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

**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****

Recent reports have established that the rugose spiralling whitefly (RSW), *Aleurodicus rugioperculatus*, has rapidly spread across peninsular India since its first detection in 2016. The first record in Karnataka confirmed infestations on multiple host plants including coconut, banana, mango, sapota, and ornamentals with damage severity reaching 20–35% in coconut and 14–26% in banana (Selvaraj *et al.,* 2017). The pest's polyphagous nature, feeding on over 120 plant species, and long-distance dispersal via infested planting material have contributed to its invasive success. Morphological features such as the rugose operculum and diagnostic spirals of eggs assist in field identification. Natural parasitism by *Encarsia guadeloupae* and *E. dispersa* was recorded but found insufficient to suppress heavy infestations without augmentation. These findings reinforce the urgent need for integrated and ecologically sound management.

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, the pest has since spread rapidly across major coconut-growing states including Tamil Nadu, Karnataka, Andhra Pradesh, and Maharashtra. 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.

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. Adult females are prolific egg layers, and nymphal development occurs concealed beneath spiralling wax filaments, making conventional chemical management approaches inadequate and environmentally hazardous. Among the notable impacts of infestation are yield decline due to impaired photosynthesis, premature nut fall, and increased vulnerability to secondary pests and diseases. Furthermore, the honeydew accumulation can render coconuts unmarketable due to black sooty mould deposition. 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. 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. Augmentative releases and conservation of *Encarsia* have been shown to significantly suppress whitefly populations. Predators such as *Chrysoperla zastrowi* sillemi (Neuroptera: Chrysopidae) and coccinellid beetles also contribute to biological control. Entomopathogenic fungi, including *Isaria fumosorosea* (formerly *Paecilomyces fumosoroseus*), have demonstrated pathogenicity against whitefly nymphs and are compatible with parasitoids, offering a promising bio pesticide option. In addition to microbial agents, botanical oils such as neem oil have been reported to exert repellent and antifeedant effects against Aleyrodid pests. 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. The deployment of yellow sticky traps for adult monitoring and mass trapping is an established non-chemical tactic in whitefly management programs. 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 agro ecological contexts. 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 (sun hemp/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 investigation demonstrated the superior efficacy of integrated pest management (IPM) modules in suppressing the rugose spiralling whitefly (RSW), Aleurodicus rugioperculatus, under field conditions. Among the tested treatments, **Module 2** which integrated foliar application of Isaria fumosorosea, augmentative release of Encarsia guadeloupae, micronutrient supplementation, and root feeding with TNAU coconut tonicconsistently outperformed other modules, recording the highest parasitism rates (71.10%) and lowest RSW populations over the four-month assessment period.

#### **Efficacy of Isaria** fumosorosea **as a Mycoinsecticide**

The effectiveness of I. fumosorosea observed in this study aligns with previous reports by Mohitha Reddy *et al.* (2022), who demonstrated that two sprays at fortnightly intervals could induce up to 91.97% adult and 82.00% nymphal mortality in field trials. This entomopathogenic fungus offers multiple advantages: it directly infects nymphal stages concealed under waxy spirals, is environmentally benign, and exhibits compatibility with parasitoids and predators (Visalakshi *et al.,* 2021). Its pathogenicity is mediated by the secretion of cuticle-degrading enzymes (e.g., chitinases), allowing for rapid colonization and mortality. In the present study, consistent suppression of nymphal populations following two applications of I. fumosorosea reflects its potential for initiating self-sustaining epizootics under field conditions.

#### **Role of Encarsia guadeloupae in Augmentative Biocontrol**

The progressive increase in parasitism observed in Module 2, peaking at 71.10%, underscores the critical role of Encarsia guadeloupae as a keystone biocontrol agent. Selvaraj *et al.* (2017) first reported the occurrence of E. guadeloupae and E. dispersa in India with natural parasitism levels up to 30%. However, natural parasitism was insufficient under field conditions, as evident from the control plots in the current study, which recorded only 39.64% parasitism. Augmentative releases (via parasitized nymph stapling or capsule methods) proved essential in elevating parasitism rates, as also validated by Selvaraj *et al.* (2024) who demonstrated that mass production and field inoculations of Encarsia facilitated significant reductions in RSW populations.

Moreover, Visalakshi *et al.* (2021) documented parasitism rates exceeding 75% when Encarsia was used in combination with I. fumosorosea. Such compatibility was clearly reflected in the current findings, wherein Module 2 exhibited both high parasitism and nymphal mortality, emphasizing the synergistic value of combined bio control interventions.

#### **Predator Enhancement through Cultural Practices**

Module 1, integrating organic soil amendments (FYM and neem cake), green manure cropping (sunhemp or cowpea), and Chrysoperla zastrowi sillemi releases, significantly increased the abundance of Mallada sp. predators. A peak of 7.02 individuals/10 leaflets was recorded by the fourth month. The habitat heterogeneity and resource availability introduced through trap crops and organic amendments may have enhanced predator foraging efficiency and survival principles consistent with the ecological engineering approaches described by Gurr *et al.* (2000). Elango *et al.* (2019) also reported the presence of natural predators such as Stethorus sp. and Dichochrysa astur in untreated coconut plantations in Tamil Nadu, further supporting the value of diversified habitat management in promoting biological control.

#### **Effectiveness of Sticky Traps in Adult Suppression**

Module 3, which focused on neem oil sprays and mass trapping using yellow sticky traps, achieved the highest adult whitefly catches (1,378/trap over 120 days). This indicates the efficacy of mechanical suppression tactics in reducing adult dispersal. While trap data highlight the importance of sticky traps as a frontline suppression tool, relatively lower parasitism and predator levels in Module 3 suggest that sticky traps alone are inadequate for sustained suppression and must be complemented with biological agents. These results corroborate findings by Visalakshi *et al.* (2021), who reported that sticky traps are most effective when used alongside bio controls to target both life stages of RSW.

#### **Limitations of Natural Biological Control in Untreated Plots**

Despite the presence of natural Encarsia and predator populations in the untreated control, parasitism levels remained below the economic threshold (<40%), and pest populations escalated significantly (56.62 RSW/leaflet at four months). These findings reinforce earlier conclusions by Stocks and Hodges (2012) and Manikandan *et al.* (2021) that unassisted natural enemies are insufficient to suppress RSW outbreaks under high pest pressure. Therefore, proactive biological augmentation and ecological support are essential.

#### **Need for Forecasting Tools and Scalable IPM**

Considering the rapid spread of RSW since 2016 (Selvaraj *et al.,* 2017), predictive tools such as the ARIMAX-based models developed by Elango *et al.* (2021) can help forecast pest outbreaks using climatic predictors like temperature (r = 0.299\*). Integrating such forecasting systems with scalable IPM modules can facilitate timely interventions and limit pest establishment.

**Conclusion**

Integrated management modules significantly reduced RSW infestations and enhanced biological control in coconut palms. Module 2 was the most effective in reducing RSW populations and increasing parasitism, while Module 3 excelled in adult trapping. These modules can be recommended as part of an eco-friendly IPM strategy.

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