



# Insights into the incidence, severity and morphometrics of the invasive Rugose Spiralling Whitefly *Aleurodicus rugiopectus* Martin in coconut belts of Tamil Nadu, India

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## Abstract

Rugose Spiralling Whitefly (RSW) (*Aleurodicus rugiopectus* Martin; Aleurodidae: Hemiptera) began invading India in 2016 from Southern Peninsula, later expanded to several other states of the country. As a result, India now considers RSW to be a serious invasive insect pest on coconut. To understand its severity in Tamil Nadu, an extensive field survey was taken up, which revealed that the RSW abundance was in decreasing trend in Cauvery Delta Zone followed by Southern zone, High Rainfall zone and Western zone. The frond damage was lowest in Southern zone (Madurai, 14.43%) and statistically on par with Western zone (Coimbatore, 28.76%) whereas highest frond and leaflet damage was observed in Cauvery Delta zone (Pudukkottai, 82.3 and 72.66% respectively). The aphelinid parasitoid, *Encarsia guadeloupeae* Viggiani adult's emergence was high in Coimbatore district with a parasitization rate of 93.25 per cent. In morphometric studies, many morphological parameters measured in *A. rugiopectus* adult male and female were high in Pudukkottai population. Score plot analysis of both sexes of *A. rugiopectus* clearly showed that no biotype existed. The nucleotide sequence of RSW was deposited in GenBank as OP 295,073 which had > 98 per cent similarity with those DNA sequences submitted in NCBI database OP0295073, OP414609 and MK 883,219. Five years down the infestation of RSW on coconut, the severity has been reduced drastically with the subsequent buildup of the parasitoid *E. guadeloupeae*. Thus conserving *E. guadeloupeae* through the establishment of “banker plants” and refraining from insecticide spraying can effectively suppress RSW in the long term.

**Keywords** Exotic whiteflies · *Encarsia guadeloupeae* · Conservation biological control · Pesticide holiday · Leaflet damage

## Introduction

Exotic insect species are considered important threats to agricultural biosecurity, occupation, human and animal health, forestry and biodiversity as they cause substantial profitable

losses. Global trade, tourism and transport along with other swift components of globalization are encouraging biological invasions at a phenomenal rate (Lelmini and Sankaran, 2021). Nowadays, geographical features contribute significantly to the invasiveness (Kumar et al. 2014; Seebans et al. 2015; Early et al. 2016). In coconut ecosystem, exotic whitefly complex viz., Rugose Spiralling Whitefly (RSW) (Shanas et al. 2016; Selvaraj et al. 2016; Srinivasan et al. 2016), Bondars Nesting Whitefly (BNW) (Josephraj Kumar et al. 2019b; Chandrika Mohan et al. 2019), Neotropical Nesting Whitefly (NNW) (Chandrika Mohan et al. 2019), Oriental Palm Whitefly (OPW) (Selvaraj et al. 2019a) are considered significant, as they upset the biotic balance.

The first existence of RSW on coconut was noticed in India during August, 2016 in Anamalai block, Pollachi

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taluk, Coimbatore district, Tamil Nadu (Srinivasan et al. 2016). It was simultaneously recorded from Kerala on coconut, mango and guava at Changanassery, Kottayam District following accidental introduction through transport of seedlings (Shanas et al. 2016). Furthermore, occurrence of RSW was expanded to various parts of India (Visalakshi et al. 2021; Chakravarthy et al. 2017) on more than 200 species of host plants. During its initial phase of incursion, the damage was severe and accounted to significant yield loss in several hybrids (Srinivasan et al. 2016; Josephrajakumar et al. 2020). Nymphs and adults of RSW sucked the sap from coconut palms and excreted copious honeydew, which resulted in sooty mould (*Leptoxyphium* sp.) development that reduced the photosynthetic activity. Recently sooty mould scavenging beetle *Leiochrinus nilgirianus* Kaszab (Coleoptera: Tenebrionidae) was discovered in Kerala during 2017 (Josephrajakumar et al. 2018).

The morphometric studies have been generally carried on homopteran insects due to its cryptic nature and formation of many biotypes and sibling species (Mehrpavar et al. 2012; Inayatullah et al. (1987). The phenotypic flexibility has caused uncertainty in the identification of populations, genetic groupings and putative species that have been identified only in *Bemisia tabaci* (Gennadius). Additionally, this has caused synonymization and redescriptions. Therefore, the populations that were physically indistinguishable or indistinct had been named as biotypes, genetic groupings or presumptive species. Such a phenotypic modulation in sucking pests urged to decipher the morphometric variables in RSW.

*Encarsia guadeloupeae* Viggiani, an aphelinid parasitoid of Hymenoptera is considered as an important parasitoid on the nymphs of RSW (Chen et al. 2015). There are three aphelinid parasitoids viz., *E. guadeloupeae*, *E. noysei* and *Aleuroctonus* found to parasitize *A. rugioperculatus* (Boughton et al. 2015). In Kerala, parasitism by *E. guadeloupeae* was reported as high as 80% on RSW (Chandrika Mohan et al. 2017). *E. guadeloupeae* can be mass reared on guava and banana plants infested with the second and third nymphal stages of RSW and can be considered as a potential candidate for the management of RSW (Francis et al. 2016). Thus, parasitism by *Encarsia* spp. is very crucial on the bio-suppression of RSW and its parasitic potential in a given population of RSW in an agro-ecological unit based on weather factors is vital for assessment.

During 2017 to 2019 survey conducted in important coconut growing districts of Tamil Nadu indicated that the damage intensity of RSW on coconut was found high in district of Coimbatore followed by Tiruppur and Erode districts of Tamil Nadu, India (Elango 2019). The coconut palm was more severely and intensely infested than the other host plants (Sundararaj et al. 2020; Selvaraj et al. 2019b). Sustained surveillance on RSW in a coconut belt is therefore decisive to understand

current level of infestation for the region so as to evolve an effective management strategy. During 2016, in Tamil Nadu and Karnataka regions the natural parasitism potential on these invasive whiteflies was very low. In some regions like Singanallur, Subbengoundenpudur and Ravanapuram of Coimbatore district of Tamil Nadu the natural parasitism was recorded about 4.5%, 6.1% and 7.1% as well as in Karnataka 7 to 80% natural parasitisation was recorded (Pradhan et al. 2022). During the initial stage of the intrusiveness of this whiteflies, many reports (Saranya et al. 2021; Abitha et al. 2022; Selvaraj et al. 2019b) showed that population of RSW was very high due to very less parasitization potential of *E. guadeloupeae*, after five years the whitefly population has also reduced and showing the increasing rate of parasitoid has been proven here.

In this backdrop, extensive field surveys were conducted to explore the distribution and incidence of RSW on coconut palms as well as its damage potential and the parasitization potential of *E. guadeloupeae* in different agro-climatic zones of Tamil Nadu. The morphometric parameters in adult whiteflies were measured and the Principal Component Analysis (PCA) for estimated variables, Eigen analysis and Score plot analysis of both sexes were performed and presented.

## Materials and methods

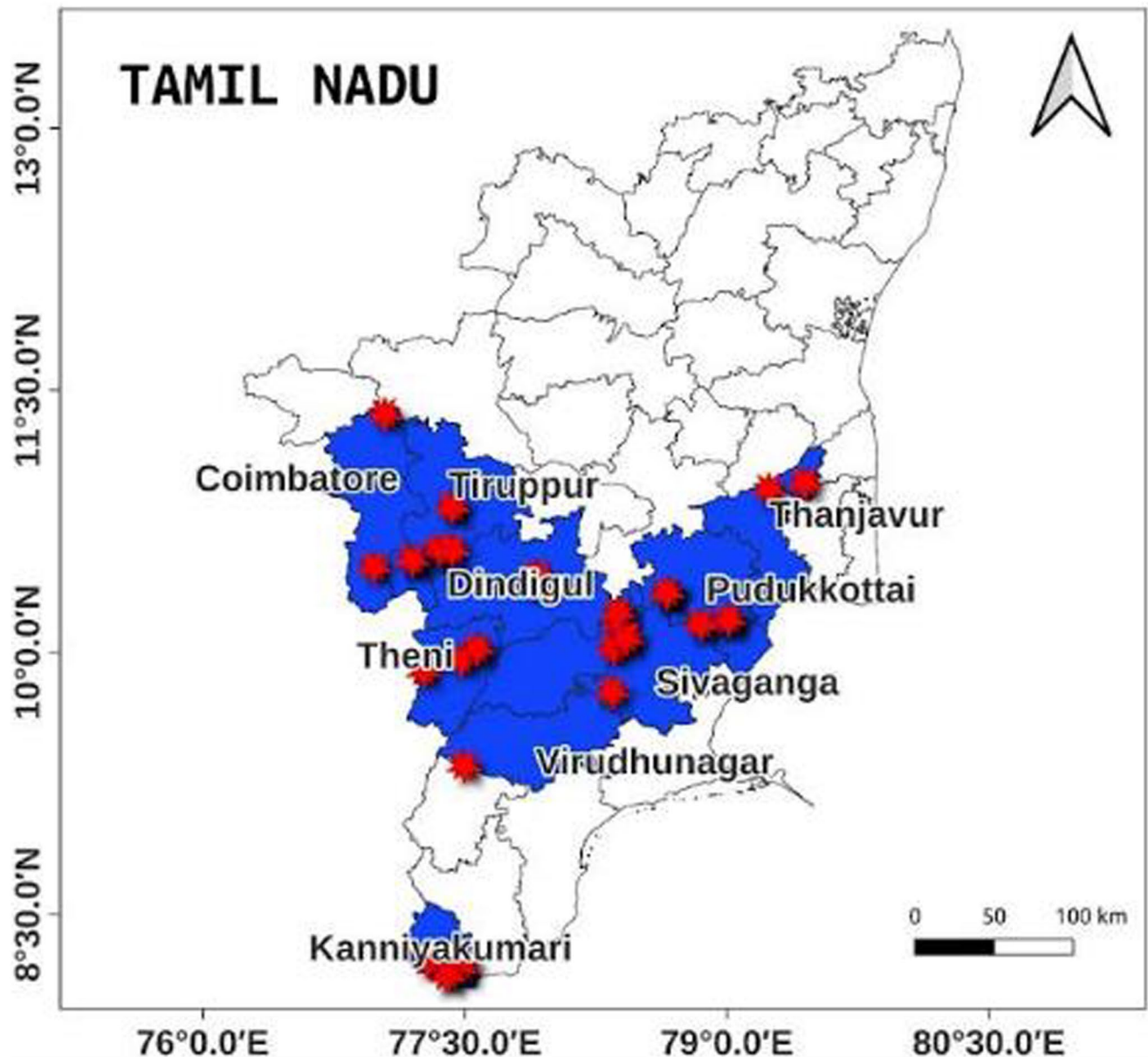
### Distribution and incidence of RSW in major coconut growing areas of Tamil Nadu

An extensive field survey was carried out during March to April, 2022 in four different agro-climatic zones of Tamil Nadu viz., Western zone (Coimbatore, Tiruppur, Theni, Dindigul), Cauvery Delta Zone (Thanjavur, Pudukkottai), Southern zone (Madurai, Sivagangai, Virudhunagar) and High Rainfall zone (Kanyakumari). Totally, 10 districts with 28 locations were surveyed (Fig. 1). In each location, ten coconut palms were selected randomly from insecticide free orchards for examination. To determine the population of RSW, five leaflets from five different fronds were sampled randomly per tree. The number of egg spirals, nymphs and adults were counted separately. The mean number of egg spirals, nymphs and adults were calculated for each district and the means are separated by least significant difference using analysis of variance (ANOVA) (Arifunnahar et al. 2016).

### Morphological identification of whitefly and parasitoid species

#### Whitefly pupal characterization

The puparia of whiteflies were processed and the slides were prepared as outlined by Martin (1999). Puparial



**Fig. 1** Distribution map showing the surveyed locations in Tamil Nadu

samples were soaked in 10% KOH and kept for 24 h. Specimens were then kept in distilled water for 10 to 15 min. To the distilled water, two drops of double or triple stain was added. Samples were removed from the stain and placed in 75% ethyl alcohol for 10 to 15 min. This process removed the stain from unsclerotized area. Samples were then transferred from 75% ethyl alcohol to 95% ethyl alcohol and allowed to sit for 15 to 20 min. Thus the staining process was completed. Samples were removed from 95 per cent EtOH and placed in clove oil for 30 min. Later the specimens were removed from the clove oil and placed on a slide with Canada balsam. Slides were labelled and cover slips

placed on specimens. Slides were put in a drier oven for three weeks at 35 °C. The puparia of whiteflies were viewed under the Leica Microscope (M205).

#### **Parasitoid *Encarsia guadeloupae* identification**

Adult *E. guadeloupae* are small (0.6–0.7 mm) with brownish body and dark coloured head. Scutellum yellow in colour (Fig. 2). Wing hyaline and fringes of hair present in wing margins. Antennae geniculate and eight segmented (Elango and Nelson 2020).

## Morphometric measurements of male and female adult RSW

For morphometric measurements, 10 females and 10 males of RSW were collected from different locations and preserved in 70 per cent EtOH. The characters such as antennal length, body length, body width, wing size (forewing length and forewing width) (Fig. 3a, b) and leg morphometry (hind-tarsal length and hind-tarsal width) (Fig. 3c), were measured using Leica Microscope (M205). The sexual dimorphism was implicated by the presence of claspers at the tip of the male abdomen (Fig. 3d) (Harish et al. 2016).

## Diversity analysis

Univariate one-way single factor ANOVA was used to identify significant characteristics (Kalaisekar et al. 2012). Then, without making any prior assumptions about groupings, Principal Component Analysis (PCA; SAS procedure; PRINCOMP; SAS version 9.1.3, SAS Institute Inc., Cary, NC, USA) was used to evaluate the components for total variation among the specimen. This was done by calculating a linear combination of variables that explained the most of the total variation. Based on the results, a Biplot / loading plot and a Scree plot were drawn (R Software, 2019). Principal component analysis was also performed using the above said software for all quantitative features (Harish et al. 2016).

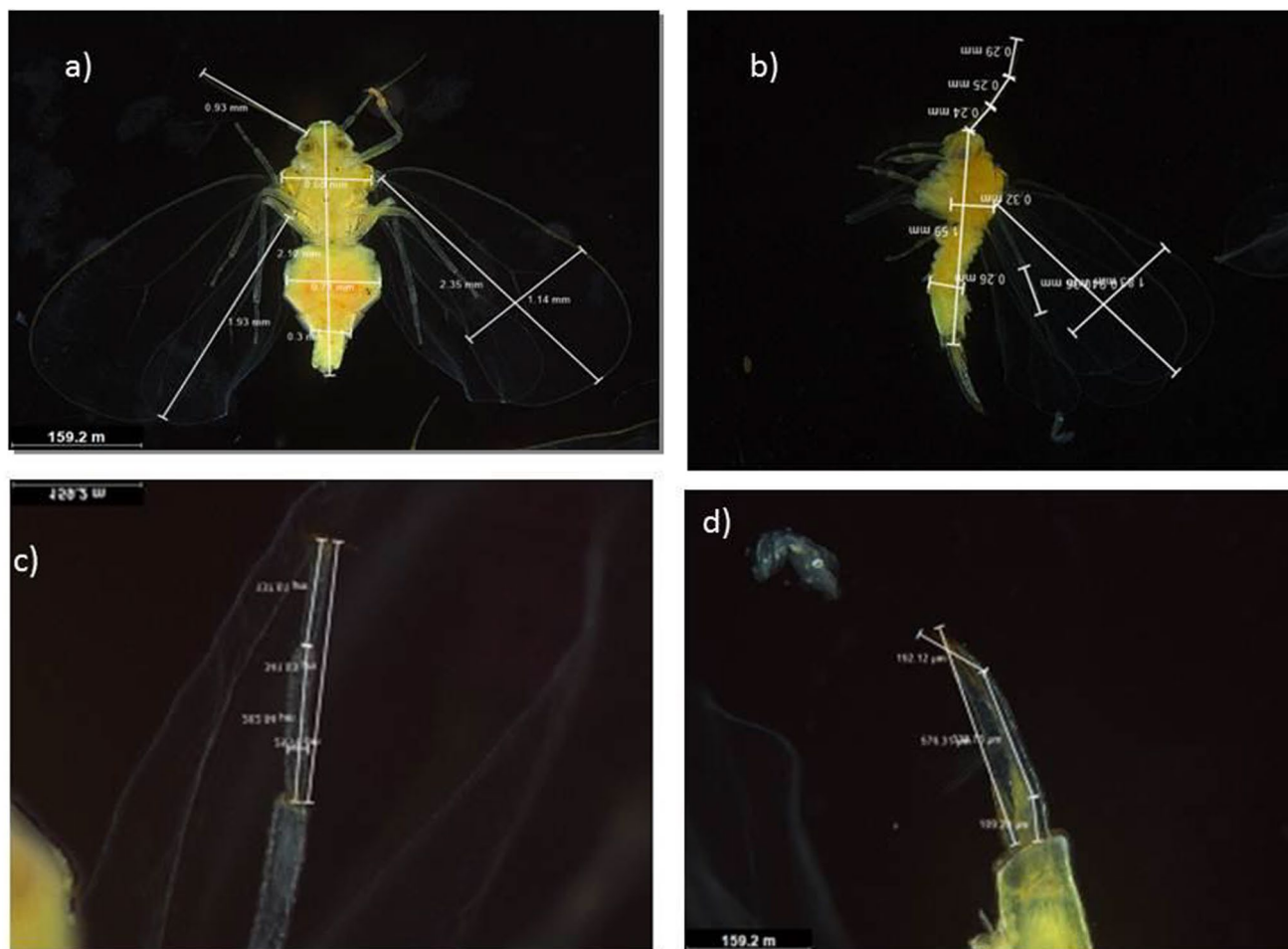
**Fig. 2** Adult parasitoid *Encarsia guadeloupe* (with yellow scutellum)



## Molecular characterization of adult RSW

Genomic DNA was isolated from adult whiteflies that emerged from puparia identified morphologically as *A. rugioperculatus* collected from coconut palm leaflets using modified CTAB method. Five adult whiteflies were transferred into sterile microfuge tube containing 500 µl of CTAB buffer and were crushed finely using micropestle. The extract was incubated at 55°C for 60 min. After incubation, the tubes were centrifuged at 5000 rpm for 5 min. The supernatant was transferred to fresh tube and added with equal volume of chloroform: isoamyl alcohol (24:1) and mixed to form an emulsion by inverting the tube. The mixture was centrifuged at 13,000 rpm for 15 min. The upper aqueous phase was removed and added with 0.8 ml isopropanol and mixed gently by inverting the tube. The tubes were incubated at -20°C for 1 h and after incubation the mixture was centrifuged at 13,000 rpm for 15 min. The supernatant was decanted and the pellet was washed with 70% alcohol (500 µl) and further centrifuged at 13,000 rpm for 15 min. The supernatant was decanted and the pellet was air dried and added with 20 µl TE buffer. The DNA was confirmed by running 0.8% agarose gel.

The primers LCO1490 5'-ggcaacaatcataaagattgg-3' and HC02198: 5'- taaacttcagggtgaccaaataatca-3' (Folmer et al. 1994) (Eurofins Genomics India, Bengaluru) in salt-free status were used for the amplification of mitochondrial cytochrome oxidase subunit I (COI) gene, and a polymerase chain reaction (PCR) was performed by following



**Fig. 3** Morphometric measurements of *Aleurodicus rugioeperculatus* (a) Female (b) Male (c) Hindtibial length (d) Clasper

the procedure detailed by Sambrook and Russell (2001). All the PCR amplifications were carried out in a thermal cycler (Techne Flexigene) as follows: initial denaturation at 95 °C for 5 min followed by 35 cycles of denaturation at 94 °C for 1 min, annealing at 55 °C for 1 min, extension at 72 °C for 1 min 30 s, and final extension at 72 °C for 10 min for end filling (Josephraj Kumar et al. 2020). The reaction products were analysed in 1.0% agarose gel, and the gel was documented using a molecular imaging system (Molecular Imager® Gel Doc XR+, Bio-Rad, Hercules, California, USA). The amplicons obtained were purified from each reaction mixture using the PCR purification kit from Qiagen. The purified products were sequenced at BioPvt. Ltd., Bengaluru and compared with the nucleotide sequences of the already identified whiteflies for validation. The COI nucleotide sequences of different whitefly species used for comparison were retrieved from GenBank (Benson et al. 1999) including nucleotide sequences deposited from our laboratory as well. BLAST (Altschul et al. 1990) was used to identify related sequences available in the GenBank database. Multiple sequence alignments were made

using ClustalW. A phylogenetic tree was constructed with COI gene sequences using Mega XI software by Neighbour joining method with 1000 replications for bootstrap analysis and *B. tabaci* as an out group.

### Phylogenetic tree construction

A partial mitochondrial cytochrome oxidase (COX1) gene sequence was used to construct the Phylogeny tree. This analysis involved 18 nucleotide sequences (retrieved from the NCBI database) which included five species, *A. rugioeperculatus*, (*A. dispersus*, *Paraleyrodes bondari*, *P. pseudonaranjae*, and (*B. tabaci*). *B. tabaci* was used as an outgroup. There were a total of 714 positions in the final dataset. Branches corresponding to partitions reproduced in less than 50% bootstrap replicates are collapsed. The percentage of replicate trees in which the associated taxa clustered together in the bootstrap test 1000 replicates are shown next to the branches. Initial tree(s) for the heuristic search were obtained automatically by applying Neighbor-Join and BioNJ algorithms to a matrix of pairwise

distances estimated using the Maximum Composite Likelihood (MCL) approach, and then selecting the topology with superior log likelihood value. The rate variation model allowed for some sites to be evolutionarily invariable ([+I], 46.01% sites). Codon positions included were 1st + 2nd + 3rd + Noncoding.

### Damage intensity of RSW

The damage intensity in the coconut grove in the above said ten districts of Tamil Nadu was calculated using the formula given below. Ten trees were randomly selected for the observation of damage intensity.

- i. Damage intensity of whiteflies in terms of per cent frond damage.

$$\text{Damage intensity (\%frond damage)} = \frac{\text{No. of fronds infested per tree}}{\text{Total no. of fronds per tree}} * 100$$

- ii. Damage intensity of whiteflies in terms of per cent leaflet damage.

$$\text{Damage intensity (\%leaflet damage)} = \frac{\text{No. of leaflets infested per tree}}{\text{Total no. of leaflets per tree}} * 100$$

- iii. Palm Infestation Index.

It was done based on the damage grade, as given by Srinivasan et al. 2016 (Table 1).

### Parasitization rate of *E. guadeloupa* on immature stages of RSW

A total of 30 whitefly-infested leaf bits of 10 cm length from each tree were excised, brought to the laboratory using sterile thin plastic covers. The emergence of *E. guadeloupa* adults were examined using microscope and confirmed using the adult emergence exit. The whitefly adults emerged

through a ‘T’ shaped hole from the pupal exuviae (Fig. 4a), whereas the parasitoid-emerged puparium had a ‘O’ shaped hole (Fig. 4b). Moreover, parasitized whitefly nymphs were found to be black in colour (Fig. 4c), while the healthy ones were cream-coloured (Fig. 4d).

The number of whitefly nymphs parasitized and the total number of nymphs were counted to calculate the per cent natural parasitization using the formula.

$$\text{Parasitization (\%)} = \frac{\text{Number of parasitized whitefly nymphs}}{\text{Total number of whitefly nymphs}} * 100$$

Furthermore, the total number of parasitized nymphs and the parasitoid-emerged puparium which had a ‘O’ shaped hole were counted to calculate the per cent adult emergence of *E. guadeloupa* by the given formula.

$$\text{Adult emergence (\%)} = \frac{\text{Number of exit holes in pupa}}{\text{Total number of parasitized nymphs}} * 100$$

## Results

### Distribution and incidence of RSW in different coconut growing districts

The results depicted that the maximum number of egg spirals was recorded in Cauvery Delta districts, Pudukkottai ( $59.99 \pm 12.8$  nos./leaflet) and Thanjavur ( $19.56 \pm 6.35$  nos./leaflet) (Table 2). The extent of nymphal population in various zones observed ranged from  $15.78 \pm 4.62$  to  $81.80 \pm 22.14$  nos./leaflet. Theni district recorded the least mean nymphal population of  $15.78 \pm 4.62$  nos./leaflet, whereas the highest population was recorded in Pudukkottai district ( $81.80 \pm 22.14$  nos./leaflet) (Table 2). The adult population of RSW on coconut leaflets was 15 times higher in Pudukkottai district ( $79.11 \pm 22.33$  nos./leaflet) compared to all other districts observed.

**Table 1** Grade scale for recording infestation index for RSW

Adult population	Grade	Category	Infestation Index
No egg spirals and sooty mould encrustation noticed	0	Nil	0
Fewer than 10 egg spirals per leaflet; presence of sooty mould encrustation in 5–6 lower most fronds	1	Low	0.1 to 1.0
10 to 20 egg spirals per leaflet; presence of sooty mould encrustation in 10–12 fronds	2	Medium	1.01 to 2.0
More than 20 adults per leaflet; presence of sooty mould encrustation in more than 12 fronds	3	High	2.01 to 3.0

**Fig. 4** Parasitized and unparasitized nymphs of *Aleurodicus rugioperculatus* (a) “T” shaped exit of adult whitefly (b) “O” shaped exit of adult parasitoid (c) Parasitized nymphs (Black coloured) (d) Healthy nymphs (Creamy colour)



### Morphological characteristics of RSW

The stained puparium of RSW (Fig. 5a) when viewed under microscope ascertained the following characters, the reticulated border and compound pores with dagger-shaped axial processes (Fig. 5b), rugosed operculum and triangular form of the lingual (Fig. 5c). Male adults possess long clasper with a small whiplash like aedugus (Fig. 5d) present within it whereas adult female genitalia have setaceous gonapophysis and smooth cement gland ending with a folded sac (Fig. 5e). Based on these features the puparium and adult characters it is identified as *A.rugioperculatus* (Fig. 5) (Josephraj Kumar et al. 2019a).

### Morphometric measurements of adult RSW

Among different morphological characters measured for male and female adults, the measurements were found higher for female RSW when compared to that of male. Variations in antennal length, body length, body width, forewing length, forewing width, hind tarsal length were found to be significantly different among the populations collected from different agro-climatic zones of Tamil Nadu. In case of adult male, the maximum antennal length

(1.006 mm), highest body length (3.596 mm), highest body width (0.760 mm), highest forewing length (2.708 mm) and highest clasper length (1.461 mm) were recorded on RSW collected from Pudukkottai district, whereas the hind-tarsal length (0.562 mm) was highest for RSW collected from Sivagangai district. In contrast, RSW-collected from Tiruppur district showed lowest antennal length (0.736 mm). The body length (3.178 mm), body width (0.434 mm) and hind-tarsal length (0.421 mm) and forewing length (2.266 mm) were low in Coimbatore district-collected RSW and those RSW collected from Madurai district showed lowest forewing width (0.926 mm) (Table 3).

Female adult characters of RSW revealed that antennal length (0.904 mm), body length (3.926 mm), body width (0.836 mm) and forewing length (2.808 mm) were found higher for RSW collected from Pudukkottai district. The forewing width was found higher in RSW collected from Thanjavur district (1.682 mm) and hind-tarsal length was higher in Sivagangai district-collected RSW (0.721 mm). The lowest antennal length (0.730 mm) was recorded in RSW collected from Coimbatore district as well as the body length (3.340 mm) and body width (0.542 mm). Forewing length (2.494 mm) was lowest in Tiruppur district and lowest forewing width were recorded in RSW collected from Theni district (1.321 mm) (Table 4).

**Table 2** Incidence of *Aleurodicus Rugioperculatus* in different coconut growing districts of Tamil Nadu (March– May, 2022)

	District*	Egg Spirals (no./leaflet) <sup>#</sup>	Nymphal Population (no./leaflet) <sup>#</sup>	Adult Population (no./leaflet) <sup>#</sup>
01	Madurai	34.37 ± 10.68 (4.75) <sup>b</sup>	24.20 ± 10.25 (4.84) <sup>bc</sup>	5.34 ± 3.43 (2.23) <sup>bc</sup>
02	Sivagangai	34.26 ± 28.95 (5.51) <sup>bc</sup>	28.33 ± 5.49 (5.31) <sup>b</sup>	2.96 ± 1.94 (1.64) <sup>cd</sup>
03	Theni	10.23 ± 2.30 (3.18) <sup>de</sup>	15.78 ± 4.62 (3.95) <sup>c</sup>	1.40 ± 0.46 (1.18) <sup>d</sup>
04	Dindigul	17.89 ± 5.55 (4.20) <sup>bcd</sup>	24.598 ± 1.28 (4.96) <sup>bc</sup>	1.93 ± 0.46 (1.38) <sup>d</sup>
05	Coimbatore	7.42 ± 1.95 (2.71) <sup>c</sup>	27.18 ± 6.87 (5.18) <sup>b</sup>	1.14 ± 0.21 (1.06) <sup>d</sup>
06	Tiruppur	15.25 ± 5.55 (3.86) <sup>cde</sup>	24.08 ± 9.82 (4.84) <sup>bc</sup>	2.98 ± 1.09 (1.70) <sup>cd</sup>
07	Thanjavur	19.56 ± 6.35 (4.37) <sup>bcd</sup>	23.41 ± 3.28 (4.83) <sup>bc</sup>	1.47 ± 0.53 (1.20) <sup>d</sup>
08	Pudukkottai	59.99 ± 12.80 (7.71) <sup>a</sup>	81.80 ± 22.14 (8.99) <sup>a</sup>	79.11 ± 22.33 (8.83) <sup>a</sup>
09	Kanyakumari	22.69 ± 11.18 (4.70) <sup>bcd</sup>	29.77 ± 5.21 (5.44) <sup>b</sup>	2.56 ± 0.65 (1.54) <sup>cd</sup>
10	Virudhunagar	21.66 ± 7.55 (5.52) <sup>bcd</sup>	25.96 ± 6.46 (5.76) <sup>bc</sup>	5.30 ± 2.55 (2.08) <sup>b</sup>
	CD(0.05)	1.913	1.209	0.889
	S.Ed	0.956	0.612	0.569

\* Mean value of 3 locations

<sup>#</sup> Mean population from 5 leaflets in 5 bottom fronds from 10 trees

In a column values are Standard deviation ± Mean values

Figures in the parentheses are square root transformed

### Principal component analysis (PCA) for estimated variables of adult whitefly

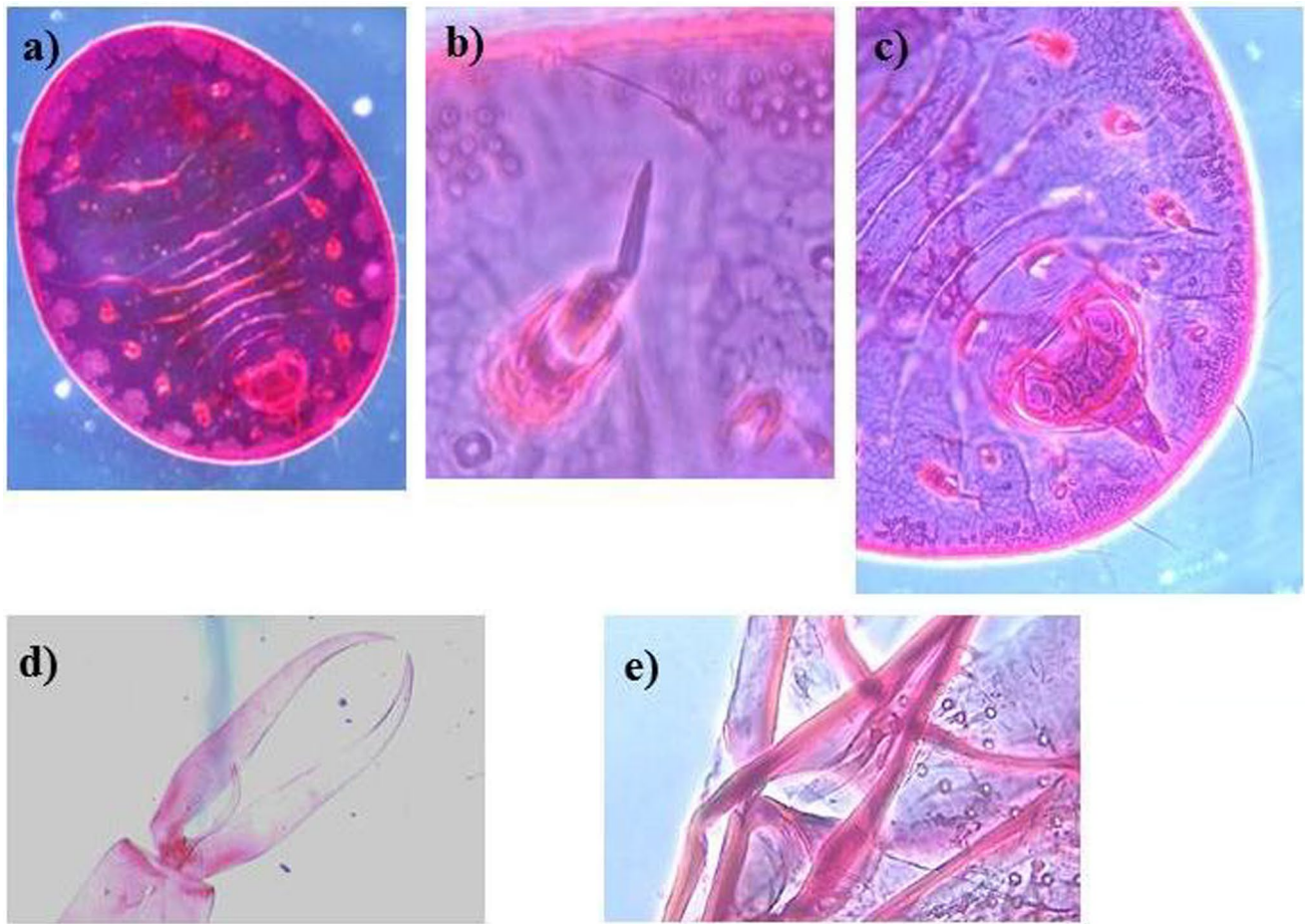
The results of PCA of adult male and female based on major eight and seven morphological characters respectively, revealed that the total cumulative variance for adult male for these principal components accounted to 58.87% adults. These principal components had Eigen values more than one. The principal component analysis divided eight traits into seven major components. The first principal component (PC 1) accounted for maximum variability into a single major group in case of adult male; which accounted for 58.87% of the total variation (Fig. 6). In PC1, the highest positive contributions are recorded in Antennal length (0.962), Forewing length (0.888) and body width (0.843). There are no negative contributions seen in PC1, PC2 and PC3. In PC2 accounted 19.97% variability, the most positive contributions are Forewing width (0.984 mm), Clasper length (0.748) and Hind tarsal length (0.33). The PC3 accounted 12.09% variance; where the positive contributors are seen in body length (0.894) (Table 5).

For the adult female, the variables are grouped into seven major principal components, where first four components

showed 56.53% for PC1, 23.70% for PC2, 11.75% for PC3 and 7.11% for PC4 (Fig. 7). Of the total major variation, PC1 showed the highest positive contribution for body width (0.899); body length (0.805), followed by forewing length (0.688), forewing width (0.255), Hind tarsal width(0.702), Hind tarsal length(0.091) and Antennal length(0.035) (Table 6). In PC 2, the positive contributions were recorded for forewing width (0.255) and negative contributions for antennal length (-0.124). In PC3, the positive contributions were recorded in antennal length (0.970) and body width (0.384) and the negative contributions was observed in Forewing length (-0.306) (Table 6). PC4 maintained merely 7.11% variability. The other principal components such as PC 5, PC 6 and PC 7 were not considered as major contributing principal components (Table 6).

### Plot of the first two principal components showing relation among various adult RSW characters

The correlation coefficient (r) between any two characters was the cosine of the angle between their vectors. The correlation coefficients indicated the relationship among the traits based on plot that had relatively large loading on PC 1 and



**Fig. 5** Pupal and adult characteristic features of *Aleurodicus rugioperculatus* (a) Habitus (b) Dagger like compound pores (c) Compound pores – Dagger like, 2 pairs of simple pores located on both sides of

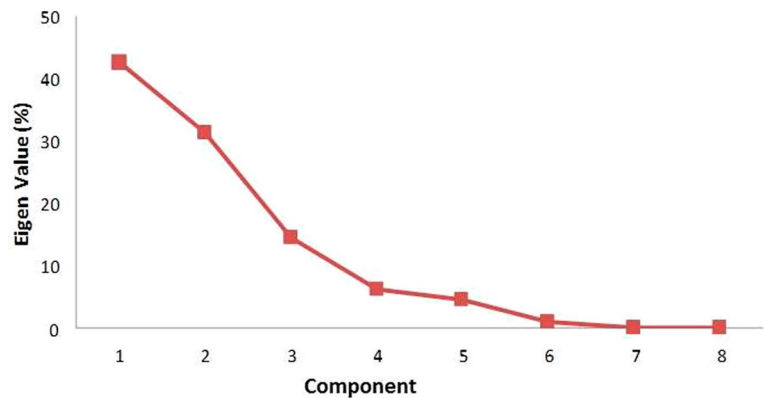
Vasiform Orifice and with rugosed operculum (d) Male genitalia – Long clasper & whiptail shaped aedagus (e) Female genitalia – Setaeous gonapophysis & Smooth cement gland with a folded sac

**Table 3** Morphometric measurements of male *Aleurodicus rugioperculatus* in different districts of Tamil Nadu

District	Antennal length (mm)	Body Length (mm)	Body width (mm)	Forewing Length (mm)	Forewing width (mm)	Hind tarsal length (mm)	Hind tarsal width (mm)	Clasper length (mm)
Madurai	0.960	3.282	0.580	2.440	0.926	0.451	0.04	1.024
Theni	0.860	3.499	0.588	2.336	1.027	0.432	0.03	1.033
Sivaganai	0.922	3.278	0.564	2.430	1.200	0.452	0.03	1.112
Thiruppur	0.736	3.378	0.494	2.294	1.122	0.562	0.03	1.240
Dindigul	0.986	3.292	0.596	2.506	1.128	0.431	0.03	1.310
Coimbatore	0.836	3.178	0.434	2.266	1.218	0.421	0.03	1.222
Thanjavur	0.978	3.570	0.584	2.500	1.280	0.561	0.04	1.452
Pudukkottai	1.006	3.596	0.706	2.708	1.240	0.560	0.04	1.461
<b>C.D</b>	0.029	0.051	0.014	0.059	0.024	0.009	0.000	0.030
<b>SE(m)</b>	0.010	0.018	0.005	0.020	0.008	0.003	0.000	0.010
<b>SE(d)</b>	0.014	0.025	0.007	0.029	0.012	0.004	0.000	0.015
<b>C.V.</b>	2.105	1.288	2.181	2.014	2.293	1.287	0.000	1.570

**Table 4** Morphometric measurements of female *Aleurodicus rugioperculatus* in different districts of Tamil Nadu

District	Antennal length (mm)	Body length (mm)	Body width (mm)	Forewing Length (mm)	Forewing width (mm)	Hind tarsal length (mm)	Hind tarsal width (mm)
Madurai	0.880	3.500	0.650	2.540	1.580	0.522	0.05
Theni	0.780	3.654	0.582	2.536	1.321	0.541	0.05
Sivagangai	0.922	3.772	0.606	2.530	1.462	0.721	0.05
Tiruppur	0.873	3.498	0.546	2.494	1.490	0.621	0.05
Dindigul	0.868	3.502	0.660	2.506	1.424	0.522	0.05
Coimbatore	0.730	3.340	0.542	2.566	1.460	0.501	0.05
Thanjavur	0.665	3.910	0.740	2.800	1.682	0.592	0.06
Pudukkottai	0.904	3.926	0.836	2.808	1.642	0.594	0.06
<b>C.D</b>	0.018	0.036	0.009	0.022	0.036	0.009	0.001
<b>SE(m)</b>	0.006	0.012	0.003	0.008	0.013	0.003	0.000
<b>SE(d)</b>	0.009	0.018	0.004	0.011	0.018	0.004	0.000
<b>C.V.</b>	1.642	1.310	1.318	0.771	2.239	1.592	1.355

**Fig. 6** Scree plot analysis of the principal components of the first two principal components showing relation among various *Aleurodicus rugioperculatus* male adult characters**Table 5** Eigen analysis of the correlation matrix in male *Aleurodicus Rugioperculatus*

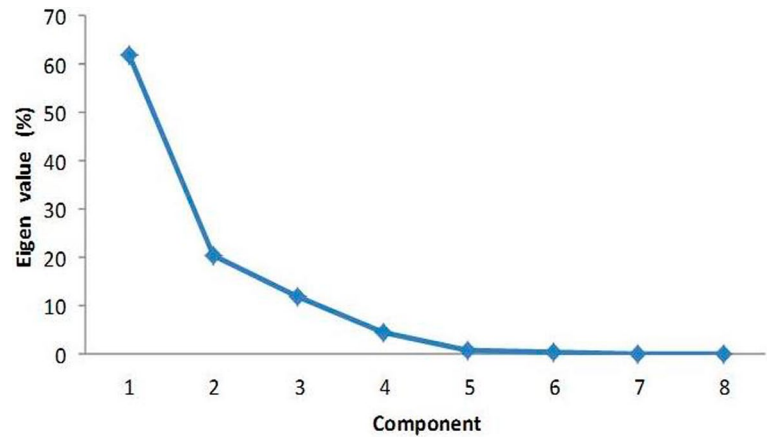
Eigen value	4.710	1.597	0.967	0.378	0.192	0.106	0.047
<b>Proportion</b>	58.874	19.972	12.092	4.796	2.407	1.325	0.590
<b>Cumulative</b>	58.874	78.847	90.939	95.675	98.083	99.409	100
<b>Principal components</b>							
	<b>PC1</b>	<b>PC 2</b>	<b>PC 3</b>	<b>PC 4</b>	<b>PC 5</b>	<b>PC 6</b>	<b>PC 7</b>
Antennal length	0.962	0.084	0.044	-0.153	0.188	0.009	-0.071
Body length	0.275	0.154	0.894	0.281	0.148	0.034	0.007
Body width	0.843	0.211	0.311	0.196	0.314	0.093	-0.135
Forewing Length	0.888	0.181	0.241	0.246	0.086	0.048	0.225
Forewing width	0.085	0.984	0.085	0.102	0.028	0.072	0.002
Hind tarsal length	0.040	0.337	0.416	0.804	0.251	0.047	0.012
Hind tarsal width	0.543	0.028	0.217	0.276	0.762	0.025	0.004
Clasper length	0.336	0.748	0.205	0.355	0.100	0.386	0.007

PC2 axes. In case of biplot for adult male there were near zero (angle 0–25) between many characters (small obtuse/acute angles between their vectors) and as correlation coefficient ( $r = \cos\theta = +1$ ) between their vectors, they had strong positive correlations. The characters with strong positive correlations are body length. In case of biplot for adult female strong positive correlations was observed between body length, body width, forewing length, forewing width and hindtarsal length (Figs. 8 and 9).

### Score plot of first two principal components for adult RSW collected from various districts

Scores for adult whitefly collected from different districts of Tamil Nadu, based on PC1 and PC2. The eight districts were grouped into 4 major distinct clusters/quarters. In case of male, the distribution pattern revealed that maximum number of entries (6) were included in quarter III, namely Madurai, Dindigul, Sivagangai and Theni (Fig. 8). Quarter III had

**Fig. 7** Scree plot analysis of the first two principal components showing relation among various *Aleurodicus rugioperculatus* female adult characters



**Table 6** Eigen analysis of the correlation matrix in female *Aleurodicus Rugioperculatus*

Eigen value	3.957	1.659	0.823	0.497	0.050	0.011	0.000
Proportion	56.536	23.701	11.757	7.111	0.726	0.167	0.00
Cumulative	56.536	80.237	91.995	99.106	99.832	99.999	100
<b>Principal components</b>							
	<b>PC1</b>	<b>PC 2</b>	<b>PC 3</b>	<b>PC 4</b>	<b>PC 5</b>	<b>PC 6</b>	<b>PC 7</b>
Antennal length	0.035	-0.124	0.970	0.204	-0.010	-0.007	0.000
Body length	0.805	0.291	-0.100	0.495	-0.079	-0.071	0.002
Body width	0.899	0.207	0.384	-0.031	-0.006	-0.003	-0.001
Forewing Length	0.688	0.629	-0.306	0.046	0.184	0.040	0.000
Forewing width	0.255	0.963	-0.026	0.074	-0.034	-0.028	0.000
Hind tarsal length	0.091	0.0544	0.209	0.972	0.007	0.006	0.000
Hind tarsal width	0.702	0.634	-0.261	0.097	0.075	0.149	0.000

three centres (Coimbatore, Thiruppur and Theni) and Quarter I (Pudukkottai) and Quarter II included Thanjavur. Score plot analysis of both sexes of RSW clearly showed that it does not have any biotypes because no such specific observations had been seen in different districts (Figs. 8 and 9).

### Molecular characterization of RSW

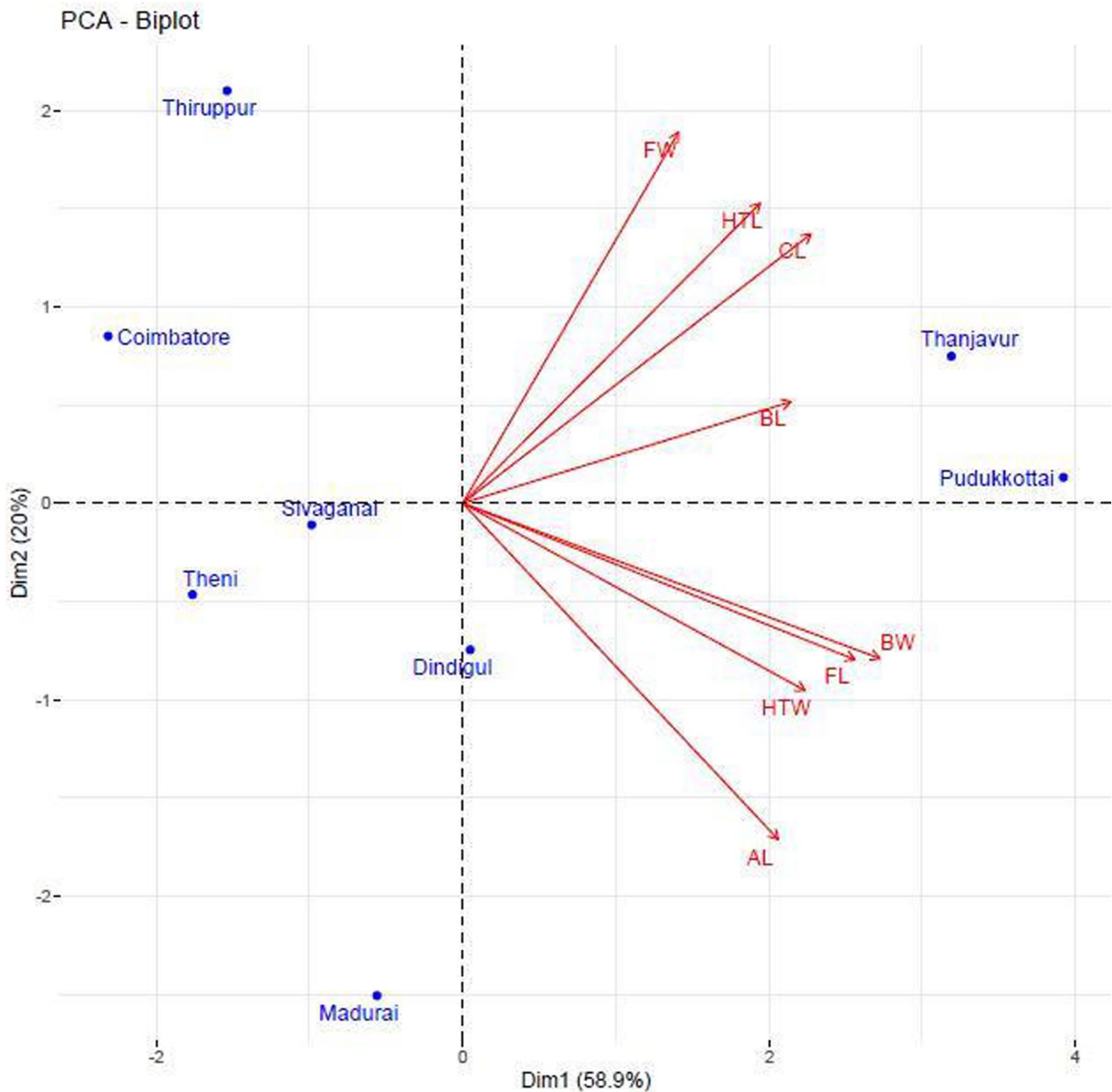
From the phylogenetic tree, it is clear that *A. rugioperculatus* and *A. dispersus* formed the same phylogenetic clade and the nucleotide of *A. rugioperculatus* obtained from the present study is about 100% similarity with those partial nucleotides of *A. rugioperculatus* retrieved from the GenBank supporting the species level identity of (*A. rugioperculatus*). Other members of Aleurodicinae (nesting whitefly group) viz., *P. bondari* and *P. pseudonaranjae* formed sister clades with *Aleurodicus* spp. which is in agreement with the evolutionary relationship and forming a typical outgroup with Aleyrodinae member, (*B. tabaci*). This established the species level identity of *A. rugioperculatus* in the present study and its genetic relatedness with other members of Aleurodicinae and Aleyrodinae group (Fig. 10). The consensus sequence has been submitted in NCBI genbank with the accession number (OP 295073).

### Damage intensity in terms of frond damage

The damage intensity of RSW on coconut palms was recorded in various districts and presented in Table 7. The total frond damage was significantly high on coconut palms in the Pudukkottai district as high as 82.3%. Coconut palms in Theni district recorded 66.74% frond damage followed by Virudhunagar, Thanjavur, Dindigul and Kanyakumari with damage intensity on a diminishing trend as 63.48%, 62.18%, 56.54% and 53.09%, respectively and were found non-significant. The lowest damage was found on coconut palms in Madurai district (14.43%) (Table 7).

### Damage intensity in terms of leaflets damage

Among all the districts surveyed, coconut palms in Pudukkottai district alone showed higher level of per cent damage intensity of 72.66 and Thanjavur was 24.0%. Coconut palms in Madurai, Kanyakumari, Dindigul, Sivagangai, Thiruppur, Coimbatore, and Virudhunagar recorded 7.03%, 8.66%, 12.33%, 14.08%, 16.06%, 17.04%, and 18.66% damage intensity, respectively (Table 7).



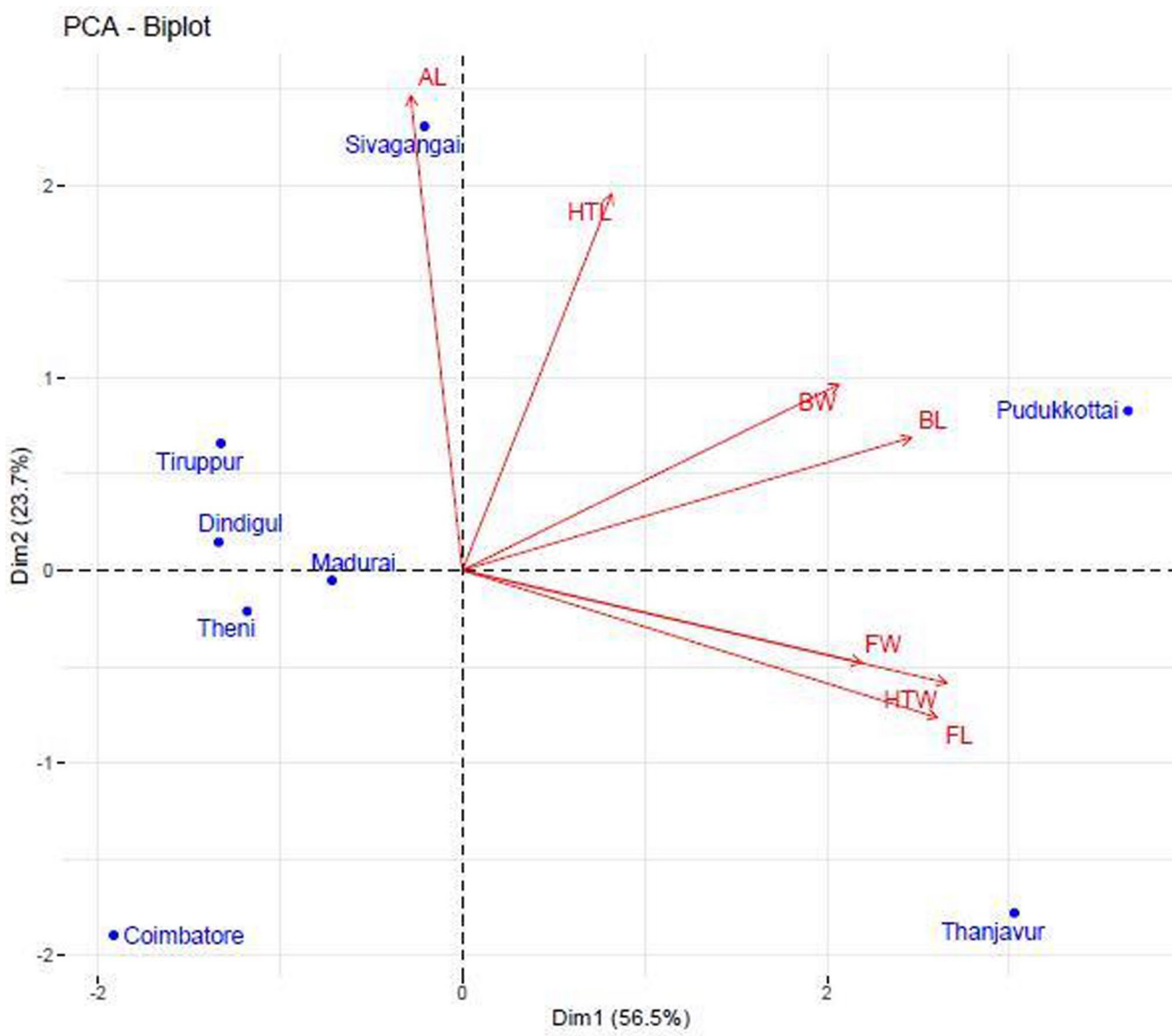
**Fig. 8** Biplot/loading and Score plot of the first two principal components showing relation among various *Aleurodicus rugioperculatus* male adult characters

### Pest index scale for the damage *A. Rugioperculatus*

According to the pest Indexing Scale on RSW-infested palms, low level of incidence was found on palms in the districts of Madurai (0.7), Theni (0.6) and Kanyakumari (0.8). Medium level of infestation was recorded on palms in Sivaganai, Dindigul, Coimbatore Tiruppur and Virudhunagar districts whereas the medium level (1.2 to 1.8) was noticed in whitefly affected palms whereas Pudukkottai and Thanjavur shows high level of infestation. (Table 7).

### Parasitism by *E. guadeloupae*

Among various locations surveyed, the highest percentage of *E. guadeloupae* parasitism was recorded on RSW-infested coconut palms in Coimbatore district (93.25%), which was statistically on par with Kanyakumari (91.40%) and Theni (92.07%) districts. These districts had nine-fold higher parasitism when compared RSW-infested coconut palms in Pudukkottai district with least parasitism (10.33%). At Dindigul district, RSW-infested palms recorded 77.83%



**Fig. 9** Biplot/loading and Score plot of the first two principal components showing relation among various *Aleurodicus rugioperculatus* female adult characters

parasitism and was on par with districts such as Tiruppur (78.69%), Thanjavur (75.88%), Virudhunagar (71.73%) and Sivagangai (77.00%) (Table 8).

**Adult emergence of *E. guadeloupae***

Adult emergence of *E. guadeloupae* with typical round hole on RSW pupae was found maximum in Coimbatore (85.99%) followed by Kanyakumari (82.87%) and Theni (81.77%) districts in a non-significant manner. RSW pupae on coconut palms at Pudukkottai showed minimum adult emergence of *E. guadeloupae* (15.93%) about five times less compared to the aforesaid districts. Adult emergence from RSW pupae recorded on palms in Tiruppur, Madurai

and Virudhunagar districts recorded between 50.73 and 66.04% and were on par with each other. Emergence of *E. guadeloupae* from RSW pupae recorded on palms in Sivagangai and Thanjavur district ranged from 39.22 to 49.26% (Table 8).

**Discussion**

In the Indian sub-continent, many exotic whiteflies were prevalent on different host plants viz., solanum whitefly, *Aleurotrachelus trachoides* (Back); RSW, *A. rugioperculatus*; Bondars Nesting Whitefly, *P. bondari* Peracchi and *P. minei* Iaccarino, guava woolly whitefly *Aleurothrixus*



**Fig. 10** Phylogenetic tree showing its genetic relatedness with other RSW

**Table 7** Damage intensity of *Aleurodicus Rugioperculatus* in terms of frond and leaflet damage

S. No.	District*	Frond damage <sup>#</sup> (%)	Leaflet damage <sup>#</sup> (%)	Palm indexing
01	Madurai	14.43 ± 1.26 (22.31) <sup>a</sup>	7.03 ± 2.41 (15.37) <sup>i</sup>	Low
02	Sivagangai	47.62 ± 6.44 (43.62) <sup>cd</sup>	14.80 ± 6.08 (22.62) <sup>f</sup>	Medium
03	Theni	66.74 ± 5.59 (54.84) <sup>f</sup>	6.33 ± 3.21 (14.57) <sup>j</sup>	Low
04	Dindigul	56.54 ± 1.00 (48.75) <sup>de</sup>	12.33 ± 8.08 (20.55) <sup>g</sup>	Medium
05	Coimbatore	28.76 ± 5.73 (32.36) <sup>ab</sup>	17.04 ± 6.31 (24.39) <sup>d</sup>	Medium
06	Tiruppur	34.77 ± 11.68 (35.91) <sup>bc</sup>	16.06 ± 16.46 (23.62) <sup>c</sup>	Medium
07	Thanjavur	62.18 ± 6.01 (52.08) <sup>de</sup>	24.00 ± 8.62 (29.33) <sup>b</sup>	High
08	Pudukkottai	82.3 ± 15.00 (66.35) <sup>g</sup>	72.66 ± 13.65 (58.47) <sup>a</sup>	High
09	Kanyakumari	53.09 ± 16.71 (46.81) <sup>de</sup>	8.66 ± 5.68 (17.11) <sup>h</sup>	Low
10	Virudhunagar	63.48 ± 3.02 (52.83) <sup>de</sup>	18.66 ± 7.76 (25.59) <sup>c</sup>	Medium
	<b>CD(0.05)</b>	<b>10.057</b>	0.478	
	<b>S.Ed</b>	5.890	0.021	

\*Mean value of 3 locations

<sup>#</sup>Mean population from 5 leaflets in 5 bottom fronds from 10 trees

In a column values are Standard deviation ± Mean values

Figures in the parentheses are arcsine transformed values

**Table 8** Parasitization potential of *Encarsia Guadeloupe* on nymphal stages of *Aleurodicus Rugioperculatus* (Mar- May 2022)

S.No.	Districts*	Parasitization (%)#	Adult emergence (%)#
01.	Madurai	85.29 ± 1.49 (67.48) <sup>ab</sup>	59.44 ± 5.18 (50.46) <sup>b</sup>
02.	Sivagangai	(77.00 ± 11.49) (61.80) <sup>b</sup>	39.22 ± 2.08 (38.77) <sup>bc</sup>
03.	Theni	(92.07 ± 1.71) (73.70) <sup>a</sup>	81.77 ± 2.05 (64.75) <sup>a</sup>
04.	Dindigul	(77.83 ± 9.94) (62.31) <sup>b</sup>	26.58 ± 0.24 (31.53) <sup>cd</sup>
05.	Coimbatore	93.25 ± 3.10 (74.06) <sup>a</sup>	85.99 ± 3.13 (68.755) <sup>a</sup>
06.	Tirupur	78.69 ± 10.01 (62.905) <sup>b</sup>	50.73 ± 20.92 (45.63) <sup>b</sup>
07.	Thanjavur	75.88 ± 4.80 (60.66) <sup>b</sup>	49.26 ± 13.15 (44.69±) <sup>bc</sup>
08.	Pudukkottai	10.33 ± 3.96 (18.50) <sup>e</sup>	15.93 ± 3.26 (22.83) <sup>d</sup>
09.	Kanyakumari	91.40 ± 2.05 (73.11) <sup>a</sup>	82.87 ± 3.61 (64.52) <sup>a</sup>
10.	Virudhunagar	71.73 ± 5.07 (60.41) <sup>b</sup>	66.04 ± 16.76 (48.19) <sup>b</sup>
	<b>CD(0.05)</b>	<b>8.201</b>	<b>13.56</b>
	<b>S.Ed</b>	<b>5.90</b>	<b>7.12</b>

\*Mean value of 3 locations

# Mean values were calculated from 30 leaf bits of 5 fronds in each location

Figures in the parentheses are arcsine transformed values

*flococcus* (Maskell) and acacia whitefly *Tetraleurodes acaciae* (Quaintance) in the recent past causing considerable damage. Out of which, RSW caused extensive damage to the coconut system and expanded to various districts in Karnataka, Kerala, Andhra Pradesh, Goa, Assam, and West Bengal (Selvaraj et al. 2017) where coconut is the key plantation crop sustaining livelihood. In this back drop, the results on distribution, incidence and damage intensity of RSW and the parasitism by the aphelinid parastoid, *E guadeloupeae* curtailing the incidence of RSW invasions on coconut are being discussed.

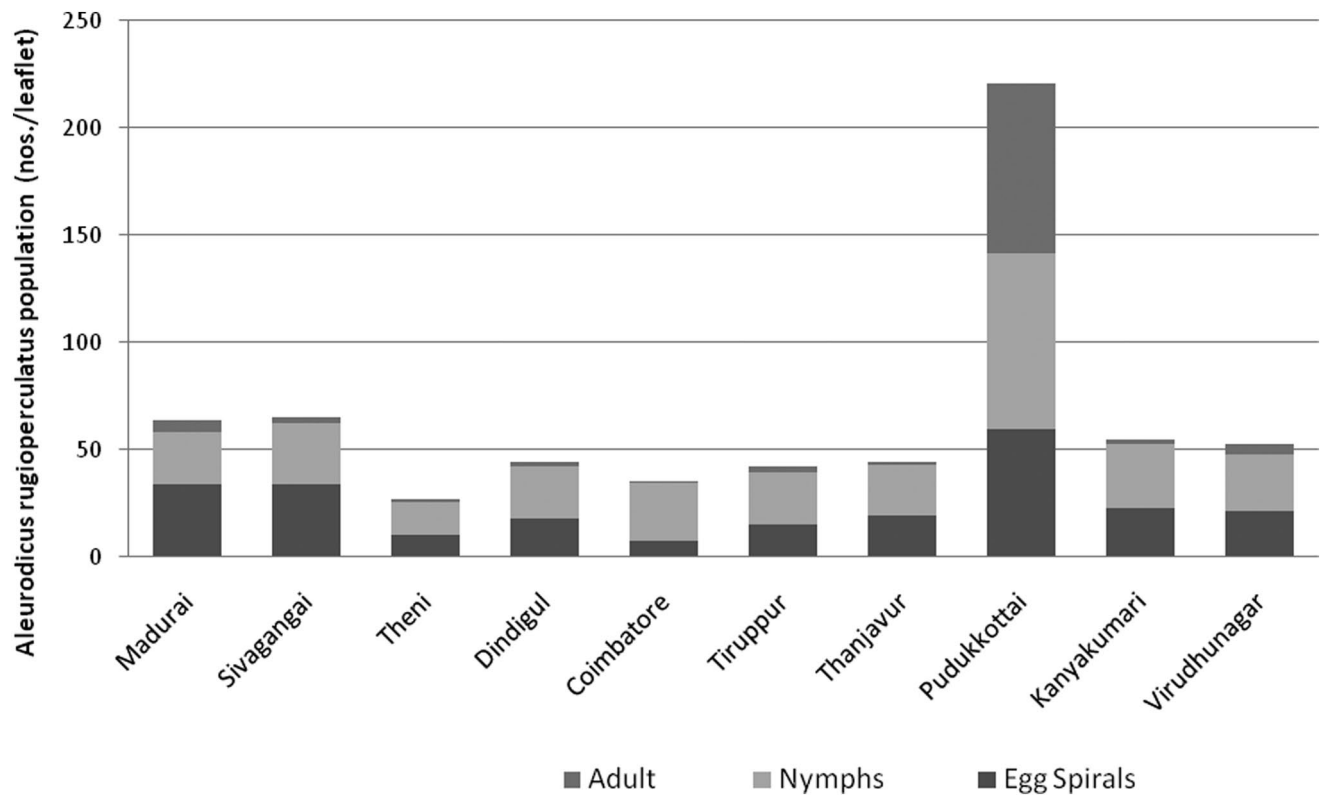
Our survey of *A. rugioperculatus* population confirm that the maximum number of egg spirals and nymphs were observed in Cauvery Delta districts followed by Southern zone districts, Western zone districts and high Rainfall zone districts. The egg spirals and nymphal population was highest in Pudukkottai as well as the adult population was 15 times higher (Fig. 11), which could be attributed to close proximity to coastal area and the reduced parasitism rates favoured its multiplication. However, Elango (2019) investigated the distribution of the RSW from August 2017 to February 2019 in major coconut growing districts of Tamil Nadu and reported that Coimbatore district had the highest prevalence, followed by Tiruppur and Erode. In coconut groves of Pollachi tract of Tamil Nadu, extensive field assessments were carried out by Srinivasan et al. (2016) and

it was observed that lower most fronds (10–12 fronds) were infested the most that have relatively crossed economic productivity and our survey also implied the same kind of damage in most districts surveyed.

Dutta et al. (2019) conducted a field survey to evaluate the pest status of RSW in coconut between September and November 2019 in four specific districts of Bangladesh. The findings showed that across different sites, RSW nymph and pupal populations per leaflet varied from 26.02 to 27.72 and 33.12 to 33.64 respectively, as well the whole tree infestation ranged from 46.66 to 68.33 per cent, whereas the similar trend of whitely population and damage was noticed in Southern and High rainfall zones of Tamil Nadu.

Many morphometric works have been carried exclusively for *B. tabaci* due to the occurrence of biotypes, cryptic and sibling species. Such a morphometric analysis made for RSW in the present study would go in a long way to decode minute variations in the natural population of the pest causing severe damage on coconut. Comprehensive analysis made by Principal Component Analysis (PCA) would serve as basic information to unveil the occurrence of any genetic variant in RSW.

According to our morphometric measurements of adult RSW, female adults were bigger in size when compared to male. Regarding adult male, several morphological parameters measured were found highest for the RSW collected



**Fig. 11** *Aleurodicus rugioperculatus* population in different coconut growing districts of Tamil Nadu (March – May, 2022)

from Pudukkottai district, whereas only a few parameters turned highest for whiteflies collected from Sivagangai district. With regard to the female adult characters also many parameters were found higher for RSW collected from Pudukkottai district and few turned higher in Thanjavur and Sivagangai district. In contrast, modulations were found the lowest for both male and female RSW collected from western zone (Tiruppur, Coimbatore and Theni).

Harish et al. (2016) studied nine distinct adult characteristics and fourteen different pupal characters of *B. tabaci* from major cassava growing districts from Kerala with no appreciable differences in majority of the analyzed characters across these agro-ecological zones. But the PCA analysis indicated that *B. tabaci* populations collected from Sulthan Bathery exhibited more variances than those from other locations. Our study corroborates that the PCA analysis for RSW accounted for maximum variability into a single major group for adult male; which accounted for 42.66% of the total variation and in female it extended up to 61.86%.

Correct identification of whitefly species through conventional puparium and adult taxonomy supported by molecular characterization using COI gene are key factors for evolving successful pest management programme (Josephraj Kumar et al. 2022). Partial nucleotide sequences of RSW existing in genebank OP414609 and MK 883,219 are with complete agreement with our sequence (OP0295073).

Additional molecular research employing these populations might provide an exact understanding of the existence of various genetic groups/biotypes in these areas. *Madrosiphoniella samborni* Gillette, a charyam aphid, was investigated for 21 morphological characteristics in 11 populations that were obtained from various geographic regions (Madjdzadeh and Melurparvar, 2009). The investigation confirmed the existence of physical barriers and climatic circumstances as the most significant factors causing population divergence, whereas in our study no such variants are been observed for RSW.

The total frond damage by RSW was significantly peaked in the Pudukkottai district to the extent of 82.3% followed by Theni district with 66.74% damage. In other districts surveyed it ranged from 14.43 to 63.48%. Similarly, Pudukkottai district showed increasing level of leaflet damage 72.66%, while in other districts surveyed it ranged from 7.03 to 24.00%. Earlier Elango (2019) reported that RSW incidence was high in Coimbatore (62.86%) district followed by Tiruppur (56.06%) and Erode (54.43%).

According to the Palm Indexing Scale, Pudukkottai district was given the grade ‘high’; Tiruppur, Thanjavur and Virudhunagar districts as Medium moreover Madurai, Sivagangai, Theni, Coimbatore and Kanyakumari as ‘low’. It could be attributed that the nymphal parasitoid, *E. guadeloupe* was alone found to be very promising in Madurai,

Dindigul, Coimbatore and Kanyakumari (Fig. 12) and lowered the population of RSW. Due to the lower parasitism rate by *E. guadeloupeae* on RSW nymphs, the damage intensity and scale were found highest in Pudukkottai district. This clearly highlights the role of the aphelinid parasitoid, *E. guadeloupeae* in the bio-suppression of RSW.

The highest percentage of *E. guadeloupeae* parasitism was recorded on RSW-infested coconut palms in Coimbatore district (93.25%), which was statistically on par with Kanyakumari (91.40%) and Theni (92.07%) districts (Fig. 12). Our result is in corroboration with the observations of Chien et al. (2000); Nijhof et al. (2000); Mani et al. (2004), wherein *A. dispersus* population was drastically reduced by *E. guadeloupeae* parasitism (78 – 98%).

A survey conducted from 1996 to 2003 on *A. dispersus* affected regions and several crops of Natitingou and Bemberke in Benin showed that *E. dispersa* arrived less than a year in these regions and become a dominant biocontrol agent, inducing 89% by *E. dispersa* on coastal south and 84% in the northern regions (Obinna et al. 2011). These findings are also similar to our results of 92.07–93.25% parasitism by *E. guadeloupeae* on RSW. The tropical climatic conditions prevailing in Tamil Nadu was ideal for the development of *E. guadeloupeae*, in congruence with countries lying on tropics like Benin, Togo, Ghana, Nigeria, Philippines, Thailand, Canary, Polynesia, Hawaii, Micronesia, Nauru, Papua New Guinea, Mexico, India and Sri Lanka was reported by Chen et al. 2015. Moreover, the adult emergence of *E. guadeloupeae* on RSW pupae was found maximum in Coimbatore (85.99%) followed by Kanyakumari (82.87%) and

Theni (81.77%) districts in a non-significant manner. Thus, it could be concluded that successful establishment of *E. guadeloupeae* with high adult emergence resulted in the bio-suppression of RSW.

Elango (2019) reported that parasitism by *E. guadeloupeae* was 60.75 per cent in Kanyakumari district, while the least parasitism was recorded in Erode district (47.06%) in Tamil Nadu. Our results after two consecutive years of invasion, indicated increase to as high as 90% parasitism. Interestingly during initial phase of RSW emergence during 2016 in India, low parasitism of about 40–60% prevailed in Karnataka (Selvaraj et al. 2016), whereas in high RSW-infested zones of Pollachi, Coimbatore district, Tamil Nadu parasitism by *E. guadeloupeae* reached up to 78.20% (Srinivasan et al. 2016).

Across the diverse agro climatic zones of Karnataka, natural parasitism by *E. guadeloupeae* on *A. rugioperculatus* ranged from 7 to 80% (Pradhan et al. 2022) whereas in Tamil Nadu parasitism ranged from 10 to 93%. These reports clearly depicted that *E. guadeloupeae* have succeeded in controlling *A. rugioperculatus* populations in a short period of time which is similar to our findings from Tamil Nadu. The pesticide holiday approach as well as the conservation biological control of the aphelinid parasitoid *E. guadeloupeae* played a key role in the bio-suppression of the RSW in all pest inflicted zones. Though RSW incursion was found higher during the initial period, the severity diminished in a short span of 4–5 months after the establishment of *E. guadeloupeae* (Josephraj Kumar et al. 2019a).

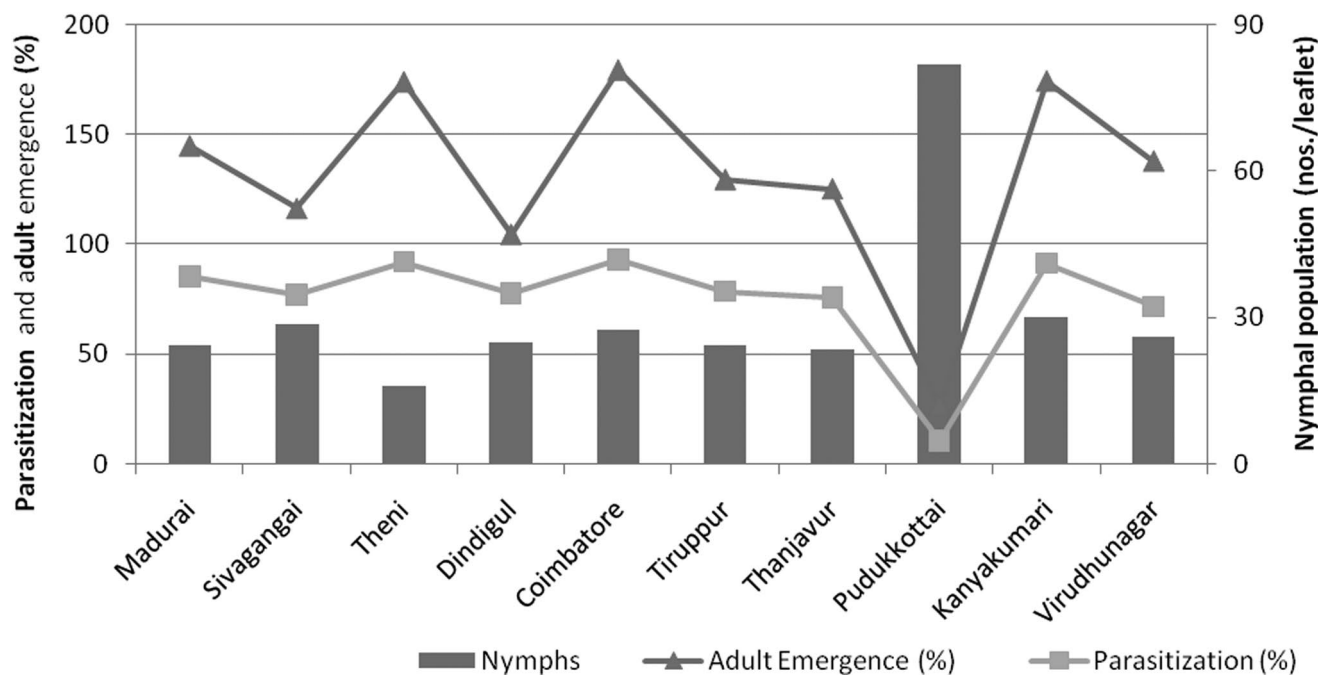


Fig. 12 Nymphal population of *Aleurodicus rugioperculatus* vs. *Encarsia guadeloupeae* parasitization

Five years down the infestation of RSW on coconut, the severity was reduced drastically with the subsequent buildup of the parasitoid *E. guadeloupae* in all pest infested areas leading to the successful promotion of conservation biological control in the long-term management of RSW in India. In order to maintain and increase the parasitoids activities establishment of “banker plants” in a crop pluralistic garden are essential for the realistic habitat for natural enemies in its respective crop ecosystems (Gurr et al. 2017). Nandhini and Srinivasan (2022) highlighted the importance of banker plants sustaining the defender population in various cropping system in Tamil Nadu during 2016. Some banker crops including custard apple, sour soup, sugar apple and peepal trees show high number of parasitoid activities and these plants harbor them exclusively in coconut ecosystem which helps in suppressing this invasive whitefly.

## Conclusion

The current study highlights RSW dynamics in different district of Tamil Nadu and the influence of aphelinid parasitoid, *E. guadeloupae* in the bio-suppression of the pest. The pest population has diminished significantly in most gardens by the buildup of the parasitoid to a greater level. Correct identification of the pest and the defender are crucial for successful pest management in coconut. Though RSW flared up in the initial phase, its subsequent reduction and the conservation biological control promulgated with refraining from insecticide spray have saved millions of rupees in terms of environmental health and evolving environmentally responsible farming approach to tackle exotic pests in the country. The geo-morphometric variation on surveyed locations also revealed the absence of any biotypes or other possibilities for forming any genetic variants.

**Data availability** The data are available on request from the corresponding author.

## Declarations

**Ethics approval and consent to participate** Not applicable.

**Consent for publication** Not applicable.

**Competing interests** Not applicable.

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