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Invasive Rugose Spiralling Whitefly on Coconut

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Introduction

Biological invasions by non-native (exotic) species constitute one of the major threats to environment and biodiversity including forestry, livestock and agro-ecosystem. Invasions by alien species cause an imbalance in native ecosystems and many of them cause considerable economic loss in the initial phase of entry. Such invasive species are likely to breed profusely in the absence of natural enemies in the newly found environment and cause biotic upsets, out-competing native species. Biological invasions, through the routine importation (both accidental and deliberate) of harmful non-native organisms occur frequently, and are estimated to cost more than $100 billion per year world-wide. Nearly 25% economic losses due to bio-invasions are attributed to invasive weeds, pests and diseases. Invasive species are second only to habitat destruction as the major cause of biodiversity loss. In the globalized era, goods and services produced in one part of the world are increasingly available in other parts of the world and people around the globe are more connected to each other than ever before paving the way for accidental introduction of invasive pests.

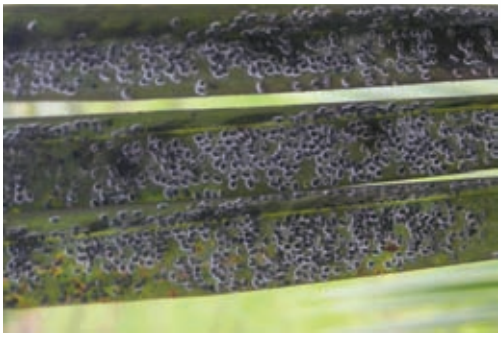
Invasive pests

Coconut eriophyid mite, *Aceria guerreronis* Keifer, Asian grey weevil, *Myllocerus undatus* Marshall, inflorescence moth, *Batrachedra arenosella* and spiralling whitefly, *Aleurodicus dispersus* Russell are a few exotic pests that have challenged coconut industry during its initial phase of entry into the country. Besides the initial flare up, such accidental entry of invasive pests would impose quarantine restrictions for export of value-added coconut products from the country which could diminish international trade. All the aforesaid invasive pests infesting coconut are under check and no severe outbreaks have been reported in the recent past, which could be attributed to the establishment of natural enemies suppressing the pest population. The period of establishment of natural enemies to suppress the outnumbering population of invasive pests is so critical and a longer gap could cause extensive damage and widespread infestation. ICAR-CPCRI has evolved systematic integrated pest management strategies to combat these invasive pests and sensitize farming community to counter the challenges posed by accidental introduction of invasive pests in coconut sector.

Aceria guerreronis damage on nuts

Aleurodicus dispersus on coconut

In addition, arecanut whitefly, *Aleurocanthus arecae* has been reported to feed on mature coconut leaflets as well as coconut seedlings in nursery. Adult whiteflies are small (1-3 mm), fly-like, fragile and smoky-greyish in colour laying eggs in spiral rings on the abaxial of leaves. Nymphs and adults feed on the phloem sap and secretes honeydew supporting the growth of sooty mould fungus. Lady beetles *viz.*, *Serangium parcesetosum*, *Jauravia pallidula* and a hump-backed nitidulid predator, *Cybocephalus* sp. were found predaceous on adults and nymphs of *A. arecae.* Eggs of *A. arecae* were also consumed by an anthocorid bug in Kerala. Natural biological suppression is found to be very successful and no intervention with insecticides is recommended for the management of *A. arecae*.



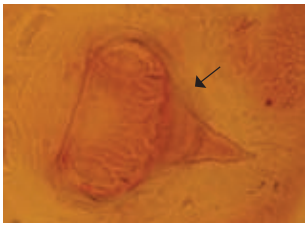
A. arecae on coconut leaflet

Close view of *A. arecae* on coconut leaflet

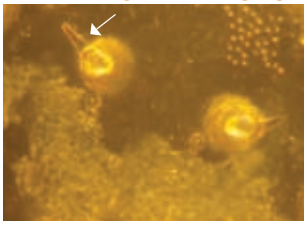
In this backdrop, a recent introduction of an invasive pest, rugose spiralling whitefly, *Aleurodicus rugioperculatus* Martin reported from Pollachi, Tamil Nadu and Palakkad, Kerala during July-August 2016 assumes significance. The pest was initially presumed as *A. dispersus*, which, however, did not cause serious damage to coconut during 1990. The extensive damage and specific confinement on coconut by this spiralling whitefly reinforced the occurrence of a new *Aleurodicus* sp. The identity was subsequently confirmed by Kerala Agricultural University and ICAR-NBAIR, Bengaluru as *A. rugioperculatus* based on the puparial features. Occurrence of reticulated cuticle on dorsum, presence of compound pores in abdominal segments VII and VIII, presence of corrugation on the surface of operculum and acute shape of the apex of lingula were reported as unique features of *A. rugioperculatus*. The compound pores were distinct with dagger-like process of about 280 µ. On the other hand, the whitefly puparia of *A. dispersus* collected from guava at Kayamkulam, Kerala, India had no corrugation in operculum and the lingula is blunt and tongue-like. The compound pores were distinct and double rimmed with no dagger-like process. Nymphs of *A. dispersus* were found to have two prominent fluff tail-like structure on the posterior side which was found merged as one broader fluff with regard to *A. rugioperculatus.* Rugose spiralling whitefly (RSW) adults can be distinguished by their large size and the presence of a pair of irregular light brown bands across the wings. RSW was first described by Martin in 2004 from samples collected in Belize on coconut palm leaves and subsequently in Florida from Miami-Dade County in 2009. The whitefly genus

Aleurodicus Douglas encompasses 35 species, of which only the spiralling whitefly *Aleurodicus dispersus* Russell was so far known to occur in India and subsequently the introduction of *A. rugioperculatus* during 2016.

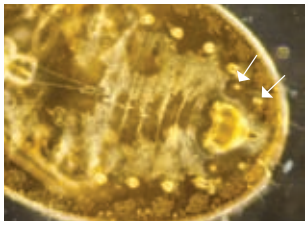
Taxonomic identity of *A. rugioperculatus*



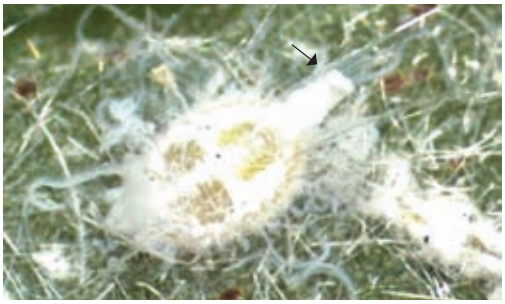
Rugose operculum with triangular lingula



Compound pores with dagger-like process



Smaller compound pores in VII and VIII segments

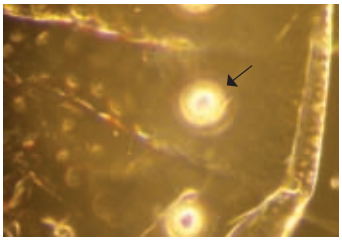


Single broader fluff at posterior end of nymph

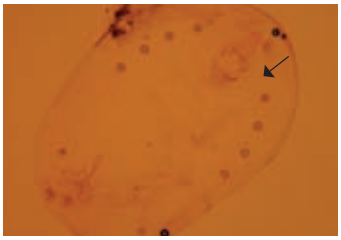
Male and female *A. rugioperculatus*

Taxonomic identity of *A. dispersus*

No corrugation in operculum
Blunt and tongue-like lingula



Double rimmed compound pores



Compound pores absent in VII and VIII segments

Two prominent fluff tail-like structures

Thinner adult with no brown markings

Molecular identification

Molecular characterization of mitochondrial cytochrome c-oxidase subunit I (*COI*) gene of *Aleurodicus* sp. collected from coconut in Chathenkari, Pathanamthitta (WFPT1, GenBank No. KY574536), Kozhinjampara, Palakkad (CN-WFP1a, GenBank No. KY574535), Oachira, Kollam (CN-WFKOa GenBank No. KY499623), Kumarakom, Kottayam (WFKT1, GenBank No. KY574534**)**, Krishnapuram, Alappuzha (WFAL1, GenBank No. KY574533), Vellangallur, Thrissur (WFTb2, GenBank No. KY574537) and Pollachi, Coimbatore (WFTN2, GenBank No. KY574538) indicated 100% similarity with that of mitochondrial *COI* sequence of *A. rugioperculatus* reported from Florida, USA (GenBank No. KP032219) thus confirming the molecular taxonomic identity as *A. rugioperculatus* in confirmation with species-specific morphological characters. On the other hand, *Aleurodicus* sp. collected from guava in Krishnapuram, Alappuzha (WFG1AL1, GenBank No. KY574539) and Kumarakom, Kottayam (WFG1KT1, GenBank No. KY574540) identified as *Aleurodicus dispersus* based on morphological taxonomic keys showed 100% similarity with *COI* sequences of *A. dispersus* thus confirming the molecular taxonomic identity as *A. dispersus* (GenBank No. KC822647). All seven sequences of *A. rugioperculatus* obtained from Kerala and Tamil Nadu as well as two sequences of *A. dispersus* recorded from guava in Kerala were deposited in NCBI GenBank.

Lane 1 : 1 kb DNA ladder

Lane 2-5 : *A. rugioperculatus* from different locations

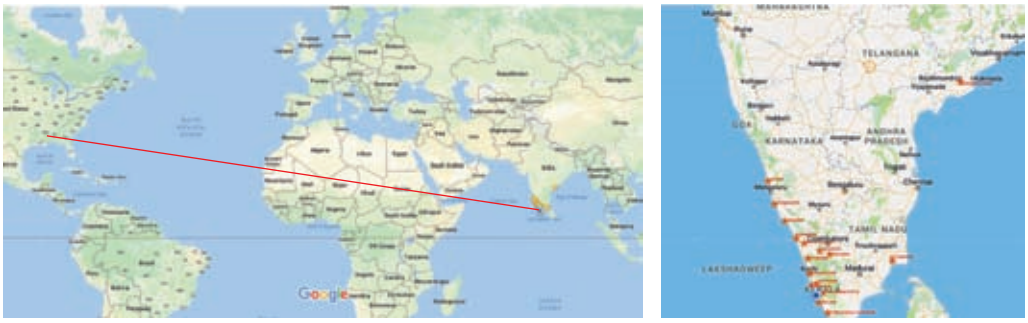
Amplicons of *COI* gene of *A. rugioperculatus*

Phylogenetic tree was constructed by the *COI* gene sequences of *A. rugioperculatus* and *A. dispersus* by neighbor joining method using *B. tabaci* (GenBank no. KF059958.1) as out group. From the phylogenetic tree, it is observed that *A. dispersus* and *A. rugioperculatus* are widely separated by molecular phylogeny, however, genetic closeness in having a common parasitoid, *E. guadeloupae* suppressing both the whitefly species is worth experimenting.

Distribution

The pest, distributed in Central and North America, is limited to Belize, Mexico, Guatemala and the United States. In continental United States, the first established population of rugose spiralling whitefly was reported from Florida in 2009, and since then, its distribution range has expanded considerably within the state. There have been reports of damage caused by this pest to ornamental plant hosts in at least 17 counties of Florida, with the maximum damage reported from Broward, Collier, Lee, Martin, Monroe, Miami-Dade, Palm Beach and St. Lucie.

In India, in a period of six months (August 2016-January 2017), it has spread in limited pockets of Kerala (Palakkad, Malappuram, Thrissur, Idukki, Kozhikode, Kannur, Ernakulam, Kasaragod, Pathanamthitta, Alappuzha, Kollam and Thiruvananthapuram districts), Tamil Nadu (Pollachi and Pattukottai), Karnataka (Udupi) and isolated parts of Andhra Pradesh (Kadiyam). The pest is distributed unevenly along the National and State highways, isolated gardens near water bodies and restricted gardens in midland regions. Extensive spread along the coastal regions is predicted owing to

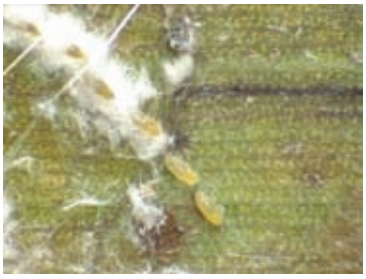


Transboundary movement of RSW from Florida to South India

the congenial weather factors and wide prevalence of coconut palms. Transboundary movement of coconut across the state as well as festivities utilizing coconut could aid the spread in different parts of the country. Movement of pilgrims carrying coconut and pest-infested banana leaves from different parts of the country to Kerala could have enabled the pest to enter with ease and widespread occurrence of the palm across the state of Kerala might have easily made the establishment faster. Transport of coconut seedlings from Kerala to Andhra Pradesh paved the entry of the pest into East Coast initially and also the movement of seedlings from Pollachi to Pattukottai eased introduction in the new locations indicating the scope for strengthening domestic quarantine. RSW could also stick to the moving vehicles and get transported to far off places and through movement of tender coconuts.

About the pest

RSW is a small sap sucking insect belonging to Order Hemiptera which is taxonomically related to mealybugs and aphids. The adult RSW looks like a very small moth and have a body length of about 2.5 mm relatively larger than common whiteflies. Adults have a pair of irregular light brown bands across the wings with greyish eyes. The males are slightly smaller than females and have elongate claspers at the distal end of the abdomen. Eggs are elliptical and yellowish in colour, 0.3 mm long, translucent with a short stalk and are associated with irregular spiralling deposits of white flocculent wax surrounding each egg in a semi-circular spiralling fashion. The spiralling of waxy material is the feature from which its common name, spiralling whitefly is derived. Adult whiteflies have prominent glands on the ventral side through which the white



Eggs laid in spiral manner

Mobile crawler

Nymphs

Emergence slit of RSW

A. rugioperculatus colonies on coconut leaflets

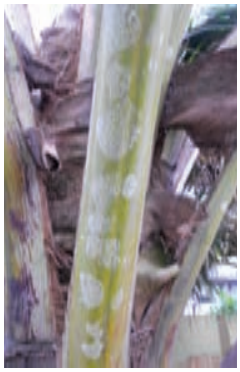
flocculent material emerges out. The first-instar crawlers are the immature stage with functional legs and distinct antennae and are mobile. Subsequent larval stages are sedentary and have oval shaped soft bodies that are cream-coloured studded with white waxy material on the sides. Immature stages become more convex with the advancement of life cycle. The final immature stage is the pseudo-puparium, which is about 1 mm in length and is used in taxonomic identification.

Nature of damage and economic significance

The immature and adult whitefly by their sucking feeding habit, siphon out coconut sap by selective feeding from the abaxial of the coconut leaflets. De-sapping by RSW would induce stress on the palms due to removal of water and nutrients, but neither colour change nor necrosis of leaflets has been reported. Extensive feeding of the insect also leads to the excretion of honey dew which subsequently gets deposited on the upper surface of the leaves down beneath and also on other under storey crops. In case of severe attack, egg spirals could be located on leaf petiole as well as on tender coconuts. Honey dew excrement, being sweet and watery, attracts ants and encourages growth of the fungus, *Capnodium* sp. which causes disfigurement of leaves affecting the photosynthetic efficiency of the plant. Since the outer whorl of

Sooty mould on coconut

Sooty mould on banana



Egg spirals on leaflet, petiole and nut

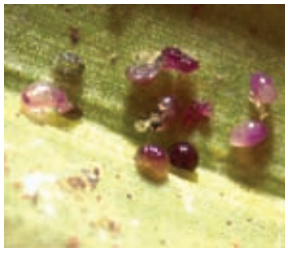
fronds of coconut palm, which already bear coconut bunches of different maturity, do not contribute to the nut yield considerably, the whitefly infestation, with minimum tissue damage, and sooty mould on the outer whorl of fronds may not result in yield loss. Since the black tinge on crop plants (sooty mould) are mere sugar feeding fungus, farmers need not be worried about such black deposits on crop plants as they are not poisonous. Waxy flocculent material produced by the adult whiteflies, however, can be another nuisance to human beings, as they get dispensed with a fluff of white dust, the moment insects are disturbed. In the recent survey conducted in heavily affected gardens and from all age groups of palms, as high as 60-70% of the fronds were found infested by the pest. Despite heavy incidence of whitefly on coconut, it does not practically cause any economic crop loss and, therefore, there is absolutely no need for any panic. The prevalence of the pest was noticed from the outer whorls and slowly progressing towards the inner whorls, whereas, the immature fronds were not infested. Resurgence-induced excessive feeding damage by RSW on coconut leaflets was observed in Pollachi, Tamil Nadu that were subjected to indiscriminate use of synthetic pyrethroids sprayed more than six rounds in a span of 2-3 months.

Sooty mould feeding beetle

Of late, a Leiochrini beetle, *Leiochrinus nilgirianus* Kaszab 1946 (Tenebrionidae : Coleoptera) and immature stages were found feeding on sooty mould developed over the honey dew excreted by RSW especially during early morning hours. Complete cleaning of the sooty mould laden palm leaflets could be accomplished auguring *Swachh* palm *abhiyan* in the experimental plots at Kayamkulam. Grubs that are black in colour are highly elastic in locomotion and assume ball-shaped when disturbed and develop cream-coloured patches on dorso-lateral sides nearing pupation. Usually adult beetles

Leiochrinus nilgirianus

Purplish eggs



Emerging neonates

Grub

Pre-pupa

Pupa

Adult beetle

and grubs are restricted on undersurface of leaflets during bright sunshine and reach out to sooty mould during night and early morning hours. Purplish eggs are laid in groups and cream-colored pupae restrict on undersurface of palm leaflets. Adult beetles are ferrugineous with bristle-like tarsomeres and sharp claws favouring movement on fungal mat and resemble lady beetles in shape and complexion inducing mimicry. This is a novel discovery reported on the economic significance of tenebrionid beetles for the first time.

Characteristic symptoms of RSW infestation

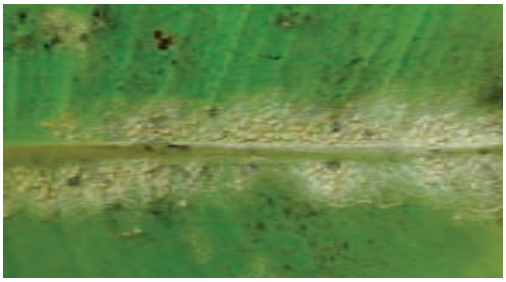
- Egg spirals on the abaxial of the leaflets which coalesce and extend to the entire leaflet in due course of time.
- Heavy white waxy material produced by RSW on the undersurface of leaflets.
- Sticky honeydew in the immediate vicinity of feeding area.
- Development of black sooty mould fungus on the upper surface of leaflets which is quite visible from distance.

Estimation of damage level

ICAR-CPCRI has standardized the estimation of damage level caused by RSW by scoring the presence of live egg spirals on each coconut leaflet. It is categorized as low (<10 egg spirals/ leaflet), medium (10-20 egg spirals/leaflet) and high (>20 egg spirals/ leaflet). Based on the level of damage incurred in Pollachi, Tamil Nadu, dwarf coconut cultivars were found to be highly susceptible than the tall genotypes. Among the dwarfs, Chowghat Orange Dwarf was found to be highly susceptible. In Kerala, the damage level was also noticed under high category for tall cultivars recorded from all districts.

Host plants

A total of 118 host plants from 43 families were reported worldwide for RSW. In the recent survey, twelve alternate host plants (*Psidium guajava, Musa* sp., *Myristica fragrans*, *Colacasia* sp., *Garcinia* sp., *Annona muricata, Murraya koenigii, Spondias mombin, Mangifera indica, Strelitzia reginae, Heliconia stricta* and *Artocarpus heterophyllus*) in coconut homesteads could be recorded, but the pest is relatively more confined to coconut and the reason for its selective preference more aligned towards coconut indicates its host preference. Nevertheless, spiralling whitefly collected from guava in Kumarakom, Kerala where coconut palms were found infested by *A. rugioperculatus* revealed molecular identity as *A. dispersus*. This observation strongly supports the species level host recognition of *A. rugioperculatus* preferring coconut and *A. dispersus* confined to guava in the same location of random feed choice option of the pest. Despite egg laying noticed in other crops, except for banana and bird of paradise, *A. rugioperculatus* could not complete its life cycle in other crop hosts. As coconut is a homestead crop in Kerala with intercrops such as banana,



RSW colony on banana

RSW colony on curry leaf

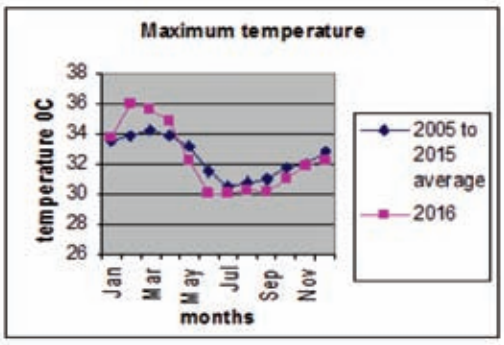
RSW egg spirals on mango

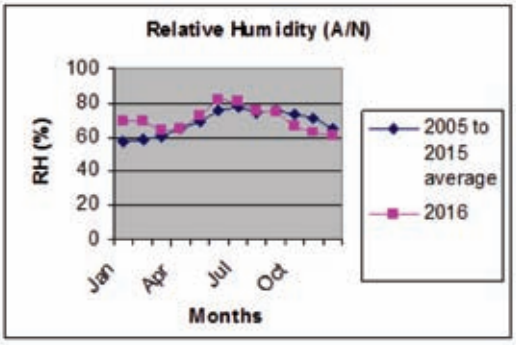
RSW colony on *Heliconia stricta*

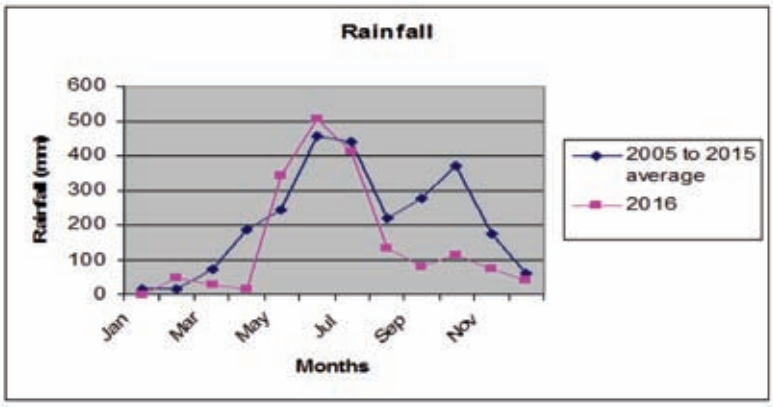
vegetables, curry leaf, tapioca, *etc.* grown along with it, the sooty mould developed on coconut and other crops is of concern to the farmers.

Weather factors

Analysis of meteorological data obtained from ICAR-CPCRI, Regional Station, Kayamkulam indicates a shift in weather pattern reflected as deficit monsoon attributing one of the primary reasons for immediate upsurge of RSW. They are so sensitive to wet season and heavy rains and the recent deficit in monsoon (>35% in







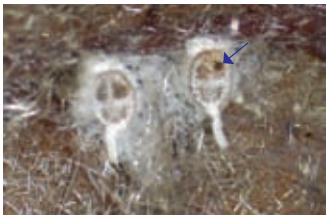
Kerala), which triggered a drop in relative humidity (up to 7% compared to the previous year), are the immediate reasons for the flare up. Increase in temperature over 2°C during summer is another pre-disposing factor for the increase in pest population. Emergence of sucking pest as a butt of climate change, thus, warrants close scrutiny.

Natural enemies

Observations from different parts of RSW prone tracts of Kerala indicated more than 60% of the RSW nymphs parasitized by a tiny hymenopteran parasitoid, *Encarsia guadeloupae* Viggiani (<1 mm size) confirming the natural build up of the parasitoids. This is one of the classical biological control strategies and any disturbance in the build up of *E. guadeloupae* would invariably affect the long-term approach in pest bio-suppression. Adult *E. guadeloupae* was identified by the presence of yellow scutellum (a triangular plate on thorax between the wings) against their brownish body and dark coloured head. Parasitized pupa has the exit hole of the parasitoid, *E. guadeloupae* whereas, the non-parasitized pupa has slit-like opening of the emerged whitefly. The taxonomic identity of the parasitoid was also confirmed as *Encarsia guadeloupae* (GenBank no. KY607910) by characterization of *COI* gene.

In addition, lady beetles belonging to *Jauravia pallidula*, *Sasajiscymnus dwipakalpa* and a wide array of spiders were also noticed. With the emergence of *A. rugioperculatus* in coconut and natural build up of *E. guadeloupae* in Kerala, it could be well understood that the pest-defender system should be carefully conserved in the region so as to encourage population build up of the natural enemies. Fortuitous introduction of *E. guadeloupae* along with the pest or wide-range parasitic ability of the indigenous *E. guadeloupae* suggest possible options of co-emergence in this association. However, the co-evolutionary occurrence of the parasitoid *E. guadeloupae* with the dynamic emergence of the exotic *A. rugioperculatus* suggests for natural suppression once the parasitoid adapts to the new host. Under such situations, no insecticides should be applied to manage the pest. Introduction of parasitized pupae is a good strategy in the emerging pest inflicted zones for effective bio-suppression of RSW.

Parasitized RSW pupa



Exit hole of *E. guadeloupae*

E. guadeloupae

Predatory grub of lady beetle

Jauravia pallidula

Resurgent RSW population

Parasitism was relatively low in pesticide-sprayed gardens in Pollachi, Tamil Nadu which ranged from 25-30% initially indicating an upset in the distribution of parasitoid due to indiscriminate use of pesticides.

Extensive augmentative release of the lady beetle, *Nephaspis oculata* in the bio-suppression of *A. rugioperculatus* was found very successful in Florida, USA. Intensive search for the lady beetle should be attempted to locate the beetle which could have happened as fortuitous introduction.

Field efficacy of natural parasitism

With the outbreak of *A. dispersus* during 1995 in India in many crops including coconut, the population could subdue only after the successful establishment of two aphelinid parasitoids *viz*., *Encarsia guadeloupae* Viggiani and *Encarsia* sp. nr. *haitiensis* Dozier in early 2000. Once the parasitoids got established, *A. dispersus* went beyond recognition.

Incidence of RSW in Chathenkari (Pathanamthitta, Kerala) as well as Kumarakom (Kottayam, Kerala) was found to be high with more than 60-70% of fronds in lower whorls recording >15 live egg spirals/leaflet during October 2016. Upon re-examination during January 2017, the damage level was reduced to <1 live egg spiral/ leaflet with tremendous establishment of aphelinid parasitoid, *E. guadeloupae* and high population build up of lady beetles belonging to *Jauravia pallidula* and spiders in the ecosystem. During October 2016, parasitism was found to be about 30% in both the regions, however, in January 2017 the parasitism rose up to 70.4% at Chathenkari and 58.4% in Kumarakom inferring significant enhancement in parasitism in a period of four months ($t=5.64$; $p<0.05$). Once parasitism level enhanced, the pest population in both regions diminished considerably. Early establishment of *E. guadeloupae* is one of

the positive encouraging signals that could bio-suppress the population of RSW. While >60% natural parasitism was recorded in Kerala, the scenario is absolutely reversed in Tamil Nadu, where resurgence is being realized in gardens sprayed with several rounds of insecticides. In addition, the natural parasitization was less than 30% in pesticide sprayed gardens. It is in this context, a careful intervention is sought for the area-wide bio-suppression of RSW and adoption of pesticide holiday for the effective survival and enhanced parasitic potential of *E. guadeloupae* is recommended.

Being a new invasive whitefly species, the initial spread will be quite rampant. Since the natural enemy build up of *E. guadeloupae* has been initiated, RSW may not go beyond action threshold as expected. Therefore, awareness campaigns are to be followed in all epidemic zones to sensitize the farming community about the whitefly pest and the need for conserving the natural enemies and scavenging beetles to ward off the pest. Sensitization programme focusing on the natural build up of the parasitoid, *E. guadeloupae* in RSW endemic areas should be projected as a classical example of bio-control strategy in sustainable pest management in coconut system. Our approach should, therefore, be to encourage the niche survival of *E. guadeloupae* and habitat conservation of *L. nilgirianus* for effective bio-suppression of *A. rugioperculatus*. ICAR-CPCRI has conducted pest-alert campaign through mass media and sensitized about the invasive pest and the precautions to be handled to suppress the pest.

Strategies for incursion management

I. Quarantine

- Strict quarantine should be enforced.
- Avoid coconut leaves in packaging during transit from pest-infested locations.
- Complete screening of planting materials, soil and organic matter *etc.*, under transport from pest-prone zones.
- Baggage check for ornamental plants, palms and commercial flowers with emphasis on bird of paradise.
- Monitor domestic quarantine and issual of strict phytosanitary certificate.

II. Surveillance

- Enforce direct surveillance surveys in sensitive zones.
- Monitoring of airports and seaports of strategic importance.
- Examining coconut leaves and sooty mould symptoms systematically.
- Formation of **Incursion Management Team** with scientists from all disciplines.

III. Awareness campaign

- Organizing nation-wide seminars, workshops and sensitization campaigns.
- Capacity building on mass production of bio-control agents.

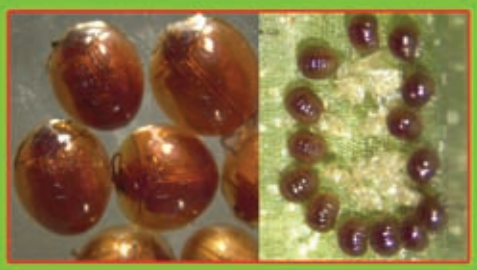
- Intensive bio-control programmes in endemic regions.
- Display big posters in lounges of airports.
- Mass media programme in *Prasar Bharati, Doordarshan* and through news clippings.

IV. IPM strategies

- Application of 1% starch solution on leaflets to flake out the sooty moulds.
- Installation of yellow sticky traps on the palm trunk to trap adult whiteflies.
- Encourage build up of parasitoids (*E. guadeloupae*) and re-introduce parasitized pupae to emerging zones of whitefly outbreak.
- In severe case, spray neem oil 0.5% and no insecticide is recommended.
- Complete destruction of RSW and immature stages on coconut seedlings by spraying imidacloprid 0.005% to avoid spread of the pest to new areas.
- Habitat conservation of sooty mould feeding scavenging beetles (*L. nilgirianus*) in the palm ecosystem.

Outbreak of invasive pests will upset the biodiversity of the new site of introduction at the initial phase and rugose spiralling whitefly, *A. rugioperculatus* is thus expanding its feeding domain. The aphelinid parasitoid of *A. dispersus*, *viz., E. guadeloupae* was found successfully and efficiently parasitizing RSW, *A. rugioperculatus* in Kerala and Tamil Nadu evincing >60% kill. Genetic closeness between *A. dispersus* and *A. rugioperculatus* is indicated at least in parasitization by *E. guadeloupae*. Further, strengthening of quarantine, effective sensitization of public on the potential invasive pest through display posters in strategic points of airports, seaports and mass media display in TV channels, formation of an incursion management team to combat such outbreak and conservation of *E. guadeloupae* as well as sooty mould feeding scavenging beetles in coconut ecosystem are effective measures to counter such biosecurity issues.

Efforts are to be intensified to look out for the lady beetle, *N. oculata* in RSW endemic zones for conservation and subsequent augmentation. In a nutshell, advent of the parasitoid, *E. guadeloupae* and the scavenger beetle, *L. nilgirianus* considerably reduced the pestiferous potential of *A. rugioperculatus*. This could be considered as an eye-opener for conservatory biological control and for the first time, habitat conservation of scavenger beetles highlighted the potential of saving several crores of rupees in the agricultural sector by avoiding chemical pest management options.



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