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A Prophylactic Application of Systemic Insecticides Contributes to the Management of the Hibiscus Bud Weevil *Anthonomus testaceosquamosus* Linell (Coleoptera: Curculionidae)

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Abstract: The hibiscus bud weevil is an invasive pest that attacks tropical hibiscus. Its management has been challenging due to its cryptic adult and concealed immature stages. We evaluated the efficiency of four systemic insecticides (spirotetramat, chlorantraniliprole, flupyradifurone, and cyantraniliprole) against the pest using two approaches: one applied 4 weeks before infestation (prophylactic) and the other 1 week after (curative). The number of eggs, larvae, and feeding holes per sampled bud were recorded 7, 14, 21, and 28 days after the infestation (prophylactic), and after the application (curative), respectively. In general, a greater number of treatment effects were detected in the prophylactic approach in comparison with those in the curative. With the prophylactic approach, the mean number of larvae and feeding holes per actively growing bud was significantly greater for the control (water) than for all insecticides. Among fallen buds, chlorantraniliprole, cyantraniliprole, and spirotetramat had significantly fewer feeding holes than those in the control. With the curative approach, the mean number of feeding holes was greater in the control with no differences among insecticides. The prophylactic application can effectively suppress initial HBW infestation, in contrast to the curative application targeting already high populations. This provides the opportunity for reducing the impact of this regulated pest in areas of expansion.

Keywords: invasive species; chemical control; ornamentals; integrated pest management

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1. Introduction

The hibiscus bud weevil (HBW), *Anthonomus testaceosquamosus* Linell (Coleoptera: Curculionidae), originally from northeastern Mexico and southern Texas, USA, was first found in Florida in May 2017, becoming a new pest for tropical hibiscus (*Hibiscus rosa-sinensis*, (Malvales: Malvaceae) in Florida [1]. Florida leads hibiscus production in the U.S. with a 12% contribution nationally, while 20–25% of plants sold annually in Miami-Dade County are hibiscus [2,3]. While HBW adults feed primarily on flower buds, they can also feed on stems and leaves. Females oviposit in young flower buds and larvae develop internally by feeding on pollen. Due to the larval feeding, flower buds begin to decay and then detach from the plant. Weevils exit from the bud only when they have reached adulthood [4]. With heavy infestations, severe bud drop decreases the marketability of hibiscus plants, resulting in economic losses for the growers. To prevent the further spread of the pest, regulations on the HBW have been imposed by the Florida Department of Agriculture and Consumer Services, Division of Plant Industry (FDACS-DPI). Nurseries that the HBW has infested are required to sign a compliance agreement to guarantee that no HBW are present on the plants before transporting to retailers, nationally or internationally [4].

HBW has been associated with at least 15 plant species in the family Malvaceae [5] and at least 18 tropical hibiscus varieties; varietal preferences have also been observed for this pest under field conditions [6]. No information is available on whether alternative hosts may affect HBW infestation in the nurseries, but population dynamics seem to be affected by plant phenology and climate. In Miami-Dade and Broward counties, HBW populations are high from February to July, with a peak between March and June, with little or no occurrence from August to January, a time during which they could be surviving on wild alternative hosts when hibiscus plants are not available, or okra [5]. The population fluctuations may be associated with the availability of flower buds throughout the growing season [4].

Previous studies have shown that management of HBW could be achieved through a combination of cultural practices, including crop rotation, sanitation (removal of fallen flower buds that might be infested), and timely pesticide applications targeting adult weevils [7]. However, since the HBW spends most of its life cycle inside a closed bud, it is difficult to control via direct contact insecticides [4]. Moreover, HBW adults can survive between 14–50 days with only water, making it difficult to eliminate from nurseries even when no commercial host plants are available, as hibiscus plants have been shipped and are at their final destination [4].

Since the products under study here are commonly employed for managing other significant hibiscus pests, such as the pink hibiscus mealybug, *Maconellicoccus hirsutus* (Green) (Hemiptera: Pseudococcidae), whose population dynamics may not align with those of the HBW, we wonder if the use of these products could prevent or reduce the establishment of HBW populations. While prophylactic applications of insecticides have traditionally been associated with frequent or calendar-based treatments [8], we propose a distinct use of this term within the context of commercial HBW pest management. Our primary objective was to explore alternatives that offer sustained residual effects and will potentially and indirectly benefit HBW management. A prophylactic application could reduce HBW establishment and population growth once these products were already used for other hibiscus-associated pest problems and before the HBW begins its cyclic outbreaks, thereby preventing the need for periodic curative applications. In addition to that, a timely application based on early detection could prevent the pest from reaching any economic impacts, leaving space for more environmentally friendly alternatives to be incorporated into the system, such as cultural and biological management methods. In contrast, curative and repetitive applications—very common in this ornamental system—leave small room for alternatives to chemical applications.

To identify potential systemic insecticides for incorporation into our two different application approaches for HBW, we considered three chemical classes that differed in mode of action: (1) the anthranilic diamides (chlorantraniliprole and cyantraniliprole, IRAC group 28) that function at the level of the muscular calcium channels, (2) the tetronic and tetramic acid derivates (spirotetramat, IRAC group 23) that function at the level of lipid synthesis, and (3) a butenolide (flupyradifurone, IRAC group 4D) acting on the insect nicotinic acetylcholine receptors, but with a different bioactivation route than neonicotinoids [9]. In general, the idea was to explore efficient means that are more environmentally friendly and have a lower impact on honeybees than neonicotinoids. It is important to note, however, that although none of the tested products can be considered completely harmless to honeybees, they are relatively less harmful compared with neonicotinoids [10–12].

While untested against the HBW, the aforementioned products have previously shown significant lethal and sublethal effects on other economically important weevil pests (Coleoptera: Curculionidae). Cyantraniliprole, for instance, was found to cause mortality and antifeeding effects in adult pepper weevils, *Anthonomus eugenii* Cano, resulting in mortalities ranging from 50% to 90% when applied at rates ranging from

5.6 to 9.7 mg ai L^{-1} [13]. Similarly, chlorantraniliprole exhibited an LC50 of 6 mg ai L^{-1} against boll weevil adults, *Anthonomus grandis* Boheman [14]. Red palm weevil larvae, *Rhynchophorus ferrugineus* Olivier, demonstrated susceptibility to spirotetramat, leading to a recovery of approximately 65% of damaged trees 60 days after being injected into the trunk [15]. Furthermore, when flupyradifurone was administered via trunk injection in oil palm hosts, it resulted in larval mortality of at least eight times higher than when applied through spraying [16].

This study investigated two approaches for reducing HBW populations by applying selected systemic insecticides. We explored the effectiveness of insecticide applications before HBW infestation (prophylactic approach) and after HBW infestation (curative approach). Our goal was to identify the most efficacious insecticide and determine whether a preventive or reactive approach is more effective in managing this invasive pest. We also discuss important factors such as timely implementation and the population dynamics of the pest. Here, we excluded the evaluation of neonicotinoids due to environmental and retailer restrictions [17]. As a result of concerns regarding the proven detrimental effects of neonicotinoid insecticides on pollinators [18], there is a demand for plants that are free from these products in the ornamental market. Consequently, this demand is impacting nursery pest management practices, leading to the substitution of neonicotinoids with repeated applications of alternative products like pyrethroids. However, this approach may inadvertently open the door to other issues, such as the occurrence of secondary pest outbreaks [17]. We discuss the results under an Integrated Pest Management (IPM) prism, where actions taken at early pest colonization stages could decrease insecticide applications to allow time for additional pest management practices, such as cultural and biological control tactics.

2. Materials and Methods

2.1. Hibiscus Bud Weevil Colony

Adult weevils, originally collected from commercial nurseries in southern Florida, were introduced to infest freshly removed flower buds (var. 'Painted Lady') within mesh cages (30.5 × 30.5 × 30.5 cm, BioQuip Products Inc., Compton, CA, USA) under laboratory conditions. The weevils were held in a stock colony in a climate-controlled incubator (Percival I-36LL, Percival Geneva Scientific, Williams Bay, WI, USA) at 27 ± 1 °C, 12:12 h L:D, and 70 ± 10% RH. Buds used as feeding and oviposition substrate were removed from cages twice per week and maintained in plastic containers (20.5 × 19 × 37 cm Rubbermaid, Atlanta, GA, USA) until adult emergence. These containers' lids were adapted with a fine mesh (100 μm diameter) to allow ventilation. Adult weevils emerging from containers were then moved to new mesh cages containing fresh hibiscus buds.

2.2. Experimental Design

Experiments were carried out at conditions as close as possible to commercial production in relation to the plant material, the nutrition program, and the irrigation frequency. The trials were developed under greenhouse conditions (25 ± 2 °C; 70% ± 10% RH) between 30 August 2021 and 25 October 2021 (prophylactic) and 2 November 2021 and 14 December 2021 (curative), using a completely randomized design. Hibiscus bushy plants in 3 gal (3.78 L) pots were sourced from commercial nurseries and had been grown for two months without the use of pesticides before being transferred to the greenhouse for trials. The substrate used in the greenhouse was identical to the commercially used substrate, consisting of a mixture of Florida Peat (40%) and Wood Fines (60%). Initially, plants with a minimum of 20 small- to medium-sized buds (1.5–2.5 cm length) were selected for the study. After the plants were set in the greenhouse, an automatic drip irrigation system provided water for 4 min once per day at 2 p.m. However, this irrigation was suspended 24 h prior to the application day and resumed 24 h after the application. Six bushy hibiscus plants (var. 'Painted Lady') (40–45 cm tall) in full production of flower buds and leaves were placed individually within their own mesh cage (99 × 66 × 59.7 cm) (each plant representing one replicate). Each plant was infested with four 5-day-old weevils (two females and two males) manually released onto the foliage, and six plants were used for each treatment.

2.3. Application of Treatments

Treatments consisted of four systemic insecticides registered for ornamentals under nursery production at the maximum label rate, plus a water control. Suspension concentrates of commercially available products were obtained via online distributors. The application solutions were prepared using the label-recommended rate into 1 L of water: spirotetramat (22.4% SC; Kontos®; Bayer, Leverkusen, Germany) (1.21 mL/L), chlorantraniliprole (18.4% SC; Acelepryin®; Syngenta, Basel, Switzerland) (1.25 mL/L), flupyradifurone (17.09% SC; Altus®; Bayer) (0.29 mL/L), and cyantraniliprole (18.66% SC; Mainspring®; Syngenta) (0.95 mL/L).

Each plant was drenched with a solution at 500 mL/11.3 L pot. However, before the application, 500 mL of water was applied to moisten the soil. Preliminary observations under previous conditions demonstrated that leaching of the application was effectively prevented using this method. In the prophylactic approach, plants were drenched 4 weeks prior to weevil release; in the curative, plants were drenched 2 weeks post-weevil release. The selected timeframe for both approaches was based on recommendations provided by the label and personnel from the pesticide manufacturers. These recommendations indicated that for observing the effects of the diamides in the plants, a timeframe of at least 3–4 weeks was desirable for the prophylactic approach. For the curative approach, a one-week period was considered sufficient for adult weevils to reproduce and for the presence of eggs and larvae in the flower buds.

2.4. Data Collection

Samples were collected at 7, 14, 21, and 28 days after weevil release in the prophylactic approach, while collections were made at 7, 14, 21, and 28 days after insecticides were applied for the curative approach. On each sampling day, 5 actively growing buds were randomly collected from foliage per plant (as many as possible if a plant had <5), and all fallen buds were collected within the cage and the pot's surface. The number of eggs, surviving larvae, and feeding holes per bud were documented. Due to the cryptic behavior of the HBW adults and the challenges posed by the cage volume and various hiding spots available on the plants, assessing the survival of the initially infested weevils directly was difficult without disturbing the system. Therefore, observations were focused on the resultant offspring to determine the establishment and survival of the initial weevils. Additionally, these observations served as a measure of the effectiveness of the treatments on the concealed larvae. Data from the prophylactic and curative approaches were collected separately.

2.5. Data Analysis

In both approaches, the mean number of larvae, eggs, feeding holes per bud, and fallen buds per plant were independently compared among treatments and sampling days using a generalized linear mixed-effects model (GLMM; "glmmTMB" package in R) [19]. Each model includes the categorial variable 'sampling days' and 'treatment', as well as their interaction, as fixed effects. Additionally, the replicate 'plant' was treated as a random effect nested within the variable 'sampling day'. If the inclusion of the interaction term prevented model convergence (prophylactic and curative: eggs in actively growing buds, larvae in fallen buds; prophylactic fallen buds; and curative feeding holes in fallen buds), the categorical fixed effects of sampling days and treatment were individually included in each model. For models in which the inclusion of the interaction term prevented contrasts among treatments and sampling days from being calculated (prophylactic and curative feeding holes in actively growing buds and curative fallen buds), a model containing the individual categorical fixed effects of sampling days and treatment in place of the interaction term was used to obtain the contrast estimates. In such cases, all statistics reported herein (except for the contrast estimates) are from the original model including the interaction term. A negative binomial error distribution was used if response variables had a variance: mean ratio of >3 [20]. If the variance: mean ratio was <3 for a given response variable, a Poisson model was used. Contrasts (Tukey-adjusted) were implemented with the estimated marginal means method using the "emmeans" package in R [21]. In the prophylactic approach and specifically in relation to the number of larvae, the separation of mean treatments did not occur when contrasts were performed due to the usage of the Tukey familywise error rate adjustment. This result is in accordance with our decision to adjust for pairwise comparisons in this study, as we chose to minimize the probability of making a Type I error (i.e., rejecting a null hypothesis when there is no true effect). All statistical analyses were performed using R version 4.2.1 [22].

3. Results

3.1. Prophylactic Approach

The number of larvae per actively growing bud was at least double and significantly greater in control plants than in treatment plants (χ^2 = 14.88; df = 4; p = 0.004; Figure 1A). After the first week, there was a significant decrease in the number of larvae over the next three weeks in all treatments (χ^2 = 17.53; df = 3; p < 0.001), but the interaction between treatment and time was not significant (χ^2 = 3.25; df = 12; p = 0.993).

Even though the number of eggs per actively growing bud showed a tendency to be greater in control plants, this was not confirmed statistically (χ^2 = 6.47; df = 4; p = 0.166), but the number of eggs per bud significantly decreased after the first week of observation for all treatments (χ^2 = 14.78; df = 3; p = 0.002; Figure 1B).

Control plants had significantly more feeding holes per actively growing bud (χ^2 = 13.54; df = 4; p = 0.018; Figure 1C) than those in flupyradifurone- (approximately one-third fewer), spirotetramat-, and chlorantraniliprole-treated plants (approximately two-thirds fewer, respectively). The number of feeding holes per actively growing bud in cyantraniliprole-treated plants was not statistically different from those in control plants. In addition, the number of feeding holes per actively growing bud in all treated plants significantly decreased one week after infestation (χ^2 = 95.21; df = 3; p < 0.001). The interaction between treatment and time was insignificant (χ^2 = 5.34; df = 12; p = 0.945).

In fallen buds, nearly four times more feeding holes were observed on flupyradifurone-treated plants than on those plants treated with cyantraniliprole, spirotetramat, and chlorantraniliprole (χ^2 = 33.71; df = 4; p < 0.001; Figure 2A). There was also a significant effect of sampling day (χ^2 = 48.76; df = 3; p < 0.001), with a greater number of larvae at 7 days than at any other sampling day.

Significantly more larvae per bud were found in fallen buds at 7 days than that at 28 days after the infestation of adult weevils (χ^2 = 16.52; df = 3; p < 0.001; Figure 2B), with 14 and 21 days at the intermediate level. While the number of larvae per fallen bud was also significantly affected by treatment (χ^2 = 11.22; df = 3; p = 0.01; Figure 2B), means separation did not occur when contrasts were performed due to the usage of the Tukey familywise error rate adjustment. Because zero larvae were found in fallen buds treated with cyantraniliprole, this treatment was removed from the analysis to allow for model convergence.

The number of fallen buds per plant was approximately fivefold greater for spirotetramat-treated plants than in those treated with cyantraniliprole, flupyradifurone, and water (control) (χ^2 = 25.22; df = 4; p < 0.001; Figure 2C). Furthermore, no significant difference was found in relation to the number of fallen buds when considering the effect of sampling days (χ^2 = 2.94; df = 3; p = 0.400).

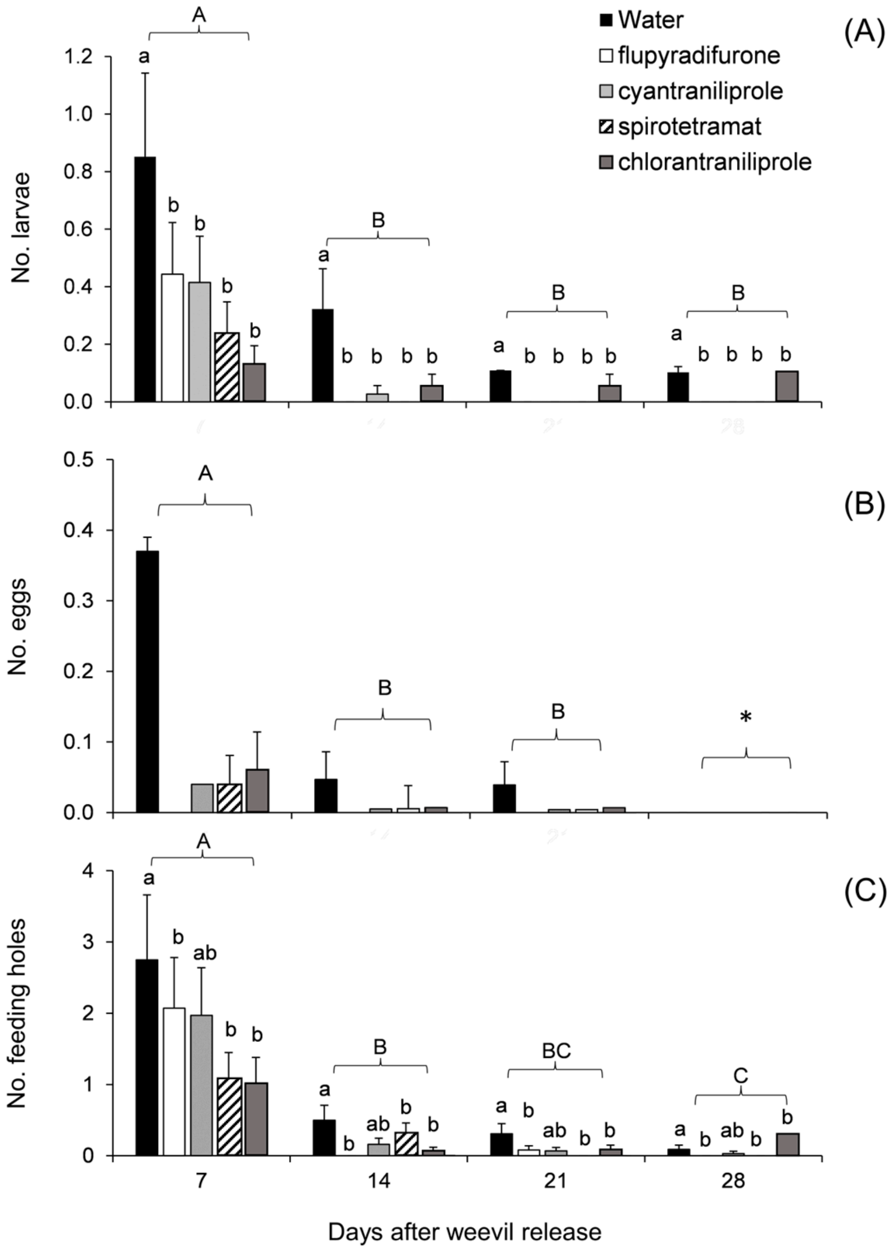

Figure 1. Estimated marginal means (± SEM; generalized linear mixed-effects model) for live larvae (**A**) and eggs (**B**) of hibiscus bud weevil and their feeding holes (**C**) on actively growing buds of tropical hibiscus, following the prophylactic application of four systemic insecticides. The insecticides were applied 4 weeks before the weevil infestation, and data were collected 4 sampling days after the infestation. Statistically different treatments are separated with lowercase letters within each sampling day, while statistically different sampling days are separated with uppercase letters across sampling days (Tukey adjustment, α = 0.05). As no significant interaction was observed between treatment and sampling dates, treatment means were not compared with each other across sampling dates. * There was no variability in this treatment combination; therefore, statistical contrasts with the other treatments were not possible.

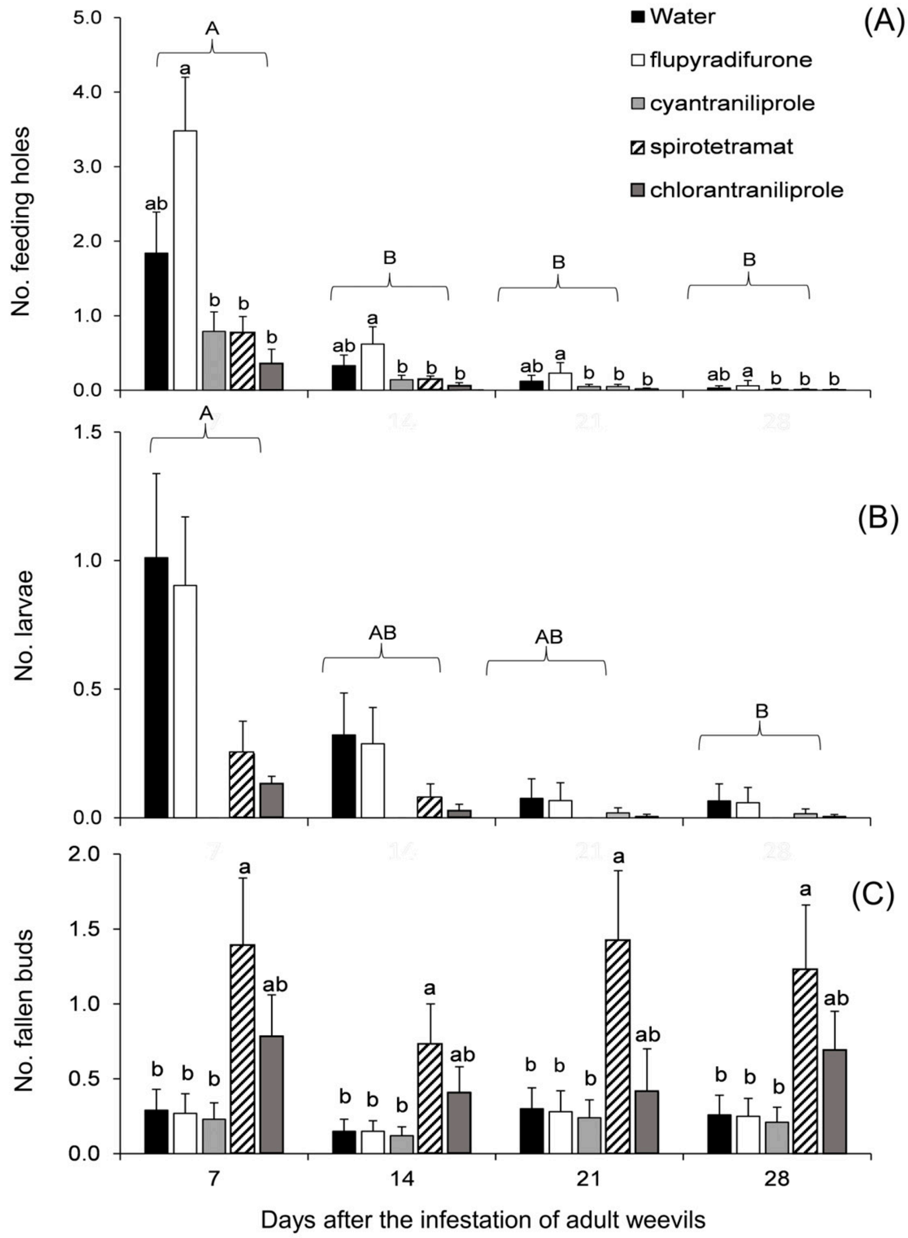

Figure 2. Estimated marginal means (±SEM; generalized linear mixed-effects model) for feeding holes (**A**) and live larvae (**B**) of hibiscus bud weevils on fallen buds on hibiscus plants, as well as for the number of fallen buds on hibiscus plants (**C**), following the prophylactic application of four systemic insecticides. The insecticides were applied 4 weeks before the weevil infestation, and data were collected 4 sampling days after the infestation. Statistically different treatments are separated with lowercase letters within each sampling day, while statistically different sampling days are separated with uppercase letters across sampling days (Tukey adjustment, $\alpha = 0.05$). As no significant interaction was observed between treatment and sampling dates, treatment means were not compared across sampling dates.

3.2. Curative Approach

The number of larvae per actively growing bud was not affected by treatment ($\chi^2 = 0.15$; df = 4; $p = 0.997$; Figure 3A), but there was a significant effect of time on number of larvae per bud ($\chi^2 = 18.47$; df = 3; $p < 0.001$), with a greater number on 7 days and the lowest at 14 days after insecticide application. Overall, the interaction between treatment and time was not significant ($\chi^2 = 2.24$; df = 12; $p = 0.998$).

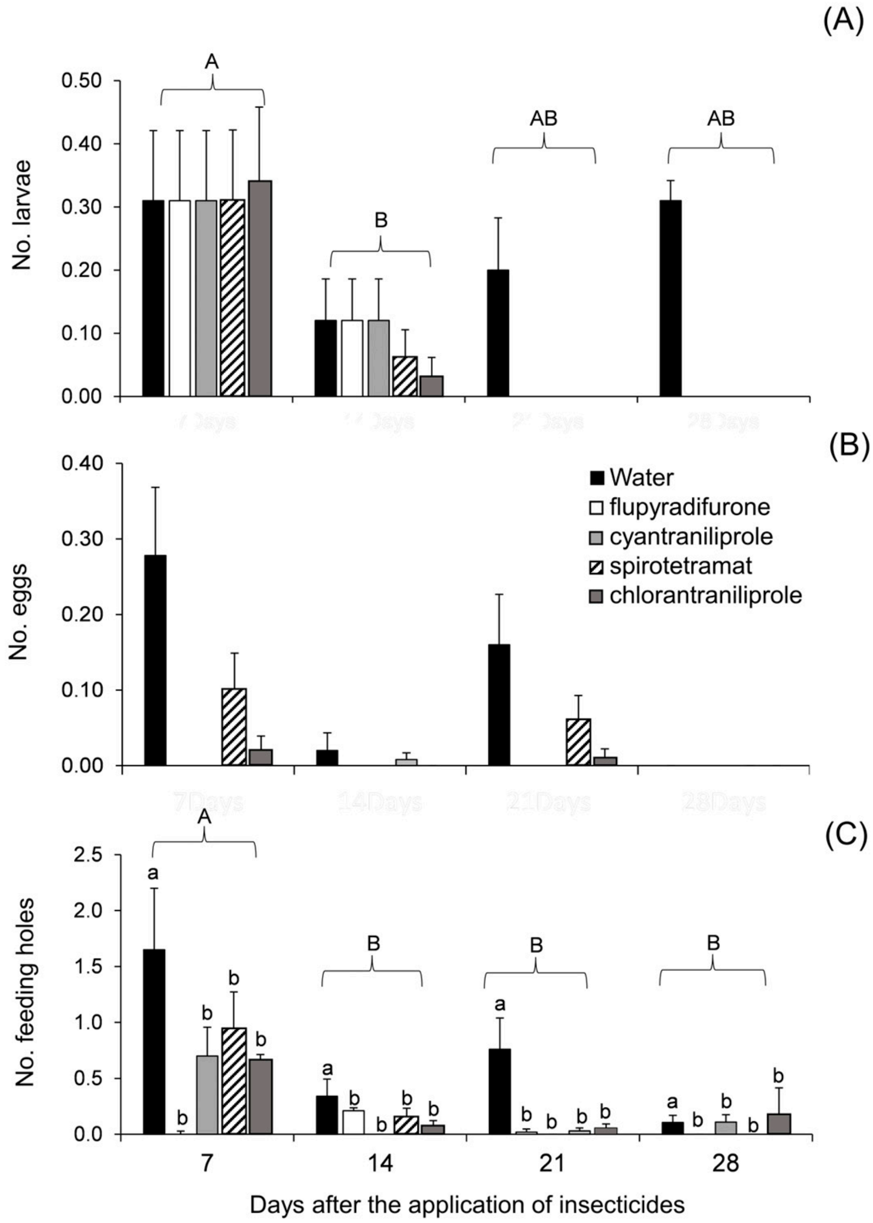

Figure 3. Estimated marginal means (±SEM; generalized linear mixed-effects model) for live larvae (**A**) and eggs (**B**) of hibiscus bud weevil and their feeding holes (**C**) on actively growing buds of tropical hibiscus, following the curative application of four systemic insecticides. The insecticides were applied 1 week after the weevil infestation, and data were collected at 4 sampling days after insecticide application. Statistically different treatments are separated with lowercase letters within each sampling day, while statistically different sampling days are separated with uppercase letters across sampling days (Tukey adjustment, $\alpha = 0.05$). As no significant interaction was observed between treatment and sampling dates, treatment means were not compared across sampling dates.

The number of eggs per actively growing bud was neither significantly affected by treatment ($\chi^2 = 9.08$; df = 4; $p = 0.059$; Figure 3B) nor by time ($\chi^2 = 6.19$; df = 3; $p = 0.102$). Model convergence was assisted by the inclusion of the random effect of replicate (plant) instead of sampling days nested within the replicate.

All treated plants had significantly fewer feeding holes per actively growing bud than those on the water control ($\chi^2 = 16.24$; df = 4; $p = 0.006$; Figure 3C), with a reduction of approximately one-half in the case of cyantraniliprole and chlorantraniliprole, an approximately one-third reduction in relation to spirotetramat, and an approximately 15-fold reduction in relation to flupyradifurone. There was also a significant effect of time on the number of feeding holes (χ^2 = 47.06; df = 3; p < 0.001), with a decreasing number of feeding holes per bud along with increased time after treatment for all insecticides. No interaction was found between treatment and time (χ^2 = 2.24; df = 12; p = 0.140).

On fallen buds, no significant difference in the number of feeding holes was found among treatments (χ^2 = 3.58; df = 4; p = 0.466; Figure 4A) nor across sampling time (χ^2 = 5.44; df = 3; p = 0.142). Similarly, there was no significant difference in the number of larvae among treatments (χ^2 = 4.08; df = 4; p = 0.396; Figure 4B) at any sampling time (χ^2 = 4.07; df = 3; p = 0.254). No significant interaction was found between treatment and time (χ^2 = 2.35; df = 4; p = 0.671).

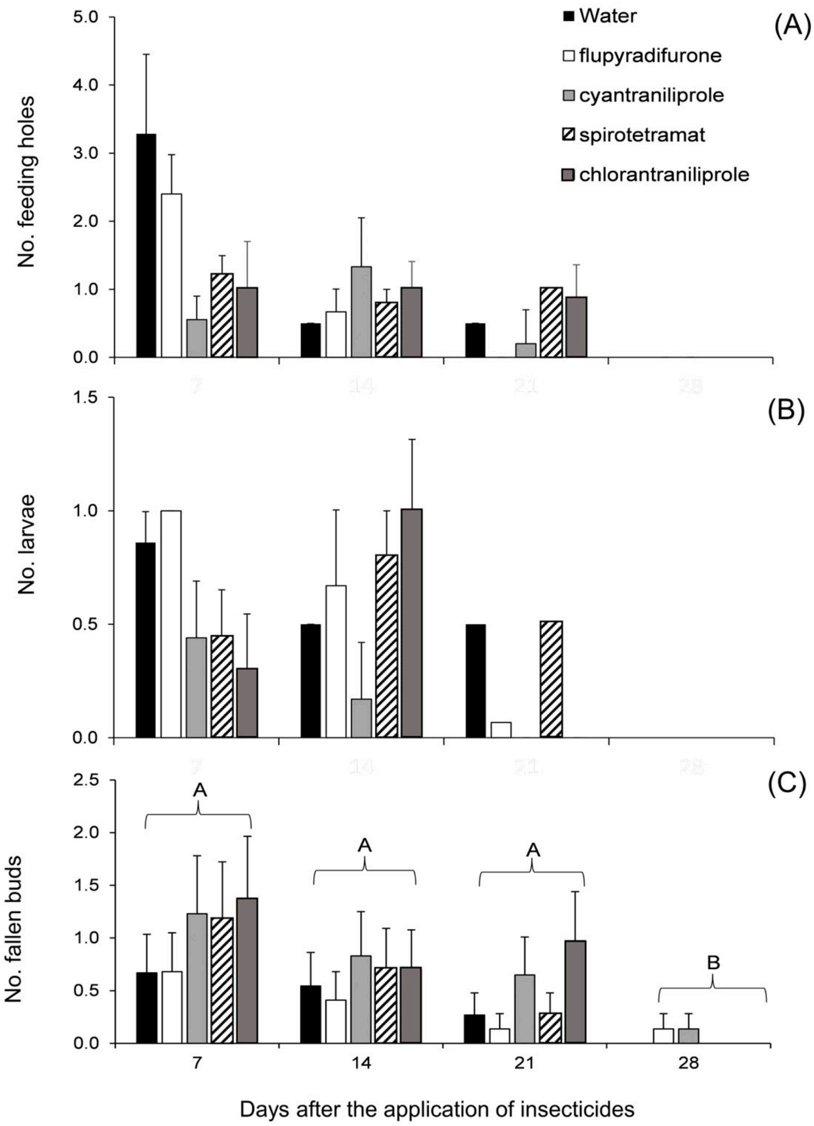

Figure 4. Estimated marginal means (±SEM; generalized linear mixed-effects model) for the feeding holes (**A**) and larvae (**B**) of the hibiscus bud weevil on fallen buds of tropical hibiscus, as well as for the number of fallen buds (**C**) on hibiscus plants, following the curative application of four systemic insecticides. The insecticides were applied 1 week after the weevil infestation and data were collected 4 sampling days after insecticide application. In panel (**B**), error bars are absent at 21 days as only one plant possessed fallen buds. Statistically different sampling days are separated with uppercase letters across sampling days (Tukey adjustment, α = 0.05). As no significant interaction was observed between treatment and sampling dates, treatment means were not compared across sampling dates.

The number of fallen buds per plant was not significantly affected by treatment (χ^2 = 5.56; df = 4; p = 0.350; Figure 4C). However, there were fewer fallen buds at 28 days after insecticide application, in comparison with all other sampling days (χ^2 = 9.60; df = 3, 69; p = 0.047). No interaction was found between treatment and time (χ^2 = 2.57; df = 12, 69; p = 0.997).

Overall, a greater number of treatment effects were observed on the measured variables in the prophylactic approach compared with the curative approach (see Figure S1). When considering actively growing buds, treatment effects were detected in the number of larvae and holes per bud, whereas in the curative approach, treatment effects were only observed in the number of holes per bud. Regarding fallen buds, treatment effects were found in the number of holes per bud and in the number of fallen buds per plant in the prophylactic approach, while no effects were detected in any of the variables in the curative approach.

4. Discussion

Under a preventive scenario (i.e., prophylactic treatment), differences in the tested systemic insecticides were more consistent and mainly associated with the number of feeding holes and larvae per bud. By drenching hibiscus plants four weeks prior to weevil release, active ingredients were able to reduce adult HBW feeding and larval survival. With the prophylactic approach, chlorantraniliprole, spirotetramat, and flupyradifurone disrupted HBW feeding behavior and potentially prevented females from ovipositing. Although the number of eggs did not differ significantly among treatments, fewer eggs were present in treated plants than in the control plants at each sampling time. This trend would support the reduction in the number of larvae per bud in comparison with the control plants. A similar trend was also observed in fallen buds, as chlorantraniliprole, cyantraniliprole, and spirotetramat treatments reduced the number of feeding holes and larvae in comparison with the control plants, which suggests that the insecticides affected the feeding and reproductive behaviors of HBW on flower buds that had already dropped from plants.

With the prophylactic approach, the number of fallen buds per plant was higher when spirotetramat was applied compared with the untreated control plants at all sampling times. This result is consistent with previous observations of phytotoxic symptoms after spirotetramat application on ornamentals [23,24], especially on monocotyledonous plants, some of which are explicitly prohibited from using spirotetramat for pest control (e.g., orchids, neanthe bella palm, ferns, and others) [25]. Although phytotoxicity was not confirmed under the curative approach, which may be attributable to the shorter exposure of plants before the beginning of our observations (one week) compared with the five weeks of exposure in the prophylactic approach, it suggests that special attention needs to be given with regard to the recommended label rates and the calibration of injectors used in commercial applications of these active ingredients to prevent negative impact to hibiscus plants [25].

With the curative approach, the only difference associated with treatments was related to a reduction in the number of feeding holes per bud in actively growing buds. It is therefore speculated that under this approach, the reduction in the number of feeding holes is due to either the mortality of adults or adults being repelled when plants were drenched with insecticides. Although no information is available on the metabolism of these systemic insecticides in hibiscus plants, chlorantraniliprole can provide protection against the rice water weevil, *Lissorhoptrus oryzophilus* Kuschel (Coleoptera: Curculionidae), at early developmental stages of rice plants after being used as seed treatment, with concentrations of the product found in plant tissues not only at the vegetative but also at reproductive stages after 9 and 13 weeks of seed treatments, respectively [26]. For flupyradifurone, 75% mortality of the alfalfa weevil *Hypera postica* (Gyllenhal) (Coleoptera: Curculionidae) was observed on alfalfa three weeks after application [27]. In the case of spirotetramat, it is known that once it is taken up by the plant it degrades quickly into the acid spirotetramat-enol, with physicochemical properties for moving both ways through the xylem and phloem tissues [28]. For ornamentals, it is unclear how long these active ingredients take to reach each plant tissue, including flower buds. Our data suggest that pesticides started killing HBW larvae at 4 weeks after the application in the prophylactic approach. In the curative approach, however, 2 weeks after the pesticide application, there were still live larvae present in buds, suggesting that more time is required for the pesticide to reach these reproductive tissue systems.

Our study highlights the efficacy of chlorantraniliprole against the HBW at two different life stages, altering adult feeding (i.e., number of feeding holes) and reducing the number of surviving larvae in actively growing buds. Moreover, our findings indicate that under the prophylactic approach, cyantraniliprole resulted in zero larvae found in fallen buds. These observations have significant implications for HBW pest management, as fallen buds at ground level play a substantial role in the pest population. Fallen buds were found to have ten times more signs of feeding damage than those buds actively growing in the plants, with 66% of these containing eggs and larvae from all three instars of the pest [7]. It is worth noting that the favorable results seen with these diamides stand in contrast to the limited efficacy of chlorantraniliprole in controlling the black vine weevil *Otiorhynchus sulcatus* (F.) (Coleoptera: Curculionidae) in various other ornamental plants, such as *Astilbe*, *Euonymus*, *Heuchera*, *Rhododendron*, *Sedum*, and *Taxus.* In those cases, no effects were detected on survival and adult weight, except for a reduction in adult feeding observed on *Taxus*, 12 days after the application [29].

Chemical control is the predominant method employed for pest management in ornamentals, driven by a near-zero tolerance policy towards damage, which requires frequent and intensive application of insecticides [30,31]. Additionally, the regulatory considerations surrounding the HBW issue, such as the chances of quarantine and the inability to sell plants, further compel growers to maximize spraying efforts to minimize potential risks. The idea of discussing these two approaches—prophylactic and curative—is to assess how an IPM program can be best utilized in a system that heavily relies on chemical insecticides. The implementation of an effective IPM program in hibiscus would be beneficial for managing not only the HBW but for other challenging pests, such as the pink hibiscus mealybug *M. hirsutus*, whose management could also be achieved with the systemic insecticides tested in this study.

In this study, preventive applications were highly disruptive of pest population dynamics, as applications altered adult feeding behavior and killed larvae mortality in the buds that eventually wound up falling to the ground. Nevertheless, preventive applications would not necessarily mean calendar applications, but such measures may suppress further population growth if implemented sparingly (e.g., once in early spring when HBW populations are still low) instead of a series of back-to-back applications during pest outbreaks. Non-chemical preventive measures have also found success, such as the peachtree borer, *Synanthedon exitiosa* (Say) (Lepidoptera: Sesiidae), which can be managed by periodic prophylactic applications of the entomopathogenic nematode *Steinernema carpocapsae* [32].

The idea of preventive measures using insecticide applications is complementary to the traditional pest thresholds in IPM, whereby attention is paid to already present infestations. With preventive actions, the focus is on the suppression of initial pest population growth. In that sense, control interventions are devised to delay pest colonization and expansion, thereby requiring sensitive sampling procedures tailored to the HBW. It has been suggested that prophylactic pest control tactics (e.g., transgenic crops) have complemented the effective adoption of IPM, especially when it comes to high-value crops (e.g., ornamental crops), where rates of economic return, convenience, and scale of operations are the driving factors [33].

Although these findings have been discussed under the framework of an IPM proposal for an invasive pest, it is crucial to recognize the regulatory aspects associated with an invasive species that has expanded its range from northeastern Mexico to Texas, and it is now in southern Florida. This invasive species poses a significant threat to a major agricultural industry, leading to potential regulatory measures and restrictions on plant sales. Consequently, growers must intensify their spraying efforts to minimize potential risks while restricting the use of efficacious but environmentally prohibited alternatives, such as neonicotinoid insecticides. As presented here, the implementation of prophylactic applications offers an alternative to prevent the further spread of this pest. This can pave the way for establishing a comprehensive, long-term IPM program.

With the goal of establishing a pragmatic IPM program for the HBW, plant phenology considerations could be beneficial. From August to January, very low HBW populations in South Florida nurseries occurred, and this coincides with unfavorable weather conditions and low availability of hibiscus or other flowering host plants [6]. Pest populations generally increase from February through July, with peak numbers between March and June. If prophylactic applications targeting initial pest population growth are exercised starting in February, a single application employed during the growing season may be sufficient to delay the population increase, which typically occurs between March and June. Additionally, during the spring season, the combination of foliar applications of contact chemical insecticides [34] and other management options, such as entomopathogenic nematodes and/or entomopathogenic fungi, can synergistically suppress the population to low levels. This approach could also be used for non-conventional options for ornamentals, such as the use of insect repellents like Kaolin clay [35]. Regarding biological control, the use of entomopathogenic nematodes warrants research in exploring their effectiveness against the concealed larval stages of the HBW. *Steinernema* species, known for their high mobility [36], show promise in effectively targeting these hidden larval stages. Additionally, for controlling the adult stage of HBW, potential options include using strains of *Beauveria bassiana* and bacterial bioinsecticides. These alternatives present new avenues for research in developing pest management alternatives for HBW-integrated pest management.

5. Conclusions

Under the prophylactic approach, tested insecticides resulted in significant adult feeding disruption and larval mortality. However, it is also noteworthy that all insecticides tested here (notwithstanding the phytotoxic potential of spirotetramat) represent effective, non-neonicotinoid options for HBW pest management, thereby alleviating environmental concerns on pollinators and the commercial use restrictions imposed by retailers on neonicotinoid insecticides.

While this study identified a way to increase the efficacy of different systemic control options for the HBW, additional research on many aspects of ornamental plant protection in nurseries is necessary, such as the implementation of sanitation and biological control, use of contact insecticides during shipping periods, and the development of sampling procedures. In summary, we argue that crop phenology and the reduction in initial HBW colonization and population growth are likely to be key factors to be considered as we seek to develop a successful IPM program for the HBW. By doing so, a future in which ornamental operations remain profitable and invasive pests such as the HBW are managed in an environmentally sustainable manner can be expected.

Beyond testing registered insecticides, which typically aim to provide growers with a list of effective options, we have demonstrated the effectiveness of preventive insecticide applications in reducing damage and populations of the HBW. By utilizing different modes of action and incorporating them into a rotation program, these preventive measures can effectively curb the further spread of this regulatory and invasive pest. Furthermore, we propose that these preventive applications could serve as a foundation for an IPM framework. This framework would consider crop phenology and explore alternative management, such as repellents and biological control, with the goal of minimizing losses and safeguarding the hibiscus ornamental industry.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agriculture13101879/s1, Figure S1: Summary of findings on the effects of two application methods, prophylactic and curative, of systemic insecticides on hibiscus bud weevil infestation in tropical hibiscus.

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