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Biosecurity and economic concerns on invasion by exotic whiteflies in India and their biocontrol strategies

***Bakthavatsalam, N., Selvaraj, K., Sundararaj, R[1] and Sumalatha, B.V**

Division of Germplasm Conservation and Utilization, ICAR- National Bureau of Agricultural Insect Resources, Bengaluru-560024, India

[1]Forest Protection Division, Institute of Wood Science and Technology, Malleswaram, Bengaluru-560024, Karnataka, India

ABSTRACT: Among the potentially important invasive species globally are the whiteflies. Out of over 110 exotic insect species reported to have invaded India, whiteflies and mealybugs constitute a major part .Their related implications on biosecurity and economic concerns have been rather significant for Indian agriculture-horticulture and forestry ecosystems. The relevant information along with illustration of the biocontrol strategies adopted towards their containment and sustainable management at national level are summarised herein.

Key words: invasive whiteflies, biosecurity, economic concerns, biocontrol strategies, India

Whiteflies (Hemiptera:Aleyrodidae) are distributed throughout the major zoogeographical regions of the world, with their greatest diversity in tropical and south temperate regions. The trade of exotic plants is attributed to many accidental introductions of insects from their native geographical area. Besides, the enormous increase in the volume, diversity and swiftness of movement of plant produce throughout the world has led to the proliferation and dissemination of invasive species, particularly the ones which are closely associated with host plants, such as scales and whiteflies (Simala *et al.,* 2015).In view of their smaller size, cryptic nature and immature stages being attached to the host-plant, the

*Author for correspondence. Email: nbakthavatsalam@yahoo.com

whitefly species are one of the most commonly transported invasive arthropod groups. They are also among the most successful groups in terms of invading new geographical areas. Moreover, changes in climate and global warming could influence new introductions and distribution of exotic whitefly species and increase the chances of their survival in new environment. So far more than 110 exotic insect species had been reported from India, of which, whiteflies and mealybugs constitute a major part of the invasive species (Mandal, 2011) and become one of the world's worst invasive pests. Exotic invasive whiteflies in India cause direct and indirect yield losses in agriculture, horticulture and forestry crop plants. Recently there is a surge in the invasion of exotic whiteflies to India particularly through south India.

Moreover, exotic whitefly pests can multiply in large proportion in a short time, exhibit high phenotypic plasticity, and have a strong potential to compete with native species and cause damage to economically important crop plants. In India, 469 whiteflies species belonging to 71 genera are known to breed on agriculture, horticulture and forestry crop plants. India experienced its first invasive whitefly, spiralling whitefly, *Aleurodicus dispersus* Russel in the Western Ghat of mountain range in South India during 1995 (David and Regu, 1995) and established on many host plants including economically important crops in India. Recently within a span of five years, seven whiteflies *viz.,* solanum whitefly/pepper, *Aleurotrachalus trachoides* (Back) (2015) (Dubey and Sundararaj, 2015); rugose spiralling whitefly, *Aleurodicus rugioperculatus* Martin (2016) (Sundararaj and Selvaraj, 2017); Bondar's nesting whitefly, *Paraleurodes bondari* Peracchi (Josephrajkumar *et al.,* 2019); nesting whitefly, *P. minei* Iaccarino (Mohan *et al.,*2019); legume feeding whitefly, *Tetraleurodes acacia* (Quaintance) (2018) (Sundararaj and Vimala, 2018); palm infesting whitefly/coconut whitefly, *Aleurotrachelus atratus* Hempel (Selvaraj *et al.,* 2019) and woolly whitefly, *Aleurothrixus floccosus* (Maskell) (2019) (Sundararaj *et al.,* 2020) invaded India. Most of these invasive species are believed to be native of Neotropical origin, especially, Central America and the Caribbean regions. Simultaneous co-existence/co-occurring of these exotic whiteflies with similar habits shows the more or less the same niche for the growth and development.

Symptoms of damage: Nymphs and adults suck the sap from the leaves by direct feeding especially on underside of the leaves. Adults produce prodigious quantities of honeydew which in turn gets darkened by the development of sooty mould on the upper surface of infested leaves and anything under the infested plants. The typical concentric waxy spiralling symptoms on various parts of host plants including on leaf petiole and tender nuts is the sign of infestation. These invasive whiteflies cause direct damage to their host by sucking the plant sap which leads to removing of the nutrients and water there by interfering with its normal growth, and causing premature leaf drop. Indirectly, they cause damage by producing wax and excreting sticky honeydew which provides a substrate for the growth of black sooty mould on infested plant (Kumar *et al.*, 2018) reducing the photosynthetic capacity of the plant and some species such as Solanum whitefly reported to act as vector for transmission of begomovirus (Chandrasekhar *et al.,* 2020). Production of waxy flocculent material profusely in severely infested areas creates nuisance to human being.

Distribution: The spiralling whitefly was first invasive whitefly recorded in India; it was first

reported in the Western Ghats of south India on tapioca and is now distributed throughout the country including the Andaman, Nicobar and Lakshadweep islands. Solanum whitefly/pepper whitefly was found heavily infesting the ornamental plant, *Duranta erecta* and cultivated plant, *Capsicum annum* in South India (Karnataka) (Dubey and Sundararaj, 2015). Subsequently it spread to Kerala, Tamil Nadu and Maharashtra within span of five years of incursion. Incidence of rugose spiralling whiteflywas recorded on coconut at Pollachi, Coimbatore district of Tamil Nadu. Further spread to Karnataka, Kerala, Andhra Pradesh, Goa, Assam, West Bengal and recently to Maharashtra, Gujarat, Meghalaya, Telangana, Odisha, Chhattisgarh and Lakshadweep islands was observed in the subsequent years. Similarly, Bondar's nesting whitefly was reported in India on coconut palms from Kerala and subsequently reported from Karnataka, Tamil Nadu, Andhra Pradesh, The Andaman and Nicobar Islands and Lakshadweep islands.

Nesting whitefly was reported on coconut in Kerala and in Andaman and Nicobar Islands. Subsequently, this species rapidly spread to Karnataka and Tamil Nadu. Legume feeding whiteflywas recorded on subabulin Bengaluru, Karnataka (Sundararaj and Vimala, 2018) and its infestation was also reported on orchid and tamarind. Palm infesting whitefly/coconut whiteflywas recorded initially on coconut and ornamental palm in Mandya district of Karnataka (Selvaraj *et al.,* 2019) and subsequently spread to Mysore, Ramanagara, Hassan, Kodagu, Tumkur, Bengaluru Rural and Bengaluru Urban district of Karnataka and Dharmapuri district of Tamil Nadu. Incidence of woolly whitefly was observed on guava in Kozhikode district of Kerala. Later it spread to Ramanagara, Bengaluru Rural, Bengaluru Urban, Mysore, Udupi and Mandya districts of Karnataka and Coimbatore, Salem, Krishnagiri, Namakkal and Dharmapuri districts of Tamil Nadu and few islands of Lakshadweep. All these whiteflies were spreading mostly through movement of infested seedling from pest affected areas.

Host Plants: All these invasive whiteflies are highly polyphagous and have host preference towards many economically important crop plants such as coconut, guava, banana, custard apple, oil palm, etc. Moreover, these invasive whiteflies were found increasing their host range. Spiralling whitefly was reported to infest 481 host plants throughout the world, of which it is known to attack 253 host plant species in India (Srinivasa, 2000) and it has been reported on over 320 plant species belonging to 225 genera and 73 families in India (Sundararaj and Pushpa, 2012). Solanum whitefly was found to breed on 37 host plants, representing 11 families (Sundararaj *et al.* 2018) mostly plants belonging to the Solanaceae, Araceae, Apocynaceae and Convolvulaceae families (Dubey and Sundararaj, 2015).

Rugose spiralling whiteflyis highly polyphagous and reported to feed on about 120 plant species including economically important cultivated and palm plants. In India, it was found to feed on about 45 host plants especially coconut, banana, mango, sapota, guava, cashew, ramphal, oil palm, maize, oil palm, Indian almond, water apple, jack fruit and many other ornamental plants like bottle palm, Indian shot, false bird of paradise and butterfly palm (Selvaraj *et al.*, 2017; Selvaraj *et al.,* 2019). Bondar's nesting whitefly was reported to feed on more than 25 host plants which include banana, citrus, cassava, custard apple, coconut, guava, subabul and ficus in India (Vidya *et al.,* 2019). Similarly, *P. minei* was found to colonize on coconut, banana, guava, mango, jamun, *Ixora* sp., and *Heliconia* (Mohan *et al.*, 2019; Sujithra *et al.*, 2019). Legume feeding whitefly infested mainly the plants belonging of family

Fabaceae including subabul, the host on which it was found breeding in Bangalore and Udupi districts of Karnataka.

Incidence of Neotropical palm infesting whitefly was observed on coconut, are canut, oil palm and ornamental areca palm. However, it was recorded to colonize on more than 110 plant species belonging to Arecaceae, Rutaceae, Solanacee, Cycadaceae and Lauraceae (Malumphy and Treseder, 2011). Woolly whitefly was feeding on 20 plant families and exhibits a strong host preference for citrus but so far in India, it was found to infest on guava only. These invasive whiteflies expanding itshost range could be a mechanism to overcome abiotic stress and this can buffer the depletion of available optimal resources. Host preference of these invasive whiteflies towards coconut and guava in the country of their origin would have led to quicker establishment on these host plants in the newly introduced regions. Out of the eight invasive species, spiralling whitefly, rugose spiralling whitefly, woolly whitefly, nesting whiteflies were found to infest guava and coconut in India. The host range expansion is ultimately leading to increases in population growth and potentially to geographic range expansion (Crowl *et al.*, 2008).

Natural enemies of the invasive whiteflies: Explorative surveys were carried out for the natural enemies of these invasive pests through naturally occurring insect predators, parasitoids and entomopathogens 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. disperses and A. rugioperculatus* (Mani 2010; Selvaraj *et al.,* 2017). These parasitoids believed to have been accidentally introduced along with the *A. disperses* into India. *Encarsia guadeloupae* was the dominant parasitoid which parasitized 62-95% and 56-82% on *A. disperses* and *A. rugioperculatus,* respectively (Mani 2010; Selvaraj *et al.* 2016; Selvaraj *et al.,* 2017) whereas *E. dispersa* parasitized 28 -92% *and 5-10% on A. dispersus* and *A. rugioperculatus (*Mani, 2010*; Selvaraj et al., 2017).*

Predators such as *Pseudomallada astur* Banks *(Neuroptera: Chrysopidae)*, *Jauravia pallidula* Motschulsky, *Cheilomenes sexmaculata* (Fabricius) *(Coleoptera: Coccinellidae)* and *Cybocephalus indicus* Tian & Ramani (Coleoptera: Nitidulidae) were also observed to be feeding on *A. rugioperculatus and A. dispersus* (Mani 2010; Selvaraj *et al.,* 2017). In addition, entomopathogenic fungus, *Isaria fumosorosea Wize* was found to be effective against all the life stages of *A. rugioperculatus* (Sumalatha*et al.,* 2020). *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. *Pseudomallada astur*, *Cybocephalus indicus, Axinoscymnus puttarudriahi* Kapur, *Cryptolaemus montrouzieri* Mulsant (Coleoptera: Coccinellidae) and *Acletoxenus indicus* Malloch (Diptera: Drosophilidae) were recorded on solanum whitefly, nesting whiteflies and woolly whitefly (Selvaraj *et al.,* 2019; Sundararaj *et al.*, 2020). In India, no parasitoid was known to attack on these whiteflies still date.

Co-occurrence: As many as seven exotic whiteflies have been reported from different regions in India in rapid succession. During present study, it was observed simultaneous coexistence of *A. rugioperculatus*, *P. bondari*, *A. dispersus, A. floccosus*and *P. minei* in many of the host plants

coconut. Similar observations on their co-existence on coconut were reported by Josephrajkumar *et al.* (2019) and Mohan *et al.* (2019). We observed *A. rugioper culatus* co-existing with *Aleurotra chalusatratus, P. bondari, A. disperses* and *P. minei* on coconut; *P. minei, P. bondari, A. rugioperculatus* and *A. dispersus*with *Aleuroth rixusfloccosus* on guava; *A. trachoides* with *Bemisia tabaci* on tobacco; nesting whiteflies with *B. tabaci* cotton. The infestation of *A. atratus* and *A. rugioperculatus* along with native whitefly species *Aleurocanthus arecae* was commonly observed on coconut.

Aleurodicus rugioperculatus and *Aleuroth rixusfloccosus* showed their dominance in their niche irrespective of their co-occurring species on majority of host plants. Co-existence of the nesting whitefly, *Paraleyrodes minei* and the woolly whitefly, *Aleuroth rixusfloccosus* was also recorded on citrus from Greece (Kalaitzaki *et al.,* 2016).The synchrony of coexistence and mutual survival of these competing insect species, is could be due to the marked time partitioning of the resource use among the species except they are demographically nearly equivalent. In such co-occurrence, 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 lead to temporal variation was observed among these invasive species.

Economic importance of invasive whiteflies: 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 selectively separated from their natural enemy complexes (Duan *et al.* 2015). Further, enhancement of invasion processes from initial introduction through establishment and spread under extreme climatic conditions (Diez *et al.,* 2012) and the on-going dispersal of exotic species or rearrangement of species geographical is one of the most striking biological outcome of global climatic changes (Gao and Reitz, 2017).

The global invasive species program proposes three major management options: prevention, early detection, and eradication for the management of alien species. Prevention of an invasion is the most economical option as it contains pest 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.

A, **Classical biological control of the spiralling whitefly, *Aleurodicus dispersus*:** The introduction and establishment of the coccinellid beetle-*Nephaspis oculatus* (Blatchley) (Coleoptera: Coccinellidae) and the parasitoid- *Encarsia haitiensis* Dozier (Hymenoptera: Aphelinidae) successfully controlled *A. dispersus* on guava in highland and lowland areas of Honolulu, Hawaii. In 1980-81, peak population densities of *A. dispersus* were reduced by 79% in the lowlands and 98.8% in the highlands.

Rainfall, temperature and predator, *Allograpta obliqua* (Say) Diptera: Syrphidae) probably also contributed to the reduction of *A. dispersus* populations (Kumashiro *et al.,* 1983; Beardsley, 1992). The biological control of *A. dispersus* was successful in Hawaii; there have been further successes on Pacific Islands which was through *E. haitiensis* and complementary action by one or more of the introduced coccinellids. Parasitoids *viz., E. haitiensis* and *E. guadeloupae* were introduced in Benin for the management of *A. dispersus* for the first time in 1993 and achieved excellent control (D'Almeida *et al.,* 1998).Similar results were obtained in Australia by importing *E. haitiensis* (Lambkin, 1998).

In India, two exotic aphelinid parasitoids, *E. guadeloupae* and *E. dispers* were reported on spiralling whitefly and believed that they have been accidentally introduced along with the host. Nearly five years after the pest introduction, *Encarsia* sp. nr. *Meritoria* was found to parasitize on *A. dispersus* in Kerala during 1998 (Beevi*et al.,* 1999). Subsequently, this species was recorded from Bangalore (Srinivasa *et al.,* 1999). Another parasitoid, *Encarsia guadeloupae* was first reported from Minicoy Island in the Lakshadweep in 1999 and later deliberately introduced into the mainland for the control of *A. dispersus* (Ramani, 2000). Parasitism levels due to both parasitoids vary from 29 to 70% and exceed 90% in subsequent year of release year. Wherever parasitism was heavy, the pest population was substantially reduced subsequently. *E. guadeloupae* is performing better than *E. dispersa,* of late, *the* former species having been displaced almost completely through competitive replacement. It has established in Kerala, Tamil Nadu, Karnataka and many other states in India. Now the pest population was kept under check by these parasitoids along with predators *Cybocephalus indicus*, *Axinoscymnus puttarudriahi* Kapur & Munshi and *Cheilomenes sexmaculata* (Fabricius). These parasitoids populations increased phenomenally through breeding for several years on the expanding host population. Since 2017, *E. guadalouape* is also keeping the invasive rugose spiralling whitefly under control in India. Besides, entomopathogenic fungus *Beauveria bassiana*, *Metarhizium anisopliae, Lecanicillium lecanii* and *Isaria fumosorosea* with 49 to 74mortality on spiralling whitefly was recorded (Boopathi *et al.,* 2015).

Biological control of rugose spiralling whitefly, *Aleurodicus rugioperculatus*

The parasitoid, *Encarsia guadeloupae* which was introduced for the management of *A. disperses* has adopted *A. rugioperculatus* and has since established. Farmers and other stakeholders were advised to re-distribute the parasitoids wherever they were absent or found in inadequate numbers by using field insectary techniques such as strategically placing the field collected parasitized nymphs in, on or next to infested vegetation for augmentation and further they were strictly advised not to apply chemical pesticides. In areas where chemicals were not applied, parasitoids were observed to have multiplied rapidly and natural parasitism increased phenomenally thus preventing severe outbreaks. Frequent monitoring of the pest occurrence was carried out done and pesticide holidays were declared so as to conserve the natural enemies. Banana and *Canna indica* were found to be harbouring maximum population of parasitoids in field as well as in net-houses. The growers were advised to grow these plants as banker plants in coconut garden for conservation and augmentation.

Entomopathogenic fungus, *Isaria fumosorosea:* a promising bioagent: ICAR-NBAIR has identified a promising entomopathogenic fungus, *Isaria fumosorosea* (ICAR-NBAIR pfu-5) based on laboratory bioassays and also on multi-locational field evaluation in Andhra Pradesh, Karnataka, Kerala

and Tamil Nadu. The fungus was effective in killing all the life stages of the pest. The egg and early instar nymphal mortality was up to 91% and the late nymphal instars and pupal mortality was up to 80%. Mass production technology for this fungus has been standardized using solid state fermentation (rice grains) and liquid state fermentation technology (Saboroud dextrose yeast broth, potato dextrose broth). Talc, rice grain and oil formulations have been developed with long shelf life Due to its high field efficacy there is a huge demand for this biocontrol agent from the coconut farming community. Farmers in Andhra Pradesh are regularly trained on farm level production of this fungus using rice grains as substrate for their use in the coconut gardens.

ICAR-NBAIR has carried out extensive research on biological control of this pest on a priority basis under its core programme as well as under a project funded by the Coconut Development Board, Kochi. ICAR-NBAIR has developed biocontrol strategies using parasitoids and the entomofungal pathogen *I. fumosorosea* for the efficient management of the RSW within a short span of time. Economic analysis of the impact of conservation and augmentation of *E. guadeloupae* and foliar application of *I. fumosorosea* for management of RSW indicated that about Rs 9500/ha crop protection cost and 900 ml of pesticides/ha are being saved.

Future thrust: 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 spiralling whitefly and rugose spiralling whitefly populations to sub-economic numbers. It would seem to be highly desirable to augment and conserve the host specific natural enemies like *Encarsia guadeloupae* to any locality seeking biological control. Moreover it is imperative to mention that correct and timely identification of this complex is very essential for carrying out further studies on their bioecology, population dynamics on different environments and development of management strategies especially biocontrol programs. There is urgent need to document a potential natural enemy complex or introduce from their native countries to develop efficient biocontrol management strategies for nesting whiteflies, woolly and palm infesting whiteflies. Further, a nation-wide surveillance programme is required to mapping of the potential areas of its distribution, and host range to prevent further spread by restricting the exchange of planting materials.

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