and early 2000s, where its detrimental impacts have been well documented (Gressitt 1953, Catley 1969, Hinckley 1973, Marshall et al. 2017, Paudel et al. 2024).

The 2013 discovery of CRB on O'ahu, Hawai'i and subsequent efforts responding to this invasion have led to the deployment of physical, cultural, and chemical man-agement tools across the island (Kellar 2018, Vowell et al. 2023, Paryavi et al. 2025, CRB Response - Hawai'i 2025). Canopy application of pyrethrin and pyrethroid insecticides using both ground and aerial application platforms has emerged as an important short-term tool for suppressing CRB populations near ports of exit and for eradicating nascent populations that have appeared on other Hawaiian Islands. Pyrethrins are plant-derived contact insecticides that are considered low-impact due to their low or temporary toxicity to mammals at concentrations typically used in insect control and their inability to persist in the environment, especially when exposed to UV radiation (Blackith 1952, Antonious et al. 1997, Proudfoot 2005). Pyrethroid insecticides, which are synthetic analogs based on pyrethrin molecules, similarly work by contact. Synthetic pyrethroids are typically more potent insecticides with similar mammalian toxicity to pyrethrins, and are able to persist longer on the treatment site, reducing the number of applications (Casida 1980, Aldridge 1990). It is unclear, however, exactly how long applications of pyrethrins and pyrethroid-based insecticides remain effective in palm canopies for CRB control. Documented use of pyrethroids for CRB control report canopy applications being made at two-week intervals (i.e., Ismail et al. 2009, Moore 2013), but the basis for this application interval is not clear.

In this study, we evaluated the per-sistence of five pyrethrin or pyrethroid-based products labeled for use on either agricultural or ornamental palms in Hawai'i in order to provide guidance for re-application intervals. We used a "treated article" approach with burlap fabric to evaluate insecticide efficacy and persistence. "Treated articles" refer to articles or substances that have been intentionally impregnated with or incorporate a pesticide, such as an antimicrobial, insecticide, or herbicide, to protect them from degradation or damage by pests (U.S. EPA 2016). Insecticide-treated clothes and nets had been previously evaluated to control vector-borne diseases (Banks et al. 2014, Curtis et al. 2003), but few studies have been conducted directly on controlling agricultural pests. The use of insecticide-treated burlap demonstrated in this study may eventually expand the way these products can be used in CRB management programs, and also reduce negative impacts associated with their use in the environment.

Materials and Methods

Insect source. Adult CRB were reared at the University of Hawai'i's Arthropod Containment Laboratory (UH-ACL) under environmentally-controlled conditions (Vowell et al. 2023). The CRB colony was established using adult beetles originally collected from traps deployed around O'ahu. Specimens used in this study were primarily from this colony. In the event not enough laboratory-reared adults were available, specimens collected from the field and temporarily maintained in the UH-ACL were used.

Insecticides evaluated. The five insecticides and their application rates evaluated in this study are listed in Table 1. All five insecticides have active ingredient(s) from the Insecticide Resistance Action

Table 1. Pyrethrin and pyrethroid insecticides evaluated for residual activity against coconut rhinoceros beetle (*Oryctes rhinoceros*).

Brand name	Abbreviation (EPA #*)	Manufacturer	Active Ingredient(s)	Mode(s) of Action (IRAC** code)	Amount of product diluted in water to 190 mL total (Label rates)
Evergreen® Pyrethrum Concentrate	Evergreen (1021-2560)	MGK®	pyrethrins 5%	3A	0.74 mL (0.5 fl. oz./ gal., spot treatment)
Suspend® Polyzone®	Suspend (432-1514)	Bayer CropScience	deltamethrin 4.75%	3A	2.2 mL (1.5 fl. oz./gal., spot treatment)
OneGuard® Multi MOA Concentrate	OneGuard (1021-2809)	MGK®	lambda-cyhalothrin 4%, prallethrin 0.4%, pyriproxyfen 1.3%, piperonyl butoxide 6%	3A & 7A	2.2 mL (1.5 fl. oz./gal., spot treatment)
Demon® Max	Demon Max (100-1218)	Syngenta Crop Protection	cypermethrin 25.3%	3A	3.7 mL (0.5 % a.i., spot treatment)
Mustang® Maxx	Mustang Maxx (279-3426)	FMC Corporation	zeta-cypermethrin 9.15%	3A	0.6 mL (0.4 fl. oz./gal., minimum volume per area)

*Environmental Protection Agency registration number
**IRAC = Insecticide Resistance Action Committee. IRAC codes: 3A = Pyrethroids, Pyrethrin; 7A = Juvenile hormone analogs.

Committee (IRAC) Group 3A, pyrethroids and pyrethrin. Evergreen as a concentrated plant extract is classified as an organic pyrethrin, while the other four products are formulated with synthetic pyrethroids. In addition to pyrethroids, OneGuard also includes active ingredients from Group 7A, juvenile hormone analogs. All five insecticides are licensed for use in the State of Hawai‘i on palms including Demon Max under a Section 18 emergency exemption for CRB control (all islands in Hawai‘i except O‘ahu) and Mustang Maxx, which is a restricted use pesticide. In this study, insecticide products were diluted with water to a total volume of 190 mL according to their foliar application label rates for spot treatment (Evergreen, Suspend, OneGuard, and Demon Max) or the minimum volume per area (Mustang Maxx) (Table 1).

Insecticide exposure. Sections of burlap fabric (~75g dry weight; Figure 1A) were soaked for 1 to 5 minutes in each diluted insecticide or water (control), then allowed to drain and air dry. Burlap fabric was used as a surrogate for the fibrous, burlap-like sheath tissue present at the base of coconut (and other) palm fronds (Figure 1D–E) that would be treated in palm canopies. Three subsections (4 to 5 g each) from each insecticide-treated and water control burlap fabric were excised and placed in separate 500 mL Nalgene bottles with a perforated lid for air exchange. Four adult CRB were then added to each bottle (12 total CRB per treatment). After a 24-hour exposure, the health of individual CRB was assessed by an observer familiar with CRB behavior in a double-blind trial (Figure 1C). Insect health was assessed using the following

Figure 1. Sections of burlap fabric (**A**) treated with water or one of five insecticides were either immediately evaluated, or were allowed to weather in the canopy of a palm seedling fully exposed to local environments (**B**). Every four weeks, subsections of burlap were removed from the canopy and evaluated for their ability to kill adult coconut rhinoceros beetles in a contact exposure bioassay (**C**). Burlap fabric was used as a surrogate for the fibrous sheath tissue present at the basal end of coconut palm fronds (**D** to **F**).

1 to 5 scale: 1) Dead: no movement when agitated and/or no resistance when prodding the head and pronotum; 2) Severe paralysis: minimal movement only when agitated; 3) Moderate paralysis: limited and uncoordinated movement; 4) Lethargic: slow, coordinated movement; 5) Normal: typical movement of a healthy adult CRB.

The remaining sections of burlap were woven into the canopies of coconut palm seedlings exposed to full sun and rain at the University of Hawai‘i’s Magoon Research and Instruction Facilities

(GPS: 21.307089, –157.809224) (Figure 1B). Every four weeks ending in the twelfth week, three subsections of burlap from each treatment were removed and evaluated for effects on CRB as described above.

Statistical analysis. Adult CRB health ratings (1 to 5 scale) assigned to each beetle were analyzed to assess the efficacy of insecticide-treated burlap against CRB over time. Two cumulative link mixed models (CLMM) were first constructed to determine whether insecticide efficacy changed over time (indicated by whether the interaction factor between treatment and evaluation dates was significant or not). Insecticide treatments and evaluation dates were included as fixed effects, and the bottle block factor was a random effect in both CLMM models, while one was with and another without the interaction of treatments and evaluation dates as a fixed factor. Results of a likelihood ratio test fitted between the model with and without the interaction factor indicated a significant interaction between treatments and evaluation dates (Table S1). (For supplemental material Tables S1 to S6, see [hyperlinked ScholarSpace URL].) Thus, treatment effects were examined separately by each evaluation date, while evaluation date effects were evaluated for each treatment in the following analysis. Separate ordinal logistic regression (OLR) models were fitted using the cumulative link model (CLM) functions from the ordinal package in R. However, the warning of numerically singular Hessian and lack of parameter estimates indicated OLR models were not fit for the data collected in this study (Table S2). Thus, the non-parametric Kruskal-Wallis test was used for further analysis. The Kruskal-Wallis test is a rank-based test used to compare differences between multiple groups when the data do not meet the assumptions of parametric tests (Kruskal and Wallis 1952). First, CRB health ratings were compared among water or insecticide treatments within each evaluation date. Second, CRB health ratings were analyzed to assess changes in efficacy over time by comparing ratings across the four evaluation dates for each water or insecticide treatment. Post-hoc Dunn's tests with Bonferroni correction were used for pairwise multiple comparisons. All analyses were conducted in R (version 4.4.1), using the ordinal package (version 2023.12.4.1) for the CLMM and CLM model, the stats package (version 4.4.1) for Kruskal-Wallis tests, and the FSA package (version 0.9.5) for Dunn's tests. Detailed results from the statistical analyses are provided in the supplementary material.

Results

A total of 288 adult CRB were treated in this study to evaluate the persistence of five pyrethrin and pyrethroid insecticides in coconut palm canopies for CRB control using the burlap method. Regardless of evaluation dates, results showed there were statistically significant differences in adult CRB health ratings among different water or insecticide treatments (at day(s) after burlap being treated [DAT]): 1 DAT: χ^2=68.79, df=5; P=1.83E–13; 28 DAT: χ^2=53.63, df=5; P=2.49E–10; 56 DAT: χ^2=51.93, df=5; P=5.56E–10; 84 DAT: χ^2=54.50, df=5; P=1.65E–10). Pairwise comparison results among treatments indicated that all synthetic pyrethroid pesticides including Suspend, OneGuard, Demon Max, and Mustang Maxx, significantly reduced the health of adult CRB compared to water and Evergreen (Figure 2; Table S3, S4).

Insect health ratings were also examined across different evaluation dates for each water or insecticide treatment to determine how long treated burlap could stay effective in controlling CRB. There

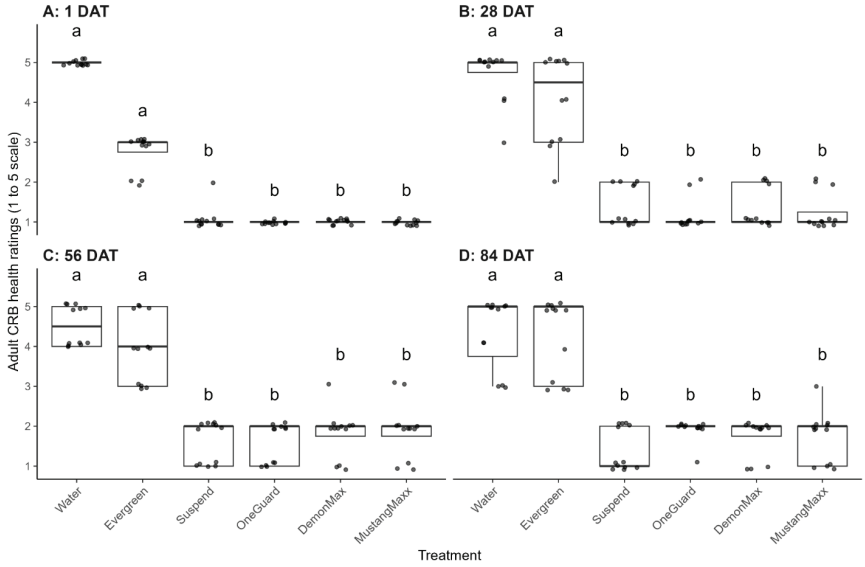

Figure 2. Health ratings (y-axis) of adult coconut rhinoceros beetle (CRB) after a 24-hour exposure to pesticide-treated burlap by each evaluation date. CRB were exposed to the burlap immediately after treatment (**A**), or after the burlap was placed in a palm seedling canopy for 4 weeks (**B**), 8 weeks (**C**), or 12 weeks (**D**). The full name and other information of the pesticides utilized in these experiments are listed in Table 1. A description of the 1 to 5 CRB health rating (1 = dead through 5 = healthy) are described in the Materials and Methods section. Each dot represented the health rating of one individual adult CRB. Letters above the boxes in each panel indicate significant difference among treatments at the α level of 0.05 using Kruskal Wallis test followed by post hoc Dunn's test with Bonferroni correction.

were no significant differences in CRB health ratings among different evaluation dates when exposed to burlaps treated with Suspend (χ^2=6.61, df=3; *P*=0.085; Figure 3C; Table S5). For Evergreen, significantly lower health ratings were found in 1 DAT compared to the three later evaluation dates (χ^2=16.00, df=3; *P*=0.001; Figure 3B). Significant lower health ratings were found on 1 DAT compared to 56 and 84 DAT when exposed to burlap treated with OneGuard, Demon Max, and Mustang Maxx (OneGuard: χ^2=24.84, df=3; *P*=1.67E–05; Demon Max: χ^2=18.73, df=3; *P*=3.00E–04; Mustang Maxx: χ^2=18.28, df=3; *P*=4.00E–04; Figure 3D 3E, 3F; Table S5, S6). However, most health ratings of CRB exposed to burlap treated with synthetic pyrethroid pesticides were 1 or 2 across the different evaluation dates, making them incapable of causing damage.

Discussion

In this study, we determined that burlap treated with synthetic pyrethroid insecticides, including Suspend (active ingredient(s): deltamethrin), OneGuard (prallethrin and lambda-cyhalothrin), Demon Max (cypermethrin), and Mustang Maxx (zeta-cypermethrin), were more effective in controlling CRB than the organic insecticide Evergreen (pyrethrins). Synthetic pyrethroid pesticides retain

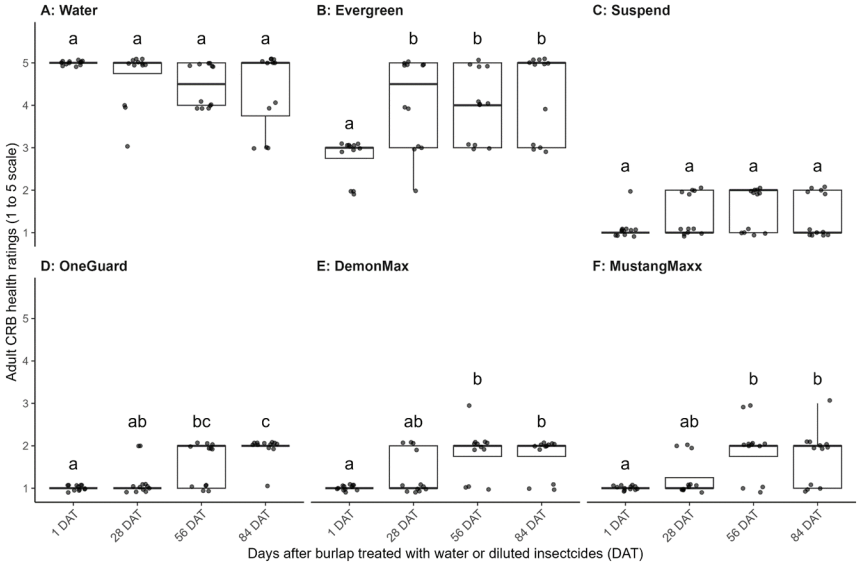

Figure 3. Health ratings of adult coconut rhinoceros beetle (CRB) over different evaluation dates for each water or insecticide treatment. CRB was exposed to burlap soaked with water (**A**) or diluted insecticides including Evergreen Pyrethrum (**B**), Suspend Polyzone (**C**), OneGuard Multi MOA (**D**), Demon Max (**E**), and Mustang Maxx (**F**). The full name and other information of the pesticides utilized in these experiments are listed in Table 1. A description of the 1 to 5 CRB health rating (1 = dead through 5 = healthy) are described in the Materials and Methods section. Each dot represented the health rating of each individual adult CRB. Letters above the boxes in each panel indicate significant difference at the α level of 0.05 using Kruskal Wallis test followed by post hoc Dunn's test with Bonferroni correction.

toxicity against CRB for at least 12 weeks, even when exposed to the environmental conditions present in palm canopies. The lone pyrethrin pesticide evaluated, Evergreen, did not retain this toxicity. These results are congruent with the increased persistence of synthetic pyrethroids in comparison with natural pyrethrins (Casida 1980, Aldridge 1990). Our results are also consistent with other studies that evaluated the persistence of pyrethroids against beetle pests. As part of an indoor, controlled environment trial, Arthur et al. (2018) found that khapra beetles (*Trogoderma granarium*) experienced high larval mortality and minimal adult emergence when exposed to wood and metal surfaces treated by pyrethroids three months prior. Baumler and Potter (2007) found that most of the pyrethroid formulations they evaluated against Japanese beetle (*Popillia japonica*) were effective 19 days post-application on *in situ* linden (*Tilia cordata*) shoots. However, our results contrast with some studies that evaluated the persistence of pyrethroids for beetle control. For example, Brown et al. (2020) found that permethrin-treated trunk sections placed in a natural environment had a significant increase in ambrosia beetle attacks between 17 and 24 days post-treatment.

One factor that likely contributed to the high efficacy observed in our study is

that adult CRB in our study were confined to a small space with pesticide-treated burlap for a full 24-hour period. The fact that these adult CRB had no choice but to be exposed to the treated burlap, and that their innate behavior was to burrow and intertwine themselves into the burlap, certainly increased their exposure to the chemicals. In natural conditions, beetles may not experience such prolonged or concentrated exposure, and therefore the results here may overestimate effectiveness when compared to practical situations. Additionally, beetles were only assessed once, at 24 hours post-exposure. Individual beetles with intermediate health scores (especially scores 3 and 4) might recover after this observation period and potentially resume normal activity, including feeding. Future studies should aim to assess the effects of varied exposure durations and include longitudinal monitoring to determine whether pesticide-paralyzed beetles could recover over time.

Palm leaf petioles are sheathed by a burlap-like tissue at their basal end, but it is unknown whether treatment of this tissue as part of a canopy application would result in absorption and protection similar to what was observed for burlap (jute fiber). In Hawai‘i, ornamental palms are typically pruned every 3 to 5 months. Should the burlap-like palm tissue have similar uptake to jute fiber, a canopy application of one of the products registered for ornamental palms at the time of pruning in a manner consistent with the label, and perhaps in conjunction with a systemic insecticide, may provide an effective management option for high-value ornamental coconut palms. Only one of the products evaluated, Mustang Maxx, is currently registered for agricultural coconut production (and not for use on ornamental coconut palms). We are currently evaluating additional products labeled for tree nuts (crop group 14 and 14–12) that can potentially be used for CRB control; results will be shared in future publications.

The use of treated burlap in this trial was purposeful as it could also represent an alternative approach for protecting palm canopies using contact pesticides. Spray applications, even with coarse droplet sizes, are prone to drift in the elevated wind conditions and eddies experienced at typical palm canopy heights. This drift is compounded by the lateral distance a droplet can travel from these heights due to prevailing winds. This can lead to unintended applicator exposure, and having pesticides reach unintended sites on the ground. Placing dried, treated burlap in a palm canopy might offer several advantages over conventional liquid applications, including improved applicator safety and elimination of pesticide drift. The placement of burlap in a palm canopy can be largely inconspicuous due to its resemblance to the natural sheath tissue, and it can be quickly placed with a precision difficult to obtain using spray applications. Such precision may also help mitigate any contact with palm fruit or inflorescences visited by pollinators. Critically, a large percentage of ornamental palms in Hawai‘i are pruned by workers manually climbing the trunk. The weight and bulk of a spray apparatus make liquid applications infeasible and potentially dangerous. However, a climber could easily carry a pouch of treated burlap for placement in the canopy.

To minimize the risk of sublethal pesticide exposure, which can select for behavioral and physiological resistance traits in insect populations (Sparks and Nauen 2015), treated burlap should be removed or replaced during routine pruning, typically occurring every 3 to 5 months. As the residual efficacy of

pyrethroid formulations may decline over time due to biological or environmental degradation (Thatheyus and Selvam, 2013, Yu 2014), prolonged exposure to declining residues could promote resistance development in *O. rhinoceros*. Integrating treated-burlap replacement with routine pruning practices can be helpful in maintaining lethal exposure levels while minimizing resistance risks. Future experimentation and field trials are needed to better evaluate the use of pyrethroid-treated burlap as a CRB management tool and to support any pesticide label changes required to undertake this approach.

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