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Guide on Diagnosis of Invasive Whiteflies and Their Natural Enemies

ISBN 978-81-927161-1-4

Compiled and Edited by
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February, 2024

Contents

Forward

Exotic invasive whiteflies 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 including economically important crops in India. Recently within a span of five years, as many as seven exotic whiteflies *viz.,* Solanum whitefly, *Aleurothrixus trachoides* during 2015*;* rugose Spiraling whitefly, *Aleurodicus rugioperculatus* during 2016, Bondar's nesting whitefly, *Paraleyrodes bondari* and nesting whitefly, *Paraleyrodes minei* during 2018, legume feeding whitefly, *Tetraleurodes acaciae* during 2018, palm infesting whitefly, *Aleurotrachelus atratus* and woolly whitefly, *Aleurothrixus floccosus* during 2019 invaded in India. All these invasive species are native to the Neotropical region, mostly from Central America and the Caribbean, highly polyphagous and have a host preference towards many economically important crop plants.

Extensive spread along the coastal regions and gardens near the backwater of India is predicted owing to the favorable weather factors and availability of host plants. 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. The most insidious spread of these species in India is likely mediated by humans through movement of infested seedlings and plant materials.

Soon after the report of these invasive species in India, ICAR-NBAIR took proactive measure to contain the damage, and spread through regular monitoring, exploration of biocontrol agents and development of management strategies. Precise identification of pest and natural enemies coupled with proper deployment of suitable biological control agent at appropriate time ensures timely management of invasive insects.

In this technical bulletin has enumerated the identification, distribution, host plants, biology, and symptoms of damage, co-existence and economic importance of invasive whiteflies which will be of immense use for growers, extension scientists, students and other stakeholders. I appreciate the efforts made by the authors in bringing out this publication.

Bengaluru
20 February 2024

S. N. Sushil
Director

Preface

Invasive insect species constitute one of the most serious economic, social and environmental threats of 21st century causing huge economic losses and social disturbances. Recently across the world, there have been frequent invasions by insects, mites and vectors of plant diseases. It is greatly felt that introduction of unwanted species can affect the ecosystem health and productivity of natural and managed systems in India. The enormous increase in the volume, diversity and swiftness of movement of plant products throughout the world has led to a proliferation and dissemination of invasive insect species like scales and whiteflies. ICAR-NBAIR is striving hard in identifying and documenting invasive species including whiteflies through constant monitoring and surveillance in order to avoid spread and outbreaks situation.

Monocropping, excessive use of chemical inputs and improper irrigation management might have triggered the outbreak of certain pests and has caused a substantial reduction in the yield. Furthermore, Pest dynamism mostly due to invasive pests is constantly changing with resultent diminising productivity and threatening livelihood security in the recent past. ICAR-NBAIR is developing biocontrol strategies and popularizing research, extension and capacity building. Preventing the introduction of potentially important invasive whitefly species by far has been the preferred strategy. Integrated efforts involving mechanical, biological, chemical and other methods are considered appropriate. The intensity of infestation of rugose Spiraling whitefly on coconut, banana and oil palm, woolly whitefly on guava, palm infesting whitefly and nesting whiteflies on coconut was severe. These species spread rapidly in the large geographical region of India mostly through transportation of infested seedlings.

This technical bulletin describes in detail about the nature of damage, biology, natural enemies, life cycle, economic importance and this knowledge is very much essential for proper decision making in initiating the pest management activities. This bulletin will certainly be useful for coconut growers, extension workers, students, teachers, and other stakeholders for accurate identification and diagnosis of invasive whiteflies and their potential natural enemies. The authors are very much thankful to the Director, ICAR-NBAIR for providing necessary facilities to conduct research and in bringing out this bulletin. Authors are also grateful to the Chairman, Coconut Development Board, Kochi for providing financial grant to carryout various research and monitoring activities.

Selvaraj, K
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1. Introduction

Invasive insect pests are non-native or exotic organisms that occur outside their natural adapted habitat and great dispersal potential. Invasive species constitute one of the most serious economic, social and environmental threats of 21st century causing huge economic losses and social disturbances. Recently across the world, there have been frequent invasions by insects and mites, some of which are vectors of plant diseases. It is greatly felt that the introduction of unwanted species can affect the ecosystem, health and productivity of natural and managed systems in India. The enormous increase in the volume, diversity and swiftness of movement of plant products throughout the world has led to a proliferation and dissemination of invasive insect species like scales and whiteflies (Wosula *et al.,* 2018). So far, more than 110 exotic insect species had been reported from India, of which whiteflies and mealybugs constitute a major part (Mandal, 2011) and represent some of the world's worst invasive pests. Whiteflies (Hemiptera: Aleyrodidae) are small inconspicuous phytophagous insects and an economically important group infesting a wide range of host plants.

Whiteflies are distributed throughout the major zoogeographical regions of the World, with their greatest diversity in tropical and south temperate regions. Most alien species of whiteflies were accidentally introduced along with their host plants and regularly dispersed among countries as a consequence of plant trade, the small in size their cryptic nature and immature stages being attached to the host-plant (Simala *et al.,* 2015). Due to these characteristics they are one of the most commonly transported and most successful arthropod groups invading new geographical areas Moreover, changes in climate and global warming could influence new introductions, distribution and establishment of exotic whitefly species and increase the chances of their survival in the new environment.

The introduced insect species become invasive in the new area due to wider host range, high fecundity, absence of natural enemies and wider climatic adaptability favourable to establish in the new ecosystem. These 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. These invasive pests causes direct damage to their host plants by feeding and bringing the host under tremendous stress by removing the nutrients and water thereby interfering with its normal growth, and causing premature leaf drop; they cause indirect damage by producing wax and excreting sticky honeydew which provide a substrate for the growth of black sooty mould which reduces the photosynthetic capacity of the plant and some species-vector plant viruses such as a begomovirus by *A. trachoides* (Kumar *et al.,* 2018; Chandrasekhar *et al.,* 2020).

Preventing the introduction of potentially important invasive whitefly species by far has been the preferred strategy. Integrated efforts involving mechanical, biological, chemical and other methods

are considered appropriate. In this technical bulletin, identification of invasive whitefly species and their potential natural enemies, diagnosis, distribution, host range, symptoms of damage, co-existence and their potential impact on the Indian agro-ecosystem are briefed in detail.

2. Whitefly Species Biodiversity in India

In India, 471 whiteflies species belonging to 72 genera are known to feed on many agricultural, horticultural and forestry plants which include 8 invasive species. Around 25 years ago, India experienced first invasive whitefly i.e the Spiraling whitefly *Aleurodicus dispersus* Russell in the Western Ghat and established on many host plants including economically important crops (David and Regu, 1995). Between 2015-2019, the following seven exotic whiteflies *viz.,* solanum whitefly, *Aleurothrixus trachoides* (Back) during 2015 (Dubey and Sundararaj, 2015); rugose Spiraling whitefly, *Aleurodicus rugioperculatus* Martin during 2016 (Sundararaj and Selvaraj, 2017); legume feeding whitefly, *Tetraleurodes acaciae* (Quaintance) during 2017 (Sundararaj and Vimala, 2018); Bondar's nesting whitefly, *Paraleyrodes bondari* Peracchi (Josephrajkumar *et al.,* 2019) and nesting whitefly, *P. minei* Iaccarino during 2018 (Mohan *et al.,* 2019); palm infesting whitefly, *Aleurotrachelus atratus* Hempel (Selvaraj *et al.,* 2019) and woolly whitefly, *Aleurothrixus floccosus* (Maskell) during 2019 (Sundararaj *et al.,* 2020) were discovered. These invasive species are native to the Neotropical region mostly from Central America and the Caribbean.

Out of the eight invasive whiteflies of India four species *viz., A. dispersus, A. rugioperculatus*, *P. bondari* and *P. minei* belonging to subfamily Aleurodicinae while the remaining four species *viz., A. trachoides*, *T. acaciae, A. atratus* and *A. floccosus* belonging to subfamily Aleyrodinae. Invasion of exotic species normally leads to abrupt outbreaks in new location due to favourable weather condition and availability of suitable host plants. The most insidious spread are those mediated by humans and the transboundry movement of these invasive whiteflies believed due to import of ornamental plants. Normally, introduction of invasive species is through single or multiple entries and later establishes successfully due to favourable weather conditions prevailing at the new locations.

3. Importance of whitefly identification

Correct and timely identification of insect species is crucial for accurate identification of new and existing invasives. Identification of insect species is an important pre-requisite for initiating the appropriate decision making process and predict their range expansions and for consistent communication regarding management outcomes. Continuous appearance of new pests in agricultural areas has increased the demand for taxonomists for the identification as never before. The knowledge and expertise in pest identification enable us to work with ease not only in experiments related to insect management but also in promotional, advisory and other outreach activities.

Although pest identification is a very vast, complex subject and essentially needs the knowledge of taxonomy, morphology, different life stages of insects and their damage symptoms facilitate

proper identification of the insects. Characters related to the specific life stages of a particular insect may be considered for easy and quick identification for their management. In whiteflies, species and genera are usually distinguishable by characters of the puparium except species under subfamily Aleurodicinae which are defined based on both preparaium and adult characters.

3.1. Morphological identification of whiteflies

The identification of whiteflies is mainly based on the fourth nymphal instar, the so called 'puparium'. The slide-mounted puparia of whiteflies should be clear from body contents as the obscure characters present on the puparial surface. The field appearances of whitefly puparia are very similar to other genera or within the species of a single genus that enhances chances for misidentification of species. So, whiteflies can be accurately identified by observing the morphological characteristics of slide-mounts of the puparium and the best slide mounts can be obtained from puparial cases from which adults had emerged.

The whitefly puparial cases slightly vary with the hardness and pigmentation like dark and pale pupae. The puparial cases taken out from the host plant leaves should be washed in 70% alcohol to remove fluffy or gelatinous waxy covering. Then transfer puparial cases into 10% KOH solution for overnight or until bleached at room temperature. Then add a few drops of acid alcohol to neutralize the basic content of solution. Puparial cases should now be transferred to Essing Aphid Fluid (E. A. F.) and allow them to be flat and clear. Keeping for 3-5 days in E. A. F. will make the specimens clear and transparent. Once the white puparial cases are cleared add 2-3 drops of acid Fuchsin and keep 3 hours to over- night, thick specimens need less time to stain compared to thin specimens. After staining puparial cases should be placed in 100% alcohol and then transferred into clove oil.

Now the specimens should be mounted on clean glass slides using Canada balsam. While mounting the dorsal and ventral surface of puparial cases can be separated and dorsal surface of puparia should be placed upside for identification. Mounting of single puparial case on each slide is useful for type designation. Black puparial cases do not need any staining. However, pale puparia after staining need sequential dehydration to make sure the stain is permanent and not to be lost after a few weeks.

The identification of whitefly puparial cases can be done by using some important regional keys. The characteristics of the puparial cases vary with the host plants leaf texture on which they develop, and this may lead non-specialists to misidentify the species. The important basic characteristic features such as anterior and posterior setae, cephalic and abdominal setae, caudal, marginal and sub-marginal setae, dorsal pore, sub-marginal striations, spiracles, operculum, lingual of puparium and antenna, male and female genitalia and wax plates of adults are to be considered are presented diagrammatically with brief explanation (Fig. 1). For example vasiform orifice on the dorsal surface of the caudal segment of the abdomen is characteristic of the Aleyrodidae and within the family and it is taxonomically diagnostic because its shape varies according to the species.

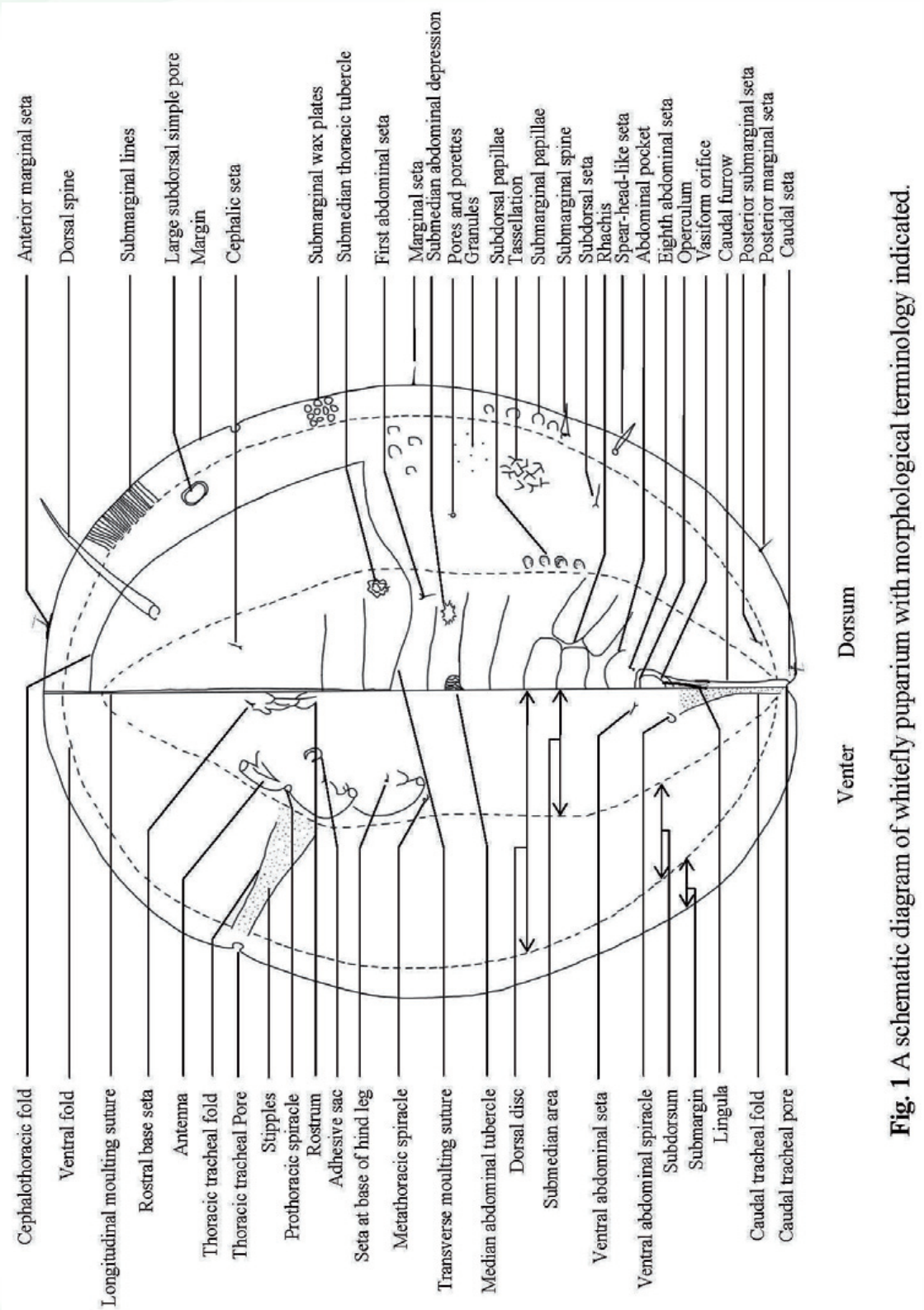

Fig. 1 A schematic diagram of whitefly puparium with morphological terminology indicated.

3.2. DNA Barcoding and Molecular characterization of whiteflies

In case of whiteflies, puparial taxonomy will continue to play a major role in whitefly systematic based on morphological characteristics and studies on adult whiteflies will play a supportive role. Whitefly puparium and adult have several taxonomic characters for morphological identification but often show high intra-specific variability, phenotypic plasticity and vary with host plants and environment. DNA barcoding has great advantages for identifying taxa which are morphologically difficult to distinguish like whiteflies and it is relatively fast.

Further to establish the phylogenetic and reproductive relationship, integrative taxonomy is considered a reliable approach for accurate identification of closely related and cryptic species like *Bemisia* species complex by integrating genetic, ecological and morphological characters.

While morphological data are usually time consuming and needs specialists. DNA barcoding techniques are uniform, practical method of species identification of insects and can be used for the identification of all developmental stages of insects, their food webs, biotypes and this may not be possible with morphology based taxonomy. Fragments or damaged specimens identity can be determined using DNA barcode. DNA-based species identification will speed up analysis of known species and reveal cryptic species within species by population genetic analysis. DNA barcoding can play an important role in studying the arrival of invasive species.

DNA barcoding can pinpoint the geographic source of an invading species and measure the distances over which pest species can travel. DNA barcoding may lead to discover new species by sampling biodiversity hotspots, unexplored regions. The COI gene has proved to be suitable for species identification in a large range of animal taxa, including whiteflies.

A DNA barcode is a short sequence from standardized portions of the genome (a 648 bp of mtCOI). DNA barcoding is technically a simple and rapid approach, in which a small DNA fragment is amplified by polymerase chain reaction (PCR) from total genomic DNA and PCR product is directly sequenced. The following are the set of Universal primers for the identification of species.

Universal Primers

LCO 1490 5’-GGT CAA ATC ATA AAG ATA TTG G-3’

LCO 2198 5’-TAA ACT TCA GGG TGA CCA AAA AAT CA-3’

The sequence generated is aligned and checked similarity with the help of NCBI nucleotide database. The barcode is then generated using the Barcode of Life Database by uploading the sequence with NCBI accession number.

4. Exotic whiteflies under the subfamily Aleurodicinae

4.1. Spiraling whitefly, *Aleurodicus dispersus* Russell

Distribution

- Spiraling whitefly, *Aleurodicus dispersus* is native to the Caribbean islands in Central America and the species was first collected on coconut in Florida.
- *Aleurodicus dispersus* was the first invasive whitefly recorded in India; it was first reported in the Western Ghats of south India and is now distributed throughout the country including the Andaman, Nicobar and Lakshadweep islands.

Hosts plants

- *Aleurodicus dispersus* is highly polyphagous affecting on a wide range of host plants and is known to feed on about 500 plant species in the world and in India, it was found to breed on 320 plant species belonging to 225 genera and 73 families.

Identification

- Pupal margin smooth, not dentate and abdominal compound pores number only four: decreasing in size from abdominal segment 3 to 6, the last slightly larger than the prothoracic one (Fig.2).
- Caudal pair of compound pores below the level of the vasiform orifice and the 8-shaped pores in a single row from the body margin.
- Sub-marginal double-rimmed pores in a single row; wide-rimmed pores distributed 1 or 2 deep between septate, septate pores present in median and sub-median area of most segments, but absent from abdominal segment.
- Lingula is oval shape and caudal setae located in row of double-rimmed pores.

Fig. 2. *Aleurodicus dispersus*: (a - b) mounted puparium, (c) operculum

Description and biology

- Female whitefly lays elliptical, smooth surfaced yellowish white eggs in a typical spiral pattern which hatch in 4-7 days and fecundity ranges from 51.8 to 64.06 eggs/ female (Fig.3).
- There are four nymphal instars, which are greenish, white and oval and total nymphal duration lasts for 13-14 days. Fourth instar nymphs (pupae) are covered with heavy white wax materials.
- The total nymphal period is normally lasts for 12 to 14 days and pupal period lasts for 2 to 3 days. Development from egg to adult occupies 18 to 29.66 days.
- Adults are larger (1.74 mm) coated with a fine dust like waxy secretion and fore wings with characteristic dark spots and live for 13 to 22 days.

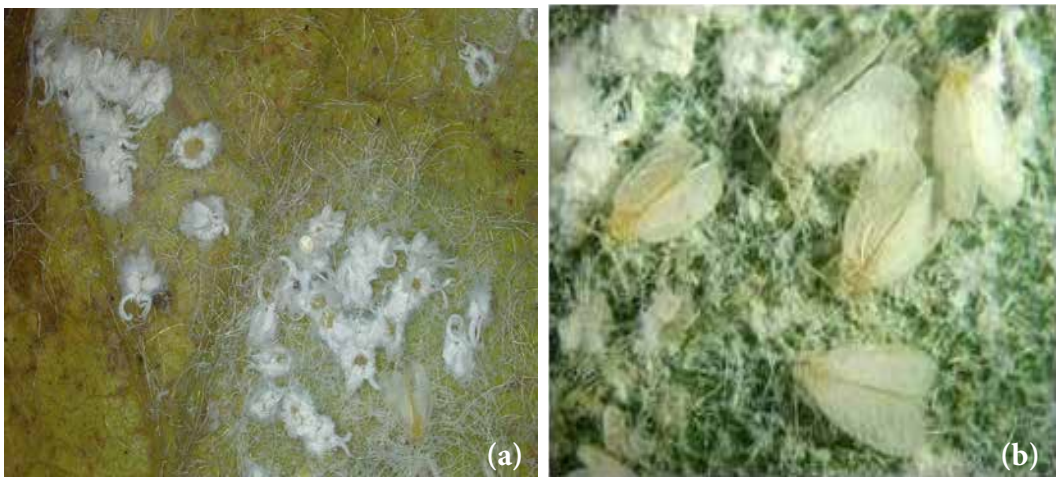

Fig. 3. Life stages of *Aleurodicus dispersus:* (a) nymphs, (b) adult

Nature of damage

- Nymphs and adults are congregate generally on the lower surface of leaves and secrete copious white, waxy flocculent materials which are readily spread elsewhere by wind and create a very unsightly nuisance (Fig.4).
- By sucking the sap which depletes nutrients and water from host plants and causes premature drying under severe infestation.
- Sticky honeydew is excreted which serves as a substrate for dense growth of sooty mould which may interfere with normal photosynthesis of affected plants.

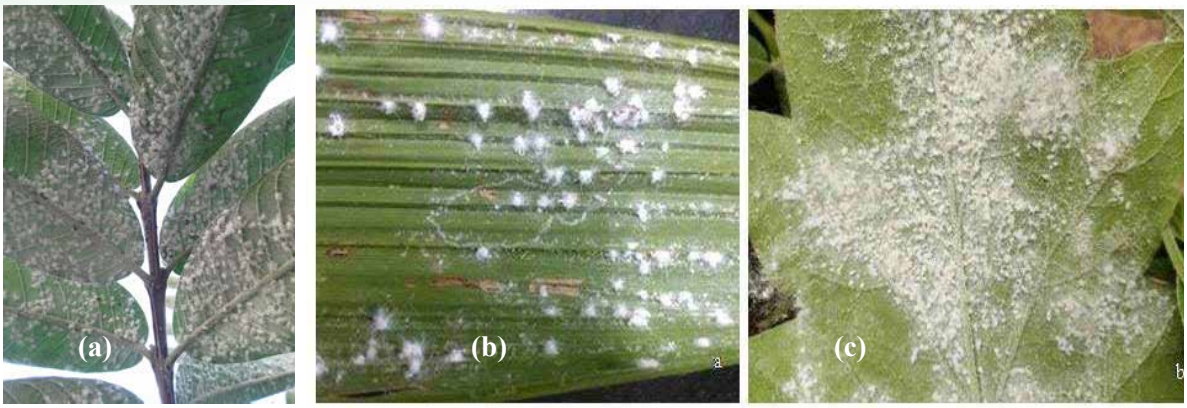

Fig. 4. Infestation of *Aleurodicus dispersus*: (a) guava, (b) coconut & (c) brinjal

4.2. Rugose Spiraling whitefly, *Aleurodicus rugioperculatus* Martin

Distribution

- Rugose Spiraling whitefly was first described from coconut in Belize and has been reported as a pest on gumbo limbo (*Bursera simaruba*) in Miami-Dade county of South Florida in 2009. This whitefly is believed to have originated from Central America and its incidence is limited to Belize, Mexico, Guatemala and Florida in Central and North America (Evans, 2008).
- In India, its incidence was recorded on coconut and many other crop plants in Pollachi, Tamil Nadu during 2016. Subsequently it has spread to other states like Karnataka, Kerala, Andhra Pradesh, Goa, Assam and West Bengal.
- Further it was observed in Lakshadweep islands, coastal districts of Maharashtra, Gujarat, Telangana, Odisha, Chhattisgarh and few districts of Meghalaya.

Host plants

- Rugose Spiraling whitefly is a highly polyphagous pest reported to feeds on about 120 plant species including economically important cultivated crops and palms.
- In India, RSW was found to feed on about 50 host plants especially coconut, oil palm, banana, mango, sapota, guava, cashew, ramphal, oil palm, maize, Indian almond, water apple, jack fruit and many other ornamental plants like bottle palm, Indian shot, false bird of paradise and butterfly palm and ornamental areca palm (Table 1).

Table 1. Host plants of rugose Spiraling whitefly, distribution and their co-existence

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, A. arecae*

S.No	Plant species	Distribution	Co-existence
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, A. 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, Wet Bengal	*P. minei*
14	Ruffled fan palm, *Licuala grandis* (Arecaceae)	Karnataka, Kerala	-
15	Citrus, *Citrus* spp. (Rutaceae)	Tamil Nadu, Karnataka, West Bengal	*P. minei*
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*
18	Jack fruit, *Artocarpus heterophyllus* (Moraceae)	Tamil Nadu, Kerala, West Bengal	*P. bondari*
19	Indian tulip, *Thespesia populnea* (Malvaceae)	Kerala, Karnataka, Lakshadweep	*P. minei*
20	Rangoon creeper, *Combretum indicum* (Combretaceae)	Kerala, Karnataka	-
21	China rose, *Hibiscus rosasinensis* (Malvaceae)	Kerala, Karnataka	-
22	Ficus, *Ficus religiosa* (Moraceae)	Karnataka, Lakshadweep	*Singhiella simplex*

S.No	Plant species	Distribution	Co-existence
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	-
26	Ficus, *Ficus bengalensis* (Moraceae)	West Bengal	-
27	Arjun, *Terminalia arjuna* (Combretaceae)	Karnataka	-
28	Traveller palm, *Palmeira ravenala* (Strelitziaceae)	Andhra Pradesh	*A. dispersus* *P. minei*
29	Frangipani, *Plumeria alba* (Apocynaceae)	Karnataka	*A. dispersus*
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* *A. dispersus*
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	-

Identification

- The puparium is typically characterized by broadly cordate vasiform orifice, operculum ventro-basally spinulose and dorsally characteristically rugose, with a pair of ventro-median fine setae, lingual head protruding beyond vasiform orifice, finely spinulose, apically acute, its four setae situated close to apex (Fig.5).
- The puparium can be easily distinguishable from *A. dispersus*, the other known species in India by the presence of a pair of small compound pores on each of abdominal segments VII and VIII, characteristically rugose operculum and atypically narrowly acute lingual apex.

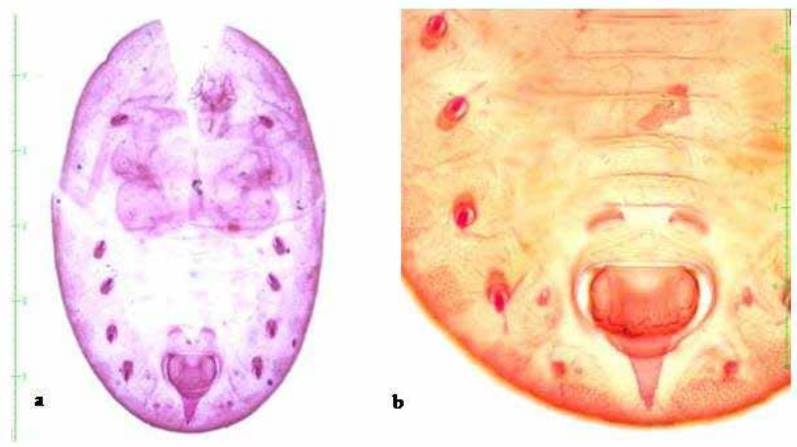

Fig. 5. *Aleurodicus rugiopercuatus*: (a) mounted puparium, (b) operculum

Description and biology

- The adult female lays eggs in concentric circular on the ventral surface of the leaves and sometimes on fruits and stems (Fig.6). The eggs are elliptical, yellowish in colour and the average fecundity is 49.50± 4.09 eggs.
- 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. These are golden yellowish in colour 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. Ribbon like wax filaments are also present and they are as long as or longer than the body and flat on the ventral surface.

- The total duration of the nymphal instars 23.2 ± 1.38 days and the life cycle including adult longevity is 37.6 ± 2.55 days.
- Adults are about three times larger (approx. 2.5 mm) than the commonly found whiteflies and are lethargic by nature. This species closely related to Spiraling whitefly, *A. dispersus.*
- Adults can be distinguished by the presence of a pair of irregular light brown bands across the wings. Males have long pincer-like structures at the distal end of the abdomen.

Fig. 6. Life stages of *Aleurodicus rugioperculatus:* (a) adult, (b) eggs, (c) third instar nymphs, (d) pupae

Nature of damage

- The typical concentric waxy Spiraling symptoms on under surface of the leaves and also various parts of host plants including on leaf petiole and tender nuts (Fig. 7).
- 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 especially 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.7. *Aleurodicus rugioperculatus:* a) adult, (b-c) infestation on coconut, (d) sooty mould

4.3. Bondar's nesting whitefly, *Paraleyrodes bondari* Peracchi

Distribution

- *Paraleyrodes bondari* described on citrus (*Citrus* spp.) from Brazil in 1971 (Peracchi, 1971). This species is native to the Neotropical region and has since been reported from Belize, Honduras, Puerto Rico, Madeira, Comoros, Mauritius, Taiwan, Hawaii and Florida (USA) (Stocks, 2012).
- Bondar's nesting whitefly was first reported in India on coconut palms from Kerala during 2018 (Josephrajkumar *et al.,* 2019), Karnataka and The Andaman and Nicobar Islands (Vidya *et al.,* 2019). Recently, its occurrence was noticed in Lakshadweep islands, Tamil Nadu, Gujarat, Telangana, Assam, Chattishgarh and Andhra Pradesh.

Host plants

- *Paraleyrodes bondari* is a polyphagous species that has been reported to feeds on more than 25 host plants including banana (*Musa* sp.), mango (*Mangifera indica*), citrus (*Citrus* spp.), cassava (*Manihot esculenta*), custard apple (*Annona squamosa*), coconut (*Cocos nucifera*), guava (*Psidium guajava*) and subabul (*Leucaena leucocephala*) in India (Vidya *et al.,* 2019). The complete host plants of *P. bondari* is furnished (Table 2).
- The severity of infestation is moderate in coconut and insignificant in other host plants in majority of locations.

Table 2. Host plants of Bondar's nesting whitefly, its distribution and co-existence

S.No	Plant species	Distribution	Infestation	Co-existence with
1	Citrus, *Citrus* spp. (Rutaceae)	Coimbatore, Tamil Nadu	Low	*A. rugioerculatus*
2	Coconut, *Cocos nucifera* (Arecaceae)	West Godavari, Andhra Pradesh; Mandya, Karnataka	Low	*A. rugioperculatus; A. atratus P. minei*
3	Ficus, *Ficus religiosa* (Moraceae)	Bengaluru Urban, Karnataka	Low to moderate	*A. rugioperculatus*
4	Ficus, *Ficus* sp. (Moraceae)	Kavaratti, Lakshadweep	Moderate to severe	-
5	Noni, *Morinda citrifolia* (Rubiaceae)	Kavaratti, Lakshadweep	Low to moderate	-
6	Guava, *Psidium guajava* (Myrtaceae)	Coimbatore, Tamil Nadu; Kavaratti, Lakshadweep	Low to moderate	*A. rugioperculatus, A. floccosus & A. dispersus*
7	Rain tree, *Samanea saman* (Fabaceae)	Coimbatore, Tamil Nadu	Low	-
8	Ashoka tree, *Saraca asoca* (Fabaceae)	Coimbatore, Tamil Nadu	Low	*A. dispersus*
9	Jamun, *Syzygium cumini* (Myrtaceae)	Coimbatore, Tamil Nadu	Low	*A. dispersus*
10	Portia tree, *Thespesia populnea* (Malvaceae)	Kavaratti, Lakshadweep	Low to moderate	*A. rugioperculatus*
11	Cotton, *Gossypium hirsutum* (Malvaceae)	Bengaluru Urban, Karnataka	Moderate	*B. tabaci P. bondari*
12	Custard apple, *Annona quamosa* (Annonaceae)	Mandya, Karnataka	Low	*P. minei*
13	Subabul, *Leucaena leucocephala* (Fabaceae)	Bangalore Urban	Low	*T. acaceae*
14	Banana, *Musa* spp. (Musaceae)	Bangalore Urban, Dakshina Kannada, Udupi	Low	*A. rugioperculatus*
15	Cassava, *Manihot esculenta* (Euphorbiaceae)	Bangalore Urban	Low	*A. dispersus*
16	Custard Apple, *Anona Squamosa* (Annoonaceae)	Mandya	Low	*Pealius nager-coilensis*

Identification

- Puparial characters include one larger cephalic pore and four abdominal compound pores and outer ring with ovoid cellular facets giving the appearance of stylized flower-petals (Fig.8).
- The last four abdominal compound pores with the simple discoidal pores and 2-3 discoidal pores with the two reduced abdominal pores which are half the size which comprise 7–8 flower petal-like facets.
- The male genitalia are characteristic with the apex of aedeagus possessing a single dorsal and ventral horn and a pair of apicolateral processes.

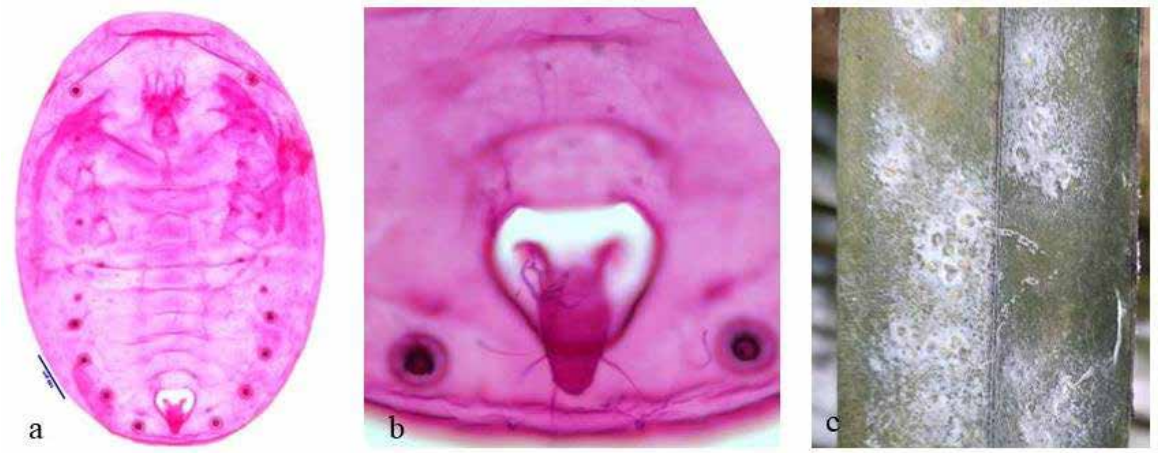

Fig. 8. *Paraleyrodes bondari:* (a) mounted puparium, (b) operculum, (c) infestation on coconut

Description and biology

- *Paraleyrodes bondari* adults are smaller than *A. rugioperculatus* and it constructs nests with densely woven, irregular layer of fiberglass-like woolly wax strands (Fig.9).
- Lays yellowish stalked eggs in clusters in the woolly wax nest without wax covering.
- Early instar nymphs are creamy yellow, transparent, oval shaped, absolutely flat (0.9 mm). The margin of the nymph is covered with a band of white wax and short setae are observed all around
- Fourth instar nymphs are oval in shape, translucent yellowish and the lateral margin is fringed with a narrow band of clear wax with short filaments (1mm long).
- Adult whiteflies are in dull yellow body with white wings. Two oblique grey bands occur on each forewing, and converge toward the midline such that it appears to form an “X”-pattern.
- Total life span including adult longevity is 32 –34 days.

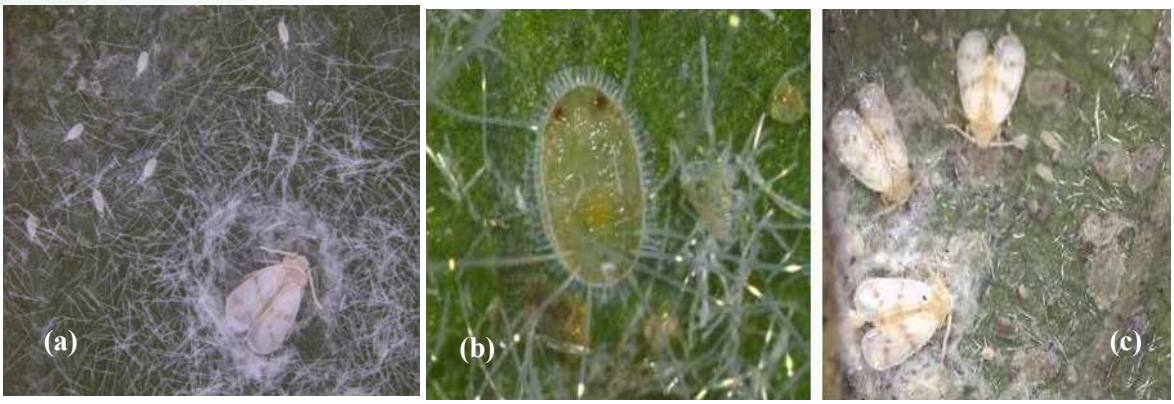

Fig. 9. Life stages of *Paraleyrodes bondari:* (a) Eggs, (b) third instar nymph, (c) adults

Nature of damage

- Excessive de-sapping by the adults and nymphs in severe condition produces honey dew leading to deposits of sooty mould on plant surface which may affect the photosynthetic efficiency (Fig. 8).
- The feeding damage is not so intense like *A. rugioperculatus* with minimal honey dew excretion and sooty mould deposits.

4.4. Nesting whitefly, *Paraleyrodes minei* Iaccarino

Distribution

- *Paraleyrodes minei* Iaccarino described from Syria on citrus (*Citrus* spp.) in 1990 but, it is considered a native of the Neotropical region (Iaccarino, 1990). It was reported in California, USA in 1984 and has also been reported in Belize, Guatemala, Mexico, Puerto Rico, Bermuda, California, Florida, Texas, Lebanon, Morocco, Spain, Syria, Turkey and Benin (Martin, 2004).
- In India, it was reported on coconut in Kerala during 2018 (Mohan *et al.* 2019; Sujithra *et al.* 2019) and in Andaman and Nicobar Islands (Dubey, 2019). Subsequently, this species rapidly spread to different parts of Karnataka, Andhra Pradesh, Telangana, Maharashtra, West Bengal and Tamil Nadu.

Host plants

- Nesting whitefly is found to colonize on coconut (*Cocos nucifera*), banana (*Musa* sp.), guava (*Psidium guajava*), mango (*Mangifera indica*), jamun (*Syzygium cumini*), *Ixora* sp. and *Heliconia* (Mohan *et al.,* 2019; Sujithra *et al.,* 2019). Besides it was found to feed on *Hibiscus,* citrus, sapota, sandal, tapioca, custard apple, capsicum, pomegranate, solanum spp. ficus and several ornamental palms (Table 3).

Table 3. List of host plants distribution for nesting whitefly in India

S.No	Plant species	Distribution	Infestation	Co-existence with
1	Custard apple, *Annona quamosa* (Annonaceae)	Bengaluru Rural, Karnataka	Low to moderate	*Pealius nagerkoilensis*
2	Ramphal, *Annona muricata* (Annonaceae)	Tumkur, Karnataka	Low	-
3	Purple morning glory, *Argyrea cuneata* (Convolvulaceae)	Bengaluru Rural, Karnataka	Low	*A. trachoides*
4	Manorangini, *Artabotrys odoratissimus* (Annonaceae)	Bengaluru Rural, Karnataka	Low	-
5	Indian laureal, *Calophyllum inophyllum* (Calophyllaceae)	Mandya, Karnataka	Low	*A. rugioperculatus*
6	Sweet pepper, *Capsicum annuum* (Solanaceae)	Bengaluru Rural, Karnataka	Low to moderate	*A. trachoides*
7	Day blooming jasamine, *Cestrum diurnum* (Solanaceae)	Bengaluru Rural, Karnataka	Low to moderate	*A. trachoides*
8	Lemon, *Citrus* spp. (Rutaceae)	Bengaluru Rural, Karnataka	Low to moderate	*A. woglumi*
9	Yellow butterfly palm, *Dypsis lutescens* (Arecaceae)	Bengaluru Rural, Karnataka	Low to moderate	*A. rugioperculatus*
10	Oil plam, *Elaeis guineensis* (Arecaceae)	Mandya, Bengaluru Urban, Karnataka	Low	*A. rugioperculatus*
11	Peepal tree, *Ficus religiosa* (Moraceae)	Bengaluru Rural, Karnataka	low	*A. dispersus*
12	China rose, *Hibiscus rosasinensis* (Malvaceae)	Bengaluru Rural, Karnataka	Low	*A. dispersus*
13	Sapota, *Manilkara zapota* (Sapotaceae)	Bengaluru Rural, Karnataka	Low	*A. rugioperculatus*
14	Mahuwa, *Mathuca longifolia* (Sapotaceae)	Bengaluru Rural, Karnataka	Low to moderate	-
15	Cassava, *Monihot esculenta* (Euphorbiaceae)	Bengaluru Rural, Karnataka	Low to moderate	*A. dispersus*
16	Indiana gooseberry, *Phyllanthus emblica* (Phyllanthaceae)	Bengaluru Rural, Karnataka	Low to moderate	*Aleurocanthus* sp.

17	Frangipani, *Plumeria alba* (Apocynaceae)	Bengaluru Rural, Karnataka	Low	*A. dispersus* & *A. trachoides*
18	Royal palm, *Roystonea regia* (Arecaceae)	Bengaluru Rural, Karnataka	Low	*A. rugioperculatus*
19	Sandal wood, *Santalum alum* (Santalaceae)	Bengaluru Urban, Karnataka	Low	*A. dispersus*
20	Poison nut, *Strychnos nixvomica* (Loganiaceae)	Bengaluru Rural, Karnataka	Low	-
21	Rose apple, *Syzygium jambos* (Myrtaceae)	Bengaluru Rural, Karnataka	Low	-
22	Portia tree, *Thespesia populnea* (Malvaceae)	Bengaluru Rural, Karnataka	Low	*A. dispersus*
23	Peacock chaste tree, *Vitex altissima* (Lamiaceae)	Bengaluru Rural, Karnataka	Low	
24	Cotton, *Gossypium hirsutum* (Malvaceae)	Bengaluru Urban, Karnataka	Moderate	*B. tabaci*
25	Pongam, *Millettia pinnata* (Fabaceae)	Karnataka	Low	-
26	Orchid, *Bauhinia variegata* (Fabaceae)	Karnataka	Low	*A. dispersus, T. acaceae*
27	Indian rose wood, *Dalbergia sissoo* (Fabaceae)	Karnataka	Low	*Aleurolobus marlatii*
28	Pomogranate, *Punica granatum* (*Lythraceae*)	Bengaluru Urban, Karnataka	Low	-
29	Ashoka tree, *Saraca asoca* (Fabaceae)	Bengaluru Urban, Tumkur, Karnataka	Low	*A. dispersus*

Identification

- Puparial characters include one larger cephalic pore, four abdominal compound pores and outer ring with ovoid cellular facets giving the appearance of stylized flower petals (Fig.10).
- The last four abdominal compound pores with simple discoidal pores and 2-3 discoidal pores two reduced abdominal pores which are half the size of the larger abdominal pores which comprise 8–9 flower petal-like facets.
- The tongue-like lingula is extended beyond the posterior margin vasiform orifice with two pairs of apical setae and the operculum partially covers the lingula and the vasiform orifice.
- Male claspers have a strong nail and the aedeagus has a characteristic cockhead-shaped apex comprising three short appendixes located on the upper and posterior surface, and two long and thin appendixes projected downwards beneath the short anterior appendix.

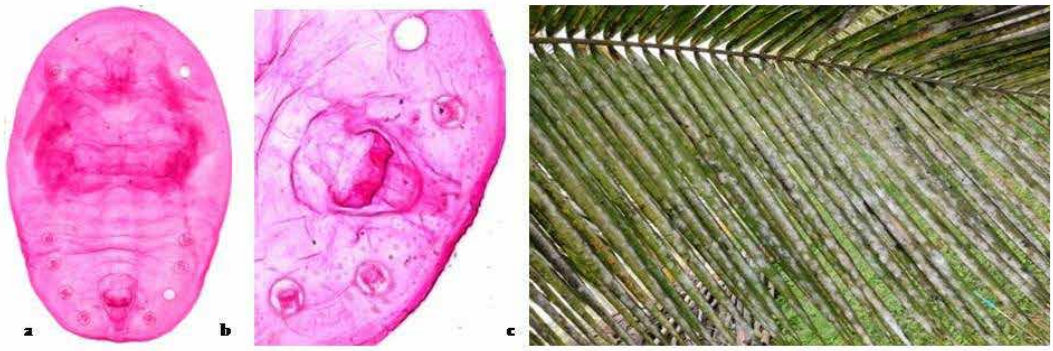

Fig. 10. *Paraleyrodes minei*: a) mounted puparium, (b) operculum, (c) infestation on coconut

Description and biology

- Female adults constructs loosely woven, woolly wax nest this characteristic feature helps in differentiating nesting whitefly from the Bondars nesting whitefly that constructs conspicuous dense woolly wax nest (Fig.11).
- Eggs are cream-coloured laid in clusters with short stalks that turn slight pinkish upon eclosion on the lower surface of leaflets bending inwards towards the leaf surface.
- The emerging mobile crawlers are creamish, sub-elliptical with flocculent wax on the dorsum extending from thorax to abdomen. The crawlers shed their appendages, remain fixed, and become flat and creamish, producing a fringe of short hyaline wax rods rising from the dorsum with fibreglass-like wax rods.
- Female adults have broad and swollen abdomen with well-developed wax plates, whereas in male abdomen is narrow becoming pointed at the apex and the wax glands are not well developed.
- Adults are in dull yellow body with whitefly wings without any marking and spread wings wider.
- Total life cycle span including adult longevity is 31-32 days.

Fig. 11. Life stages of *Paraleyrodes minei:* a) adults and eggs (b) third instar nymph, (c) colony

Nature of damage

- *Paraleyrodes minei* nymphs and adults feed from abaxial leaf surface and produce honeydew which in turns leads to sooty mould deposits on adaxial leaf surface and interfere with photosynthetic efficiency of the palms (Fig.10).

5. Exotic whiteflies under the subfamily Aleyrodinae

5.1. Solanum whitefly, *Aleurothrixus trachoides* (Back)

Distribution

- *Aleurothrixus trachoides* (Back) described from *Solanum seaphorthianum* in Cuba. The species is native to the Neotropical Region and established in Tahiti during the 1930s. Among the whitefly genera, *Aleurothrixus* Quaintance & Baker is a New World genus which includes 20 species in the world (Martin and Mound, 2007).
- In India, the species was first found severe infestation on ornamental plants, *Duranta erecta* and *Capsicum annum* in South India (Karnataka) in 2015 (Dubey and Sundararaj, 2015) and has subsequently spread to Kerala, Tamil Nadu, West Bengal and Maharashtra.

Host plants

- *A. trachoides* prefers to colonize on plants belonging of Solanaceae and also feeds on several other plants of Araceae, Apocynaceae and Convolvulaceae (Dubey and Sundararaj, 2015).
- In India, so far it is found breeding on 24 host plants representing 11 families and observed in Karnataka, Kerala, Maharashtra and Tamil Nadu (Sundararaj *et al*., 2018).
- In addition, new host distribution are *Argyrea cuneata*, *Ipomoea purpurea*, *Ipomoea batatas* (Convolvulaceae), *Cestrum diurnum*, *Cestrum nocturnum*, *Nicotiana tabacum*, *Solanum lycopersicum*, *Solanum nigrum, Withania somnifera* (Solanaceae), *Cleodendrum inerme* (Lamiaceae), *Plumeria alba* (Apocynaceae), *Tabebuia avellanedae* (Bignoniaceae) and *Tectona grandis* (Verbenaceae).

Identification

- The puparia are black with a fringe of white wax around the margin, elliptical, anterior and posterior end narrow, broadest at middle area (Fig.12). Margin is crenulate, each marginal tooth with a wax secreting gland at the base.
- Caudal and thoracic tracheal pore areas not indicated in the margin. Submargin is separated from the dorsal disc by a thorasic fold. Submargin with bands of minute tubercles.
- The mid-length of the cephalothorax is equal to the length from the first abdominal segment to the base of the vasiform orifice.
- Vasiform orifice is subcordate to subcircular, inner wall of vasiform orifice with many microtrichea.

- Operculum is subcordate, the posterior end near lingula with microtrichea. Lingula is visible, overlapping posterior end of the vasiform orifice, apex bi-lobed and a pair of sub-apical setae present.
- Cephalic and the first abdominal setae are absent. Eighth abdominal setae are antero-lateral to vasiform orifice.

Fig. 12. *Aleurothrixus trachoides*: a) mounted puparium, (b) infestation on duranta, (c) brinjal

Symptoms of damage

- Major symptoms such as presence of white, waxy material, sticky honeydew around and below the whitefly infested area and presence of black sooty mould (Fig.12).
- Contineous sucking of plant sap by the nymphs and adults causes the chlorotic spots and curling of leaves resulting in premature shedding and in severe infestation causes the death of chilly and tomato seedlings was observed.
- *Aleurothrixus trachoides* was considered as a non-virus vector, however, it was found as vector of begomovirus and transmits duranta leaf curl virus to tomato, bell pepper and potato (Chandrashekar *et al.,* 2020).

Description and biology

- Adults are small, 1-2 mm in size, and covered with a white waxy layer. Females lay tiny, translucent, oblong eggs on the undersides of leaves, which turn yellow to grayish-brown as they mature (Fig.13).
- Early nymphal instars are flat, round to oval shaped, light to golden yellow, and may also bear eight spherical patches on the dorsal surface. As the nymphs mature it become more convex and turns darker, and they produce dense, cottony long, thin, waxy filaments.
- Total life cycle span including adult longevity is 32-36 days.

Fig.13. Life stages of *Aleurothrixus trachoides:* (a) Eggs, (b) crawler, (c) second instar nymph, (d) third instar nymphs, (e) pupae, (f) adult

5.2. Legume feeding whitefly *Tetraleurodes acaciae* (Quaintance)

Distribution

- *Tetraleurodes acaciae* (Quaintance) described from mesquite (*Acacia* sp.) from Mexico and is known from Belize, Costa Rica, Cuba, Dominican Republic, Guatemala, Haiti, Jamaica, Mexico, Nicaragua, Panama, Puerto Rico, Trinidad, United States and Venezuela (Nakahara, 1995) and Taiwan (Dubey and Ko, 2008).
- In India, it was first recorded on subabul, *Leucaena leucocephala* in Bengaluru, Karnataka (Sundararaj and Vimala, 2018). Further, pest occurrence found in Andhra Pradesh, Tamil Nadu and West Bengal.

Host plants

- *Tetraleurodes acaciae* prefer to feed on plants belonging under Fabaceae family. Infestation of this whitefly species were observed on orchid tree, *Bauhinia variegata*; tamarind, *Tamarindus indica* and rain tree, *Samanea saman* and on an unidentified pulses crop (Fabaceae).

Identification

- Puparia pale, dark brown or black, sub-oval or broadly oval, margin strongly toothed, tips rugose, tracheal pore areas usually not differentiated from margin (Fig.14).
- Conspicuously sculptured, separated from the dorsal disc by fold; at least a row of geminate pores present; cephalic and eighth abdominal setae usually present, first abdominal setae usually absent.

- Dorsal disc elevated from the leaf by vertical ubmargin; vasiform orifice elevated, usually subcircular, surrounded by a sclerotized rim; operculum almost filling vasiform orifice; concealing lingula; caudal furrow absent; caudal setae near margin; tracheal folds defined.

- Submarginal gland tubercles is present, median tubercles on abdominal segments are present, transverse moulting suture turned anteriorly on subdorsal area, eighth abdominal setae placed far from the base of orifice almost in the middle of abdominal segment VIII.

a) b)

Fig. 14. *Tetraleurodes acaciae*: a) mounted puparium, (b) submarginal region

Symptoms of damage

- The presence of slight to moderate white, waxy material is the most common symptoms observed (Fig.15). Adult and nymphs suck plant juices, usually from the under surface of leaves.

- Severe infestations caused chlorotic speckling on the upper surface of leaves resulting in premature shedding of leaves. These whiteflies excrete copious amounts of honeydew colonized by sooty mould.

Fig. 15. Infestation of *Tetraleurodes acaciae*: (a) subabul, (b) orchid tree

Description and biology

- Adults are about 1.2 mm in length, wings whitish and nymph brown during initial instar the shed molts are being placed on their dorsum (Fig.16).

- First instar nymphs are elongate oval, smaller than the second instars, the second instar nymphs similar in shape to the third instars but smaller (length 358-440 µm) and width (245 390 µm), dorsum sclerotized, black.

- The fourth instar stages are black with a prominent whitish wax fringe.

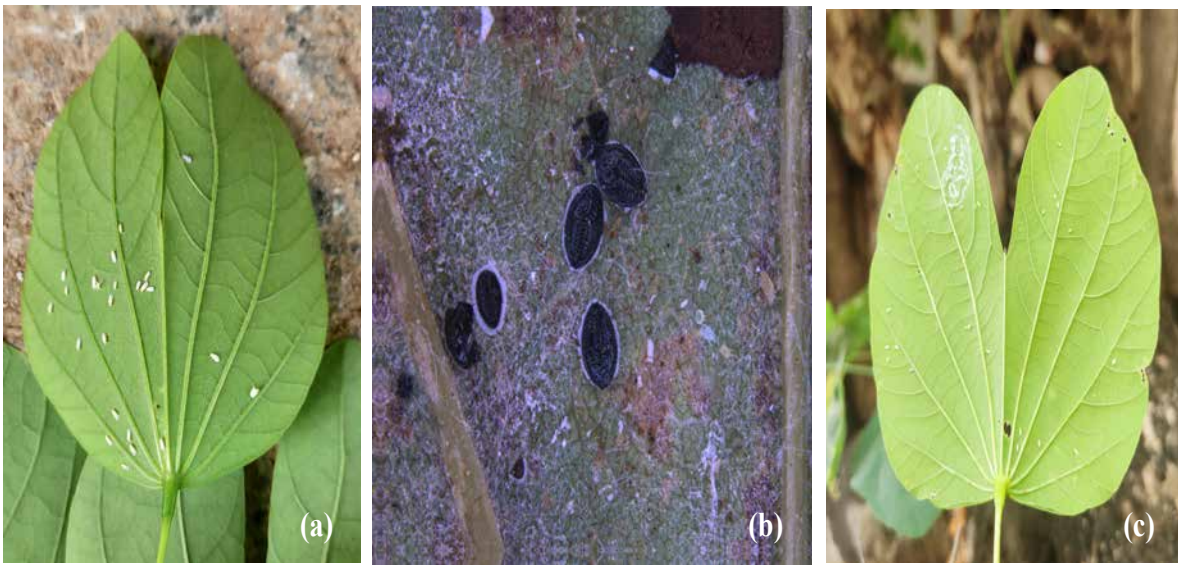

Fig. 16. Life stages of *Tetraleurodes acaciae:* a) eggs & adults (b) nymphs (c) adult

5.3. Palm infesting whitefly, *Aleurotrachelus atratus* Hempel

Distribution

- *Aleurotrachelus atratus* is a Neotropical whitefly, originally described by Hempel (1922) from Brazil. It was also found to occur in Africa, North America, South America, Central America, the Caribbean and Europe (Borowiec *et al.,* 2010).

- In India, it was first recorded on coconut and ornamental palm during 2019 in Mandya district of Karnataka (Selvaraj *et al*., 2019) and subsequently spread to other coconut and oilpalm growing states such as Tamil Nadu, Kerala, Andhra Pradesh and Telangana.

Host plants

- It colonizes on more than 110 plant species belonging to Arecaceae, Rutaceae, Solanacee, Cycadaceae and Lauraceae.
- In India, so far it's infestation noticed on coconut, areca nut, oil palm and many ornamental palm plants belonging to Arecaceae family.

Identification

- Elongate oval puparium with entire dark cuticle; marginal teeth separated, with converging subtruncate or rounded apices, each one with serrated margins; absence of first abdominal and mesothoracic setae (Fig.17).
- Metathoracic setae extending beyond 2nd abdominal segment, 8th abdominal setae longer than the vasiform orifice, caudal setae very long and set on tubercles; submarginal area with rows of flat, elongate granules of subequal size; lingula tip rounded.
- Each puparium can be seen having a distinct diagnostic pair of sub-marginal longitudinal cephalothoracic folds that extend into the abdomen.

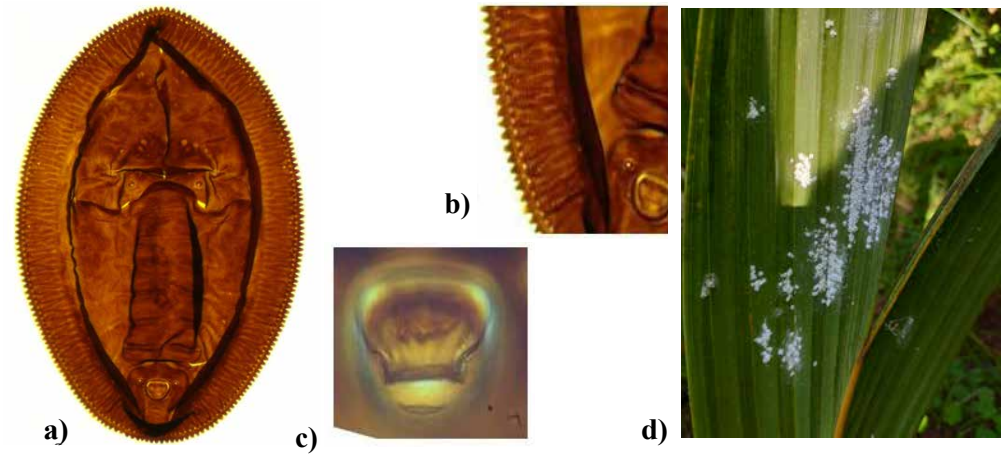

Fig. 17. ***Aleurotrachelus atratus:*** **a) mounted puparium, (b) margin, (c) lingual & (d) infestation on coconut**

Nature of damage

- *Aleurotrachalus atratus* colonizes on the under surface of leaflets in groups and produce white wax mass from second nymphal instar onwards (Fig.18).
- Both nymphs and adults suck the sap continuously and deplete nutrients from host plants results in necrosis, loss of vigour, drying and drooping of leaflets.
- Indirect damage is caused by the excreted honeydew that serves as a medium for the growth of sooty mould.

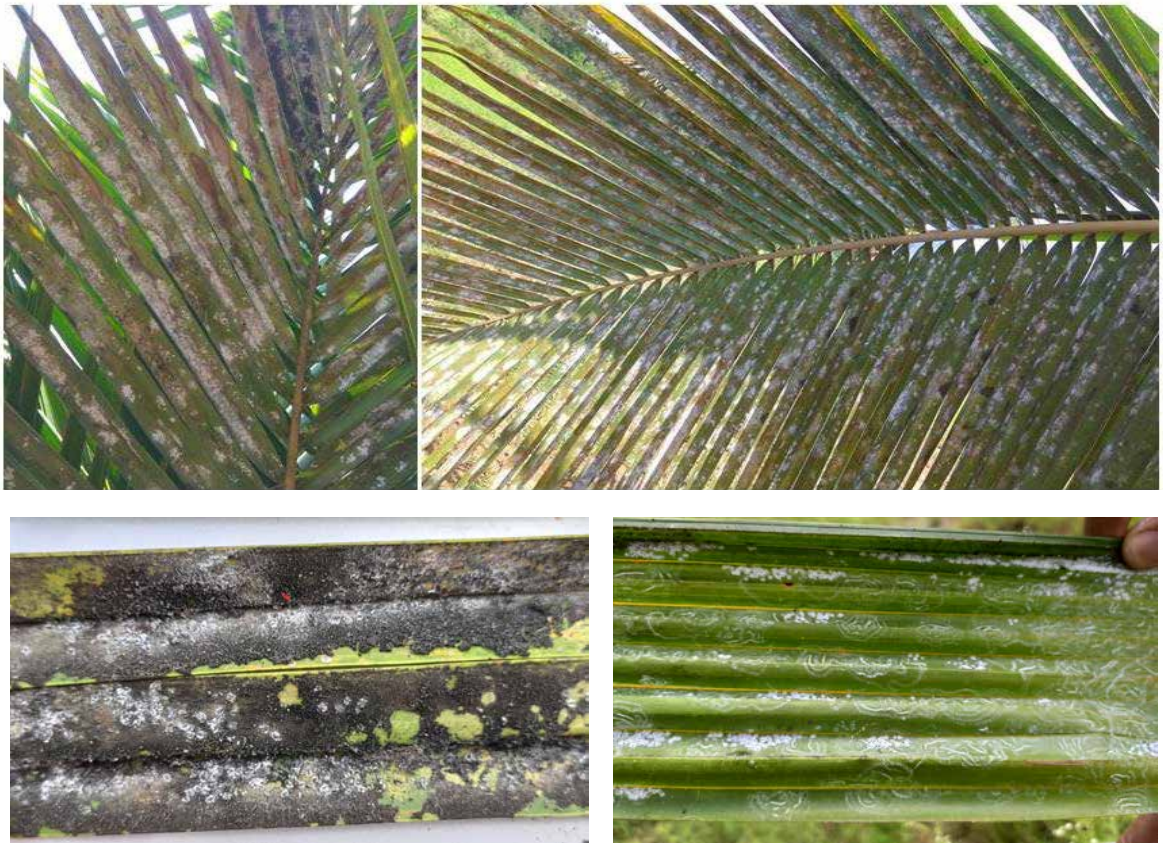

Fig. 18. Infestation of *Aleurotrachalus atratus* on coconut

Description and biology

- Eggs are stalked and laid in semicircular pattern in groups, initially creamy white and turn to black before hatching (Fig.19).
- The first instars are initially transparent black and have four pairs of wax plumes on dorsal surface excreted by glands at the base of dorsal setae.
- Each dorsal seta has curving longitudinal grooves that guide the wax flakes as they are secreted from the setal base and all the nympal instars are black in colour.
- Puparia are elliptical, black, 1.0-1.1 mm long with a long marginal white wax fringe and dorsal wax filaments that often completely cover the pupae.
- Adults differ from the other invasive whiteflies infesting palms; smaller than *A. rugioperculatus* but larger than *P. bondari* and *P. minei* and without any wavy marking on the wings.
- Total life span about 54-59 days.

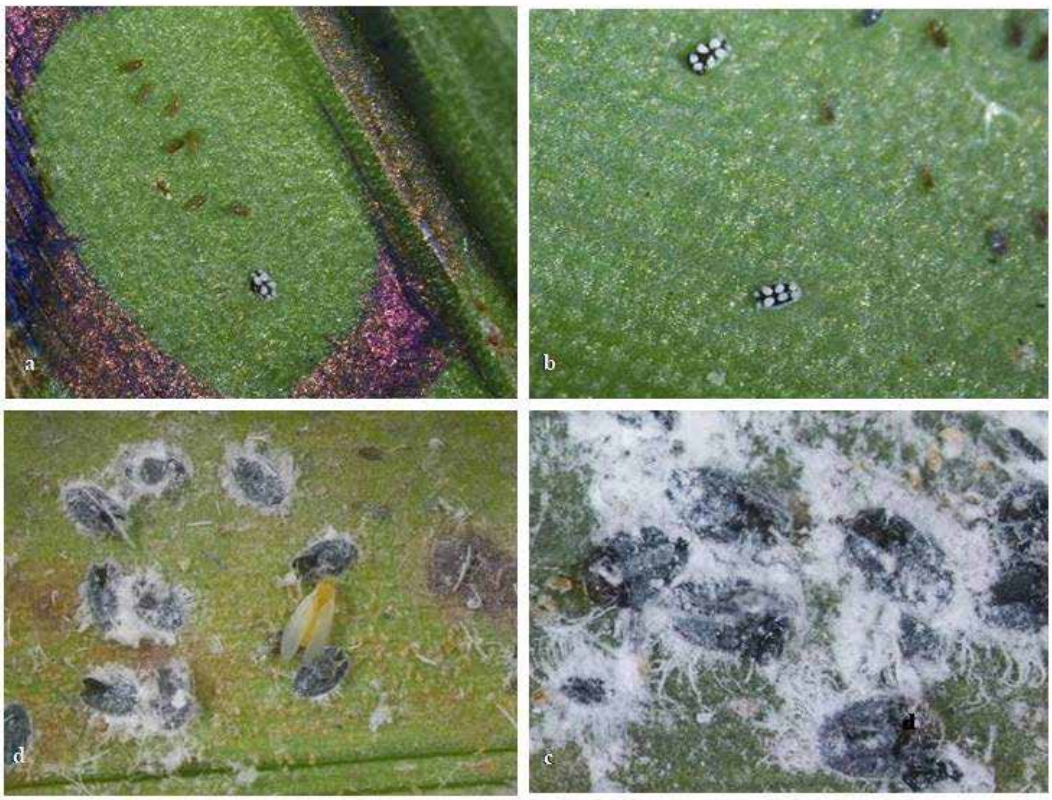

Fig. 19. Life stages of *Aleurotrachelus atratus:* a) Eggs, (b-c) second & fourth instar nymphs, (d) adult

5.4. Woolly whitefly, *Aleurothrixus floccosus* (Maskell)

Distribution

- The woolly whitefly *Aleurothrixus floccosus* Maskell was described from *Citrus* sp. in Cuba (Maskell 1896) and is native to the Neotropical region wherever citrus is grown (Malumphy *et al.,* 2015).
- In India, it was first reported on guava (*Psidium guajava*) in the Kozhikode district of Kerala during 2019 (Sundararaj *et al.,* 2020). Later it was found in Karnataka; Tamil Nadu, Maharashtra, Andhra Pradesh and Lakshadweep on same host plant.

Host plants

- *Aleurothrixus floccosus* is a polyphagous species, known to feed on 20 different plant families; it exhibits a strong preference for citrus but so far in India, It has been found to infest on guava

Identification

- Puparia is pale white to light brown covered with flocculent wax; puparial margin not deflexed, overall concentric, regularly toothed, each tooth with a basal gland, without any modifications at thoracic and tracheal pore regions (Fig.20).

- Submargin is widely separated from dorsal disc by submarginal/ subdorsal fold, which arranged in distinct sections and complete; cephalic and first abdominal setae absent, submedian metathoracic setae present, eight abdominal and caudal setae long extending beyond puparial margin;

- Inner submargin with a row of five pairs of minute setae in cephalothorax and anterior abdomen; submedian ridge prominent; vasiform orifice elevated, transversely elliptical, operculum similarly shaped, almost filling the orifice and obscuring the lingual.

- *Aleurothrixus floccosus* is quite distinct from *A. trichoides* by the submargin without band of microtubercles; submarginal/ subdorsal fold almost concentric with margin, arranged in distinct sections and complete between vasiform orifice and puparial margin; comparatively longer 8th abdominal and caudal setae, 8th abdominal setae reaching beyond puparial margin; inner submargin with a row of five pairs of tiny setae in cephalothorax and anterior abdomen and lingula tip not bilobed.

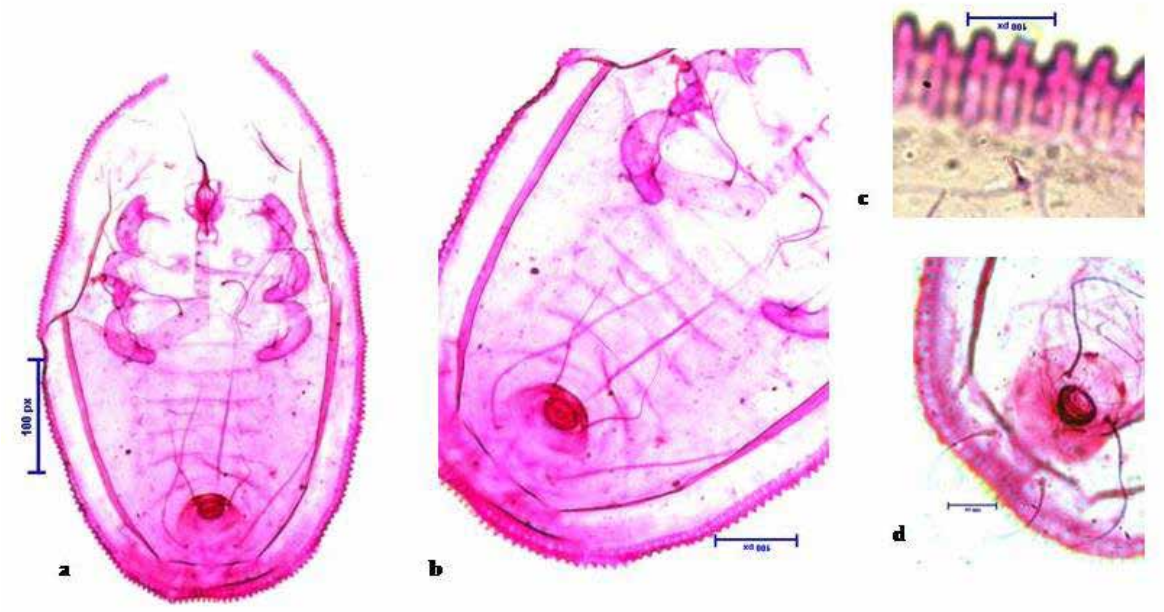

Fig. 20. *Aleurothrixus floccosus*: a) mounted puparium, (b) posterior region showing elongated caudal & 8th abdominal setae, (c) submargin with submarginal seta, (d) enlarged vasiform orifice

Symptoms of damage

- Nymphs and adults suck phloem sap from host plants and these infested plants showed sever feeding damage such as wilting, yellowing and leaf fouling and indirectly causes by depositing honeydew droplets, get dried and turned brownish orange as they became contaminated with saprophytic fungi (Fig. 21)
- Presence of ants, profuse white mealy wax and black sooty mould is the sign of infestation of this pest. .
- Severe infestation leads to complete blackening which might reduce the photosynthetic ability of infested plants significantly, resulting to leaf fall, senescence and eventual death.
- The population was normally increased whenever there was new leaf/flush growth on the plants.

Fig. 21. Infestation of *Aleurothrixus floccosus* on guava (a-b)

Description and biology

- The sausage shaped, pale white eggs were deposited in a circular pattern and attached to the leaf with stalks which changes to brown colour before hatching (Fig.22).
- The first instar nymphs are light green, flattened, oval shaped and there was a little marginal wax and three pairs of wax dots on the dorsal surface.
- Subsequent instars are sedentary, turn brown and often completely obscured by copious amounts of wooly wax that was several times thicker than the body of insect, honeydew droplets and cast skin was observed.
- The adult is approximately 1.5 mm in length, with a yellow-white body and wings that are covered with a white waxy powder and they prefer to feed and oviposit on the undersides of young leaves that sprout when the host trees are actively growing.
- Total life span including adult is about 51- 57 days.

Fig. 22. Life stages of *Aleurothrixus floccosus:* a) eggs, (b-c) second& third instar nymphs, (d) adults

6. Co-existence / co-occurance with other whiteflies

As many as eight exotic whiteflies have been reported from different regions of India in rapid succession. All these whitefly species are highly polyphagous and have a host preference towards many economically important crop plants such as coconut, guava, banana, custard apple, oil palm. During the present study, *A. rugioperculatus*, *P. bondari*, *A. dispersus* and *P. minei* were observed to simultaneous coexistence on many of the host plants (Fig. 23). We observed *A. rugioperculatus* co-exist with *Aleurotrachalus atratus, P. bondari*, *A. dispersus* and *P. minei* on coconut; *P. minei, P. bondari, A. rugioperculatus* and *A. dispersus* with *Aleurothrixus floccosus* on guava; *A. trachoides* with *Bemisia tabaci* on tabacco, brinjal and tomato; nesting whiteflies (*P. bondari* and *P. minei*) with *B. tabaci* on cotton. Infestations of *A. atratus* and *A. rugioperculatus* along with *Aleurocanthus arecae,* a native whitefly species were commonly observed on coconut. *A. rugioperculatus* and *A. floccosus* were the dominant species in their niches irrespective of the co-occurring species on the majority of host plants. In Greece, co-existence of the *P. minei* and *A. floccosus* was recorded on citrus.

The synchrony of coexistence and mutual survival of these competing insect 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 co-existence 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.

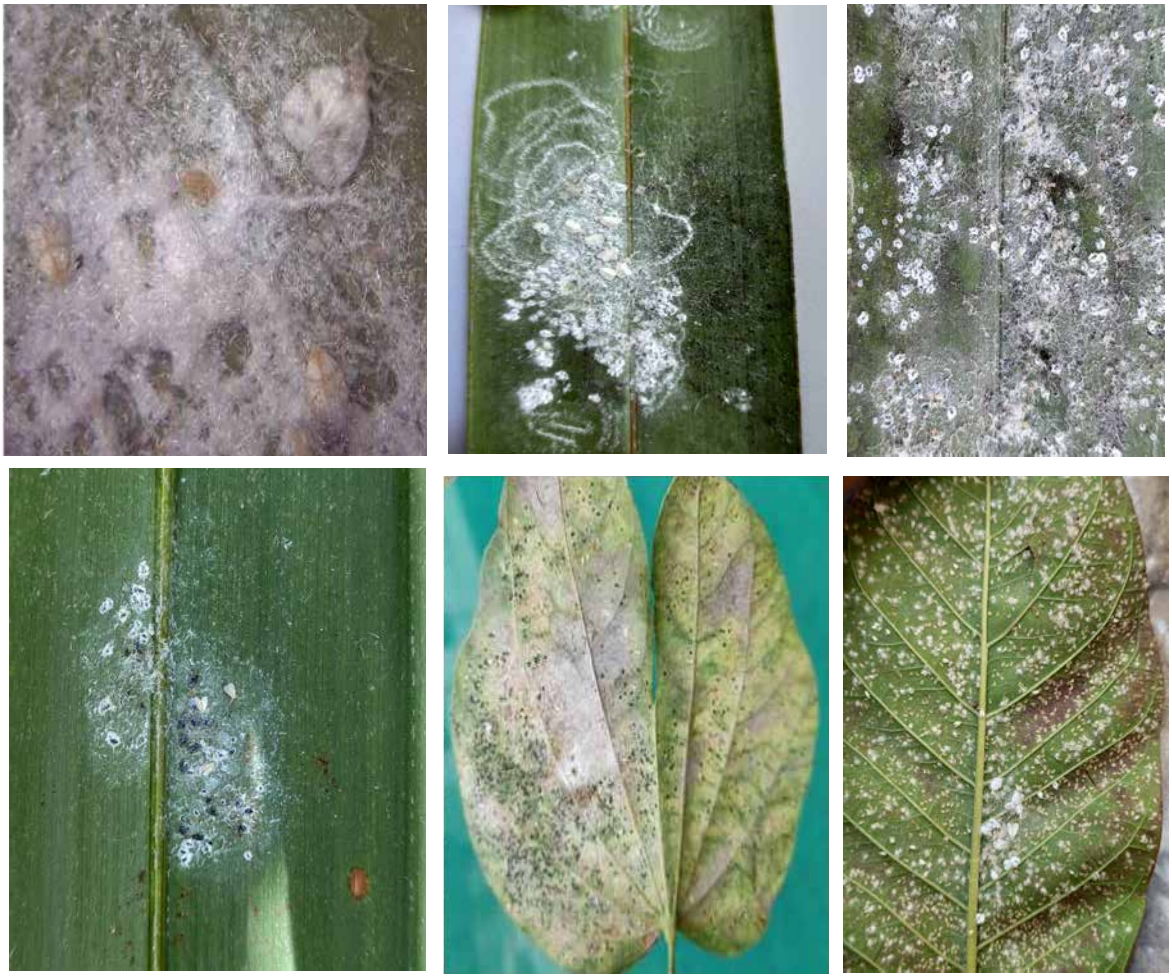

Fig. 23. Co-existence of invasive whiteflies on different host plants

7. Identification and documentation of natural enemies

Explorative surveys were carried out for the biological control of these invasive pests through naturally occurring insect predators and parasitoids which are economically feasible, ecologically compatible and environmentally benign. Two parasitoids, *Encarsia guadeloupae* Viggiani and *E. dispersa* Polaszek (Hymenoptera: Aphelinidae) were found to colonize *A. dispersus* and *A. rugioperculatus*. During 2021, occurrence of parasitoid, *Encarsia cubensis* on *A. atratus* in India and its natural parasitism was ranged from (46-68%) on coconut. Predators 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* and *A. dispersus* (Mani, 2010; Selvaraj *et al.,* 2017).

In addition, three species of entomopathogenic fungi, *Lecanicillium lecani, Simplicillium cylindrosorum* and *Cordyceps* (=*Isaria*) *fumosorosea* (Hypocreales: Clavicipitaceae) were found to be effective against different the life stages of *A. rugioperculatus* and *A. dispersus* (Boopathi *et al.,* 2013; Sumalatha *et al.,* 2020; Sujithra *et al.,* 2020). *Cordyceps (=Isaria) fumosorosea* was highly pathogenic to the egg and early nymphal instar stage with mortality up to 91% in these stages and up to 80% mortality in the late nymphal instar stages of invasive whiteflies. *Simplicillium cylindrosporum* caused about 21.8 to 52.80% mortality in *A. rugioperculatus*. Neither parasitoids nor native predators such as *A. astur*, *Cybocephalus indicus, Axinoscymnus puttarudriahi* (Coleoptera: Coccinellidae), *Cryptolaemus montrouzieri* (Coleoptera: Coccinellidae) and *Acletoxenus indicus* (Diptera: Drosophilidae) were recorded for the other invasive whitefly species (Selvaraj *et al.,* 2019; Sundararaj *et al.,* 2020a).

7.1. Parasitoid, *Encarsia guadeloupae* and *E. 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. *E. guadeloupae* is distributed in Canary Islands, French Polynesia, Hawaii, Micronesia, 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* was reported to parasitize *A. rugioperculatus*; *A. dispersus*, *A. floccissimus;* Giant whitefly, *A. dugesii*; coconut whitefly, *Aleurodicus cocois* and *Trialeurodes vaporariorum* (Evans, 2008). *E. dispersa* was reported from *A. dispersus*, *A. maritimus*, *A. pulvinatus*, *Aleurothrixus floccosus*, *Paraleyrodes urichii* and *Tetraleurodes acaciae* (Polaszek *et al.,* 2004; Noyes, 2017).
- *Encarsia guadeloupae* is solitary in nature and its per cent parasitism about 17-97% on *A. dispersus* and 64-82% on *A. rugioperculatus*. *E. dispersa* is also solitary in nature and was found to parasitize to the extent of 5-10% on *A. rugioperculatus* and *A. dispersus*. *E. guadeloupae* is being completely displaced by *E. dispersa* within a short span of 2-3 years in most of the places in South India where it was colonized.

Description and biology

- ***Encarsia guadeloupae:*** Adult wasps pierce the nymph preferable second instar and lay about 96 eggs in her life time. The parasitized nymph turns black on 14-16th day of parasitisation. Adult female longevity is 7 days. The total life cycle is 27-31 days. Female parasitoids are emerged from fertilized eggs.
- ***Encarsia dispersa:*** Adult wasp prefers to parasitize the second instar and the total developmental period is 31 days. Adults live for 4-6 days. The parasitized nymph turns black on 17th day of parasitisation and the female parasitoids are emerged from fertilized eggs.

Diagnosis

- ***Encarsia guadeloupae:*** This solitary endo-parasitoid, adult wasps can be identified by their yellow scutellum (a triangular plate on their back between the wings; the thorax area) against their brownish body (Fig. 24a).
- ***Encarsia dispersa:*** Adult wasps are yellow in colour except mesoscutal-scutellar transverse suture distinctly pigmented dark brown-black and body length of 0.57 mm and width of 0.26 mm (Fig. 24b).

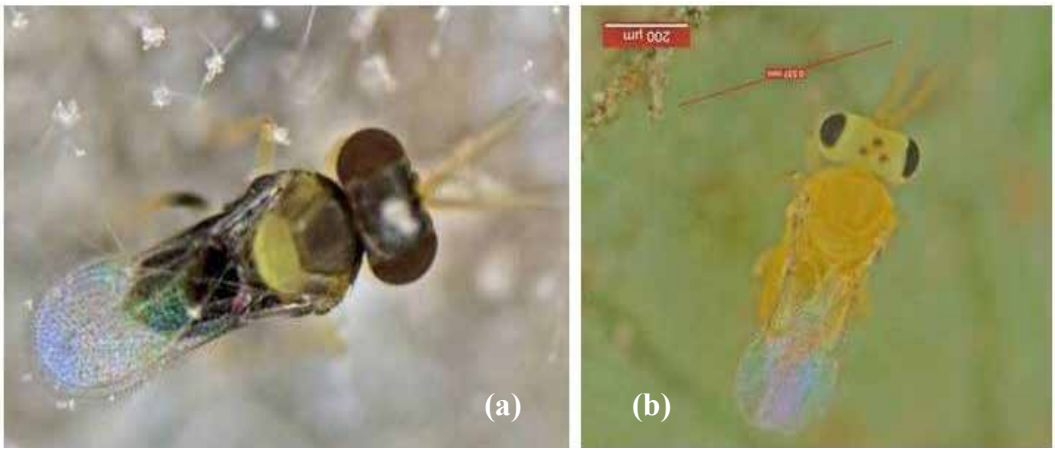

Fig. 24. Parasitoids: a) *Encarsia guadeloupae*, b) *Encarsia dispersa*

7.2. *Encarsia cubensis* Gahan (Hymenoptera: Aphelinidae)

- The aphelinid parasitoids recovered from palm infesting whitefly *Aleurotrachelus atratus* were identified as *Encarsia cubensis* Gahan (Hymenoptera: Aphelinidae), an invasive species for the first time in India.
- *Encarsia cubensis* is minute, solitary and develops as primary endoparasitoid on the puparium (2th nymphal instar).

Distribution

- Brazil, Costa Rica, Cuba, Dominican Republic, Guadeloupe, Haiti, Mexico, Puerto Rico, USA (Noyes, 2022; Myartseva & Evans, 2007; Schauff & Evans 1996) and India (**new record**).

Host insects and bio efficacy

- The known hosts of *E. cubensis* are *Aleurothrixus floccosus* (=*howardi*), *Aleurotrachelus trachoides*, *Bemisia tuberculata* (Noyes, 2022; Myartseva & Evans, 2007) and *Aleurotrachelus atratus* (Borowiec et al., 2010).

- Natural parasitism rate of *E. cubensis* on the puparia of *A. atratus* varied from 46-68% on coconut across the different locations in Karnataka.

Description

- *Encarsia cubensis* was described by Gahan (1931) from Cuba based on a female reared from the woolly whitefly, *Aleurothrixus howardi* (Quaintance), a junior synonym of *Aleurothrixus flocossus* (Maskell). Dozier (1937) reported the species in very abundant numbers from *A. floccosus* on *Spondias mombin* in Haiti and transferred the species to the genus *Trichaporus*. Later, Evans and Polaszek (1998) reviewed and provided a key and illustrations of species in the *Encarsia cubensis* species group.

Diagnosis

- The species is placed in the *Encarsia cubensis* group which is characterized by having the tarsus of the middle leg 4 segmented and the fore wing broad with a large asetose area under the stigma vein.
- The adult female of *E. cubensis* differs from other species in the group by having 2 pairs of setae on the midlobe of the mesoscutum, the body mostly dark colored except for the scutellum, the lateral margins of the mid-lobe of the mesoscutum and central portion of metasomal tergites I and II which are yellow and the 2nd funicle segment of the antenna longer than the 3rd funicle segment (Fig. 25).
- *Encarsia cubensis* is similar to *E. quaintancei* but differs from that species which has the metasoma entirely dark brown; the 2nd funicle segment shorter than the 3rd funicle segment and the midlobe of the mesoscutum with 3 pairs of setae.

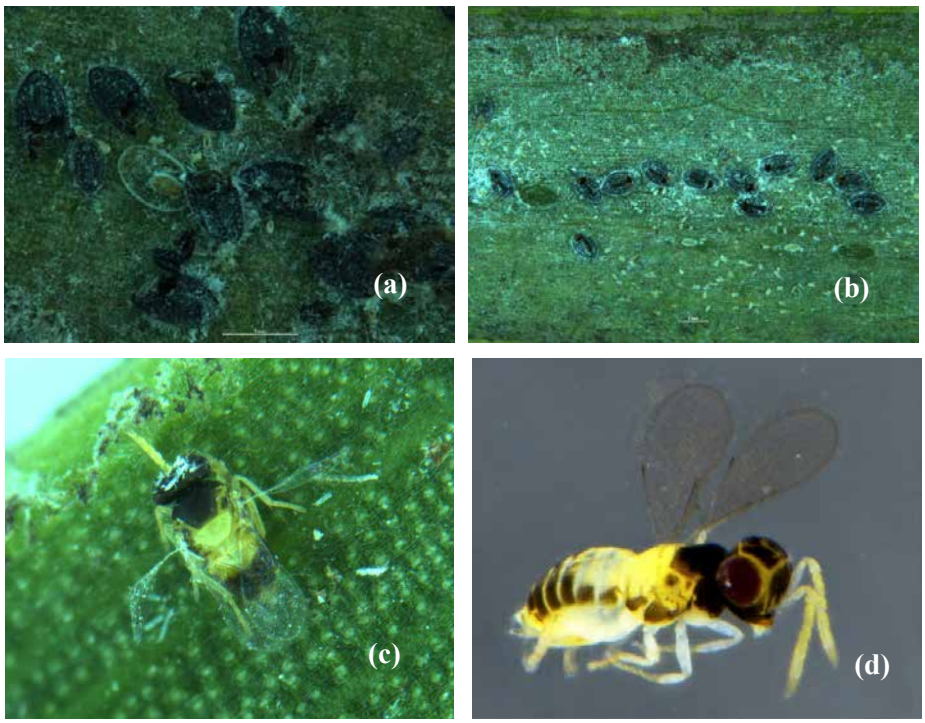

Fig. 25. a). *Aleurotrachelus atratus* adult emerged, b). *E. cubensis* emerged puparium; c-d) *Encarsia cubensis* adults

7.2 Predator, *Apertochrysa* (=*Pseudomallada*) *astur* and *Cybocephalus indicus*

Distribution: Cosmopolitan

Host Insects and efficacy: *Apertochrysa astur* is a generalist predator, prey on mealybugs, whiteflies, bollworms, aphids and red spider mite**.** A total of 200 whitefly nymphs are consumed by a single larva of *A. astur*. The genus *Cybocephalus indicus* (Coleoptera: Nitidulidae) are predacious on scales, whiteflies and rarely feed on mites.

Description and biology

- ***Apertochrysa astur*:** The predator was found to lay stalked eggs in groups of 12–23 and the egg period is 3.26 ± 0.63 days. The durations of the first, second, and third grub of *A. astur* larvae averaged 2.76 ± 0.48, 4.66 ± 0.52, and 4.86 ± 0.42 days, respectively. The short prepupal and pupal periods averaged 1.66 ± 0.52 and 7.26 ± 0.63 days, respectively, and the total larval period is 12.16 ± 0.57 days. The total developmental period is 24.16 ± 0.99 days.
- ***Cybocephalus indicus*:** The eggs are spherical yellowish and microscopic nature. The egg hatched in 5-6 days and the larval period includes 7-8 days. The total pupal period is 16-17 days. The total life cycle is completed from 27-37 days. Fecundity is 110 eggs and the adult longevity is 90 days.

Fig. 26. Predators: (a-b) *Apertochrysa astur*, (c-d) *Cybocephalus indicus*

Diagnosis

- ***Apertochrysa astur*:** Larva broad at middle and tapering towards both ends (fusiform) and carry debris (Fig. 25a & b). Mandible-maxilla as long as, or longer than cephalic capsule and adults green in colour, abdominal segments with several dorsal rows of hooked setae.

- ***Cybocephalus indicus*:** The larvae are outwardly similar to coccinellid larvae, yellowish in colour often white mealy coating when they are associated with whitefly colonies (Fig. 26 c & d). The adults are strongly convex on the dorsal side, with a dumpy, hump-backed body. Females are usually fully black and the males have yellowish head and pronotum with black elytra.

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

Distribution: *Cordyceps (=Isaria) fumosorosea* is used as a myco-insecticide commercially for whitefly management in many countries both in greenhouses as well as in an open field conditions.

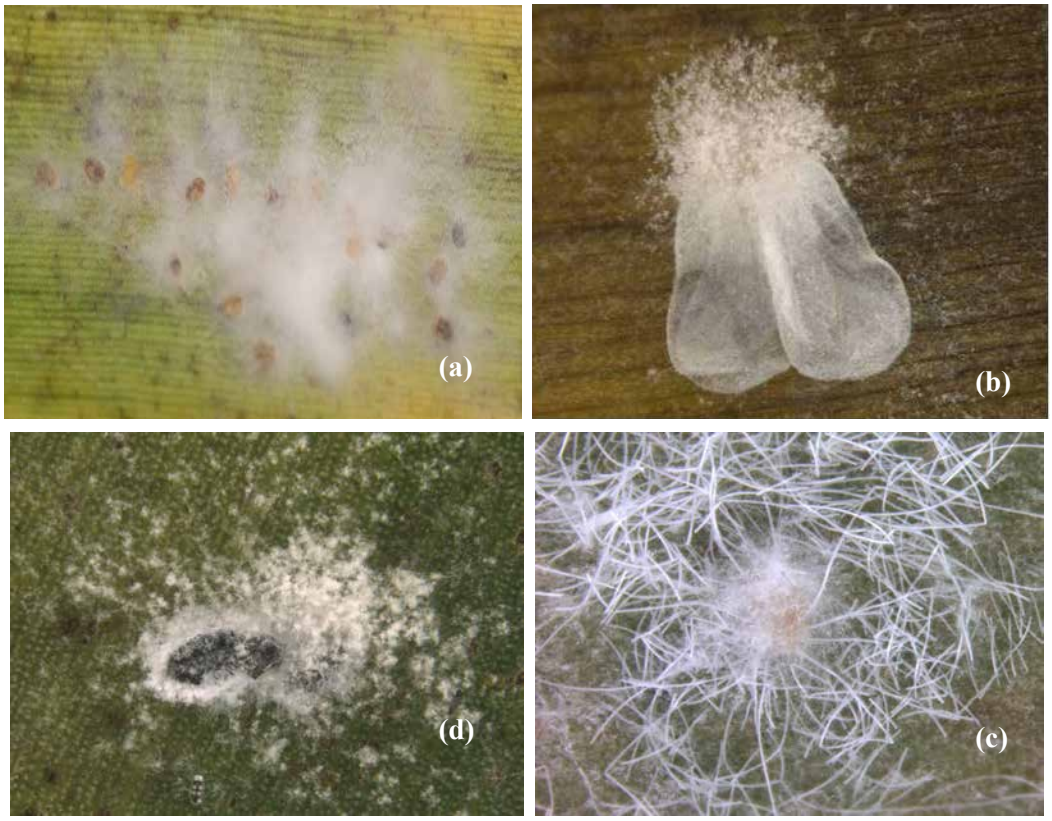

Fig.27. Infection of *Cordyceps (=Isaria) fumosorosea* on rugose spiraling whitefly (a-b), nesting whitefly (c) and palm infesting whitefly (d)

Host Insects and efficacy

- *Cordyceps (=Isaria) fumosorosea* formerly known as *Paecilomyces fumosoroseus* infects a large number of arthropods such as whiteflies, thrips and mealybug.
- ICAR-NBAIR identified & validated a *Cordyceps* (=*Isaria*) *fumosorosea* (ICAR-NBAIR Pfu-5) - "**Shatpada Rugose Whitefly Kill"** for the management of these invasive whiteflies, which have been commercialized. Further, it was found that infected whitefly adult which capable to transfer, *C. fumosorosea* conidia to others healthy individual which causes the spread of infections and the onset of epizootics under field conditions.

- This fungus was used as potential biocontrol agent against *A. rugioperculatus, Paraleyrodes bondari* in Florida (Ali *et al.,* 2015; Kumar *et al.,* 2016); *Bemisia tabaci* (Eslamizadeh *et al.,* 2013; Tian *et al.,* 2015), *Trialeurodes vaporariorum* (Lacey *et al.,* 2008 and Spiraling whitefly, *A. dispersus* (Boopathi *et al.,* 2013).
- The fungus is effective in killing all the life stages of rugose spiraling whitefly, Bondar's nesting whitefly, Nesting whitefly, palm infesting whitefly (Fig. 27). The fungus kill the egg and early instar nymphal stage of rugose Spiraling whitefly to the extent of 91% and the late nymphal instars and pupal mortality up to 80%.

8. Molecular characterization of whiteflies and Natural Enemies

After confirmation of species based on the puparial taxonomic characteristics specific to the species, adult whitefly is used for used for the molecular identification through DNA barcoding. The identity of the whitefly species is confirmed by the senior author based on the morphological characteristics of the puparia (4th instar nymph) and comparing them with the original and additional descriptions of respective species. Further, the partial mitochondrial cytochrome c oxidase I (COI) gene of 658 bp size was amplified and sequenced.

The sequences *viz.,* MK421974, MF449463, MF371113, MT422352, MT422350, MT422351, MN027508, MW629855, KY223606 and ON881119 were submitted to GenBank for *Aleurodicus dispersus, Aleurodicus rugioperculatus, Aleurothrixus trachoides, Paraleyrodes bondari, Paraleyrodes minei, Aleurotrachalus atratus, Aleurothrixus floccosus, Tetraleurodes acaciae* and *Encarsia guadeloupae* and *E. cubenisis,* respectively. The COI sequences showed a 98-100% match with species reported elsewhere and submitted in National Center for Biotechnology Information database. A barcode for each species was also generated with help of the barcode of life data system and RSW Barcode (Fig. 28). The sequence detail is given in table 4.

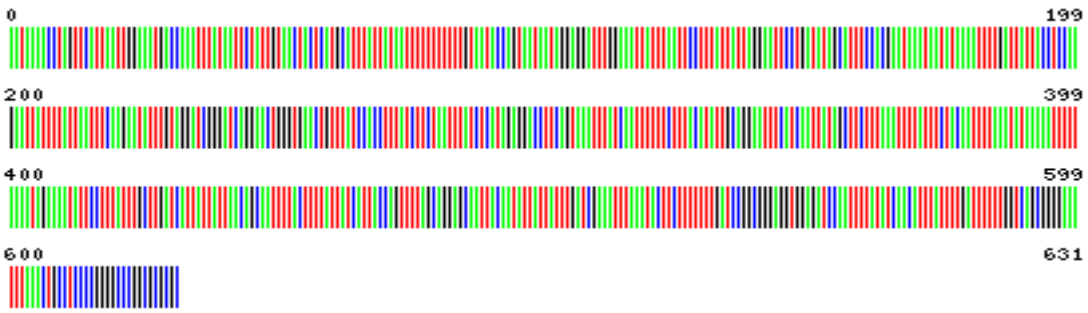

Fig. 28. DNA borcode of rugose spiraling whitefly

Table 4. Molecular characterization of exotic whiteflies and parasitoids

S. No	Species	Genebank accession number	NCBI reference accession No
1	*Aleurodicus dispersus*	MK421974, MK472717,	KR063274
2	*Aleurodicus rugioperculatus*	MF449463, MF445090, KY209909, KY492358,	KP032219
3	*Aleurothrixus trachoides*	MF371113, MF149999	KF059957
4	*Paraleurodoes bondari*	MT422352	KP032215
5	*Paraleurodes minei*	MT422350	KX925200
6	*Aleurotrachalus atratus*	MT422351	MN266486
7	*Aleurothrixus floccosus*	MN027508	KF059956
8	*Tetraleurodes acaceae*	MW629855	AY521262
9	*Encarsia guadeloupae*	KY223606	KY607910
10	*Encarsia cubensis*	ON881119	-

9. Economic importance of invasive whiteflies

Exotic invasive whiteflies in India cause direct and indirect yield losses in agriculture, horticulture and forestry crop plants. *A. trachoides* was found to infest 37 plant species including medicinal plants; *A. rugioperculatus* on 50 host plants, *P. bondari* on 34 host plants and *P. minei* on 25 host plants, *T. acaciae* on 5 host plants mainly leguminous plants, *A. atratus* on 4 host plants and *A. floccosus* on guava in India. Based on extensive surveys on host plant distribution of these invasives, it may be believed that majority of pests could have invaded India due to import of ornamental plants especially plants belonging under Arecaceae family. Coconut and guava are most common host plants for major invasive species *viz., A. rugioperculatus, A. atratus, P. bondari, P. minei* and *A. dispersus*.

Coconut is an important crop grown mainly in the tropical and subtropical regions of the world. India is one of the leaders in coconut farming and stands 3rd largest coconut producing country in the world. Similarly, guava is a common tropical fruit, native to Mexico, Central America and cultivated in many tropical and subtropical regions. India is the largest producer of guava, with 41% of the world production. These species have some host preference towards coconut and guava might be due to they are originated from same regions. This leads to close association and quicker establishment in newly introduced regions. There is no doubt that invasive species can cause severe ecological and

economical damage. The agricultural economy in India is vulnerable to threat from exotic pests/ diseases and there are 116 alien insect species (Mandal, 2011). Non-native species can achieve invasive pest status when they are accidentally moved to new locations if they become separated from their natural enemy complexes and if local (indigenous) beneficial species (predators and/or parasitoids) are unable to suppress those (Duan *et al.,* 2015).

The invasive whiteflies are establishing the pest status as they are found attacking the economically important fruits, vegetable crops, medicinal crops and trees. Early detection of invasive species and immediate implementation of biological control methods could minimize the economic losses. Fortunately, most such invasions especially the Hemiptera of the suborder Sternorrhincha are amenable for classical biological control. Effective biological control programme has been implemented for *A. dispersus, A. rugioperculatus* resulting in saving millions of rupees by mitigating their adverse impacts on agriculture.

10. Conclusion

The invasive whiteflies pose a challenge to Indian economy as biologists and the public world-wide increasingly recognize the damage caused by invasive non-indigenous species. Despite the severe ecological damage and economic loss caused by the invasive species, the factors contributing to successful invasion remain elusive. Non-native species can achieve major pest status when they are accidentally moved to new locations as they become separated from their natural enemy complexes. Further, enhancement of invasion processes from initial introduction through establishment and spread under extreme climatic conditions and it's also believed that the on-going dispersal of exotic species is one of the most striking biological outcomes of global climatic changes.

The global invasive species program proposes three major management options: prevention, early detection, and eradication for the management of alien species. Prevention of an invasionis the most economical option as it contains pest to 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 of the suborder Sternorrhyncha, which includes whiteflies, scale insects, aphids, psyllids and some smaller families are amenable for classical biological control. Effective biological control programme has been implemented for *A. rugioperculatus* and *A. dispersus* resulting in saving millions of rupees by mitigating their adverse impacts on agriculture.

These whiteflies are 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 *E. 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, woolly and palm infesting whiteflies. Further, a nation-wide surveillance programme is required for mapping of the potential areas of its distribution, and host range to prevent further spread by restricting the exchange of planting materials.

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