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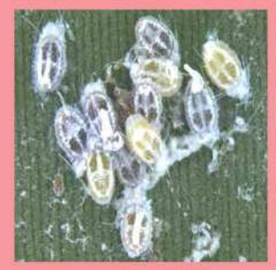
Biological Control of Invasive Rugose Spiraling Whitefly *Aleurodicus rugioperculatus* Martin on Coconut and Oil palm





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Forward

The coconut and the oil palm are cultivated throughout the tropics where it is interwoven into the lives of the people and also provide a variety of products. Pest problem is one of the major constraints for achieving higher production and productivity in these palms. Black headed caterpiller, *Opisina arenosella*, red palm weevil *Rhynchophorus ferrugineus* Olivier, rhinoceros beetle, *Oryctes rhinoceros* and scales are common pests infesting coconut and oil palm. Rugose spiraling whitefly (RSW), *Aleurodicus rugioperculatus* Martin is an invasive pest, native to the Central America and predominantly a pest of Arecaceae family but attack more than 120 host plants.

In India, rugose spiraling whitefly was recorded for the first time on coconut in Pollachi, Tamil Nadu during 2016 and within a few years of its invasion, it has spread rapidly northward along the coastline of Tamil Nadu, Kerala, Karnataka, Andhra Pradesh, Goa, Gujarat, West Bengal, Odisha, Maharashtra and also distributed in Lakshadweep islands. The slower spread was noticed in interior states like Telangana, Assam, Chhattisgarh and Meghalaya. This species is rapidly spreading to other coconut growing areas mostly through infested seedlings and planting materials.

Soon after the report of this invasive species in India, ICAR-NBAIR took proactive steps to contain the spread and damage through regular monitoring, exploration of biocontrol agents and development of management strategies. Natural enemies of insect pests play a key role in reducing the levels of pest population below those causing economic injury to crop plants. Both natural and applied biological control tactics are important in successful management of pest population. Unlike annual crops, plantation crops provide the more congenial conditions for parasitoids, predators and entomopathogens for their growth and perpetuation.

With the extensive extension efforts of the scientists in motivating farmers to adopt biological control strategies through field level trainings and demonstrations, majority of farmers have understood the value of the biological control. In this technical bulletin, the diagnosis, distribution, host plants, symptoms of damage, biology, co-existence with other whiteflies and management strategies especially biocontrol strategies are provided which will be of immense use for coconut and oil palm growers, extension scientists, students and other stakeholders. I appreciate the efforts made by the authors in bringing out this publication.

Bengaluru
21 February 2024

S.N. Sushil
Director

Preface

Invasive species pose a constant threat to agriculture and a strategic science based approach is needed to promote environmentally sustainable plant health management practices to reduce excessive reliance on chemical pesticides. Biological control through the use of parasitoids, predators and entomopathogens constitutes a significant component in holistic management of insect pests. Coconut and oil palm is an important plantation crops grown mainly in the tropical and subtropical regions of the world. India is one of the leaders in coconut farming and stands third largest coconut producing country in the world.

The rate of invasion of especially whitefly species has increased internationally in recent decades due to expansion of global trade and regularly dispersed through the movement of plant products. A number of eight invasive whiteflies invaded India and cause direct and indirect yield losses in agriculture, horticulture and forestry crop plants. Among, spiraling whitefly, rugose spiraling whitefly, Bondar's nesting whitefly, nesting whitefly and palm infesting whitefly prefer to colonize and feed on especially hybrid and dwarf varieties of coconut. Chemical control is not practicable because of the abundance of host plants and widespread distribution.

ICAR-NBAIR is striving hard in identifying and documenting invasive whiteflies through constant monitoring and surveillance to contain its spread and avoid outbreak situation. ICAR-NBAIR plays a vital role in developing biocontrol strategies and popularizing them through research, extension and capacity building in the country. Biological control using parasitoids, predators and entomopathogens are the most feasible, efficient, eco-friendly non-chemical methods and alternative to the use of insecticides. Success of any biological control programme depends on their effectiveness and timely application in a systematic way. This can be made possible by early detection of the pest, creating awareness in farmers, frequent monitoring, large scale approach and repeated release of the potential natural enemies.

This technical bulletin describes in detail about the biology, life cycle, nature of damage and the knowledge of which is very much essential for proper decision making in pest management activities. This bulletin will certainly be useful for coconut and oil palm growers, extension workers, students, teachers, and other stakeholders. The authors are very much thankful to the Director, ICAR-NBAIR, Former Director, ICAR-NBAIR for the constant support and guidance in bringing out this technical bulletin. Authors are also grateful to the Chairman, Coconut Development Board, Kochi for providing financial grant for carrying out various research and extension activities to manage this notorious pest.

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1. Introduction

Coconut, *Cocos nucifera* L. (Arecaceae) is an important plantation crop grown mainly in the tropical and subtropical regions of the world, and millions of people depend on coconut either directly or indirectly for their livelihood. India is one of the leaders in coconut farming and stands third largest coconut producing country in the world. Coconut is grown in a large area of more than 21 lakh hectares in 15 states and union territories in India with an annual production of 21,500 million tonnes nuts. Among coconut producing states, Tamil Nadu, Kerala, Karnataka and Andhra Pradesh are the leading coconut producing states which account for more than 90% of the total coconut produced in the country. Productivity increased to 11516 fruits / hectare in 2017-18 as compared to 10122 in 2013-14. Between 2014-2018, 13,117 hectares were brought under new plantation as compared to 9,561 hectares during 2010-2014. India has been exporting coconut oil to Malaysia, Indonesia and Sri Lanka and dry coconut in large quantities to the U.S and European countries.

Oil palm, *Elaeis guineensis* Jacq. (Arecaceae) is a native to West Africa and it is the crop of the present and future vegetable oil economy of the India as well as world. Palm oil contributes about 70% of total vegetable oil import and is one of the cheapest oil due to high productivity per hectare. The oil palm is the richest source for vegetable oil production with a capacity of 4-6 tons of oil/ ha/ year. In India, oil palm covers an area of about 0.3 million hectares with a production of about 1.2 million tonnes. Out of this, Andhra Pradesh covers major area and production of about 0.15 million hectares and 1.1 million tones. In India, Andhra Pradesh, Karnataka, Odisha, Telangana, Mizoram and Tamil Nadu are major oil palm growing states. Pest problem is one of the major constraints for achieving higher production and productivity in these palm plants.

2. Pests scenario in coconut and oil palm

The coconut palm is attacked by several insect and mite pests all around the year and more than 900 species of pests are associated with cultivated and wild coconut. Coconut Eriophid mite, *Aceria guerreronis* Keifer (Eriophyidae: Acari), rhinoceros beetle, *Oryctes rhinoceros* L (Coleoptera: Scarabaieidae), red palm weevil, *Rhynchophorus ferrugineus* Olivier (Coleoptera: Curculionidae), black headed caterpillar, *Opisina arenosella* Walker (Lepidoptera: Oecophoridae) and white-grub, *Leucopholis coneophora* Burmeister (Coleoptera: Scarabaieidae) are considered as the major pests of coconut. While the two whiteflies *viz*., areca nut whitefly, *Aleurocanthus arecae* David and Manjunatha (Hemiptera: Aleyrodidae) and spiraling whitefly, *Aleurodicus dispersus* recorded on coconut in India are considered as minor pests (Fig. 1). Insect pest dynamism in coconut ecosystem is ever increasing which lead to diminishing palm productivity and threatening livelihood security.

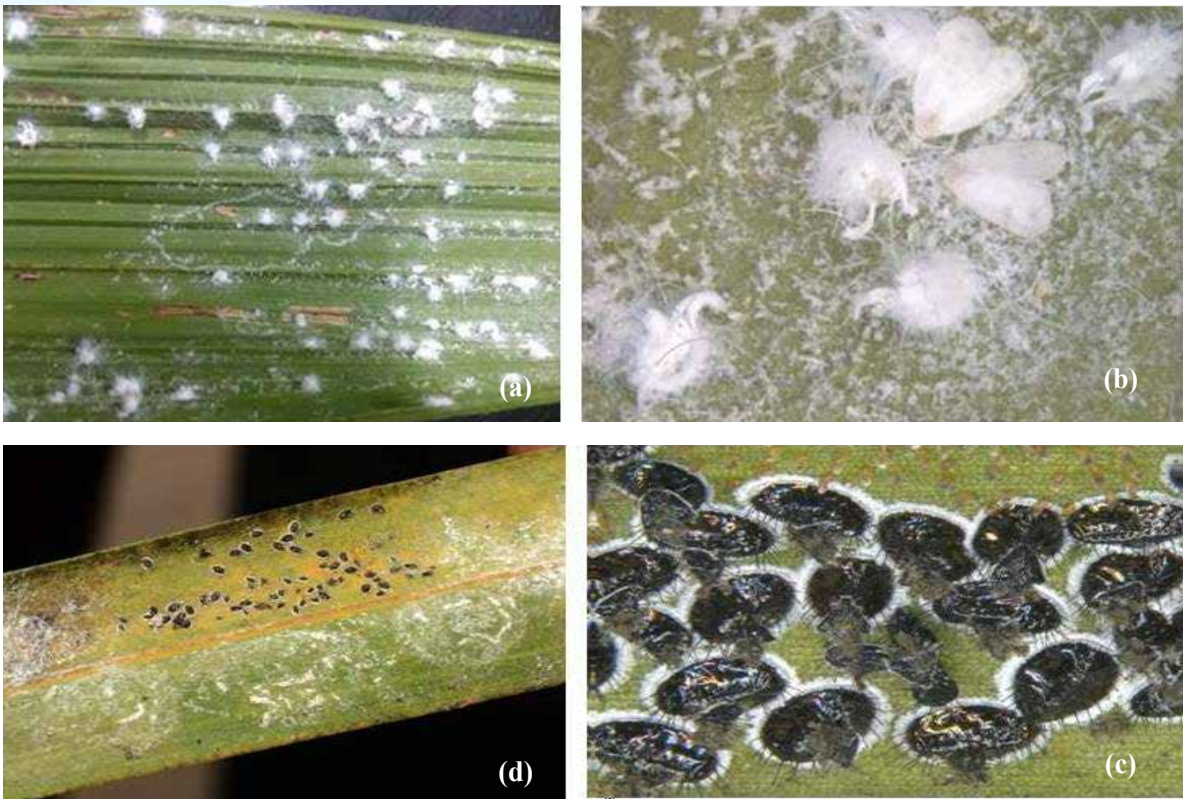


Fig. 1. Infestation of, *Aleurodicus dipsersus* (a-b) **and *Aleurocanthus arecae*** (c-d) **on coconut**

Similarly, about 60 insect species were reported to infest on oil palm of which many pests are affecting the yield and yield parameters significantly. Rhinoceros beetle, *Oryctes rhinoceros* (L.); leaf web worm, *Acria* sp.; psychid, *Mestia plana*; slug caterpillar, *Dama catenatus*; scales and mealybugs were reported as major pests. Most of these pest populations were found migrating to other palms such as coconut and areca nut which are commonly seen in the adjoining areas of oil palm plantations. The pest occurrence and intensity is increasing over the period of cultivation and beside area under oil palm plantations is also expanded significantly in the country.

The yield loss estimation of oil palm due to the above pests was in the range of 20%-30% extending to three years after attack (Kalidas, 2012). The pests which are common for both coconut and palmyrah are migrating to oil palm and vice-versa. The psychid and the slug caterpillars, which are reported to be minor pests of coconut, palmyrah and arecanut were found to cause heavy infestation on oil palm causing yield losses up to 50% (Kalidas and Saravanan, 2013).

3. Invasion of rugose spiraling whitefly

The rate of invasion of whitefly species (Hemiptera: Aleyrodidae) has increased internationally in recent decades with the expansion of global trade and regularly dispersed through the movement plant materials. Most alien species of whiteflies are accidentally introduced with their host plant among countries as a consequence of plant trade, the small in size, their cryptic nature and immature

stages being attached to the host-plant. Due to these characteristics, they are one of the most commonly transported and most successful arthropod group invading new geographical areas. Moreover, exotic whitefly pests can multiply in large proportion in a short time, exhibit high phenotypic plasticity, and have a strong potential to compete with native species and cause damage to economically important crop plants.

Exotic invasive whiteflies (Hemiptera: Aleyrodidae) in India cause direct and indirect yield losses in agriculture, horticulture and forestry crop plants. Around 25 years ago, the spiraling whitefly, *Aleurodicus dispersus* Russell invaded and established on many host plants in India. During 2016, highly invasive, polyphagous rugose spiraling whitefly, *Aleurodicus rugioperculatus* Martin was invaded to India. RSW was initially found to feed on coconut (Fig. 2) and later it expanded its host range on many economically important crop plants. Hybrid and dwarf coconut varieties *viz.,* Chowghat orange dwarf, Malayan orange dwarf, Malayan yellow dwarf and Ganga bondam are most severely affected and attain outbreak situation in many location in India. The RSW have the great potential to spread and reproduce throughout the year with multiple and overlapping generations in India. It has now become one of the most important pest of coconut and many other economically important crop plants, warranting control measures to avoid crop losses. Total area affected by rugose spiraling whitefly is estimated about 1.35 lakh hectare of coconut and oil palm.

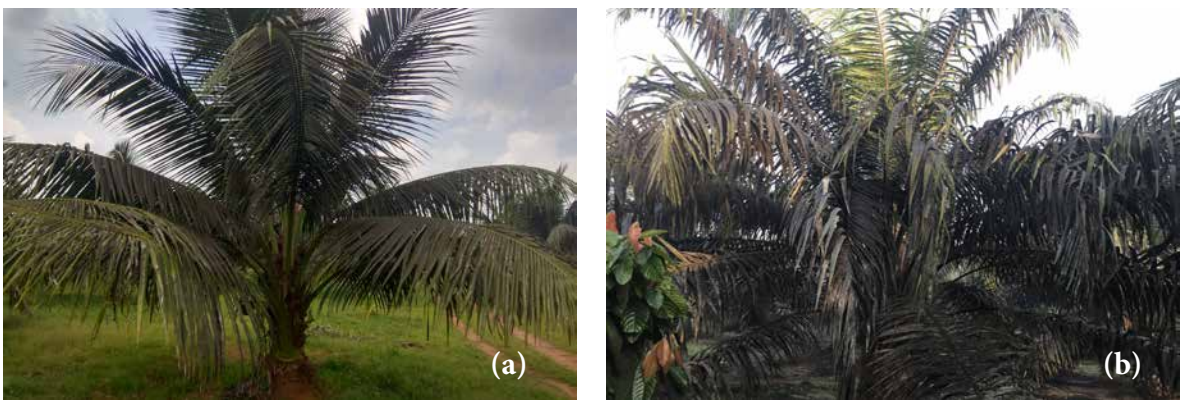


Fig. 2. Rugose spiraling whitefly infested coconut (a) and oil palm (b) with severe sooty mould

Severe incidence and infestation of rugose spiraling whitefly, *Aleurodicus rugioperculatus* was reported on oil palm during 2017 in Andhra Pradesh and Karnataka (Selvaraj *et al.,* 2019) (Fig. 3). The RSW infested oil palm plantations about 11,744 ha in East Godavari, West Godavari, Krishna, Srikakulam, Vizianagaram and Visakhapatnam districts of Andhra Pradesh and 4000 ha in Khammam district of Telangana were among the most affected

Fig. 3. Infestation of rugose spiraling whitefly on oil palm

areas with this pest. Furthermore, pests dynamism in the oil palm ecosystem is changed in the recent past due to invasion of this exotic whitefly in many a time which diminishing palm productivity and threatening livelihood security.

In this technical bulletin, introduction of invasive RSW, identification, distribution, host range, symptoms of damage, associated natural enemies and management strategies with special reference to biological control are briefed in details. Besides, integrated pest management strategies, various research initiatives, awareness and field demonstration by ICAR-NBAIR are briefed in details.

3.1. Origin and distribution

Aleurodicus rugioperculatus Martin was described from coconut in Belize and Subsequently, it was reported as a pest on gumbo limbo (*Bursera simaruba* L) in Miami-Dade county (South Florida) in 2009 by Florida Department of Agriculture and Consumer Services, which referred to it as the gumbo limbo spiraling whitefly. This pest has been classified as the serious threat for coconut palm including many other host plants in Florida (Stocks and Hodges, 2012). This whitefly is believed to have originated from Central America and its incidence limited to Belize, Mexico, Guatemala and Florida in Central and North America (Evans, 2008). In Florida (USA), it has been found in Broward, Collier, Indian River, Lee, Martin, Miami Dade, Monroe, Palm Beach, Polk, and St. Lucie counties (Taravati *et al.,* 2013). Recent reports suggest it has invaded Orlando, located in central Florida. Based on its dispersal potential, RSW may establish in eight other adjacent counties of Florida in the near future (Kumar *et al.,* 2013).

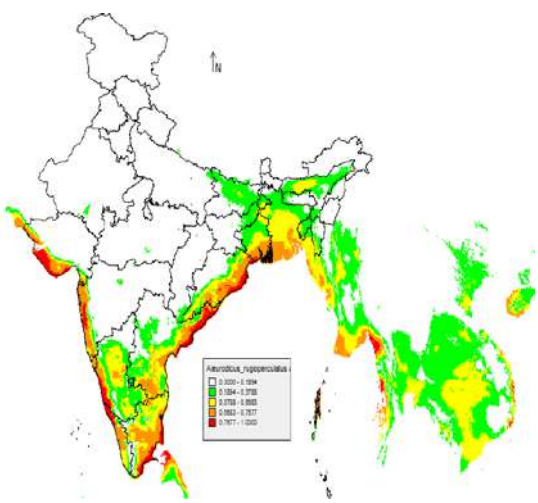


Fig. 4. Distribution of *A. rugioperculatus* in India

In India, rugose spiraling whitefly incidence was recorded on coconut and many other crop plants during 2016 at Pollachi, Tamil Nadu (Sundararaj and Selvaraj, 2017); subsequently, it has spread to different districts of Karnataka, Kerala, Andhra Pradesh, Goa, Assam and West Bengal (Selvaraj *et al.,* 2017 & 2019) and it was recently observed in Lakshadweep islands, coastal districts of Maharashtra, Gujarat, Telangana, Odisha, Chhattisgarh and few districts of Meghalaya and Assam (Fig. 4). Until 2016, it has not reported from Oriental region, therefore, this record represents its first record of its presence in India as well as in the Oriental region.

3.2. Mode of spread

Aleurodicus rugioperculatus is well distributed along coastal tracts, unevenly along the national & state highways, isolated garden near water bodies, back water areas and even in islands. The mode

of entry of rugose spiraling whitefly into India is unknown. However, it is likely interception through plant materials trade. The most insidious spread of these species in India is likely mediated by humans through the movement of infested seedlings and plant materials (Fig. 5). Transportation of infested nursery plants is primary factor which play major role in rapid dispersal of this pest within short span of time.

Extensive spread of RSW along the coastal regions is predicted owing to the congenial weather factors and prevalence of host plants that favors the profuse multiplication and pest is active throughout the year. Mostly spread through the transportation of infested coconut seedling and further paved the entry of the pest into other parts of India (Fig. 5).

Fig. 5. Infested coconut seedling (a) and their transportation (b)

3.3. Host plants: *Aleurodicus rugioperculatus* is a highly polyphagous pest reported to feeds on about 120 plant species including economically important cultivated plants and palms. In India, it was found to feed on about 44 host plants especially coconut (*Cocos nucifera*), oilpalm (*Elaeis guineensis*), banana (*Musa* sp.), mango (*Mangifera indica*), sapota (*Manilkara zapota*), guava (*Psidium guajava*), cashew (*Anacardium occidentale*), ramphal (*Annona reticulata*), maize (*Zea mays*), Indian almond (*Terminalia catappa*), water apple (*Syzygium samarangense*), jack fruit (*Artocarpus heterophyllus*) and ornamental plants *viz.,* bottle palm (*Hyophorbe lagenicaulis*), Indian shot (*Calophyllum inophyllum*), false bird of paradise (*Heliconia rostrata*) and butterfly palm (*Dypsis lutescens*) (Table 6 & 7).

Rugose spiraling whitefly host range includes field, plantation crops, horticultural crops, ornamental and landscape plants of both native and non-native species. However, it prefer to feeds on palm plants like coconut, oil palm and ornamental palms. It well established on non-native plants than natives. *A. rugioperculatus* is extending its host range rapidly, this could be a mechanism to overcome the abiotic constraints and buffer the depletion of optimal resources. Further, host range expansion leads to increases in population growth and potentially to greater geographic range expansion.

Fig. 6. Host plants of rugose spiraling whitefly, *Aleurodicus rugioperculatus*

Fig. 7. Host plants of rugose spiraling whitefly, *Aleurodicus rugioperculatus*

3.4. Symptoms of damage

- The typical concentric waxy spiraling symptoms on under surface of the leaves and also on various parts of host plants including on leaf petiole and tender nuts (Fig. 8).
- White mealy waxy flocculent material produced by nymphs and adults causes nuisance to human being in heavily infested areas.
- Nymphs and adults suck the leaf sap aggressively by direct feeding which results in depletion of nutrients and water which leads to loss of vigour.
- Adults excrete the prodigious quantities of honey dew which in turn completely darken by sooty mold development on the upper surface of leaves and also on understory crops.
- Extreme growth of black sooty mould may lead to reduction in photosynthetic efficiency of affected palms and also affects the aesthetics value of the palms. Severe infestation leads to premature drying and complete dropping of fronds.

Fig.8. *Aleurodicus rugioperculatus:* adult (a), infestation on coconut (b-c), sooty mould (d)

3.5. Biology

- The adult female lays eggs in concentric circular or loose spiral pattern on the ventral surface of the leaves (Fig. 9a) and sometimes on leaf petioles, stems and fruits.
- The stalked eggs are elliptical, yellowish and the average fecundity/female is 49.50 ± 4.09 eggs (Fig.9b).
- The first instar nymphs is known as crawlers, which is the mobile stage having functional legs and these are transparent to light to golden yellowish in colour devoid of wax.
- Second instar nymphs are immobile, fringed with marginal wax along the transverse grooves

on their dorsum and the compound pores produce glassy wax filaments (Fig.9c). They are transparent to light to golden yellowish and bigger in size compared to first instar.

- Third instar nymphs have numerous evenly spread short, glass rods like waxy filaments along the sides of the body. Cottony white waxy secretions.
- Fourth instar nymphs are covered with copious amount of opaque white waxy material dorsally as tufts and the dorsal waxes produced from compound pores are long, cylindrical and often longer than the length of the puparium (Fig.9d).
- The total duration of the nymphal instars is 23.2 ± 1.38 days and 37.6 ± 2.55 days taken to complete life cycle on coconut including adult longevity, respectively.

Fig. 9. Life stages of *Aleurodicus rugioperculatus:* adult (a), eggs (b), third instar nymphs (c) pupae (d)

- It is closely resemblance existing invasive spiraling whitefly, *Aleurodicus dispersus.*
- Adults are about three times larger than the commonly found whiteflies and are lethargic by nature.
- Adults can be distinguished by the presence of a pair of irregular light brown bands across the wings (Fig. 10).
- Males have long pincer-like structures at the distal end of the abdomen.

Fig. 10. Female and Male adults of RSW

3.6. Co-existence with other whiteflies

As many as four exotic whiteflies *viz.,* rugose spiraling whitefly, *A. rugioperculatus* Martin during 2016; Bondar's nesting whitefly, *Paraleyrodes bondari* Peracchi during 2018 (Josephrajkumar *et al.,* 2019); nesting whitefly, *P. minei* Iaccarino during 2018 (Mohan *et al.,* 2019) and palm infesting whitefly, *Aleurotrachelus atratus* Hempel during 2019 have been reported from different regions in India in rapid succession in coconut and many other crop plants. All these whitefly species are highly polyphagous and have a host preference towards coconut, guava, banana, custard apple and oil palm (Sundararaj *et al.,* 2021).

Species of exotic whiteflies with similar habits co-exist in more or less the same niche and have a similar pattern of growth and development. *Aleurodicus rugioperculatus*, *P. bondari*, *A. dispersus* and *P. minei* were found to co-exist on many of the host plants. It was observed that *A. rugioperculatus* co-existing with *A. atratus, P. bondari*, *A. dispersus* and *P. minei* on coconut (Fig. 11). Infestations of *A. atratus* and *A. rugioperculatus* along with *Aleurocanthus arecae,* a native whitefly species were commonly observed on coconut. In oil palm, *Aleurodicus rugioperculatus* coexist with *A. atratus, P. minei* and *P. bondari*.

The co-occurrence of more than one invasive species in a functional niche is rare exception. As per the competition exclusion principle, two identitical species competing for the same limiting resource cannot coexist at constant population values.

Fig. 11. Co-existence of invasive whiteflies in coconut

Table 1. Host plants of rugose spiraling whitefly, *Aleurodicus rugioperculatus*

S.No	Plant species	Distribution	Co-existence
1	Coconut, *Cocos nucifera* (Arecaceae)	Tamil Nadu, Kerala, Karnataka, Andhra Pradesh, Goa, Assam, West Bengal, Meghalaya, Gujarat, Odisha, Chhattisgarh	*A. dispersus, A. atratus, P. minei, P. bondari*
2	Banana, *Musa paradisiaca* (Musaceae)	Tamil Nadu, Kerala, Karnataka, Andhra Pradesh, West Bengal	*P. minei, P. bondari*
3	Custard apple, *Annona squamosa* (Annonaceae)	Tamil Nadu, Kerala, Karnataka, Andhra Pradesh	*P. minei, Pealius nagercoilensis*
4	Mango, *Mangifera indica* (Anacardiaceae)	Kerala, Karnataka	-
5	Guava, *Psidium guajava* (Myrtaceae)	Tamil Nadu, Kerala, Karnataka, West Bengal, Odisha	*P. minei, Aleurothrixus floccosus, A. dispersus*
6	Bird of paradise, *Strelitzia reginae* (Strelitziaceae)	Tamil Nadu, Kerala, Karnataka	-
7	Sapota, *Manilkara zapota* (Sapotaceae)	Tamil Nadu, Kerala, Karnataka	*P. minei*
8	Indian almond, *Terminalia catappa* (Combretaceae)	Kerala, Karnataka	*A. dispersus*
9	Rose apple, *Syzygium samarangense* (Myrtaceae)	Karnataka, West Bengal	-
10	Indian-laurel, *Calophyllum inophyllum* (Calophyllaceae)	Karnataka	*P. minei, P. bondari*
11	Betel vine, *Piper betle* (Piperaceae)	Karnataka, Andhra Pradesh, West Bengal	-
12	Rubber fig, *Ficus elastica* (Moraceae)	Karnataka	*P. minei*
13	Areca palm, *Dypsis lutescens* (Arecaceae)	Tamil Nadu, Kerala, Karnataka, West Bengal	-
14	Ruffled fan palm, *Licuala grandis* (Arecaceae)	Karnataka, Kerala	-
15	Citrus, *Citrus* spp. (Rutaceae)	Tamil Nadu, Karnataka, West Bengal	*P. minei*

S.No	Plant species	Distribution	Co-existence
16	Malabar plum, *Syzygium cumini* (Myrtaceae)	Karnataka, West Bengal	*P. minei*
17	Oil palm, *Elaeis guineensis* (Arecaceae)	Andhra Pradesh, Karnataka, West Bengal	*P. minei, A. atratus P. bondari*
18	Jack fruit, *Artocarpus heterophyllus* (Moraceae)	Tamil Nadu, Kerala, West Bengal	*P. bondari, P. minei*
19	Indian tulip, *Thespesia populnea* (Malvaceae)	Kerala, Karnataka	*P. minei*
20	Rangoon creeper, *Combretum indicum* (Combretaceae)	Kerala, Karnataka	-
21	China rose, *Hibiscus rosasinensis* (Malvaceae)	Kerala, Karnataka	*A. dispersus*
22	Ficus, *Ficus religiosa* (Moraceae)	Karnataka, Lakshadweep	*Singhiella simplex*
23	Maize, *Zea mays* (Poaceae)	Andhra Pradesh, Karnataka, Telanagana	-
24	Spanish cherry, *Mimusops elengi* (Sapotaceae)	West Bengal	-
25	Akashmoni, *Acacia auriculiformis* (Fabaceae)	West Bengal, Odisha, Karnataka	-
26	Ficus, *Ficus bengalensis* (Moraceae)	West Bengal	-
27	Arjun, *Terminalia arjuna* (Combretaceae)	Karnataka	-
28	Traveller palm, *Palmeira ravenala* (Strelitziaceae)	Andhra Pradesh	-
29	Frangipani, *Plumeria alba* (Apocynaceae)	Karnataka	-
30	Cashew, *Anacardium occidentale* (Anacardiaceae)	Karnataka, Andhra Pradesh	-
31	Curry leaf, *Murraya koenigi* (Rutaceae)	Tamil Nadu	-
32	Indian gooseberry, *Phyllanthus emblica* (Phyllanthaceae)	Andhra Pradesh	*P. bondari*

S.No	Plant species	Distribution	Co-existence
33	Champak, *Magnolia champaca* (Magnoliaceae)	Andhra Pradesh, Karnataka	*A. dispersus*
34	Lipstick tree, *Bixa orellana* (Bixaceae)	Karnataka	*A. dispersus*
35	Ficus, *Ficus microcarpa* (Moraceae)	Karnataka	-
36	Indian shot, *Canna indica* (Cannaceae)	Karnataka, Kerala	*P. minei*
37	Sandal, *Sandallum album* (Sandalaceae)	Karnataka	-
38	Sugarcane, *Saccharum officinarum* (Poaceae)	Tamil Nadu, Andhra Pradesh, Karnataka	-
39	Ginger, *Zingiber officinale* (Zingiberaceae)	West Bengal	-
40	Turmeric, *Curcuma longa* (Zingiberaceae)	West Bengal	-
41	Taro, *Colacasia esculenta* (Araceae)	West Bengal	-
42	Pepper, *Piper nigrum* (Piperaceae)	Kerala, Karnataka, Andhra Pradesh, West Bengal	-
43	All spice, *Pimenta dioica* (Myrtaceae)	Lakshadweep	-
44	Noni, *Morinda citrifolia* (Rubiaceae)	Lakshadweep	-

The synchrony of coexistence and mutual survival of these competing species could be due to the marked time partitioning of the resource use among the species and need detailed study. Such co-occurrence has been observed among these invasive species, in which one species occupies the breeding and feeding niche of another species under optimum weather parameters and attempts to displace one or more of its competitors gradually which leads to temporal variation. These offer a promising avenue for developing a unifying theory of biodiversity in limited resources under fluctuating environments which might predict the co-occurrence, within the same community, of species that are ecologically either very similar, or very different. Further, this mutual survival of more than one species indicates deferred its existing pest management options in various crop plants.

3.7. Natural enemies

Explorative surveys were carried out to document the natural enemies for the management of RSW through biocontrol based approach. The natural enemies such as two parasitoids, *Encarsia*

guadeloupae Viggiani and *E. dispersa* Polaszek (Hymenoptera: Aphelinidae) were found to colonize on *A. rugioperculatus* (Selvaraj *et al.,* 2017). Major pr*edators such as Apertochrysa (=Pseudomallada) astur* (Neuroptera: Chrysopidae), *Jauravia pallidula, Cheilomenes sexmaculata* (Coleoptera: Coccinellidae) and *Cybocephalus indicus* (Coleoptera: Nitidulidae) were also observed to be feeding on *A. rugioperculatus* (Selvaraj *et al.,* 2017). In addition, entomopathogenic fungus, *Cordyceps* (=*Isaria*) *fumosorosea* (Wize) Kepler, B. Shrestha & Spatafora (Hypocreales: Clavicipitaceae) (ICAR-NBAIR Pfu-5) was found to be effective against all the life stages of *A. rugioperculatus* (Sumalatha *et al.,* 2020; Sandeep *et al.*, 2022).

3.7.1. Parasitoid, *Encarsia guadeloupae* and *Encarsia dispersa* (Hymenoptera: Aphelinidae)

Distribution: Both are exotic parasitoids, fortuitously introduced in India in the late 1990s along with *A. dispersus* and well established in entire South India. *Encarsia guadeloupae* is distributed in Canary Islands, French Polynesia, Hawaii, Papua New Guinea, Philippines, Thailand, India, Benin, Guadeloupe, Mexico and Florida. *E. dispersa* is an exotic parasitoid of New World (Neotropical) origin and originally collected from Trinidad.

Host Insects and efficacy

- *Encarsia guadeloupae* is reported from *A. rugioperculatus*; *A. dispersus*, *A. floccissimus;* Giant whitefly, *A. dugesii*; coconut whitefly, *Aleurodicus cocois* and greenhouse whitefly, *Trialeurodes vaporariorum* (Evans, 2008). *E. dispersa* reported on *A. dispersus*, *A. maritimus*, *A. pulvinatus*, woolly whitefly, *Aleurothrixus floccosus*, *Paraleyrodes urichii* and legume feeding whitefly, *Tetraleurodes acaciae* (Polaszek *et al.,* 2004).
- *Encarsia guadeloupae* is a nymphal parasitoid, solitary in nature and the parasitism was 17-97% on *A. dispersus* and 64-82% on *A. rugioperculatus,* respectively (Ramani *et al.*, 2002; Selvaraj *et al.,* 2017). Host feeding behaviour of this parasitod on eggs and nympal stage is also observed. *E. dispersa* is also solitary and parasitize to the extent of 5-10% on *A. rugioperculatus* and *A. dispersus*.

Description and biology

Encarsia guadeloupae	*Encarsia dispersa*
• The parasitized nymph turns black on 14-16th day of parasitisation (Fig. 12).	The parasitized nymph turns black on 17th day of parasitisation.
• Adult wasp prefers to parasitize second instar and lay about 96 eggs in her life time.	Adult wasp prefers to parasitize the second instar.
• Adult female longevity is 7-10 days and the total life cycle is about 27-31 days.	Adult female longevity is 4-6 days and the total developmental period is 31 days.

• Parasitoid females are produced from unfertilized eggs.	Parasitoid females are produced from unfertilized eggs.

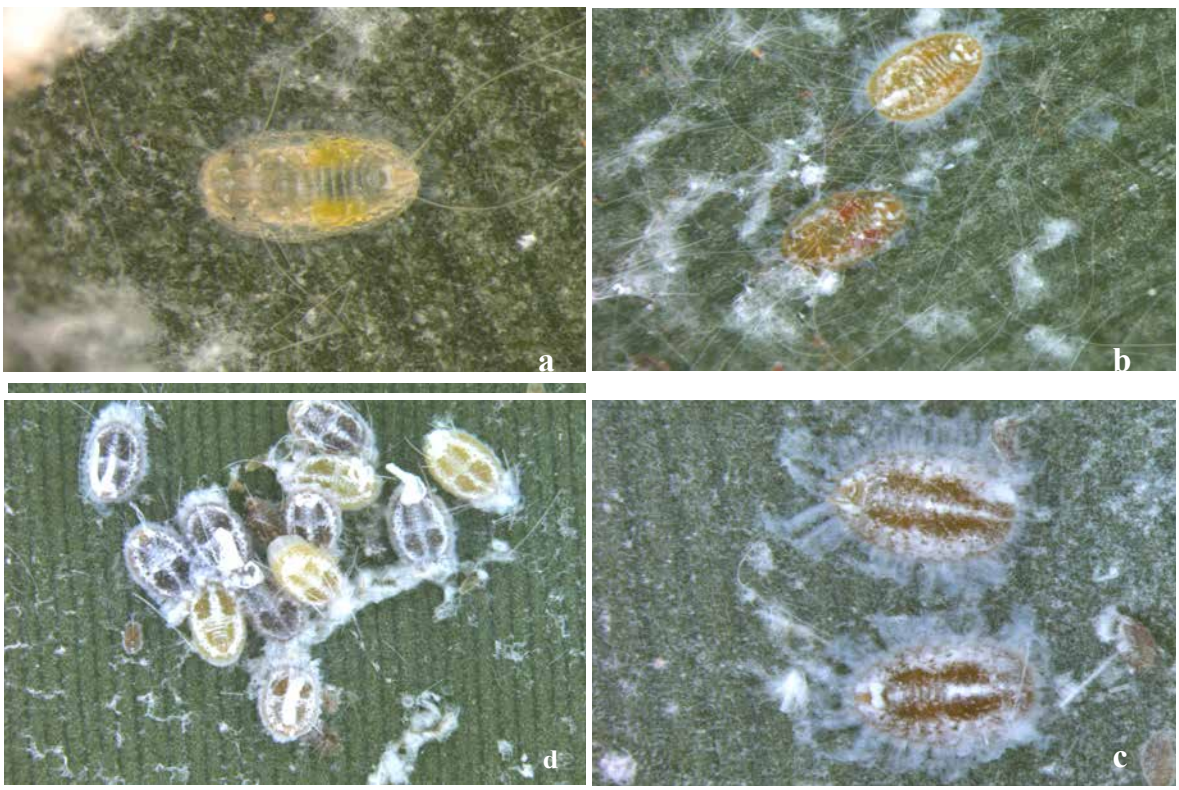


Fig. 12. Development of *Encarsia guadeloupae* on *Aleurodicus rugioperculatus*

Diagnosis

Encarsia guadeloupae	*Encarsia dispersa*
• Adult wasp are dark brown to black and scutellum is yellow with mid lobe largely dark brown; axillae brown (Fig. 13a).	Adults are yellow coloured except mesoscutal-scutellar transverse suture distinctly pigmented dark brown-black (Fig. 13b).
• Antenna pale with radical and scape brown in colour and clava as long as last two funicle segments.	Antennae are eight segmented, scape pale yellow to white, pedicel yellow, flagellum pale yellowish brown to brown.
• Wings hyaline, hind coxa and femur dark brown, legs otherwise pale yellow to white.	Wings hyaline. Legs, including coxae, yellowish except tarsal apices pale brown.

• Fore wing faintly infuscate from base to stigmal vein, 3 setae before parastigma and ovipositor with the apex dark brown to black.	Fore wing about 2.3x as long as broad with marginal fringe less than one-fifth of wing width.
• Mid tarsi-4 segmented; fore and hind tarsi-5 segmented.	Tarsal formula is 5–4–5

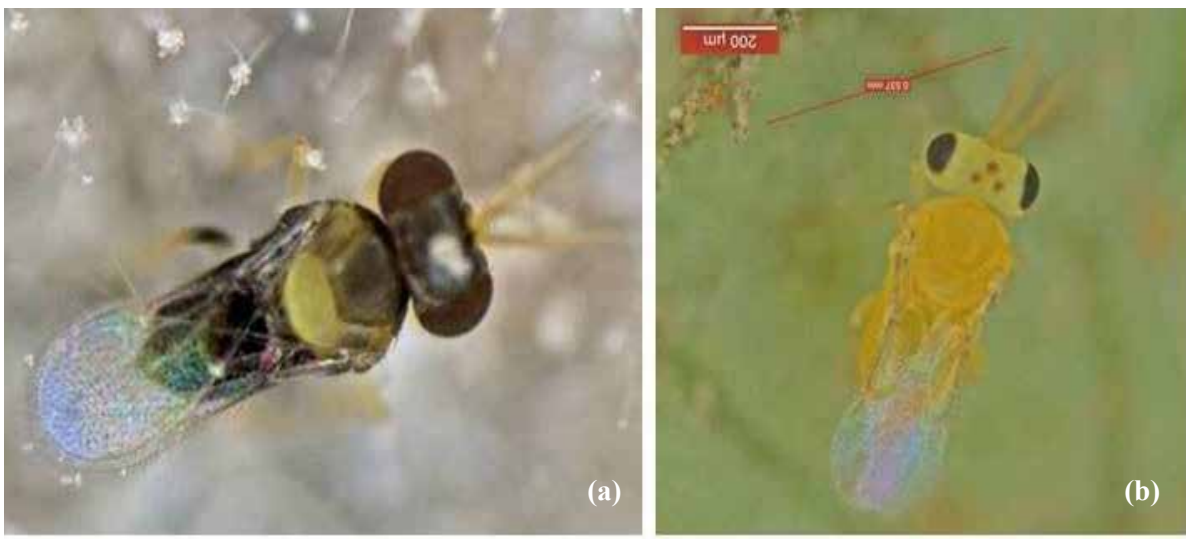


Fig. 13. Parasitoids: *Encarsia guadeloupae* (a), *Encarsia dispersa* (b)

3.7.2. Predator *Apertochrysa* (=*Pseudomallada*) *astur* and *Cybocephalus indicus*

Distribution: Cosmopolitan

Host Insects and efficacy: *Apertochrysa* (=*Pseudomallada) astur* (Neuroptera: Chrysopidae) is a generalist predator that has been reported to prey on a wide variety of pests including whiteflies, mealybug, aphids. Early instars of *P. astur* prefer to feed on eggs whereas late instars prefer to prey more on nymphs. Adult chrysopid feed on RSW adults. A total of 200 nymphs were consumed by a single larva of *P. astur*.

Description and biology

Apertochrysa (=Pseudomallada) astur	*Cybocephalus indicus*
• The predator was found to lay stalked eggs in groups of 12–23 and the duration was observed to be around 3.26 ± 0.63 days.	The eggs are spherical yellowish and hatch in 5-6 days.
• The durations of the larval period are 12-15 days and the pupal periods was 8-9 days	The larval period includes 7-8 days and the total pupal period was 16-17 days.

• The total developmental period averaged 25-26 days.	Development of the egg to adult period from 27-37 days.
• The average longevity of females was 27-28 days and the total number of eggs lay per female is 200-220 eggs.	The adult longevity is 90 days and fecundity is 110 eggs.

Diagnosis

Apertochrysa (=Pseudomallada) astur	*Cybocephalus indicus*
• Larva broad at middle and tapering towards both ends (fusiform) and carry debris in their body (Fig. 14).	The larvae are outwardly similar to coccinellid larvae, yellowish in colour often white mealy coating when they associated with whitefly colonies (Fig. 14).
• Abdomen humped with dorsal setae on abdomen long and hooked. Thoracic lateral tubercles elongate, bearing long setae.	The adults are very characteristic in their appearance - strongly convex on the dorsal side, hump-backed body, which is very clear in lateral view.
• Adults green in colour, abdominal segments with several dorsal rows of hooked setae.	Females are usually fully black and the males have yellowish head and pronotum with black elytra.

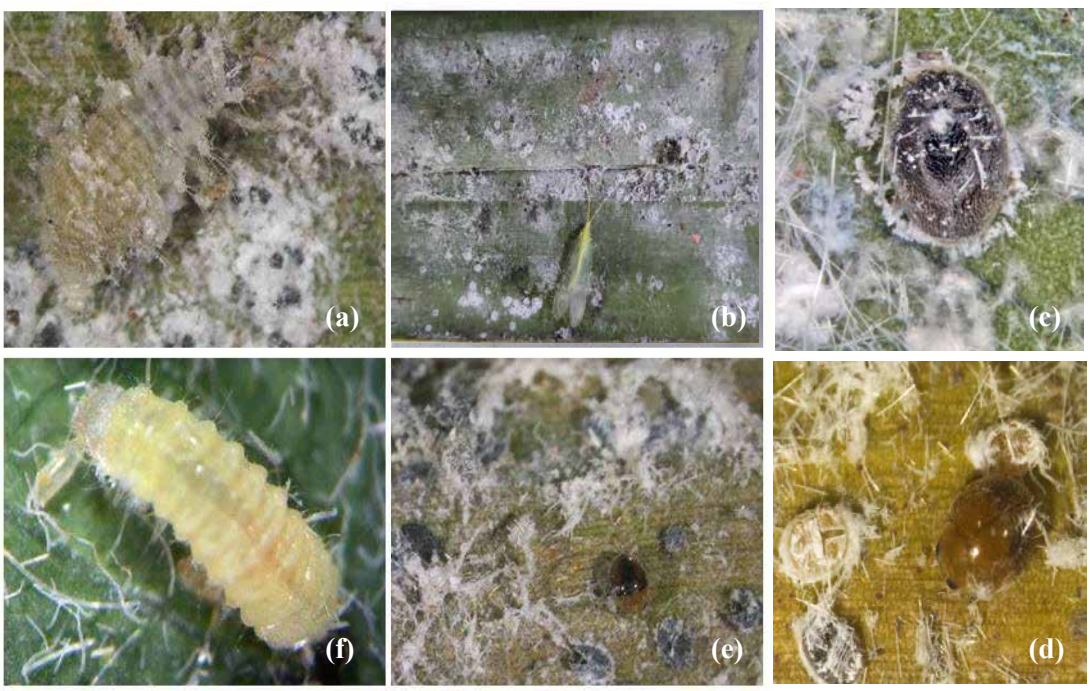


Fig. 14. Predators: *Apertochrysa (=Pseudomallada) astur* (a-b), *Cybocephalus indicus* (c-f)

3.7.3. Entomopathogenic fungus, *Cordyceps (=Isaria) fumosorosea*

Distribution: The entomopathogen is being used as a myco-insecticide for whitefly management in many countries both in greenhouses as well as in an open field conditions including rugose spiraling whitefly and nesting whitefly in Florida.

Host Insects

Cordyceps (=Isaria) fumosorosea formerly known as *Paecilomyces fumosoroseus*, infects a large number of arthropods such as whiteflies, thrips, mealybug under favourable conditions and also can initiate epizootics under natural field conditions. This fungus is used as potential biocontrol agent against *A. rugioperculatus, Paraleyrodes bondari* (Ali *et al.,* 2015; Kumar *et al.,* 2016) (Fig. 15).

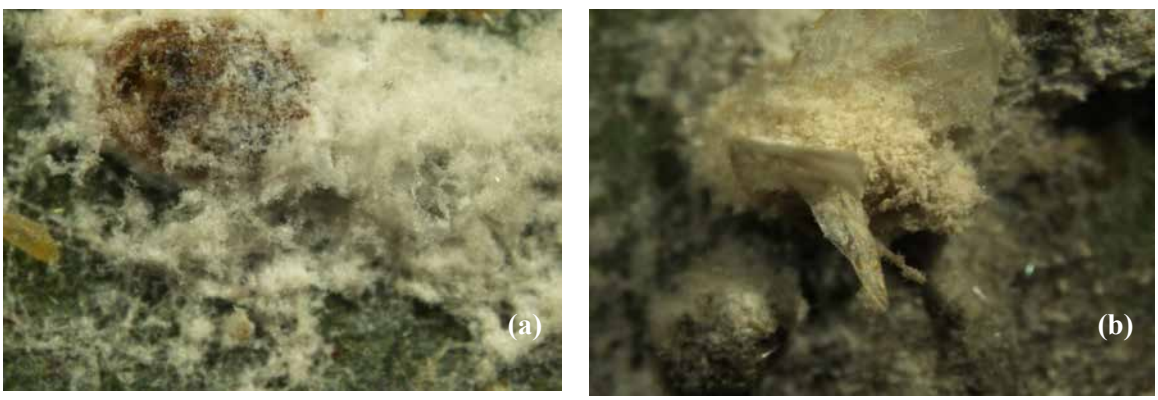


Fig. 15. Natural infection of *C. fumosorosea* on nymphs (a) & adults (b) of ***A. rugioperculatus***

4. ICAR-NBAIR initiative on management of rugose spiraling whitefly

4.1. Documentation of pest, parasitoids and pest alert

ICAR-NBAIR has identified and reported the rugose spiraling whitefly, *A. rugioperculatus* in 2016 for the first time in India as well as Oriental region. The identification of this invasive was confirmed through taxonomic characters of puparium and reconfirmed by DNA barcoding of adult whitefly using partial (658 bp) mitochondrial cytochrome oxidase 1 (CO1) gene. Based on preliminary studies, pest alert was hosted in the institute website and issued pest advisory notes to all the stakeholders in the country.

Subsequently, ICAR-NBAIR documented two exotic parasitoids, *E. guadeloupae* and *E. dispersa* which was fortuitously introduced in India in the late 1990s along with spiraling whitefly, *A. dispersus* as a parasitoids of *A. rugioperculatus.* This recovery of parasitoids paved way for biological control programme.

4.2. Pest management advisory

- Pest advisory service for the management of RSW and other invasive whiteflies was given

to Directorate of Plant Protection, Quarantine & Storage, Faridabad, Indian Council of Agricultural Research, New Delhi, Department of Agriculture & Department of Horticulture in Karnataka, Tamil Nadu, Andhra Pradesh, West Bengal, progressive Farmers, Farmers producing organizations and other stakeholders associated with coconut and oil palm.

- Extended identification of this exotic whiteflies to different ICAR institutes, State agricultural universities, Central Integrated pest management centres and state departments.

4.3. Brainstorming on invasive rugose spiraling whitefly

ICAR-NBAIR organized a brainstorming on "Invasive rugose spiraling whitefly *Aleurodicus rugioperculatus*" to curtail its further spread and damage, and prepare a detailed package of practices (POP) against this invasive pest. The brainstorming was organized in collaboration with Tamil Nadu Agricultural University, Coimbatore and Society for Biocontrol Advancement, ICAR-NBAIR, Bengaluru on 20-21 March, 2017. The meeting was sponsored by ICAR, New Delhi.

Prior to brainstorming on RSW, experts visited to farmers fields in Pollachi and Aliyar Nagar to study the extent of damage and assessment of pest status in different coconut farms. Pollachi is the major and intensive coconut producing area in Tamil Nadu with an area of 56000 ha where the incidence and infestation of the pest was noticed initially and confirmed identity as well as in alarming situation. The expert team members from different organization such as ICAR-NBAIR, Bengaluru, TNAU, Coimbatore, Coconut Research Station, Aliyar Nagar, ICAR - Central Plantation Crop Research Institute, Kasaragod, Central Integrated Pest Management Centres of Trichy, Ernakulam, Vijayawada, Bengaluru, Subject Matter Specialist from KVK, Alapuzha, ICAR-National Research Centre for Banana, Trichy, Representatives from Coconut Development Board, State Agricultural Department officials and few progressive coconut growing farmers were participated.

Fig. 16. Experts assessing the infestation of rugose spiraling whitefly

The expert team members moved across the coconut farms and interacted with farmers to collect the basic data on pest infestation, host plants, RSW impact on crop yield, adapted control measures, their efficacy (Fig. 16). Farmers appreciated efforts taken by various stakeholders to contain the pest and its management through sensitization cum awareness programme for survey and monitoring, identification of pest and natural enemies, mode of spread, host plant ranges, farmer's field school

and supply of natural enemies. The pest population reduction was observed considerably due to enhanced natural parasitism which achieved through various conservation strategies.

Experts from different institution were presented the initiative work on RSW. During plenary session, several recommendations made including immediate control measures for the pest based on deliberation and interactions. Besides, various researchable issues to address the RSW problem for long time basis were also suggested. During the inaugural function, dignitaries released extension folder on "The invasive rugose spiraling whitefly *Aleurodicus rugioperculatus* Martin (Hemiptera: Aleyrodidae) in India" (Fig. 17). After the plenary session, the programme ended with vote of thanks to all the organizers, experts and participants. This programme was widely covered in press and media.

Recommendations

1. Pesticide holiday declared and application of unwarranted insecticides may be avoided to enhance the natural parasitism.
2. Avoid transportation of infested coconut seedling or any other ornamental host plants from pest infested areas.
3. Re-distribution of parasitoid, *E. guadeloupae* to the affected areas.
4. Monitoring on pest and natural enemies in field on different host plants.
5. Apply water forcefully along with sticker if water is available in plenty.

Fig. 17. Dr. Chandish R. Ballal, Director, ICAR-NBAIR briefing on RSW (a) and Experts releasing the extension folder (b)

5. Biocontrol strategies for management of rugose spiraling whitefly

ICAR-NBAIR is carried out extensive research on biological control of invasive RSW on a priority basis under its core programme as well as under a projects funded by the Coconut Development Board, Kochi. ICAR-NBAIR has developed biocontrol strategies using parasitoid *E. guadeloupae* and the entomopathogenic fungus *C. fumosorosea* for the effective management of the RSW. Besides, continuous monitoring of these invasive pests attacking on coconut as well as on other crops. Multilocation trials for the evaluation of *C. fumosorosea* through All India Coordinated Research Project on Biological Control of Crop Pests Centres functioning under ICAR-NBAIR, Bengaluru is in progress.

5.1. Failure of chemical pesticides

The major natural enemies such as *E. guadeloupae*, *E. dispersa*, *P. astur, C. indicus*, *J. pallidula* and *C. sexmaculata* were found feeding on RSW and played a major role in reducing the pest population. During the initial stage of invasion of this pest, few farmers resorted to spraying of chemical pesticides to control but their efforts were in vain as the chemicals turned out to be a temporary fix. The pest resurgence and reduction in the natural enemies population was observed in pesticides sprayed garden. Other ill effects like environmental pollution, killing of pollinators and other non-target organisms and health risks to the people involved in spraying operations made the insecticide application a risky business apart from being uneconomical. Subsequently, growers advocated not to spray any pesticides for the management of RSW and pesticide holiday declared. Biological control based approach for the management of RSW is an effective, economically feasible, ecologically compatible, environmentally benign and sustainable solution.

5.1.1 Augmentation strategies for *Encarsia guadeloupae* and *E. dispersa*

Re-distribution/re-introduction strategies for parasitoids: Non-native species can achieve invasive pest status when they are accidentally introduced to areas where they are separated from their natural enemies and if indigenous predators and/or parasitoids are unable to suppress pest population. Moreover, predominantly RSW disperses during egg and adult stage from infested area to uninfested areas through seedlings so its natural enemies such as *E. guadeloupae* is detached from the host as this parasitoid parasitize on nymphal stages of RSW.

Parasitoids, these two exotic parasitoids, *E. guadeloupae* and *E. dispersa* have been fortuitously introduced into India along with spiraling whitefly *A. dispersus* during 1990s and well established in India. Among these parasitoids, *E. guadeloupae* was found to be most abundant and potential with natural parasitization to the extent of 60-82% on *A. rugioperculatus* on coconut and other crops (Fig.18).

Among these parasitoids, *E. guadeloupae* was found to be suppressing the RSW population effectively; farmers and other stakeholders were advised to re-distribute/re-introduce or inoculative release of these parasitoids wherever they were absent or found in inadequate numbers by using field insectary techniques such as strategically placing the field collected parasitized nymphs in, on or next to infested vegetation for augmentation.

Fig. 18. Redistribution techniques for parasitoid, *Encarsia guadeloupae*

This redistribution/inoculative release was advocated through a plastic container (35 cm height x 25 cm width) where top and side provide with wire mesh (50-60 micron) which allow to escape parasitoid adults from the container but not RSW adults (Fig.18). This way, the distribution of RSW can be avoided and the *E. guadeloupae* population could be enhanced in the field.

Innundative release of *Encarsia guadeloupae*

Repeated mass introduction of potential parasitoid have been widely used as a biological control strategy when the resident population of natural enemies is insufficient to suppress the pest. Therefore, *Encarsia guadelouape* is mass produced at ICAR-NBAIR in polyhouse using *Canna indica* as host plant and *A. rugioperculatus* as host insect. In released coconut and oil palm garden, parasitoid population increased tremendously and reduced the pest population before outbreak situation.

5.1.2. Conservation strategies for *Encarsia guadeloupae*

Conservation biological control is the implementation of farm practices that maintain and enhance the reproduction, survival, and efficacy of natural enemies of pest. Approaches for conservation of these natural enemies involve avoidance of harmful practices as well as adoption of practices that benefit them. Like other animals, insect natural enemies require food, water, and shelter, and protection from adverse conditions. One strategy to improve biological control by resident natural enemies is enhancing habitat diversity through the provision of semi-natural vegetation in or around the field.

Fig. 19. Habitat manipulation for conservation of *Encarsia guadeloupae*

Growers advocated not to spray any pesticides for the management of RSW and pesticide holiday was declared. In areas where chemicals were not applied, parasitoid population were observed to have multiplied rapidly and natural parasitism increased phenomenally thus preventing severe outbreaks. Therefore, frequent monitoring of the pest occurrence was done so as to conserve the natural enemies.

Banana and *Canna indica* were found to be harbouring maximum parasitoids population at field as well as in net-house condition (Fig. 19 & 20). The growers were advised to grow these plants as banker plants in coconut garden as intercrop or border crops for conservation and augmentation.

The main function of these banker plants are the supporting of natural enemies reproduction and the maintenance of their populations. Natural enemies can reproduce such that their numbers increase in alternative hosts or prey on banker plants.

Fig. 20. *Canna indica* as banker plant for conservation of *Encarsia guadeloupae*

5.1.3. Entomopathogenic fungus, *Cordyceps (=Isaria) fumosorosea* : a promising bioagent

ICAR-NBAIR has identified a promising fungal entomopathogenic strain of *C. fumosorosea* (ICAR-NBAIR Pfu-5) for the management of RSW in coconut and oil palm. This fungus was found to be very effective with host specific to the target insects, persistence and self-multiplicative capacity under natural favourable conditions. Once applied, they can grow on the insect surface exponentially and cause rapid killing of target insects.

Based on laboratory bioassays and multi-locational field evaluation, *C. fumosorosea* found to be effective in killing all the life stages of the pest. The eggs and early nymphal instar mortality was up to 91% and the late nymphal instars and pupal mortality was up to 80%. The eggs and first instars of *A. rugioperculatus* are highly susceptible to *C. fumosorosea* (Fig. 21). Therefore, to get maximum reduction in pest population, sprays to be initiated during early life stage of pest.

Fig. 21. *I. fumosorosea* infection on *A. rugioperculatus:* eggs (a), nymphs (b-c), adult (d)

The Pfu-5 has emerged as potential strain and field tested against RSW in Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, West Bengal and Maharashtra on coconut and oil palm (Fig. 22). This strain is recommended at 5 g or ml /litre with tween 80. Based on age of the palms, about 5-7 litre water is required and spraying should be done with high volume sprayer during evening hours. Dead stages of RSW turn brown, shrink and dry completely. Natural epizootic of this fungus on *A. rugioperculatus* is also observed under natural field conditions.

Fig. 22. Field demonstration on application of *Cordyceps (=Isaria) fumosorosea*

Effect of Pfu-5 on *E. guadelouape* showed that about 81% of adult parasitoid is emerged from nymphs exposed at 1×10^8 spores/mL and 94% at 1×10^4 spores /ml. Since these *E. guadeloupae* and *I. fumorosea* are compatible, they can be utilized together for the control of *A. rugioperculatus* in coconut and oil palm ecosystem.

Safety of this fungus also evaluated on benefical insects like mulberry silkworm (common intercrop with coconut), *Apertochrysa (=Pseudomallada) astur* (common predator on RSW) and *Goniozus nephantidis* (potential parasitoid of *Opisina arenosella*). No infectivity was observed on different stages of *B. mori, A. astur* and *G. nephantidis*.

5.1.4. Development of *C. fumosorosea* formulation: To effectively utilize this fungus for management of coconut whiteflies, it is necessary to develop appropriate formulations. Mass production technology for this fungus has been standardized using solid state fermentation (broken rice grains) and liquid state fermentation technology (Sabouraud dextrose yeast extract broth & Potato dextrose broth media). Talc, rice grain and oil formulations have been developed with long shelf life and higher bio-efficacy under field conditions (Fig. 23). Due to its high field efficacy there is a huge demand for this fungus from the coconut farming community. Farmers in Andhra Pradesh are regularly trained on farm level production of this fungus using rice grains as a substrate for their use in the coconut gardens.

Fig. 23. Different formulations (Rice grain, oil, talc) of *Cordyceps (=Isaria) fumosorosea*

5.1.5. Supply and distribution of *Encarsia guadeloupae* and *Cordyceps (=Isaria) fumosorosea*

Parasitoid *E. guadeloupae* and entomopathognic fungus *C. fumosorosea* supplied to many progressive farmers of Tamil Nadu, Karnataka, Kerala, West Bengal, Maharashtra, Gujarat, Lakshadweep and Andhra Pradesh, different stakeholders like 3f oil palm, Dr Reddys Foundation, Deejay Farm, Department of Horticulture, Department of Agriculture, Farmer Producing organization, Krishi Vigyan Kendra (KVKs) and Central Integrated Pest Management Centre (CIPMCs) located in Tamil Nadu, Karnataka.

Besides, in collaboration with Coconut Development Board regional office of Bengaluru, Chennai and Vijayawada and DSP farm, Mandya several awareness cum demonstration, training programme was conducted in the respective states. We have conducted several demonstrations and experimental trials in Karnataka, Tamil Nadu and Andhra Pradesh directly in the farmer's field for the management of RSW in coconut and other crop plants (Fig.24).

Fig. 24. Distribution of *Encarsia guadeloupae* and *Cordyceps (=Isaria) fumosorosea*

6. Biointensive Integrated Management strategies for rugose spiraling whitefly

1. Continuous monitoring on pest and natural enemies in field on different host plants.
2. Avoid transportation of infested coconut seedling or any other ornamental host plants from pest infested areas.
3. Install yellow sticky traps @ 15 /ha for monitoring the pest population.
4. Apply water forcefully along with sticker if water is available in plenty.
5. Avoid excess irrigation and nitrogenous fertilizers, apply/follow only recommended dose and maintain palm health.
6. Periodic release of predator, *Apertochrysa* (=*Psudomallada*) *astur* @ 1000 eggs/ha at 15 days interval.
7. Re-distribution of parasitoid, *E. guadeloupae* to the affected areas.
8. Pesticide holiday declared and application of unwarranted insecticides may be avoided to enhance the natural parasitism.
9. Conserve /encourage natural buildup of *E. guadeloupae* through providing reservoir plants/ banker plants like banana and *Canna indica* which protect them from the pesticides and unfavourable weather factors.
10. In undisturbed gardens, natural parasitism is also increased phenomenally over the period of time through breeding, favorable weather conditions and perennial nature of palms.

11. Foliar application (two sprays) of entomopathogenic fungus, *I. fumosorosea* @ 2x 10^8 cfu/g (5 g/litre of water) at 15 days intervals.
12. Under severe outbreak and absence of natural parasitism, neem oil (0.02%) may be applied.
13. Awareness programme on the natural build-up of the parasitoid *E. guadeloupae* is to be conducted in all epidemic zones to sensitize the farming community.
14. Community based approach warranted for the effective management of this invasive pest.

7. Extension cum awareness and demonstration programme

To sensitize the farmers and other stakeholders with respect to pest, host plants range, distribution, mode of dispersal and natural enemies, ICAR-NBAIR organized several awareness-cum training programme, field day and demonstration on "Biological control of Invasive Rugose spiraling whitefly" in Karnataka, Tamil Nadu, Andhra Pradesh, West Bengal in collaboration with department of Horticulture/agriculture, Central Integrated Pest Management Centres, State Agricultural University, Farmer producing organization, other stakeholders. The details programme lists given in the table.

Fig. 25. Inauguration of field day–cum awareness programme by Dr Chandish R. Ballal at ICAR-KVK, Mangaluru

Table 2. Awareness-cum training and demonstration programme on rugose spiraling whitefly

S.No	Title of the programme	Date and venue	Participants
1	Sensitization-cum training programme on "Integrated Pest Management for Rugose Spiraling Whitefly in Coconut"	21-22 December, 2016, TNAU-CRS, Aliyarnagar	Progressive farmers & pesticides dealers and agriculatural extension officers.
2	Sensitization-cum training programme on "Integrated Pest Management for RSW in Coconut".	20-24 February, 2016, TNAU-CRS, Aliyarnagar, Pollachi	Agricultural extension officers of Tamil Nadu and Pondicherry.

S.No	Title of the programme	Date and venue	Participants
3	Brainstorming on "Invasive rugose spiraling whitefly *A. rugioperculatus*" funded by ICAR.	20-21 March, 2017, TNAU, Coimbatore	Scientists from ICAR-CPCRI, TNAU, Experts from CIPMCs, Farmers, KVKs and CDB
4	Training programme on "RSW infestation and its management"	13 October, 2017, RICM, Bengaluru	Agricultural & horticultural officers in Karnataka
5	Awareness campaign on "RSW infestation and its management"	23 October, 2017, KVK, Mangaluru	KVK officials and famers
6	Awareness campaign on "RSW infestation and its management"	14 November, 2017, KVK, Udupi district	Extension officials of Udupi & Dakshina Kannada district
7	District level awareness programme on "Coconut rugose spiraling whitefly and black headed caterpillar"	21 December, 2017, Mangalore, Dakshina Kannada	Coconut farmers, extension official of Department of horticulture, KVKs.
8	Awareness programme on "RSW infestation and its management"	27 December, 2017, KVK, Krishnagiri	Agricultural extension officers, KVK official and farmers.
9	Awareness programme on "RSW infestation and its management"	4 January, 2018, KVK, Kanyakumari	Agricultural & Horticultural official, KVKs and farmers.
10	Field day-cum awareness on "Invasive RSW *A. rugioperculatus"*	06 February, 2018, ICAR-KVK, Mangalore	Agricultural and Horticultural departmental official, KVKs and farmers.
11	Awareness cum IPM training on RSW in coconut *A. rugioperculatus*-an invasive pest of coconut	08-09 March, 2018, CRS, Thanjavur	Agricultural extension officers and farmers.
12	Formers meet on "Invasive RSW on coconut and oil palm"	04 July, 2018, Kalavalapalli, West Godavari	Progressive farmers, extension officials of Department of Agriculture, scientist from ICAR-IIOR, YSRHU, KVK
13	Formers meet on "Invasive RSW on coconut and oil palm"	05 July, 2018 HRS, Ambajipeta, East Godavari	Progressive farmers, extension officials of Department of Agriculture, scientist from ICAR-IIOR, YSRHU, KVK
14	Farmers meet on "Invasive RSW *A. rugioperculatus* on coconut"	30 October, 2018, KVK, Krishnagiri, Tamil Nadu	Agricultural and Horticultural departmental official, KVKs and farmers.
15	Farmers meet cum demonstration on "Biological control agents for management of invasive RSW *A.rugioperculatus* on coconut and Oil Palm"	3 December, 2018, Kalavalapalli, West Godavari	YSRHU, Agricultural and Horticultural departmental official, KVKs and farmers.

S.No	Title of the programme	Date and venue	Participants
16	Farmers meet cum demonstration on "Biological control agents for management of invasive RSW *A. rugioperculatus* on Oil Palm"	4 December, 2018, Kantavarigudam, West Godavari	YSRHU, Agricultural and Horticultural departmental official, KVKs and farmers.
17	Farmers meet cum demonstration on "Biological control agents for management of invasive RSW *A. rugioperculatus* on Oil Palm"	4 December, 2018, Davarapalli, West Godavari	YSRHU, Agricultural and Horticultural departmental official, KVKs and farmers.
18	Farmers meet cum demonstration on "Biological control agents for management of invasive RSW *A. rugioperculatus* on coconut and Oil Palm"	4 January, 2019, Madavarayapalem, East Godavari	YSRHU, Agricultural and Horticultural departmental official, KVKs and farmers.
19	Awareness-cum-Demonstration on “Biological control of RSW in Coconut”	14 February, 2019, Hosur, Krishnagiri	Silk Board officials, Farmers
20	Biological control agents for management of invasive RSW *A. rugioperculatus*	7 May, 2019, Purva Midnapur, West Bengal	Agricultural and Horticultural departmental official, KVKs and farmers.
21	Training programme on “Biological control of RSW in Coconut”	18 October, 2019, Bidadi, Ramanagara,	Horticultural departmental officials and farmers.
22	Awareness-cum-Demonstration on “Biological control of RSW in Coconut”	30 November 2019, Hassan, Channarayapatna	Department of Horticulture officials, farmers
23	Training programme on “Biological control of RSW in Coconut	16 December, 2019, BCKV, Nadia, West Bengal	BCKV scientific staff, students, Department officials
24	Awareness-cum-Demonstration on “Biological control of RSW in Coconut”	7 January, 2020, Srikakulam, Andhra Pradesh	Department of Horticulture, Scientist from RARS, Farmers, officials from Dr Reddy Foundation
25	Awareness programme on Management of RSW in coconut and banana	23 January, 2020, Gopichettipalayam, Erode	Department of Horticulture officials, farmers
26	Demonstration cum training on farm level production of entomopathogenic fungi, *I. fumosorosea*	5 February, 2020, Anakapalle, Visakhapatnam	Farmers, official of Dr. Reddys foundation and Department of Horticulture officials
27	Demonstration cum training on farm level production of entomopathogenic fungi, *I. fumosorosea*	6 February, 2020, Etcherla, Srikakulam	Farmers, official of Dr. Reddys foundation and Department of Horticulture officials

S.No	Title of the programme	Date and venue	Participants
28	Demonstration cum training on farm level production of entomopathogenic fungi, *I. fumosorosea*	7 February, 2020, Ranasthalam, Srikakulam	Farmers, official of Dr. Reddys foundation and Department of Horticulture officials
29	Awareness-cum-Demonstration on Biological control of RSW in Coconut	23 February, 2020, Department of Horticulture, Erode	Department of Horticulture officials, farmers
30	Awareness-cum-Demonstration on Biological control of RSW in Coconut"	3 March, 2020, Pollachi, Coimbatore	Progressive farmers and Officials of KVK, Tiruppur.
31	Awareness-cum-Training on Biological control of RSW in Coconut"	6 March, 2020, CAU, Imphal	Progressive Farmers and other stakeholders.
32	Awareness-cum-Demonstration on "Biological control of RSW in Coconut"	13 March, 2020, Kavaratti, Lakshadweep	Department officials and farmers.
33	Awareness-cum-Demonstration on "Biological control of RSW in Coconut"	23 November, 2020, Bidadi, Ramanagara,	Department officials and farmers of Ramanagara district of Karnataka
34	Awareness-cum-Demonstration on "Biological control of RSW in Coconut"	10 December, 2020, KVK, Tumkur,	Progressive farmers of tum-kur district of Karnataka and KVK, Hirehalli
35	Awareness-cum-Demonstration on "Biological control of RSW in Coconut"	29 December, 2020, Maddur, Mandya	Department officials and farmers of Mandya district of Karnataka
36	Awareness-cum-Demonstration on "Biological control of RSW in Coconut"	5 January, 2021 KVK, Tumkur,	Progressive farmers of tumkur district of Karnataka and KVK, Hirehalli
37	Awareness-cum-Demonstration on "Biological control of RSW in Coconut"	12 January, 2021, Sendamangalam, Namakkal district	Department officials and farmers of Namakkal district of Tamil Nadu
38	Review the infestation of rugose spiraling whitefly and other emerging whiteflies on coconut and conduct demonstration with bio-control agents.	30 January, 2021, Magadi, Ramanagara	Department officials and farmers of Ramanagara district of Karnataka
39	Demonstration on biocontrol agents for management of invasive whiteflies in coconut.	08th July 2021, Ramanagara, Karnataka.	Coconut farmers

S.No	Title of the programme	Date and venue	Participants
40	Awareness-cum-demonstration on "Biological control of rugose spiralling whitefly in coconut"	02nd August 2021, ICAR-KVK, Tiptur, Karnataka	KVK, department officials and progressive farmers.
41	Awareness on management and demonstration of biological control agents in coconut.	30th September 2021, KRS, Mandya, Karnataka.	Officials of department of horticulture and technical officers.
42	Training cum demonstration on "Biological control of invasive whiteflies infesting coconut"	08th October, 2021, Paramathy, Karur, Tamil Nadu	Officials of department of Agriculture, KVKs and technical officers.
43	Farmers meet cum demonstration on management of invasive whiteflies in coconut.	11th October 2021, Srirangapattana, Karnataka.	Officials of department of horticulture and progressive farmers.
44	Demonstration of biocontrol agents for the management of invasive whiteflies in coconut.	25th November, 2021, Palakkad, Kerala	Officials of department of horticulture and agriculture and Assistant professor from RARS of KAU, Pattambi
45	Survey and farmers meet on management of invasive whiteflies on coconut.	12th January, 2022 Sendamangalam, Namakkal	Officials of department of horticulture and progressive farmers.
46	Training cum demonstration on biocontrol strategies for management of invasive whiteflies in coconut	7th October, 2022 Mandya, Karnataka	Progressive coconut farmers and Department of horticulture, Farmer producing organizations
47	Training cum demonstration on biological management of invasive whiteflies	20th January 2023, Shimoga, Karnataka	Progressive coconut farmers and Department of horticulture officials
48	Training cum demonstration on biocontrol strategies for management of invasive whiteflies in coconut	6th February, 2023 at Karur, Tamil Nadu	Progressive coconut farmers and ICAR-KVK officials
49	Training cum demonstration on biocontrol strategies for management of invasive whiteflies in coconut	21 February, 2023 Chitradurga, Karnataka	Progressive coconut farmers and ICAR-KVKs officials
50	Training cum demonstration on biocontrol strategies for management of invasive whiteflies in coconut	on 6th June, 2023 Madanapalle, Andhra Pradesh	Progressive coconut farmers and ICAR-KVK officials

Fig. 26. Awareness programme on management of rugose spiraling whitefly

8. Publications

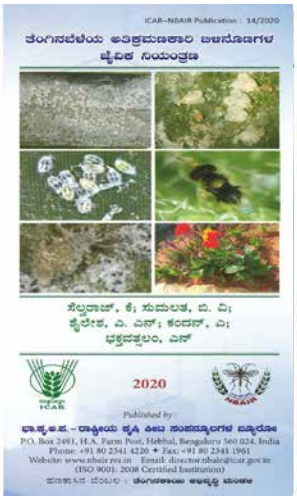
8.1. Extension folders/research note/pest alert

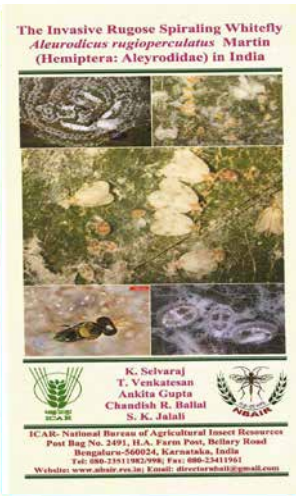
1. **Selvaraj, K.,** Sumalatha, B.V., Ramanujam, B., Poornesha, B., Venkatesan, T., Shylesha, A.N., Gupta, A., Ramya, R.S and Chandish R. Ballal (2023). Biocontrol holds back an unwelcome guest: Tackling the menace of rugose spiraling whitefly in coconut (English). Extension folder No. 14/20; Revision 2023). Published by ICAR-National Bureau of Agricultural Insect Resources, Bengaluru-24.
2. **Selvaraj, K.,** Sumalatha, B.V., Kandan, A., Venkatesan, T., Shylesha, A.N., Ankita Gupta, Rupa Kundu and S.N. Sushil (2023). Biological Control of invasive rugose spiraling whitefly in coconut (Kannada). Extension folder No. 14/20; Revision 2023. Published by ICAR-National Bureau of Agricultural Insect Resources, Bengaluru-24.
3. **Selvaraj, K.,** Sumalatha, B.V., Ramanujam, B., Kandan, A., Swathi, H.D., Chaitra, M and S.N. Sushil (2023). *Isaria fumosorosea*: a Potential biocontrol agent for rugose spiralling whitefly in coconut and oil palm. Extension folder: 11/2020; Revision 2023. Published by ICAR-National Bureau of Agricultural Insect Resources, Bengaluru-24.
4. **Selvaraj, K.,** Sumalatha, B.V., Sundararaj, R., Kandan, A., Rupa Kundu and S.N. Sushil (2023). Invasion and Establishment of Invasive Whiteflies on coconut. Extension folder: 13/2020; Revision 2023. Published by ICAR-National Bureau of Agricultural Insect Resources, Bengaluru-24.
5. **Selvaraj, K.,** Sumalatha, B.V., Sundararaj, R., Venkatesan, T and S.N. Sushil (2023). Invasion of Non-native Neotropical Woolly Whiteflies, *Aleurthirixus floccosus* on Guava in India. Extension folder: 15/2020; Revision 2023. Published by ICAR-National Bureau of Agricultural Insect Resources, Bengaluru-24.

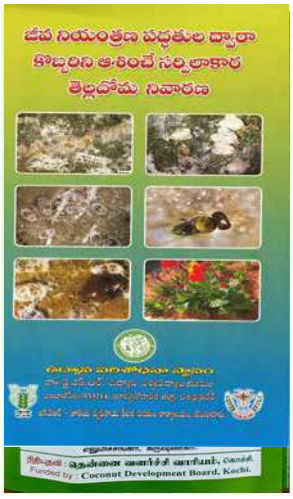
Extension folders

Fig. 27. Demonstration on management of rugose spiraling whitefly

Extension folders







9.1 News paper coverage

S.No	Details	Newspaper & Date
1	Whiteflies plaguing coconut plantations in south India. https://www.thehindu.com/news/cities/bangalore/Whiteflies-plaguing-coconut-plantations-in-south-India/article16794064.ece.	The Hindu (English), 11 December, 2016
2	"Use parasitoids to tackle whitefly menace, coconut growers told. http://www.thehindu.com/news/national/karnataka/use-parasitoids-to-tackle-whitefly-menace-coconut-growers-told / article19988710.ece.	The Hindu (English), 6 November, 2017
3	Whitefly menace: Experts warn against the use of insecticides.http://www.thehindubusinessline.com/economy/agri-business / whitefly-menace-experts-warn-against-the-use-of-insecticides /article9935395.ece	The Hindu Business line (English), 31 October, 2017
4	White-flies army entering the coast! http:// www.Prajavani.net /news/article/2017/11/12/532490.html	Prajavani (Kannada), 12 November, 2017
5	Camp on whitefly infestation on coconut crop	The Hindu (Kannada) 12 November, 2017
6	Workshop on biological control for coconut growers	Vijayavani (Kannada), 30 January, 2017
7	Spiraling whitefly infestation on coconut	The Kadalu, 12 October, 2018

S.No	Details	Newspaper & Date
8	Information camp of insect infestation on agriculture/coconut crop "whitefly control by mass releasing of parasitoids"	Vijayavani (Kannada), 1 November, 2017
9	Awareness programme on organic agriculture to be told at every month in Krishnagiri district /collector informed farmers	Dinakaran (Tamil), 29 December, 2017
10	Camp on coconut insect pest management at Arasampatti	Dinamalar (Tamil), 27 December, 2017
11	Avoid use of pesticides by Chandish Ballal, Director, ICAR-NBAIR	Vijayavani (Kannada), 7 February, 2018
12	Demonstration on management of rugose spiraling whitefly in coconut	Dinakaran (Tamil), 9 March, 2018
13	Rugose spiraling whitefly management through biological control agents	Andhra Prabha (Telugu), 6 July, 2018
14	Biological control is the viable option for rugose spiraling whitefly management	Sakshi (Telugu), 06 July, 2018
15	Rugose spiraling whitefly cannot be controlled 100 per cent	Andhra Bhumi (Telugu), 6 July, 2018
16	Management of rugose spiraling whitefly in coconut	Kadalu (Kannada), 27 October, 2017
17	Need for rugose spiraling whitefly management	Sakshi (Telugu), 6 December, 2018
18	Rugose spiraling whitefly in oil palm	Andhra Jyoti (Telugu), 6 December, 2018
19	Awareness program on rugose spiraling whitefly management	Andhra Prabha (Telugu), 6 December, 2018
20	Management of rugose spiraling whitefly through natural enemies	Eenadu (Telugu), 6 December, 2018
21	Management of rugose spiraling whitefly by using biocontrol agents	Udayavani (Kannada), 17 February, 2019
22	Many coconut tree are dying due to invading whitefly	SanbadNazar (Bengali daily), 9 May, 2019

S.No	Details	Newspaper & Date
23	Agri expert reviewed damages by mexican whitefly on coconut and betel vine	Bartaman (Bengali daily), 8 May, 2019
24	Whitefly management practices	Andhra Prabha (Telugu), 1 November, 2019
25	Be alert on rugose whitefly	Eenadu (Telugu), 1 November, 2019
26	Rugose whitefly management practices in coconut	Sakshi (Telugu), 1 November, 2019
27	Pesticides kills natural enemies	Eenadu (Telugu), 7 January, 2020
28	Pesticides kills natural enemies	Andhra Jyoti (Telugu), 7 January, 2020
29	Pesticides kills natural enemies	Prajashakti (Telugu), 7 January, 2020
30	Awareness programme for farmers regarding rugose spiraling whitefly management	Andhra Prabha (Telugu), 7 January, 2020
31	Biopesticide to control whitefly attack in coconut trees	The Hindu (English), 27 January, 2020
32	Agricultural scientist reviewed the coconut rugose spiraling whitefly in Erode	Dina Thandhi (Tamil) 23 January, 2020
33	Demonstration of new fungal pesticides for coconut ruguse spiraling whitefly	Dinathandhi (Tamil), 30 January, 2020
34	Management practices has to be taken to control rugose spiraling whitefly	Andhra Prabha (Telugu), 8 February, 2020
35	Awareness program on management of rugose spiraling whitefly	Sakshi (Telugu), 8 February, 2020
36	Everybody has to work hard to control rugose spiraling whitefly	Praja Sakthi (Telugu), 12 February, 2020

10. Economic analysis of impact of biological control of rugose spiraling whitefly

The impact of biological control was clearly evident in the pest affected coconut gardens after six months after augmentation and conservation of parasitoid, *E. guadeloupae*. The released parasitoid successfully established and regulated the RSW population. The pest population has come down (less than 10 live colony/leaflet) substantially in the entire severely infested coconut and oil palm garden. Further the self-perpetuating parasitoids prevented the spread to neighboring garden also. The joint efforts of the various organizations weaned and prevented the farmers from resorting to use of hazardous insecticides like monocrotophos 36 EC, imidacloprid 17.8 SL, spiromesifen 280 SC and synthetic pyrethroids in the coconut garden.

No studies is conducted /reported the actual yield loss *i.e* reduction in nut yield /palm. Based on assumption, the chemical intervention cost *i.e* minimum three sprays of chemical insecticide where compared with two release of parasitoid and two sprays of *I. fumosorosea*. Economic analysis on the impact of biological control revealed about Rs 9500/ha has monetary benefit in terms of reduction in crop protection cost and 900 ml of pesticides/ha are being saved. Further, this per hectar benefit may be correlated with total areas affected by the RSW in India gives the overall saving due to biological control intervention (Table 2 & 3).

An estimated benefit of approximately Rs. 128.25 crores was realised through these biocontrol intervention for the management of rugose spiraling whitefly in coconut and oil palm. In addition, the indirect benefit has been reduced exposure to hazardous pesticides, thus making the environment safe.

Economic analysis of biological control

1. Saving cost in insecticides through biological control intervention in management of rugose spiraling whitefly in coconut

Table. 2. Total areas affected by rugose spiraling whitefly in India

S.No	State	RSW affected (Area in Ha.)
1	Karnataka	15,000
2	Tamil Nadu and Pudhucherry	25,000
3	Andhra Pradesh-Coconut	10,226
	Andhra Pradesh-oil palm	11,744
4	Telangana- Coconut	32,388
	Telangana- Oil palm	2,500
5	Kerala	35,000
6	West Bengal	500
7	Maharashtra and Goa	700
8	Gujarat	500
9	Assam	450
Total area affected (ha.)		1,34,008

Table. 3. Amount saved due to biological control intervention against rugose spiraling whitefly

S. No	Particular	Imidacloprid 17.8 SL (Two spray)	Spiromesifen 280 SC (One spray)	Total
1.	Total quantity of insecticides / ha /spray (180 palm x 1.5 ml= 270 ml)	540 ml (1.5 ml/palm)	360 ml (2 ml/palm)	900 ml
2.	Cost of insecticide	800.00 (Rs 1500/litre)	1500.00 (Rs 400/100 ml)	Rs 2300.00
3.	Cost of spraying / ha /4 labour @ 600/day (include sprayer operational cost)	Rs 4800.00	Rs. 2400.00	Rs.7200.00
4.	**Total Crop protection cost /ha/3 sprays**			**Rs.9500.00**

Three sprays at 15 days intervals (two spray with Imidacloprid & one spray with Spiromesifen); spray fluid volume =5-6 litres/palm

Future thrust: Rugose spiraling whitefly is highly invasive, mobile and capable of spreading very fast from one location to another location. Available evidence suggests that new infestations have often resulted from transportations of infested plants. Chemical control is not practicable because of the abundance of host plants and wide spread distribution. It is fortunate to note that biological control agents can readily reduce the spiraling whitefly and rugose spiraling whitefly populations to sub-economic numbers. It would seem to be highly desirable to augment and conserve the host specific natural enemies *Encarsia guadeloupae* to any locality seeking biological control.

Moreover it is imperative to mention that correct and timely identification of this complex is very essential for carrying out further studies on their bioecology, population dynamics on different environments and development of management strategies especially biocontrol programs. There is urgent need to document a potential natural enemy complex or introduce from their native countries to develop efficient biocontrol management strategies for nesting whiteflies and palm infesting whiteflies. Further, a nation-wide surveillance programme is required to mapping of the potential areas of its distribution, and host range to prevent further spread by restricting the exchange of planting materials.

11. Conclusion

The global invasive species program proposes three major management options: prevention, early detection, and eradication for the management of alien species. Prevention of an invasion is the most economical option as it contains pest that further spread to neo-geographical regions. Post incursion management mostly through timely implementation of classical biocontrol programme using potential natural enemies by importation. Fortunately, most of such invasions, especially those of hemipteran species which includes whiteflies, scale insects, aphids, psyllids are amenable for classical biological control. Awareness, early detection of invasive species and immediate implementation of biological control methods could minimize the economic losses caused by the RSW.

Presently control strategies relay heavily on the augmentation and conservation of parasitoid, *E. guadeloupae,* foliar application of, *C. fumosoroea* and periodic release of predator, *A. astur*. These biocontrol agents are more effective in suppressing the RSW when implemented in integrative approach. These control strategies provide only short term control of pest and need repeated release/ application to bring down the pest population. *C. fumosorosea* may be successfully integrated with the augmentation and conservation of *E. guadeloupae* to achieve long term pest suppression of this notorious pest in coconut. *C. fumosorosea* is also considerably effective against other invasive whitefly species like nesting and palm infesting whiteflies.

Acknowledgements

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We also sincerely acknowledge the coconut growers of Karnataka, Andhra Pradesh and Tamil Nadu for their cooperation during the release of parasitoids and application of *Isaria fumosorosea*, assistance in data collection and their continuous active involvement in the project.

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Fig. 28. Training and demonstration activities

Shatpada Rugose Whitefly Kill

- **Microbial Constituent:** *Isaria fumosorosea* ICAR-NBAIR Pfu5 (NAIMCC-F-02139)
- **Type:** Talc; 1×10^8 cfu/g; Oil formulation; 1×10^8 cfu/mL
- **Shelf life:** 12 months at 25-35°C
- **Target pests and crops:** Rugose Spiralling Whitefly (*Aleurodicus rugioperculatus*) in coconut and oil palm

Different formulations (Rice grain, oil, talc) of *Cordyceps (=Isaria) fumosorosea*

- **Method of application:** Two-three foliar sprays at 5mL/L of water (or 5 g/L of water for talc formulation) at 15 days interval after pest incidence; Water required for each spray: 900 L/ha
- **Target agroecological zones/states**: Karnataka, Andhra Pradesh, Tamil Nadu and Kerala
- **Validation:** Coastal Andhra Pradesh on Coconut and Oil Palm for two years; Coastal and Southern Karnataka, Kerala and Tamil Nadu on Coconut for two years
- Toxicological data required for CIB&RC registration yet to be generated
- **Commercialization:** Available for licensing
- **Benefits:**
  - 70-75% pest reduction

Before spraying

After spraying

Effect of Shatpada Rugose Whitefly Kill on Coconut (var. ECT) Rugose spiralling whitefly (RSW) in coastal Andhra Pradesh during 2019

Infection of NBAIR Pfu-5 on Coconut RSW eggs, third and fourth instar nymphs and adult

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