Invasive Whitefly (Hemiptera: Aleyrodidae) Complex and Diversity in Coconut Landscapes in Tamil Nadu[1]

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Abstract Coconut, *Cocos nucifera* L., in Tamil Nadu, India, was invaded by four whitefly (Hemiptera: Aleyrodidae) species between 2016 and 2019, increasing the total to six, along with *Aleurodicus dispersus* Russell and *Aleurocanthus arecae* David and Manjunatha. We examined the complexity and diversity of whiteflies in coconut across different agroclimatic zones of Tamil Nadu and found high and low damage levels by whiteflies at Veppankulam (70.4%) and Rameswaram (11.0%), respectively. The rugose spiraling whitefly, *Aleurodicus rugioperculatus* Martin, was the most dominant species but was effectively managed by the parasitoids *Encarsia guadeloupae* Viggiani and *E. dispersa* Polaszek, with the highest rate parasitism of 83.8% at Aliyar Nagar and the lowest (2.9%) in the Kanchipuram district. *Aleurodicus rugioperculatus* and Bondar's nesting whitefly, *Paraleyrodes bondari* Peracchi, have spread throughout Tamil Nadu. The population of *A. rugioperculaus* was high at Veppankulam and that of *P. bondari* was higher at Dharmapuri (28.6 and 31.1 adults/leaflet, respectively). All five invasive whitefly species in coconut were found only in 7 of 34 locations—Coimbatore, Sirumugai, Salem, Dharmapuri, Krishnagiri, Vellore, and Erode. *Paraleyrodes minei* Iaccarino and *Aleurotrachelus atratus* Hempel were distributed in the northwestern zone adjoining the western ghats of Tamil Nadu. Coconut plantations at Sirumugai (western ghats) supported the most diverse collection of whiteflies, with 0.61 and 1.09 Simpson and Shannon diversity indices. Among the 29 districts, adjoining Dindigul and Theni districts showed the highest Bray–Curtis Similarity Matrix. Butterfly palm, *Dypsis lutescens* H. Wendel, custard apple, *Annona squamosa* L., and guava, *Psidium guajava* L., are whitefly hosts in coconut landscapes.

Key Words *Cocos nucifera*, whitefly diversity, invasive species

Coconut, *Cocos nucifera* L. (Arecaceae), is a multipurpose tree with culinary and medicinal benefits. India is the leading coconut producer in the world, with a total production of 20,736.12 million nuts (2020–2021). Among the states of India, Tamil Nadu is second in production with 5,439.33 million nuts and its southern neighbor Kerela producing 6,942.60 million nuts in 2020–2021 (Ministry of Agriculture and Farmers Welfare, Government of India 2022). Increased globalization

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and world trade have increased the risk of invasion of exotic organisms. The invasive species are most recognized as pests of agriculture, but they impact native ecosystems as well. A total of 464 whitefly species from 68 genera are found to cause significant damage in a range of crop plants (Selvaraj et al. 2019). The coconut agroecosystem in India has been the most disturbed in the last half decade and experienced the invasion of four exotic whitefly species—rugose spiraling whitefly (*Aleurodicus rugioperculatus* Martin), Bondar's nesting whitefly (*Paraleyrodes bondari* Peracchi), nesting whitefly (*P. minei* Iaccarini), and neotropical whitefly (*Aleurotrachelus atratus* Hempel)—all of which cause significant damage. In 4 yr, these invasive whitefly species have spread rapidly with high infestation rates. *Aleurodicus dispersus* Russell, reported from Kerala initially as a pest of (*Manihot esculenta* Crantz) (Palaniswami et al. 1995), was the first exotic whitefly species to infest coconut in India. This whitefly feeds exclusively on leaves and can transmit plant diseases (Chand et al. 2019). *Aleurodicus rugioperculatus* is the predominant species, both in size and damage, is native to the neotropical region, and has also spread across the Oriental region with high infestation rates. It was first reported from Kottayam District in August 2016 (Shanas et al. 2016). Over 5 yr, the insect has spread throughout Tamil Nadu, causing damage to coconut palms. Subsequently, *P. bondari* was reported at Kayamkulam by Josephrajkumar et al. (2019) and spread faster than *A. rugioperculatus* and colonized almost all coconut plantations in Tamil Nadu within 2 yr. The other two species, *P. minei* and *A. atratus*, are present in some northwestern Tamil Nadu locations. *Aleurotrachelus atratus*, exclusively infesting palm species, has a wide range of 56 host plants, with coconut as the primary host (Borowiec et al. 2010).

These whiteflies colonize the abaxial surface of the coconut leaflets either in clusters (*A. rugioperculatus*, *A. dispersus*, and *A. atratus*) or forming nests around them (*P. bondari* and *P. minei*) and feed on the phloem tissues. They cause primary infestation by feeding on plant fluids. Their honeydew deposits support growth of fungi *Capnodium* spp. that cause sooty mold growth on the adaxial surfaces in the lower crown canopy, affecting host plant photosynthesis (Arun et al. 2021). Under severe infestation, susceptible palms are blackish in appearance and produce fewer nuts than healthy uninfested plants. Over the past few years since their introduction, these invasive whiteflies have spread across coconut groves in the peninsular Indian region. The present study examines the distribution of the coconut whitefly complex across different locations of Tamil Nadu and their co-occurrence, which are essential to analyze establishment, interactions, and species displacement among the invasive whiteflies.

Materials and Methods

Survey and in situ collection of insect samples were by a simple random quantitative sampling method at 34 locations from the predominant coconut growing regions across 29 districts covering six agroclimatic zones of Tamil Nadu in 2021–2022. The adult and nymphal characters were used for the in situ identification of the whitefly species. Besides coconut, other host plants harboring whiteflies and causing significant damage in coconut-associated landscapes also were examined for whiteflies and recorded. Sixty palms per location, three fronds per palm, and three

leaflets per frond were examined, and damage intensity, parasitism, diversity, and the interspecies ratios were recorded.

The coconut palms at each location were also examined for fronds with intensive growth of sooty mold on the upper surface. The fronds with more than 50% necrosis caused by insect feeding were rated for damage intensity using a rating system after Pradhan et al. (2022), with Damage Intensity (%) = (Number of infested fronds per tree/Total number of frond per tree) × 100 (Elango et al. 2019).

The leaflets with late-instar nymphs and pseudo-puparium of *A. rugioperculatus* were collected, the waxy secretions were removed using ethanol, and the specimens were examined using a Pullox magnifier. Nymphs that appeared black were parasitized, whereas healthy nymphs were pale green. Puparial cases with intact parasitoids and parasitoid emergence holes were counted to calculate percent natural parasitism. Randomly collected parallel sets of infested coconut leaflets with young whitefly life stages were collected and safely stored in rearing boxes for transport to the laboratory to allow for parasitoid emergence for identification.

Analysis of species diversity at different locations was by Shannon and Simpson indices of diversity (Shannon 1949, Simpson 1949), and the Bray–Curtis Similarity Matrix (Bray and Curtis 1957) was used to calculate the compositional species similarity of two locations (Beta diversity) based on the species population in each locale. Host plant species of different whiteflies present in the coconut landscapes and ecosystems bearing significant damage were recorded and graded as detailed by Banumathi et al. (2020).

Data recorded as percentages were transformed to arcsine values, and data in numbers were square root transformed. Analysis of variance of the transformed data was conducted using the Statistical Analysis Software (SAS Institute 2022), and the mean values were compared using Tukey's HSD test at a 5% level of significance.

Results and Discussion

Coconut plantations in India are infested by six species of whiteflies, including five invasive species—*A. rugioperculatus, A. dispersus, P. bondari, P. minei, A. atratus*—and one indigenous species, *Aleurocanthus arecae* David and Manjunatha. Their occurrence on different host plants was reported earlier from Tamil Nadu by Geetha et al. (1998), Srinivasan et al. (2016), Banumathi et al. (2020), and Selvaraj et al. (2021). Globally, coconut palms in Brazil were reported with 17 whitefly species (De Omena et al. 2012), which may bode for greater whitefly problems in India agriculture if additional invasion and spread occurs. *Aleurodicus rugioperculatus* and *P. bondari* have rapidly and extensively spread over Tamil Nadu state in fewer than 6 yr from their introduction into South India, with higher damage intensity. The Coconut Research Station (CRS) in Veppankulam recorded the greatest damage intensity (70.4 ± 2.8%) among the locations sampled, followed by Pudukkottai (66.1 ± 1.8%) and Salem (63.6 ± 2.4%) ($F = 599.18$; df = 33; $P < 0.0001$). Coimbatore, a key coconut-growing district in Tamil Nadu (Kannan et al. 2017), recorded 37.5 ± 0.5% damage intensity (Table 1). Though these whiteflies have spread in Tamil Nadu, their successful establishment was

Table 1. Details of locations across six agroclimatic zones of Tamil Nadu surveyed for coconut whitefly complex, damage intensity, and percent parasitization of *A. rugioperculatus* recorded in coconut.*

Location**	Damage Intensity*** (% ± SE)	Parasitization (% ± SE) of *A. rugioperculatus*	Adults per Leaflet ± SE				
			A. rugioperculatus	*A. dispersus*	*P. bondari*	*P. minei*	*A. atratus*
Northeastern zone							
Vellore	37.8 ± 0.8ijk	34.1 ± 2.5m	6.2 ± 2.7lmn	0.1 ± 0.04de	12.8 ± 2.0gh	0.3 ± 0.1l	1.3 ± 0.1e
Tiruvannamalai	32.8 ± 1.6fg	29.8 ± 1.0n	4.1 ± 1.1o	0.0 ± 0j	11.0 ± 1.9ij	0.0 ± 0o	0.0 ± 0i
Villupuram	39.9 ± 1.4jkl	21.1 ± 0.7qr	8.0 ± 2.3h	0.0 ± 0j	10.8 ± 1.0j	0.0 ± 0o	0.0 ± 0i
Kanchipuram✦	11.5 ± 0.6a	2.9 ± 0.2u	1.4 ± 0.9s	0.0 ± 0j	3.8 ± 0.6op	0.0 ± 0o	0.0 ± 0i
Cuddalore✦	29.5 ± 1.1def	24.4 ± 1.4p	6.7 ± 1.0jk	0.0 ± 0j	12.8 ± 2.2gh	0.0 ± 0o	0.0 ± 0i
Marakkanam✦	20.6 ± 1.0c	17.1 ± 1.9s	2.6 ± 0.5pq	0.0 ± 0j	4.4 ± 0.9o	0.0 ± 0o	0.0 ± 0i
Northwestern zone							
Krishnagiri	40.8 ± 0.7klm	54.7 ± 0.7ef	5.6 ± 1.4n	0.2 ± 0.1b	25.7 ± 1.3b	2.6 ± 0.6a	3.0 ± 0.2b
Dharmapuri	43.8 ± 1.2mno	50.8 ± 0.7gh	5.9 ± 0.8mn	0.1 ± 0.04ef	31.1 ± 1.1a	1.3 ± 0.5c	3.2 ± 0.4a
Salem	63.6 ± 2.4s	46.5 ± 1.3ij	16.7 ± 2.3c	0.2 ± 0.1b	24.4 ± 1.6b	0.7 ± 0.2f	0.4 ± 0.1h
Namakkal	28.8 ± 1.0de	23.2 ± 0.5pq	5.7 ± 1.2n	0.02 ± 0i	11.9 ± 0.9hi	0.8 ± 0.1d	0.0 ± 0i
Western zone							
Coimbatore✦✦	37.5 ± 0.5ij	68.5 ± 1.7b	12.0 ± 1.6e	0.03 ± 0h	18.0 ± 0.8e	1.8 ± 0b	2.4 ± 0.1c
Tiruppur	49.5 ± 0.9pq	58.3 ± 0.9d	11.2 ± 2.2e	0.1 ± 0cd	19.7 ± 1.2d	0.6 ± 0h	0.0 ± 0i
Sirumugai✦✦	50.4 ± 2.4pq	52.7 ± 1.4fg	9.4 ± 2.1g	0.1 ± 0.04c	6.3 ± 1.1n	0.5 ± 0.1i	2.3 ± 0.2d
Aliyar Nagar, CRS✦	32.2 ± 0.6fg	83.8 ± 1.2a	7.2 ± 1.5ij	0.0 ± 0j	10.7 ± 1.9jk	0.7 ± 0.1g	1.1 ± 0.1f
Erode	52.6 ± 1.5q	44.4 ± 0.7jkl	12.1 ± 1.9e	0.03 ± 0h	19.6 ± 1.5d	0.2 ± 0.1n	0.7 ± 0.1g

Table 1. Continued.

Location**	Damage Intensity*** (% ± SE)	Parasitization (% ± SE) of *A. rugioperculatus*	Adults per Leaflet ± SE				
			A. rugioperculatus	*A. dispersus*	*P. bondari*	*P. minei*	*A. atratus*
Cauvery Delta zone							
Veppankulam, CRS	70.4 ± 2.8t	17.6 ± 1.0s	28.6 ± 3.2a	0.04 ± 0g	17.6 ± 1.7e	0.0 ± 0o	0.0 ± 0i
Karur	39.1 ± 1.1jkl	42.4 ± 2.2l	10.1 ± 1.3f	0.0 ± 0j	11.2 ± 0.6ij	0.3 ± 0.1k	0.0 ± 0i
Tiruchirappalli	51.4 ± 1.6q	28.2 ± 1.3no	9.5 ± 0.4fg	0.0 ± 0j	13.5 ± 1.5g	0.0 ± 0o	0.0 ± 0i
Perambalur	33.6 ± 1.0gh	25.8 ± 1.7op	5.9 ± 0.6mn	0.0 ± 0j	7.9 ± 1.1m	0.0 ± 0o	0.0 ± 0i
Thiruvarur	14.3 ± 0.9b	19.4 ± 0.9rs	2.3 ± 0.4q	0.0 ± 0j	7.9 ± 1.6m	0.0 ± 0o	0.0 ± 0i
Nagapattinam✦	16.8 ± 0.4b	7.4 ± 0.5t	1.9 ± 0.2r	0.0 ± 0j	4.3 ± 0.3o	0.0 ± 0o	0.0 ± 0i
Southern zone							
Madurai	57.2 ± 2.1r	44.9 ± 2.1jkl	13.9 ± 1.7d	0.2 ± 0.1a	17.8 ± 0.8e	0.0 ± 0o	0.0 ± 0i
Theni	45.5 ± 1.3no	56.8 ± 1.4de	10.2 ± 1.9f	0.1 ± 0.04de	16.0 ± 1.0f	0.0 ± 0o	0.0 ± 0i
Pudukkottai	66.1 ± 1.8s	36.7 ± 1.1m	25.2 ± 3.4b	0.02 ± 0i	18.2 ± 1.5e	0.0 ± 0o	0.0 ± 0i
Thoothukudi	27.6 ± 1.1d	37.3 ± 0.9m	4.5 ± 0.6o	0.0 ± 0j	9.8 ± 0.6kl	0.0 ± 0o	0.0 ± 0i
Tirunelveli	44.1 ± 1.4mno	42.7 ± 1.6kl	7.6 ±0.7hi	0.0 ± 0j	8.6 ± 1.1m	0.3 ± 0.1l	0.0 ± 0i
Virudhunagar	41.2 ± 0.8klm	35.7 ± 1.2m	6.4 ± 1.1klm	0.1 ± 0.04f	9.5 ± 2.1l	0.0 ± 0o	0.0 ± 0i
Tenkasi	44.2 ± 2.1mno	49.2 ± 1.5hi	9.5 ±1.7fg	0.0 ± 0j	21.8 ± 1.8c	0.3 ± 0.1m	0.0 ± 0i
Ramanathapuram	31.4 ± 2.0efg	30.4 ± 2.4n	4.6 ± 1.2o	0.0 ± 0j	8.4 ± 1.9m	0.0 ± 0o	0.0 ± 0i
Rameswaram✦	11.0 ± 0.4a	8.9 ± 0.6t	1.9 ± 0.3r	0.0 ± 0j	3.4 ± 0.6p	0.0 ± 0o	0.0 ± 0i
Sivagangai	42.4 ± 1.2lmn	37.2 ± 1.8m	6.6 ± 1.1jkl	0.0 ± 0j	6.2 ± 1.7n	0.0 ± 0o	0.0 ± 0i
Dindigul	46.9 ± 0.9op	45.9 ± 1.3ijk	9.0 ± 2.9g	0.02 ± 0i	15.9 ± 1.4f	0.0 ± 0o	0.0 ± 0i

Table 1. Continued.

Location**	Damage Intensity*** (% ± SE)	Parasitization (% ± SE) of *A. rugioperculatus*	Adults per Leaflet ± SE				
			A. rugioperculatus	*A. dispersus*	*P. bondari*	*P. minei*	*A. atratus*
High Rainfall zone							
Valliyur	41.7 ± 1.7lm	50.5 ± 2.1gh	6.0 ± 1.0lmn	0.0 ± 0j	17.7 ± 1.2e	0.4 ± 0.1j	0.0 ± 0i
Kanyakumari✦	36.3 ± 0.8hi	62.1 ± 1.9c	7.2 ± 1.7ij	0.0 ± 0j	20.2 ± 1.7d	0.8 ± 0.1e	0.0 ± 0i
P value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
CV	1.7	1.6	1.3	0.2	1.2	0.4	0.7

* Means followed by a common letter(s) are not significantly different by Tukey's HSD test at 5 percent level.
** CRS, Coconut Research Station.
*** Damage Category: 0.0, nil; 0.01–20.00, very low; 20.01–40.00, low; 40.01–60.00, moderate; 60.01–80.00, high; 80.01–100.00, very high.
✦ Locations in coastal areas.
✦✦ Locations near the Western Ghats.

rather low in Rameswaram, Kanchipuram, and Thiruvarur, resulting in damage intensity levels of 11.0 ± 0.4%, 11.5 ± 0.6%, and 14.3 ± 0.9% in those respective regions.

The parasitoids *Encarsia guadeloupae* Viggiani and *E. dispersa* Polaszek were found to be potential biocontrol agents among all the natural enemies observed against *A. rugioperculatus*. *Encarsia guadeloupae* is well established in the western zone of Tamil Nadu, with the highest parasitisation of 83.8 ± 1.2% at CRS, Aliyar Nagar, and 68.5 ± 1.7% in Coimbatore (Table 1) ($F = 1{,}110.36$; df = 33; $P < 0.0001$). In contrast, parasitism was significantly less in the Kanchipuram district of the Northeastern zone of Tamil Nadu with 2.9 ± 0.2%, followed by Nagapattinam of the Cauvery Delta zone (7.4 ± 0.5%). The higher parasitism by these parasitoids in the western zone (Table 1) resulted in reduced population levels of *A. rugioperculatus*. Contrarily, the hot and humid climatic conditions and low parasitoid establishment might have caused the higher damage intensity at CRS, Veppankulam of Cauvery Delta Zone, Pudukkottai of Southern Zone, and Salem of Northwestern Zone.

Damage intensity by *A. rugioperculatus*, as reported in previous studies, was very high in Karnataka, reaching 70.7% in the Southern Transition Zone of Karnataka (Pradhan et al. 2022). Similarly, in Tamil Nadu, the rate of infestation by *A. rugioperculatus* was relatively high in the western zone with a reported lower parasitism in 2019 (Elango et al. 2019). However, our results revealed increased parasitism of *A. rugioperculatus* in the western and southern zones of Tamil Nadu recently, which might have subsequently accounted for lower damage rates observed there.

We recorded all five invasive whitefly species in only 7 of the 34 locations surveyed—Coimbatore, Sirumugai, Salem, Dharmapuri, Krishnagiri, Vellore, and Erode—where coconut was the host plant (Table 1). *Aleurodicus dispersus*, which colonized coconut plantations in India in the 2000s, has almost been displaced from the coconut ecosystem by other invasive whiteflies. *Aleurodicus rugioperculatus* and *P. bondari* were universally found in all the locations sampled (Table 1), making them the predominant of the five invasive species. The successive introduction of *P. bondari* and *P. minei* in 2019 has, in subsequent times, reduced the population density of *A. rugioperculatus*. In areas with significant damage intensity, CRS Veppankulam and Pudukottai recorded *A. rugioperculatus*'s maximum population of 28.6 ± 3.2 and 25.2 ± 3.4 adults/leaflet, respectively ($F = 1{,}690.31$; df = 33; $P < 0.0001$). In contrast, populations of *P. bondari* were highly dense in Dharmapuri and Krishnagiri areas, with 31.1 ± 1.1 and 25.7 ± 1.3 adults/leaflet, respectively (Table 1) ($F = 1{,}202.43$; df = 33; $P < 0.0001$). Concomitantly, the population density of the other three whitefly species was lower, with the maximum of *A. dispersus* at Madurai (0.2 ± 0.1 adults/leaflet) ($F = 1{,}054.78$; df = 33; $P < 0.0001$), *A. atratus* at Dharmapuri (3.16 ± 0.4 adults/leaflet) ($F = 10{,}218.3$; df = 33; $P < 0.0001$), and *P. minei* at Krishnagiri (2.64 ± 0.6 adults/leaflet) ($F = 13{,}020.4$; df = 33; $P < 0.0001$). Earlier, Mohan et al. (2022) reported similar observations of a higher incidence of spiraling whitefly, *A. dispersus,* in the Madurai region. The neotropical whitefly, *A. atratus*, was earlier reported from the Mandya and Mysore districts of Karnataka (Selvaraj et al. 2019) and has now invaded and spread across the northwestern regions of Tamil Nadu adjoining

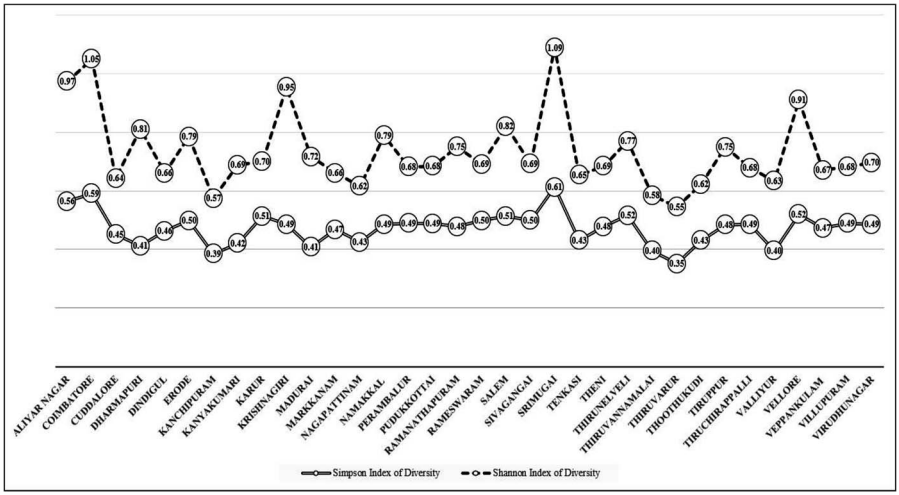

Fig. 1. Diversity indices of whitefly complex in coconut landscapes across different locations.

Karnataka. *Aleurotrachelus atratus* and the nesting whitefly, *P. minei*, are now present across the northwestern Tamil Nadu regions colonizing coconut ecosystems. However, the presence of *P. minei* in the colonies of *A. atratus* negatively impacted the latter, reducing their vigor (Josephrajkumar et al. 2020). The infestation by *P. minei* was high in the Indian Andaman and Nicobar Islands, where 20 nests per leaf were reported in *Psidium guajava* (Dubey 2019).

Aleurodicus dispersus seemingly is competitively deprived of coconut groves for survival due to the dominant nature of two other invasive whiteflies, *A. rugioperculatus* and *P. bondari,* in many coconut landscape locations. However, in coconut landscape backgrounds, *A. dispersus* remains an important pest in crops like guava, *P. guajava*, and tapioca, *Manihot esculenta* Crantz.

Both the Simpson and Shannon indices were high in Sirumugai (0.61 and 1.09), followed by Coimbatore (0.59 and 1.05) and Aliyar Nagar (0.56 and 0.97) (Fig. 1). In contrast, the Simpson and Shannon indices of Thiruvarur (0.35 and 0.55) were estimated to be the lowest, depicting low diversity of whiteflies there. The Bray–Curtis Similarity Matrix revealed the highest similarity between Theni and Dindigul (97.4%) and the lowest between Kanchipuram and CRS, Veppankulam (20.1%) (Fig. 2).

Three other plants—butterfly palm (*Dypsis lutescens* H. Wendel), custard apple (*Annona squamosa* L.), and guava (*P. guajava* L.)—supported any four of five invasive species of whiteflies with the absence of *A. dispersus* in butterfly palm and *A. atratus* in the latter two hosts (Table 2). The population of *A. rugioperculatus* was high in coconut, whereas *P. bondari* in *Annona squamosa* with a nymphal density of more than 50 nymphs/leaf (Table 2). Reasonably, the numbers and species ranges of host plants for *A. rugioperculatus* and *P. bondari* are higher than for *P. minei* and *A. atratus*, which may be a reason resulting in their limited spread. Though the egg spiral of *A rugioperculatus* was present in many plants, only a few plants (Table 2) supported all the life stages of the species.

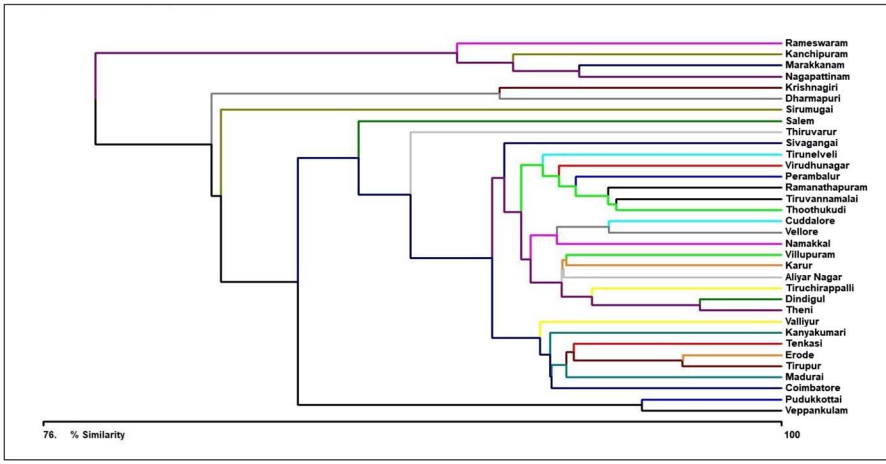

Fig. 2. Bray–Curtis Similarity Cluster analysis on populations of whitefly complex across different locations of Tamil Nadu.

Psidium guajava hosted *A. dispersus* and *P. minei*, along with another invasive whitefly, the woolly whitefly, *Aleurothrixus floccosus* (Maskell), with high infestation rates. The neotropical whitefly, *A. atratus*, was found feeding on only two palm species—coconut and butterfly palm—with significant damage. Overall, the cumulative damage of these invasive coconut whiteflies was very high in *Annona squamosa*, *Plumeria obtusa* L., and *P. guajava*. Though these invasive whitefly infestations were low in coconut along the coastal areas, considerably high damage intensity of whiteflies was observed in other host plants. Simultaneously, the locations with high damage infestation in coconut recorded significantly less damage in the alternate hosts. Metabolic changes in the coconut palms in coastal areas could have contributed to the low damage rates and needs further investigation. These results indicate that coconut is the preferred primary host for a few of these whiteflies. When the primary host becomes unfavorable due to other abiotic conditions, these whiteflies colonize alternate hosts for survival.

Invasive whiteflies have occupied coconut landscapes and infested southern peninsular parts of India. The spread of these whiteflies is rapid, with severe damage. It has become a matter of concern involving inaccessible plant protection measures owing to fears of brewing ecological disturbances and other practical issues associated with implementing plant protection measures. Interestingly, in Western regions, with the aid of parasitoids and other associated factors, the region experienced moderate damage at present compared to days of invasive whiteflies introduction. In contrast, coconut landscapes in the coastal areas recorded lower infestation levels by these invasive species, coupled with the very poor establishment of parasitoids. The low damage intensity may be due to abiotic factors that need to be investigated. At the same time, the state's central region recorded low parasitism and, consequently, high damage intensities. The complexity, diversity, and spread of these whiteflies are highly influenced by abiotic and biotic factors, which need further research for predicting the potential distribution of these pests.

Table 2. Host plant spectrum of coconut-infesting invasive whiteflies in coconut landscapes.

Host Plant	Family	Grade of Infestation*					Cumulative Damage
		A. rugioperculatus	*A. dispersus*	*P. bondari*	*P. minei*	*A. atratus*	
Annona reticulata L.	Annonaceae	I	—	III	I	—	High
Annona squamosa L.	Annonaceae	II	I	IV	I	—	Very high
Canna indica L.	Cannaceae	I	—	—	—	—	Moderate
Citrus medica L.	Rutaceae	I	—	—	—	—	Moderate
Cocos nucifera L.	Arecaceae	III	I	III	I	I	High
Dypsis lutescens H. Wendel	Arecaceae	II	—	II	I	I	High
Leucaena leucocephala Lam.	Fabaceae	—	—	II	—	—	High
Manihot esculenta Crantz	Euphorbiaceae	—	I	—	—	—	Low
Manilkara zapota (L.)	Sapotaceae	I	—	I	I	—	Low
Millettia pinnata (L.)	Fabaceae	—	I	I	—	—	Low
Musa paradisiaca L.	Musaceae	I	I	I	—	—	Moderate
Plumeria obtusa L.	Apocynaceae	—	I	II	—	—	Very high
Psidium guajava L.	Myrtaceae	I	IV	II	II	—	Very high
Syzygium cumini (L.)	Myrtaceae	—	I	I	I	—	Low
Terminalia catappa L.	Combretaceae	II	—	I	I	—	High
Theobroma cacao L.	Malvaceae	II	—	I	—	—	Moderate

* I, $\leq$10 adults and nymphs/10 cm^2; II, 10 to 30 adults and nymphs/10 cm^2; III, 31 to 50 adults and nymphs/10 cm^2; IV, $>$50 adults and nymphs/10 cm^2.

Augmenting the natural enemies and preventing the further spread of whitefly species could be the key to limiting the populations of these invasive whitefly species. Positive interactions between the pest's natural enemies could be enhanced to effectively manage whiteflies in coconut production.

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References Cited

Arun, K., E. Janeeshma, J. Job and J.T. Puthur. 2021. Physiochemical responses in coconut leaves infected by spiraling whitefly and the associated sooty mold formation. Acta Physiol. Plant. 43: 1–13.

Banumathi, K., M. Murugan, S. Jeyarani, S. Mohankumar, V. Balasubramani and C. Sowmiya. 2020. Prevalence of invasive Aleyrodidae harbouring horticultural host plants in different ecosystems of Tamil Nadu. J. Entomol. Zool. Stud. 8: 886–890.

Borowiec, N., S. Quilici, J. Martin, M. Issimaila, A. Chadhouliati, M. Youssoufa, L. Beaudoin-Ollivier, G. Delvare and B. Reynaud. 2010. Increasing distribution and damage to palms by the Neotropical whitefly, *Aleurotrachelus atratus* (Hemiptera: Aleyrodidae). J. Appl. Entomol. 134: 498–510.

Bray, J.R. and J.T. Curtis. 1957. An ordination of the upland forest communities of southern Wisconsin. Ecol. Monogr. 27: 326–349.

Chand, R., A. Jokhan and R. Kelera. 2019. Spiralling whitefly and its management practices in the South Pacific. A review. Adv. Hortic. Sci. 33: 123–131.

De Omena, R.P.M., E.C. Guzzo, J.M.S. Ferreira, F.A.C. De Mendonça, A.F. De Lim, F. Racca-Filho, A.E. Santana and X. Ni. 2012. First report on the whitefly, *Aleurodicus pseudugesii* on the coconut palm, *Cocos nucifera* in Brazil. J. Insect Sci. 12: 1–6.

Dubey, A. 2019. *Paraleyrodes minei* laccarino (Hemiptera: Aleyrodidae)—A new invasive pest threat to Andaman and Nicobar Islands, India. Phytoparasitica 47: 659–662.

Elango, K., S. Jeyarajan Nelson, S. Sridharan, V. Paranidharan and S. Balakrishnan. 2019. Biology, distribution and host range of new invasive pest of India coconut rugose spiralling whitefly *Aleurodicus rugioperculatus* Martin in Tamil Nadu and the status of its natural enemies. Int. J. Agric. Sci. 11: 8423–8426.

Geetha, B., M. Loganathan and M. Swamiappan. 1998. Record of spiralling whitefly, *Aleurodicus dispersus* Russell on groundnut. Insect Environ. 4: 55.

Josephrajkumar, A., C. Mohan, M. Babu, A. Krishna, V. Krishnakumar, V. Hegde and P. Chowdappa. 2019. First record of the invasive Bondar's nesting whitefly, *Paraleyrodes bondari* Peracchi on coconut from India. Phytoparasitica 47: 333–339.

Josephrajkumar, A., C. Mohan, M. Babu, P. Prathibha, V. Hegde and V. Krishnakumar. 2020. Diagnosis of invasive whitefly species co-occurring on coconut. Curr. Sci. 119: 1101–1105.

Kannan, B., K. Ragunath, R. Kumaraperumal, R. Jagadeeswaran and R. Krishnan. 2017. Mapping of coconut growing areas in Tamil Nadu, India using remote sensing and GIS. J. Appl. Nat. Sci. 9: 771–773.

Ministry of Agriculture and Farmers Welfare, Government of India. 2022. Coconut Development Board. 20 May 2023 . (https://coconutboard.gov.in/Statistics.aspx).

Mohan, C., A. Josephrajkumar, P. Prathibha, M. Sujithra, J.V. Sajan and K. Anes. 2022. Pests and their management in coconut, Pp. 1411–1439. *In* M. Mani (ed.), Trends in Horticultural Entomology. Springer Verlag, Singapore.

Palaniswami, M., K. Pillai, R. Nair and C. Mohandas. 1995. A new cassava pest in India. Cassava Newsl. 19: 6–7.

Pradhan, S.K., A. Shylesha, K. Selvaraj and B. Sumalatha. 2022. Distribution, host range and status of invasive rugose spiralling whitefly, *Aleurodicus rugioperculatus* Martin (Hemiptera: Aleyrodidae) in Karnataka. Agric. Res. 11: 499–505.

SAS Institute. 2022. SAS OnDemand for Academics. SAS Institute Inc., Cary, NC.

Selvaraj, K., B.V. Sumalatha and R. Sundararaj. 2021. New distributional record of invasive Neotropical coconut whitefly *Aleurotrachelus atratus* (Hemiptera: Aleyrodidae) in Tamil Nadu India. Insect Environ. 24: 230–235.

Selvaraj, K., R. Sundararaj and B. Sumalatha. 2019. Invasion of the palm infesting whitefly, *Aleurotrachelus atratus* Hempel (Hemiptera: Aleyrodidae) in the Oriental region. Phytoparasitica 47: 327–332.

Shanas, S., J. Job, T. Joseph and G. Anju Krishnan. 2016. First report of the invasive rugose spiraling whitefly, *Aleurodicus rugioperculatus* Martin (Hemiptera: Aleyrodidae) from the Old World. Entomon 41: 365–368.

Shannon, C.E. 1949. The Mathematical Theory of Communication, by CE Shannon (and Recent Contributions to the Mathematical Theory of Communication), W. Weaver. Univ. of Illinois Press, Champaign.

Simpson, E.H. 1949. Measurement of diversity. Nature 163: 688–688.

Srinivasan, T., P.A. Saravanan, A. Josephrajkumar, K. Rajamanickam, S. Sridharan, P.M.M. David, N. Natarajan and N. Shoba. 2016. Invasion of the rugose spiralling whitefly, *Aleurodicus rugioperculatus* Martin (Hemiptera: Aleyrodidae) in Pollachi tract of Tamil Nadu, India. Madras Agric. J. 103: 349–353.