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Management of Invasive Rugose Spiraling Whitefly, *Aleurodicus rugioperculatus* (Martin) through Insect Parasitoids and Fungal Pathogens in Coconut

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Abstract

Coccus nucifera L. (Coconut) is one of the useful plantation crops all over the world, especially in the coastal and southern parts of India. The destructive invasive sucking pest, rugose spiraling whitefly (RSW), *Aleurodicus rugioperculatus* Martin, reduces photosynthetic activity and causes nut fall, which directly and indirectly causes enormous crop losses. Although chemical management is fast and successful it is not at all recommended in many cases of this pest control, as it is not eco-friendly and labor intensive. So, biological management methods include biocontrol agents which include; fungal pathogens, and natural enemies which include predators, and parasitoids. Although those agents are slower in action and time-consuming than chemical insecticides, it is relatively safer and has varied modes of action. Nowadays various NGOs, bio-control organizations, and state, and central universities are engaged in mass-culture of various biocontrol agents for field release and farmers' distribution. Extensive research work is going on already to determine the effectiveness of those biocontrol agents on various climatic conditions and different whiteflies.

Introduction

The Rugose spiraling whitefly (RSW), *Aleurodicus rugioperculatus* Martin, from Central America (Belize) by Martin (2004), is a recently discovered invasive insect pest in India, among numerous pests recorded in coconut. Selvaraj et al. (2016) and Sundararaj & Selvaraj (2017) from Pollachi, Tamil Nadu discovered it in 2016, in coconut, which was later recognized as one of the destructive and polyphagous pests in coconut.

Due to its high level of polyphagy, it lived on over 118 hosts from 43 different plant families, including numerous commercially significant crops in the US (Francis et al., 2016). In addition to feeding aggressively on leaf sap, wax, and sticky honeydew are excreted by RSW nymphs and adults, in infested leaves, leading to a reduction in photosynthetic efficiency in palms. These nutrient

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and water reductions cause premature leaf drop and drying stated by Kumar et al. (2013). In India, it has been gradually considered a common pest of oil palm and coconut, necessitating control efforts to prevent crop losses.

According to Joseph et al. (2016), honeydew is secreted after the sap-sucking from the abaxial leaf surface, covering the surface of the underlying fronds. On this honeydew, Chandrika Mohan et al. (2016) found the congregation of the *Capnodium* sp. of black fungus giving it a charcoal-like appearance visible even from a longer distance.

In both small and hybrid coconut trees that were 4 to 6 years old, the infestation on the lower leaves was highly severe and was associated with middle and upper layers. Even though sooty mold is not an illness, its presence on the underneath surface of leaves causes a significant reduction in photosynthesis on the plantation (Shanas et al., 2016).

Management of RSW using bio-control method

More than 45 predators attacking *Aleurodicus rugioperculatus* Martin and *Aleurodicus dispersus* Russell, in India are primarily generalists, with some being host-specific (Mani, 2010). Mani et al. (2004) found 22 predators from Karnataka, 15 from Tamil Nadu by Geetha (2000), whereas Ramani (2000) found 40 from Karnataka and Lakshadweep so far. Below is a brief discussion of some of the main natural enemy complexes of *Aleurodicus rugioperculatus* Martin, the coconut RSW.

A. Hymenopteran natural parasitoids of RSW

Report on hymenopteran insect parasitoids includes (**Figure 1**);

1. *Encarsia guadeloupe* Viggiani (Hymenoptera: Aphelinidae) from Lakshadweep (Ramani et al., 2002; Evans, 2007),

2. *Aleuroctonus* spp. (Hymenoptera: Eulophidae),

3. *Encarsia noyesi* Hayat (Hymenoptera: Aphelinidae) and

4. *Encarsia dispersa* Polaszek (Hymenoptera: Aphelinidae).

These are a few of the parasitoids that hymenopterans have that alter RSW (Taravati et al., 2013). *Encarsia guadeloupe* Viggiani was determined to be the most promising of all the parasitoids, causing 70–80% parasitism, while *Encarsia dispersa* (Polaszek et al., 1992; Poorani and Thanigairaj, 2017) caused 5– 6% parasitism against the RSW and was provided by ICAR - CPCRI (Anon., 2017).

B. Coleopteran and Neuropteran natural predators of RSW

Many predators predate upon RSW on various plants including the following important ones (Taravati et al., 2013), which are majorly categorized under the order Neuroptera and Coleoptera, includes (**Figure 1**);

1. *Cybocephalus* sp. Erichson (Coleoptera: Cybocephalidae),

2. *Diadiplosis* sp. Felt (Diptera: Cecidomyiidae),

3. *Jauravia pallidula* Motschulsky (Coleoptera: Nitidulidae),

4. *Menochilus sexmaculatus* (F.) (Coleoptera: Coccinellidae),

5. Predatory lady beetle; *Nephaspis oculata* (Coleoptera: Coccinellidae) (Kumashiro et al., 1983; Liu et al., 1997),

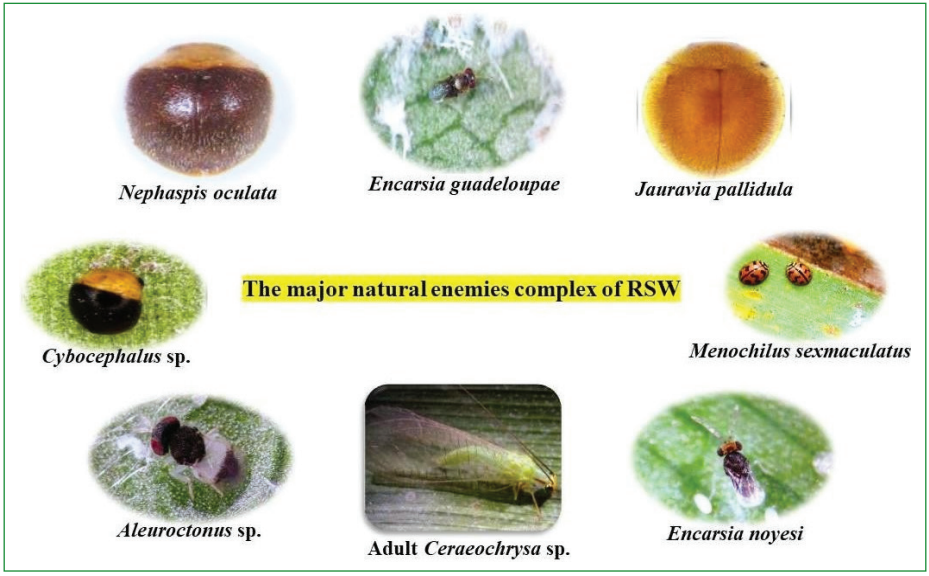
6. *Pseudomallada* sp. Tsukaguchi (Neuroptera: Chrysopidae),

7. *Scymnus coccivora* Ayyar (Coleoptera: Coccinellidae).

8. *Scymnus nubilous* Mulsant (Coleoptera: Coccinellidae), and

9. *Leiochrinus nilgirianus* Kaszab (Coleoptera: Tenebrionidae),

Among the coccinellid beetles *Scymnus saciformis* Motschulsky, *Chilocorus nigrita* (F.), and *Cryptolaemus montrouzieri* Mulsant (Ramami et al., 2002) are the most common and successful predators of RSW, including the neuropteran *Pseudomallada* spp. and nitidulid *Cybocephalus* spp. having significant results.



(Ramami et al., 2002; Taravati et al., 2013)

Figure 1. Predators and Parasitoids of *Aleurodicus rugioperculatus* Martin, in coconut

C. Fungal/ Microbial pathogens of RSW

Ou et al. (2019) and Huang et al. (2010) used fungal pathogens in conjunction with insect parasitoids as a possible biocontrol method for a variety of insects, and found that the effects on parasitoids are either compatible or negligible. The following are some common entomopathogenic fungi that are effective against RSW (Boopathi et al., 2013) (**Figure 2**);

1. *Isaria fumosorosea* Wize (Hypocreales: Cordycipitaceae)
2. *Beauveria bassiana* Bals. -Criv (Hypocreales: Clavicipitaceae),
3. *Metarhizzium anisopliae* Metchnicoff (Ascomycota: Clavicipitaceae), and
4. *Lecanicillium lecanii* Zare & Gams (Hypocreales: Cordycipitaceae)

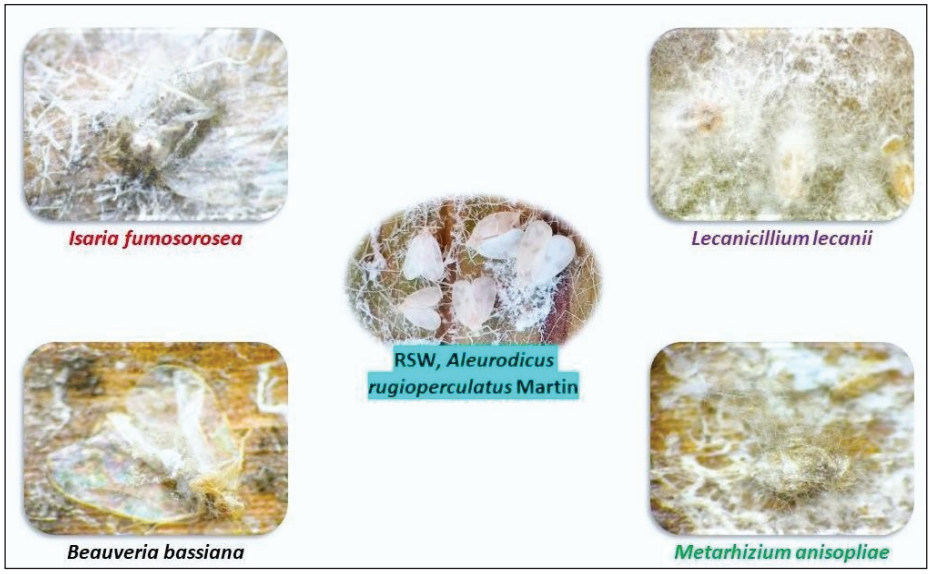


Figure 2. Fungal pathogens of Rugose spiraling whitefly (RSW)

1. *Isaria fumosorosea* Wize, pathogenic fungal strain

Isaria fumosorosea Wize, known as *Paecilomyces fumosoroseus* previously, is an entomopathogenic fungus that is efficient against insect pests, primarily whiteflies and is found all over the world according to Luangsa-Ard et al. (2005). In coconut, this fungus has been employed as a microbial agent against RSW in Florida stated by Ali et al. (2015) and Kumar et al. (2018). In the initial investigations, the ICAR-NBAIR Pfu-5 strain of *Isaria fumosorosea* demonstrated high fungal infection and pathogenicity against RSW life stages (eggs, nymphs, and adults) among the 2 strains tested with 1 x 10^8 spores ml^{-1}. While spraying the NBAIR-Pfu-5 strain of *I. fumosorosea* on coconut fields, a decrease of 58.1 - 97.03% in RSW severity (2×10^8 spores/ml or 5 g/l of H_2O), was observed by Visalakshi et al. (2021).

2. Other fungal pathogenic strains

According to Boopathi et al. (2013) and Boopathi et al. (2015), *Beauveria bassiana*, *Metarhizium anisopliae*, and *Lecanicillium lecanii* were outperformed by *Isaria fumosorosea* Wize while controlling the nymphs and adults of invasive RSW, In the field.

Boopathi et al. (2013) found that more than 35% of RSW egg mortality was caused by *Metarhizium anisopliae* (M2 strain) and *P. fumosoroseus* (P1 strain) at 8 DAT (Days after treatment), in coconuts (**Figure 2**). Sharma et al. (2015), noted that the insect diseases *Verticillium lecanii* and *Beauveria bassiana* can somewhat lower the population of RSWs. Additionally, according to Boopathi et al. (2015), the *B. bassiana* effectivity was higher compared to *Metarhizium anisopliae* and *Lecanicillium lecanii* (NBAIR VL 15) at 1×10^8 conidia/mL against *Aleurodicus dispersus* in a lab setting. In conclusion, for long-term control of the rugose spiraling whitefly, fungal pathogens can be considered a useful tool, in plantation crops.

Some successful studies regarding the biological management of RSW

Isaria fumosorosea Wize (entomopathogenic fungus), and buprofezin, (Insect growth regulator), were applied separately and combined in a biopesticide experiment conducted by Kumar et al. (2018) to mitigate *Aleurodicus rugioperculatus* Martin. The experiment also assessed the efficacy of the fungal pathogen in both laboratory and field settings. In the lab, buprofezin alone did not result in the same RSW mortality as treatments containing *I. fumosorosea*, either combined or alone. The mean whitefly mortality recorded against *Isaria fumosorosea*, against buprofezin and treatment combination, was 52.4 and 42.1%; 79.6 and 79.0%; and 87.6 and 84.3%, respectively, throughout the 10-week evaluation period in the fall of 2014 and the summer of 2015.

In July and August of 2012, the number of the introduced NEs *i.e.*, *Nephaphis oculata*, and *Encarsia guadeloupae*, significantly rose after they were successfully established in the Regional Research Center (RRC). When the biological control agents are released on the untreated trees, at least, there is potential to combine chemical (imidacloprid) and biological control of RSW in a given area. This is indicated by the fact that the mean number of RSW was highest at the beginning of the experiment in all treatments but decreased over time (Taravati et al., 2013).

After NeemAzal F (AI 5% azadirachtin) was applied at a rate of 0.05%, the coconut rugose spiraling whitefly (RSW), *Aleurodicus rugioperculatus* Martin, nymphs reduced to 66.67%.

Among the fungal strains examined, the highest mortality of 50.0% was observed after applying *Lecanicillium lecanii* (NBAIR [VL 15]) at a rate of 1×10^8 conidia/ml 10 days after treatment, which was noticeably better than other entomopathogen treatments (Elango et al., 2020).

Boopathi et al. (2013) investigated the ovicidal effect, LC_{50}, and pathogenicity of some fungal pathogens *viz, Metarhizium anisopliae* (Metschnikoff) Sorokin, *Beauveria bassiana* (Balsamo) Vuillemin, *Lecanicillium lecanii* (Zimmerman) Zare and Gams, and *Paecilomyces fumosoroseus* (Wize) Brown and Smith against spiraling whitefly, *Aleurodicus dispersus* Russell found that the higher pathogenicity of *P. fumosoroseus* (P1 strain) with a mortality of 100%

recorded at 15 days post-treatment (DAT), in

A. dispersus. Because of *M. anisopliae*'s (M2 strain) stronger ovicidal impact, 37.3% of the eggs perished during 8 DAT. The lowest egg hatchability was seen in the case of *L. lecanii* (L1 strain) at 10 DAT *i.e.*, 23.2% compared to the control (92.6%).

Elango et al. (2019) discovered that *Aleurodicus rugioperculatus* Martin is a food source for all larval stages of the predator *Chrysoperla zastrowi* Sillemi. Additionally, during its development period of 3.24 days, the predator's third instar grub consumed 313.2 whiteflies, following the predator's second and first instar grubs, who devoured a maximum of 200.2 and 140.2 whiteflies respectively. Furthermore, it was discovered that throughout its 9.43-day larval stage, a single *Chrysoperla zastrowi* Sillemi grub consumed 653.6 stages of whiteflies. The outcomes show that *Chrysoperla zastrowi* Sillemi effectively hunts the coconut rugose spiraling whiteflies.

Table 1. Effective natural enemies and fungal pathogens affecting RSW

Sl. No.	Insect pest	Effective NEs and pathogens	References
1	Rugose spiraling whitefly (*Aleurodicus rugioperculatus* Martin; Homoptera: Aleyrodidae)	*Isaria fumosorosea* Wize +Buprofezin	Kumar et al. (2018)
2		*Isaria fumosorosea* (ICAR-NBAIR Pfu-5) + Profenophos 50 EC	Sandeep et al. (2022)
3		*Encarsia guadeloupae* Viggiani, *Cybocephalus* spp., *Pseudomallada astur*	Boopathi et al. (2017)
4		*Nephaphis oculata*, *Encarsia guadeloupae*	Taravati et al. (2013)
5		*Isaria fumosorosea* NBAIR pfu-5, *Lecanicillium lecanii*	Mohitha et al. (2022)
6		*Paecilomyces fumosoroseus* (Wize) Brown and Smith	Boopathi et al. (2013)
7		*Chrysoperla zastrowi* Sillemi	Elango et al. (2019)
8		*Isaria fumosorosea*, *Mallada boninensis*	Elango et al. (2022)

All insecticides significantly reduced the percentage of parasitism of RSW and the emergence of parasitoids (*Encarsia guadeloupae* Viggiani and *Encarsia meritoria* Gahan) by 75%, in both seasons. Additionally, the insecticides were proven relatively safer for the main predators of rugose

spiraling whitefly in cassava *i.e.*, *Cybocephalus* spp., and *Pseudomallada astur*. Among the insecticides, thiamethoxam, and buprofezin were relatively safer for *Pseudomallada astur* in cassava. Among the three predators, *Scymnus coccivora* was most negatively impacted by all insecticides because its population was smaller than that of *Pseudomallada astur* and *Cybocephalus* spp. (Boopathi et al., 2017).

Based on an evaluation of *Isaria fumosorosea* NBAIR pfu-5, *Lecanicillium lecanii, Beauveria bassiana*, and *Metarhizium anisopliae*, the *Isaria fumosorosea* NBAIR pfu-5 was proven the most successful pathogen in terms of population reduction, on coconut against nymphs and adults of the pest. According to Mohitha et al. (2022), *Metarhizium anisopliae* was the least successful in controlling the number of RSW adults and nymphs.

According to Sandeep et al. (2022), the percentage of RSW infestation (82.97%), and the mean number of RSW living colonies (79.68%) were all considerably decreased by the combination treatment of *Isaria fumosorosea* (ICAR-NBAIR Pfu-5) @ 5 ml/l + profenophos 50 EC @ 2 ml/l. A study that followed the combination discovered that, when *Isaria fumosorosea* (ICAR- NBAIR Pfu-5) @ 5 ml/l compared alone, with the combination of *Isaria fumosorosea* (ICAR-NBAIR Pfu-5) @ 5 ml/l + buprofezin 25% SC @ 1.25 ml/l, the combination significantly reduced the percent infestation of RSW (79.35%). It was demonstrated that *Isaria fumosorosea* (5 ml/l) + profenophos 50 EC (2 ml/l) combination treatment, administered twice at a 15-day interval, significantly reduced the population of RSW on coconut.

In the field, *Isaria fumosorosea* (29.60%), *Metarhizium anisopliae* (24.30%), and *Beauveria bassiana* (21.00%) decreased the RSW population on coconut. In a laboratory context, *Isaria fumosorosea* caused mortality of 34.54% egg, 37.39% nymphal, and 48.30% adult RSW, respectively. On the other hand, *Lecanicillium lecanii* was responsible for 24.54, 30.76, and 28.01% of eggs, nymphs, and adult mortality, respectively. Furthermore, eggs of *Mallada boninensis* (neuropteran predator) treated with *I. fumosorosea* showed a maximum emergence of 90.33% grub in comparison to other treatments. This indicates that the fungal pathogen is highly successful in RSW population reduction and ensuring grub survival (Elango et al., 2022).

Conclusion

The Rugose spiraling whiteflies (*Aleurodicus rugioperculatus* Martin; Homoptera: Aleyrodidae) have been recorded for huge crop damage and yield losses, on coconut. Among all natural enemies, especially the hymenopteran parasitoids like *Encarsia* sp. and from the entomopathogens, *Isaria fumosorosea* have been proven as significantly effective in controlling the pest population and huge crop losses. Nowadays several types of research are ongoing for RSW management using combination products (Fungal pathogens + Chemical insecticides + Botanicals + Natural enemies) which will be a very good option for coconut-growing farmers.

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