**Evaluation of integrated management modules for Rugose Spiralling Whitefly (*Aleurodicus rugioperculatus*) in Coconut**

**Abstract**

An on-farm trial was conducted in Periyapudur village, Salem district, Tamil Nadu, to evaluate integrated management modules against rugose spiralling whitefly (RSW) (*Aleurodicus rugioperculatus*) infesting coconut palms. Three modules combining cultural, biological, and botanical interventions were compared with an untreated control in a randomized block design with five replications. All modules significantly reduced RSW population and increased parasitism by *Encarsia guadeloupae* compared to untreated control. In the Module 2, integrating *Isaria fumosorosea* sprays and *Encarsia* augmentation, achieved the highest parasitism (up to 71.10%). Module 3 recorded maximum trap catches (1,378/trap in 120 days), while Module 1 maintained higher *Mallada* predator populations. Results demonstrate the potential of these modules in sustainable RSW management in coconut ecosystems.

**Keywords:**
Rugose spiralling whitefly, *Encarsia guadeloupae*, *Chrysoperla zastrowi sillemi*, IPM modules, biological control, coconut pests

## ****INTRODUCTION****

The rugose spiralling whitefly (Aleurodicus rugioperculatus Martin) (Hemiptera: Aleyrodidae) has emerged as a highly invasive pest in India, causing substantial economic damage to coconut and a range of other perennial crops. First reported in India on coconut palms in Kerala in 2016 (Amutha et al., 2017), the pest has since spread rapidly across major coconut-growing states including Tamil Nadu, Karnataka, Andhra Pradesh, and Maharashtra (Selvaraj et al., 2017; Manikandan et al., 2018). Its infestation is characterized by dense, spiralling waxy egg masses and profuse honeydew excretion, which promotes the growth of sooty mould on foliage, reducing photosynthetic efficiency and overall plant health (Nagrare *et al.,* 2016).

The biology and ecology of A. rugioperculatus have contributed significantly to its invasive potential. The pest completes multiple overlapping generations per year and is protected by waxy secretions that confer resistance against contact insecticides (Stocks and Hodges, 2012). Adult females are prolific egg layers, and nymphal development occurs concealed beneath spiralling wax filaments, making conventional chemical management approaches inadequate and environmentally hazardous (Meyerdirk et al., 2001). Among the notable impacts of infestation are yield decline due to impaired photosynthesis, premature nut fall, and increased vulnerability to secondary pests and diseases (Shylesha *et al.,* 2018). Furthermore, the honeydew accumulation can render coconuts unmarketable due to black sooty mould deposition (Manikandan *et al.,* 2019). Among the different insecticides tested against spiraling whitefly, the least LC50 was recorded by flubendiamide 480 SC (34.55 ppm) and emamectin benzoate 5 SG (39.14 ppm) against eggs, by spinosad 45 SC with 39.78 and 106.62 ppm against nymphs and adults, respectively (Balikai and Pushpalatha, 2018). The insecticides spinosad 45 SC @ 0.2 ml/l and cyantraniliprole 10 OD @ 0.3 ml/l recorded maximum of 96.19 per cent adult mortality of spiraling whitefly at 48 hours after treatment and were on par with indoxacarb 15.8 EC @ 0.3 ml/l, which recorded 92.37 per cent mortality of adults at 48 hours after treatment (Pushpalatha and Balikai, 2015). But, the insecticides are not eco-friendly and not compatible with bioagents. Therefore, there is a critical need for sustainable, ecologically sound pest management strategies. Integrated pest management (IPM) approaches have gained prominence in recent years as viable alternatives to sole reliance on synthetic insecticides (Yambhatnal et al., 2011; Kumar and Rajagopal, 2019). Several studies have documented the role of natural enemies, particularly the aphelinid parasitoid, Encarsia guadeloupae Viggiani (Hymenoptera: Aphelinidae), which was introduced into India and has since established as an important biological control agent (Vennila *et al.,* 2019). Augmentative releases and conservation of Encarsia have been shown to significantly suppress whitefly populations (Manikandan *et al.,* 2019). Predators such as Chrysoperla zastrowi sillemi (Neuroptera: Chrysopidae) and coccinellid beetles also contribute to biological control (Amutha *et al.,* 2018). Entomopathogenic fungi, including Isaria fumosorosea (formerly Paecilomyces fumosoroseus), have demonstrated pathogenicity against whitefly nymphs and are compatible with parasitoids, offering a promising biopesticide option (Ghosh et al., 2018). In addition to microbial agents, botanical oils such as neem oil have been reported to exert repellent and antifeedant effects against Aleyrodid pests (Singh and Rathi, 2017). Nutritional and cultural practices, such as balanced fertilization, organic manuring, and intercropping with green manure crops, can improve plant vigour and tolerance to pest infestations (Chandranath *et al.,* 2020). The deployment of yellow sticky traps for adult monitoring and mass trapping is an established non-chemical tactic in whitefly management programs (Vennila *et al.,* 2019). Despite the availability of these tactics, there is limited field-based evidence on the comparative performance of comprehensive IPM modules integrating biological, botanical, and cultural measures under farmer-managed conditions. Field validation is crucial for refining and popularizing scalable strategies tailored to specific agroecological contexts (Ghosh *et al.,* 2018). This study was therefore undertaken to evaluate the efficacy of three integrated management modules combining biological control agents (Encarsia guadeloupae, Chrysoperla zastrowi sillemi), entomopathogenic fungi (Isaria fumosorosea), botanicals (neem oil), nutrient management, and mechanical trapping, compared to an untreated control under field conditions in Salem district, Tamil Nadu. The findings are expected to contribute to the development of eco-friendly, farmer-adoptable strategies for sustainable management of rugose spiralling whitefly in coconut.

## ****MATERIALS AND METHODS****

### **Experimental Site and Agroecological Conditions**

The field experiment was conducted from December 2020 to March 2021 in farmers’ fields located at Periyapudur village (11.6495°N, 78.1987°E), Salem block, Salem district, Tamil Nadu, India. The region falls under the Eastern Ghats agroclimatic zone, characterized by red loamy soils with good drainage, an average annual rainfall of approximately 1,050 mm, and a mean annual temperature ranging between 22–32 °C. The experimental site consisted of established coconut plantations of 12-year-old DJ hybrid palms, spaced at 7.5 × 7.5 m, maintained under rainfed conditions supplemented with periodic organic inputs. Prior to the initiation of treatments, the plantation had a history of moderate rugose spiralling whitefly (A. rugioperculatus) infestation, confirmed by visual inspection and presence of characteristic waxy spiralling egg masses and sooty mould deposition on foliage.

### **Experimental Design and Layout**

The study employed a randomized block design (RBD) with four treatments and five replications per treatment. Each replication comprised two adjacent coconut palms, resulting in a total of 40 palms monitored across treatments. The experimental units were demarcated with buffer rows to minimize treatment interference and cross-contamination of biological agents.

Pre-treatment counts of rugose spiralling whitefly populations were recorded one week prior to treatment application to serve as a baseline reference for subsequent comparative analysis.

### **Treatments and Application Protocols**

**Treatment 1 (Module 1: Integrated Nutrient and Biocontrol Module)**

* **Soil Nutrition:** Urea (1.3 kg/palm), super phosphate (2.0 kg/palm), muriate of potash (3.5 kg/palm), and neem cake (5 kg/palm) were applied uniformly in the basin and incorporated into the soil. Well-rotted farmyard manure (FYM) at 50 kg/palm was broadcasted and mixed.
* **Micronutrient Supplementation:** TNAU micronutrient mixture was applied at 1 kg/palm/year as per standard recommendations.
* **Root Feeding:** TNAU coconut tonic was administered through root feeding at 200 ml/palm once during the trial period. A hole was drilled into the exposed root, and the tonic was delivered via an intravenous drip bottle to ensure uniform uptake.
* **Biocontrol Augmentation:**
	+ Encarsia guadeloupae: Parasitized nymphs stapled under infested leaflets at 100 units per acre.
	+ Chrysoperla zastrowi sillemi: 400 eggs were released per acre by uniformly placing them on coconut leaflets.
* **Cultural and Mechanical Measures:**
	+ Yellow sticky traps (8 × 1.5 ft) coated with castor oil were installed at 10 traps per acre to attract adult whiteflies.
	+ Sunhemp (Crotalaria juncea) or cowpea (Vigna unguiculata) seeds were sown in the basin at 5 g per palm to promote soil health and reduce alternate hosts.

**Treatment 2 (Module 2: Biopesticide and Biological Integration Module)**

* **Micronutrient Supplementation:** TNAU micronutrient mixture @ 1 kg/palm/year applied.
* **Root Feeding:** TNAU coconut tonic @ 200 ml/palm administered once via root feeding.
	+ **Biocontrol Augmentation:** Parasitized nymphs of Encarsia guadeloupae were stapled to the undersides of infested leaves at 100 units per acre.
* .
* **Biopesticide Application:** Isaria fumosorosea (2 × 10⁸ CFU/g) was applied as foliar sprays at 5–7 g/litre of water. Two sprays were given at a 14-day interval when the RSW infestation index reached Level 1 (*i.e.,* presence of active spiralling egg masses on >25% of leaflets). Sprays were performed early morning to avoid photodegradation, ensuring thorough coverage of the lower leaf surfaces.

**Treatment 3 (Module 3: Parasitoid and Botanical Module)**

* **Parasitoid Augmentation:** *Encarsia* parasitoids were released using the TNAU capsule formulation at a rate of 100 adult parasitoids per acre. Capsules were attached to shaded portions of the canopy to facilitate emergence.
* **Predator Augmentation:** 400 eggs of Chrysoperla zastrowi sillemi were released per acre by pinning egg cards to coconut leaflets.
* **Botanical Spray:** Neem oil 0.5% (5 ml/litre) was applied as a foliar spray targeting the nymphal stages.
* **Mechanical Control:** Yellow sticky traps (5 × 1.5 ft) coated with castor oil were installed at 8 traps per acre.

**Treatment 4 (Untreated Control):**

No interventions were applied. This served as a reference to evaluate natural population fluctuations and biological control occurrence.

### **Observation and Data Collection**

**Whitefly Population Monitoring**

Whitefly populations were assessed monthly for four months after treatment initiation. On each sample date, five randomly selected leaflets per palm were examined on the underside using a hand lens (10X). The number of live RSW nymphs per leaflet was counted, and the mean per leaflet was calculated for each replication.

**Parasitism Assessment**

Parasitism by E. guadeloupae was recorded monthly by carefully observing the same leaflets used for population counts. Parasitized nymphs, distinguished by characteristic darkened, hardened bodies, were expressed as a percentage of total nymphs observed.

**Predator Abundance**

The occurrence of Mallada sp. (green lacewing) predators was recorded by counting the number of larvae and adults per 10 leaflets per replication during each assessment.

**Sticky Trap Counts**

The number of adult whiteflies trapped on sticky sheets was recorded at bi-weekly intervals. Cumulative trap catches over 120 days were calculated for each treatment.

### **Data Transformation and Statistical Analysis**

To normalize variance and meet assumptions of ANOVA, whitefly count data were subjected to square root transformation [√(x+0.5)]. Percent parasitism data were arcsine transformed prior to analysis. Analysis of variance was performed using the AGRES statistical package (version XX), and treatment means were compared by the least significant difference (LSD) test at a 5% probability level (P ≤ 0.05).

Percent change over pre-treatment counts was computed to illustrate treatment efficacy relative to the baseline population. Data were presented as untransformed means, with transformed values indicated in parentheses where applicable.

**RESULTS**

**Population Dynamics of Rugose Spiralling Whitefly**

The detailed numerical data on RSW population, parasitism, predator abundance, and trap catches across treatments are presented in Table 1. The pre-treatment counts of rugose spiralling whitefly (RSW) per leaflet ranged from 30.56 to 32.40 across treatments, indicating uniform initial infestation levels with no statistically significant differences (p>0.05). The temporal trends of RSW population across treatments are presented in Figure 1, showing a consistent decline in Module 2 and progressive increase in the untreated control over the four-month period. Temporal observations over four months after treatment revealed clear divergence in pest population trends among treatments (Table 1). At one month after treatment initiation (December 2020), RSW populations declined across all treated plots compared to the control. The reduction was most pronounced in Module 2 (24.36 RSW/leaflet), followed by Module 1 (29.40) and Module 3 (29.26), whereas the control exhibited a marginal increase to 31.60 RSW/leaflet. Statistical analysis indicated that the mean difference between Module 2 and the control was significant (CD at 5% = 0.43). Two months after treatment (January 2021), the suppression effect persisted, with Module 2 recording the lowest RSW counts (25.26), in contrast to the control (32.58). The trend continued at three months (February 2021), when Module 2 maintained a mean of 28.42 RSW/leaflet, while the control increased markedly to 42.38. At four months (March 2021), a clear distinction was evident between treatments: Module 2 had the lowest RSW population (30.30), followed by Module 1 (38.46) and Module 3 (38.60). The untreated control reached the highest recorded population of 56.62 RSW/leaflet, demonstrating the unchecked proliferation of the pest in the absence of interventions. Statistical analysis of the temporal means confirmed that the suppression achieved in Module 2 was significant (p<0.05) compared to the control during all post-treatment intervals, particularly at three and four months (CD = 0.45). The square root transformed values corroborated the same trend, with transformed means in Module 2 ranging from 5.03 to 5.59, significantly lower than the control (5.70 to 7.58).



**Figure 1: Temporal dynamics of RSW population across treatments**

**Parasitism by *Encarsia guadeloupae***

Percent parasitism of RSW nymphs by *E. guadeloupae* before and after treatment application is presented in Table 1. Initial parasitism levels before treatment ranged from 26.32 to 29.64% across treatments and 28.98% in the control, with no significant differences among plots. Following the application of management modules, parasitism rates showed substantial improvements in treated plots relative to the untreated control (Table 1). Figure 2 illustrates the progressive increase in *E. guadeloupae* parasitism, with Module 2 achieving the highest levels by the fourth month. The temporal trends of RSW population across treatments are presented in Figure 1, showing a consistent decline in Module 2 and progressive increase in the untreated control over the four-month period. At one month post-treatment, Module 2 registered parasitism of 38.60%, significantly higher than the control (26.32%). This positive trend intensified over time. By the second month, parasitism in Module 2 rose to 44.70%, while the control remained comparatively static at 32.54%. The most marked increase occurred during the third and fourth months, with Module 2 achieving 59.20% and 71.10% parasitism, respectively. The arcsine transformed values for Module 2 in the fourth month were correspondingly high (57.57), confirming statistically significant enhancement over the control (38.99).

Modules 1 and 3 also exhibited progressive increases in parasitism, albeit to a lesser extent. Module 1 reached 51.40% parasitism by four months, while Module 3 attained 49.34%. In contrast, the control plots displayed only a modest increase from 28.98% to 39.64%, underscoring the critical contribution of augmentative releases and conservation practices in enhancing *Encarsia* activity. Analysis of variance showed that treatment differences in parasitism became highly significant from the second month onward (CD = 3.91), with Module 2 consistently outperforming other modules and the control (p<0.01).



**Figure 2: Temporal progression of Encarsia guadeloupae parasitism**

**Abundance of *Mallada* sp. Predators**

Data on the abundance of *Mallada* sp. predators across treatments and sampling periods are summarized in Table 1.The pre-treatment abundance of *Mallada* sp. predators was low and comparable across treatments, ranging from 4.18 to 5.86 individuals per 10 leaflets. As shown in Figure 3, *Mallada* sp. predator abundance increased significantly in Module 1 and Module 2 compared to the control. Following treatment imposition, notable increases were observed, particularly in Module 1 and Module 2. At the fourth month of observation, Module 1 recorded the highest predator abundance (7.02 individuals/10 leaflets), followed by Module 2 (6.42), while Module 3 and control plots exhibited lower counts (4.10 and 4.28, respectively). The enhanced predator presence in Module 1 was likely attributable to the integration of organic nutrition, trap cropping (sunhemp/cowpea), and habitat conservation, which favoured natural enemy proliferation. The increase in predator numbers in treated plots was statistically significant compared to control during the later months (CD = 0.10). The square root transformed values corroborated this trend, demonstrating consistent increases in predator incidence in response to integrated management modules.



**Figure 3: Mallada sp. predator populations before and after treatment.**

**Adult Whitefly Captures in Yellow Sticky Traps**

The cumulative adult whitefly trap catches recorded over the 120-day observation period are included in Table 1 and the cumulative number of adult RSW captured in yellow sticky traps is depicted in Figure 4, highlighting the highest trap catches in Module 3. Yellow sticky trap data revealed significant differences in adult whitefly captures among treatments over the 120-day period. Module 3 recorded the highest cumulative trap counts, with an average of 1,378 adults per trap, followed by Module 1 (1,226). In contrast, no traps were installed in Module 2 and the control, precluding direct comparison for these treatments. The elevated captures in Module 3 highlight the role of sticky traps as an effective component of mass trapping strategies, particularly when integrated with parasitoid releases and botanical sprays. Figure 5 summarizes the overall percent reduction in RSW infestation relative to the untreated control, with Module 2 demonstrating the greatest efficacy.



**Figure 4: Cumulative adult RSW trapped over 120 days**



**Figure 5. Percent Reduction in RSW Infestation after 4 Months relative to control**

**Summary of Treatment Performance**

Overall, Module 2, comprising nutrient supplementation, root feeding with TNAU coconut tonic, augmentation with parasitized nymphs of *E. guadeloupae*, and foliar applications of *I. fumosorosea*, demonstrated superior performance in reducing RSW population and enhancing parasitism. Module 1 also provided substantial suppression while supporting higher *Mallada* predator abundance and significant trap captures. Module 3, despite moderate impact on nymphal populations, effectively reduced adult density through intensive mass trapping. Collectively, these findings underscore the potential of integrated modules combining biological control agents, botanicals, and mechanical interventions for the sustainable management of rugose spiralling whitefly in coconut ecosystems.

**Table 1. Evaluation of Management Modules of Rugose Spiralling Whitefly.**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Treatments** | **Population of RSW/leaflet before imposing treatments \*** | **Population of RSW/leaflet after imposing treatments\*** | ***Encarsia* Paraisitisation (%) Before treatments \*\*** | **Nymphs Parasitized by *Encarsia* sp % after imposing treatments \*\*** | **Population of *Mallada* sp before treatment****(Nos./****10****leaflets ) \*** | **Population of *Mallada*  sp.****Nos/10 leaflets after imposing treatments \*** | **RSW trapped in yellow sticky trap in 120 days****Nos./trap**  |
| **One month Dec.20** | **Two months Jan 21.** | **Three Months** **Feb 21** | **Four months****Mar 21** | **One month Dec.20** | **Two months Jan 21.** | **Three Months** **Feb 21** | **Four months****Mar 21** | **One month Dec.20** | **Two months Jan 21.** | **Three Months** **Feb 21** | **Four months****Mar 21** |
| **Module 1** | 32.40**(5.77)** | 29.40**(5.50)** | 25.24**(5.12)** | 32.10**(5.74)** | 38.46**(6.27)** | 28.42**(32.20)** | 31.60**(34.17)** | 39.60**(38.97)** | 46.30**(42.85)** | 51.40**(45.78)** | 5.86**(2.61)** | 6.32**(2.70)** | 8.64**(3.10)** | 7.42**(2.90)** | 7.02**(2.83)** | 1226.00 |
| **Module 2** | 30.68**(5.62)** | 24.36**(5.03)** | 25.26**(5.12)** | 28.42**(5.41)** | 30.30**(5.59)** | 26.32**(30.85)** | 38.60**(38.38)** | 44.70**(41.93)** | 59.20**(50.31)** | 71.10**(57.57)** | 4.18**(2.27)** | 4.60**(2.36)** | 6.25**(2.69)** | 5.64**(2.57)** | 6.42**(2.72)** | - |
| **Module 3** | 31.88**(5.73)** | 29.26**(5.49)** | 31.36**(5.68)** | 33.42**(5.86)** | 38.60**(6.28)** | 29.64**(32.97)** | 34.40**(35.88)** | 35.20**(36.36)** | 41.20**(39.90)** | 49.34**(44.60)** | 5.13**(2.47)** | 5.34**(2.51)** | 5.90**(2.62)** | 4.68**(2.38)** | 4.10**(2.25)** | 1378.00 |
| **Control** | 30.56**(5.61)** | 31.60**(5.70)** | 32.58**(5.79)** | 42.38**(6.58)** | 56.62**(7.58)** | 28.98**(32.55)** | 29.52**(32.88)** | 26.32**(30.83)** | 32.54**(34.74)** | 39.64**(38.99)** | 4.64**(2.37)** | 4.98**(2.44)** | 5.60**(2.56)** | 4.10**(2.25)** | 4.28**(2.29)** | - |
| **CD** | NS | 0.43 | 0.26 | 0.41 | 0.45 | 0.87 | 1.96 | 2.92 | 3.91 | 4.77 | 0.02 | 0.10 | 0.10 | 0.15 | 0.10 | - |
| **SE(d)** | 0.09 | 0.19 | 0.11 | 0.19 | 0.20 | 0.39 | 0.89 | 1.32 | 1.77 | 2.16 | 0.01 | 0.04 | 0.04 | 0.07 | 0.04 | - |
| **CV** | 2.76 | 5.74 | 3.44 | 5.08 | 5.11 | 1.95 | 3.99 | 5.67 | 6.69 | 7.33 | 0.71 | 2.95 | 2.64 | 4.42 | 2.91 | - |

## ****DISCUSSION****

 The present study demonstrated that integrated management modules significantly reduced rugose spiralling whiteflypopulations and enhanced the activity of key natural enemies in coconut plantations. Among the tested treatments, Module 2 which combined augmentative release of E. guadeloupae, I. fumosorosea sprays, nutrient management, and root feeding proved most effective, achieving a 46.5% reduction in RSW infestation relative to the untreated control by the fourth month.

The suppression of RSW populations observed in Module 2 corroborates earlier reports highlighting the synergistic potential of combining entomopathogenic fungi and parasitoids (Ghosh et al., 2018; Shylesha et al., 2018). Isaria fumosorosea has been extensively evaluated as a mycoinsecticide against whiteflies, including Bemisia tabaci and Aleurodicus dispersus, owing to its high infectivity and compatibility with other biocontrol agents (Manikandan et al., 2019). In the present study, the consistent reduction in live nymphal counts over four months suggests that periodic fungal sprays created sustained epizootics within the pest population, aligning with the findings of Kumar et al. (2020), who reported up to 60% mortality in RSW-infested palms following two applications of I. fumosorosea.

The remarkable increase in parasitism by E. guadeloupae observed in Module 2 (up to 71.1%) underscores the pivotal role of augmentative biological control in suppressing RSW outbreaks. Previous studies have demonstrated that Encarsia spp. can exert substantial regulatory pressure on Aleyrodid populations, particularly when conservation measures are integrated (Vennila et al., 2019; Amutha et al., 2018). The results of this experiment confirm that even under field conditions, periodic stapling of parasitized nymphs coupled with supportive ecological practices can accelerate the establishment and multiplication of parasitoid populations, ultimately reducing pest density. These findings are consistent with the reports by Ramani et al. (2017) and Selvaraj et al. (2017), who observed parasitism rates exceeding 60% within three months of Encarsia augmentation.

Module 1, which integrated organic nutrition, neem cake application, green manure sowing, and biological releases, also yielded significant suppression of RSW populations and promoted Mallada sp. predator abundance. The higher predator incidence recorded in Module 1 (7.02 individuals per 10 leaflets) suggests that diversified habitat management practices and nutrient amendments may have enhanced the foraging efficiency and survival of generalist predators (Chandranath et al., 2020). Similar observations have been reported by Reddy et al. (2018), who demonstrated that organic soil amendments and intercropping increased the abundance of lacewings and coccinellids in coconut and arecanut plantations.

Interestingly, Module 3, which emphasized mass trapping with yellow sticky traps and neem oil sprays, exhibited moderate suppression of nymphal populations but achieved the highest adult whitefly captures (1,378 per trap). Sticky traps are well-established tools for monitoring and reducing whitefly dispersal, and their integration in IPM programs has been shown to contribute to significant declines in adult populations (Shylesha et al., 2018; Nagrare et al., 2016). The observed reduction in adult density likely contributed to the partial containment of the infestation; however, the relatively lower parasitism and predator incidence in Module 3 indicates that mass trapping alone may be insufficient to control subsequent generations without concurrent biological interventions.

The sustained low parasitism observed in the untreated control plots (max 39.64%) further emphasizes the necessity of proactive augmentative releases. While ambient parasitoid populations were present, their natural activity was insufficient to regulate RSW below economic thresholds, supporting earlier assertions by Manikandan et al. (2019) and Stocks and Hodges (2012) regarding the limited impact of unassisted natural enemies under high infestation pressure.

These findings collectively reinforce the proposition that integrated approaches combining biological control agents, entomopathogenic fungi, botanicals, and mechanical tools are indispensable for the sustainable management of RSW. Unlike sole reliance on synthetic insecticides, which pose ecological risks and promote resistance development (Selvaraj et al., 2017), IPM modules such as those evaluated in this study offer durable, ecologically benign alternatives compatible with organic and low-input systems.

Furthermore, the demonstrated compatibility of E. guadeloupae, I. fumosorosea, and Mallada sp. within these modules aligns with the growing emphasis on conserving functional biodiversity to enhance pest suppression in perennial cropping systems (Gurr et al., 2017). The observed additive effects of biological agents and cultural practices underline the importance of integrating multiple tactics rather than adopting singular interventions. In conclusion, the superior performance of Module 2 highlights its potential as a scalable and farmer-friendly strategy for RSW management. The implementation of such integrated modules can significantly mitigate RSW damage, improve the resilience of coconut production systems, and contribute to sustainable intensification objectives in tropical agriculture.

**CONCLUSION**

Integrated management modules significantly reduced RSW infestations and enhanced biological control in coconut palms. Module 2, comprising nutrient supplementation, root feeding with TNAU coconut tonic, augmentation with parasitized nymphs of *E. guadeloupae*, and foliar applications of *I. fumosorosea*, demonstrated superior performance in reducing RSW population and enhancing parasitism. Module 1 also provided substantial suppression while supporting higher *Mallada* predator abundance and significant trap captures. Module 3 excelled in adult trapping. These modules can be recommended as part of an eco-friendly IPM strategy.

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