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ORIGINAL ARTICLE

New host plants, natural enemy complex and newly distributed potential areas of exotic spiralling whitefly (Hemiptera: Aleyrodidae) in India

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Abstract An intensive survey was conducted throughout India in order to study the intensity of damage caused by the exotic spiralling whitefly, *Aleurodicus dispersus* Russell (Hemiptera: Aleyrodidae) as well as the incidence on different host plants and its natural enemies. Interestingly, the incidence was found only in 12 geographical regions of India. Extreme damage intensity of *A. dispersus* was observed in Tamil Nadu, India (99.17%); Kerala, India (97.72%); and Karnataka, India (95.31%). The spiralling whitefly is reported for the first time from Andaman and Nicobar and Himachal Pradesh, which were both on guava. Nitidulid predator, *Cybocephalus* sp. was the predominant predator of *A. dispersus* predator on cassava. The most abundant parasitoids in cassava were *Encarsia guadeloupae* Viggiani and *Encarsia meritoria* Gahan. Of the recorded 147 host plants (from 53 families), 56 hosts were new host records for *A. dispersus*. Cotton, mulberry, papaya and cassava showed the highest incidence (100%), while the least incidence was observed on *Nephelium* (2.40%). Teak (168.3 ± 14.2 leaf^{-1}) and cabbage (0.07 ± 0.07 leaf^{-1}) had the highest and least spiralling whitefly population, respectively. Fifty eight host species are identified as preferred hosts based on host frequencies, incidence (>75%) and the level of population (10 individuals/leaf), which may require additional management. Given the widespread and severe incidence of exotic spiralling whitefly on a variety of host plants in India, this species is likely to pose a threat to the cultivation of economically important crops in India in the near future.

Key words Distribution · Occurrence · Damage · Host plants · Predators · Parasitoids

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Aleurodicus dispersus Russell, the spiralling whitefly, is native to Caribbean region (Russell 1965). It has been reported to occur in several Pacific Islands and Cape Verte Islands in Central America, North America, the Caribbean Islands, Africa, South America, and Asia. Spiralling whitefly is of tropical and subtropical origin, like most whiteflies (Mound and Halsey 1978). The insect was first introduced during 2000 on the West African coast; by then, the species has done huge damage losses to food crops, and several indigenous plants (Monteiro 2004). *A. dispersus* has a wide distribution with steady spread to nearly all countries from its native islands and is gaining economic importance. Because of its economic importance, it now has official quarantine status.

In India, it was first recorded on cassava (Palaniswami et al. 1995) at Thiruvananthapuram (Kerala, India) in 1993 and later at many locations in peninsular India (Mani et al. 2001; Boopathi et al. 2013, 2015a, b). Since then, the pest got distributed over the Southern, and North-Eastern India and has now become a major insect pest of horticultural, agricultural, and forest crops since the 2000s. Production of honeydew and premature leaf fall were caused by the dense *A. dispersus* population and honeydew act as a substratum for sooty mould growth during feeding (Akinlosotu et al. 1993). The sooty mould causes blackening of leaves, reduces the activity of photosynthesis and the plant vigour which sometimes disfigures the host.

The level of spiralling whitefly damage varies depending on the host species and the condition of the plant. A loss in fruit yield, amounting to >80% was observed on guava in Taiwan (Wen et al. 1995). Heavy spiralling whitefly incidences in cassava resulted in yield reductions of up to 50–80% (Geetha 2000; Boopathi et al. 2016). *A. dispersus* is currently one of the main insect pests of several field, vegetable, fruit and ornamental crops (Lambkin 1999; Boopathi et al. 2014a, b). Banana, cassava, coconut, eggplant, guava, hibiscus, Indian almond, papaya, rose and tomato are the important host plants of *A. dispersus* (Geetha 2000; Srinivasa 2000; Mani et al. 2001; Boopathi 2013, Boopathi et al. 2019).

Following the introduction of spiralling whitefly from neighboring countries such as Sri Lanka (Ranjith et al. 1996), Maldives (Muniappan 1996), and Myanmar (Burma) (Boopathi 2008; Boopathi et al. 2014c), it invaded and got established in agricultural, natural, and urban areas. Several native plants, forest trees, ornamentals and food crops have been damaged by this pest since then (Palaniswami et al. 1995; Geetha 2000; Mani et al. 2001; Boopathi 2013; Boopathi et al. 2017a). However, the geographic source and colonization process of the original population are still unknown. Despite its economic significance and serious threat to agricultural production, except for a few survey reports in India (David and Regu 1995; Ranjith et al. 1996; Mani et al. 2000; Charati et al. 2003; Boopathi 2008), little is documented about the occurrence, level and patterns of distribution of spiralling whitefly populations. Therefore, a study was formulated based on two objectives, (i) to determine the distribution and damage patterns of *A. dispersus* on an economically important agricultural crops and other alternate host plants in India, which will help to prevent the spread of this species from infested regions to other regions by complying with strict domestic quarantine regulations and also aid in enforcing better control measures to prevent further spread and (ii) to identify the potential natural enemies that can be further evaluated for their efficiency, which can then be included in the IPM program for effective control of *A. dispersus*.

Material and Methods

Assessment of potential distributive areas and intensity of damage An intensive survey was conducted in various geographical locations comprising all the states of India between August 2012 and December 2018 to study the potential distributive areas and intensity of damage caused by the spiralling whitefly. Sample units were randomly chosen at five places in each location and surveys were conducted on the most preferred plants by spiralling whitefly as hosts (cassava, guava, and rose). A standard assessment system was developed based on the damage intensity (percent) caused by the *A. dispersus* (Boopathi et al. 2014c). Based on the intensity (%), the damage was categorized into seven grades (Table 1).

Assessment of host plants and sampling method Host plant surveys were conducted in agriculturally important areas and also in areas with significant biological diversity. The incidence and presence of adults, nymphs, and spiral eggs of the pest were examined on the plants harbouring the spiralling

Table 1 Standard evaluation procedure as per the damage intensity (%) by *Aleurodicus dispersus*

Damage intensity (%)	Damage category	Grade
0	Nil	1
1–10	Very low	2
11–20	Low	3
21–40	Moderate	4
41–60	High	5
61–80	Very high	6
81–100	Extreme	7

whitefly. Host plants, which could not be identified in the field during the survey, were collected and brought back to the laboratory for identification by referring to plant botany and weed science manuals and also by consulting with experts in the Botanical Survey of India, Coimbatore, Tamil Nadu (India). A digital camera (Nikon model no. D5200) was used to take colored photographs of host plants, whitefly nymphs and adults and spiral eggs.

Twenty plants were selected for the population survey for annual crops or shrubs or small plants. For tree crops, 10 trees were chosen for survey of *A. dispersus* population. In each tree, four terminal branches were randomly chosen from the whole canopy. Therefore, a total of 40 shoots were sampled growing in all directions (Boopathi et al. 2015b). At each location/host plant, the 'leaf turn' technique was applied to determine the densities of spiral eggs, nymphs and adults by recording individuals on the upper-and under- sides of three leaves from the middle, bottom, and top using a 10x folding pocket magnifier (Boopathi et al. 2015a).

Assessment of natural enemies An intensive survey of natural enemies of *A. dispersus* was carried out in southern India (Coimbatore, Bengaluru, Erode, Namakkal, Salem, Tiruchirappalli, and Tiruppur) between 2012 and 2015 to investigate the abundance of natural enemies.

Sampling method for parasitoids In each location/host plant, the densities of immature aphelinids, *Encarsia meritoria* Gahan and *Encarsia guadeloupae* Viggiani attacking *A. dispersus* were determined by collecting 30 leaves from ten plants (3 leaves/plant). The leaves chosen for the investigation were colected from the terminal's 7th mainstem node. *E. meritoria* and *E. guadeloupae* that emerged from pupae and 4th instar nymphs of *A. dispersus* were recorded in the laboratory. The presence of the parasitoid larvae was decided on the basis of the host's mycetomes being displaced, but it was not possible to distinguish the parasitoid species in these cases. I determined a parasitism index as per the ratio of parasitized 4th-stadium nymphs combined by both parasitoid species. A subleaf sample (n = 20) from each location was observed to assess the composition of emerging adult species (Boopathi et al. 2017b). Parasitized insects were kept in a ventilated box at 28 ± 1 °C and 14 L:10D photoperiod for 2 weeks.

Sampling method for arthropod predators Arthropod predators were sampled at each location/host plant from 20 plants for annual crops, whereas in tree species four terminal branches were randomly chosen from the whole canopy in 10 plants. Density of arthropod predators; both adult and larval, were determined by visually recording individuals on the top and bottom sides of the whole plant canopy (Boopathi et al. 2017b). Predators consuming on different life stages of spiralling whitefly were observed.

Statistical analysis Analyses were carried out using version 9.3 of SAS Software (SAS 2011). The survey data of the incidence of *A. dispersus* and its natural enemies (NEs) in various geographic locations of India and on several host plants was subjected to statistical analysis and the means were separated with a standard error (SE) at $P \leq 0.01$. Distribution of arthropod predators were subjected one way analysis of variance and data interaction was estimated using the post hoc Tukey's Honestly Significant Difference test, and the average values were separated at $P \leq 0.001$.

Results

Potential distributive areas and intensity of damage of Aleurodicus dispersus Results on the distribution pattern and damage intensity of spiralling whitefly in various geographic locations of India showed extreme damage intensity in Tamil Nadu (99.17%), Kerala (97.72%) and Karnataka (95.31%) (Fig. 1). The intensity was very high in Mizoram and Andaman and Nicobar (76.57% and 72.67%), but the damage intensity was found to be low in Meghalaya (13.96%) and Telengana (24.07%). Differences in intensity of damage by *A. dispersus* ($F = 54.069$; df = 11,44; $P < 0.001$) and populations ($F = 75.049$; df = 11,44; $P < 0.001$) were statistically significant in 12 geographic regions of India. Tamil Nadu (247.1 leaf^{-1}) and Karnataka (219.6 leaf^{-1}) had the highest population density of *A. dispersus*. Telengana (11.8 leaf^{-1}) and Meghalaya (17.8 leaf^{-1}) had the least dense population of *A. dispersus*.

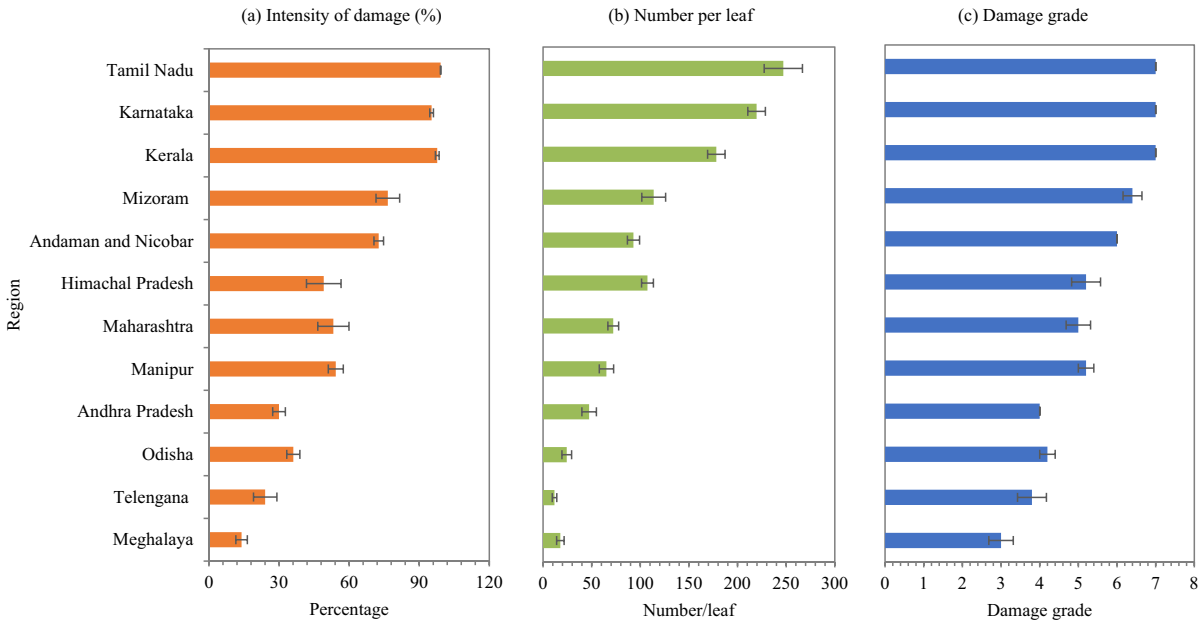

Fig. 1 (a) An intensity of damage (mean ± SE), (b) incidence (mean ± SE) and (c) damage grade (mean ± SE) of *Aleurodicus dispersus* in 12 geographic regions of India. Means separated with a standard error (SE) at $P \leq 0.01$ (n = 5)

Host plants of Aleurodicus dispersus Survey conducted in India showed that *A. dispersus* occurred on 147 host plants (Table 2 and Fig. 2). Of the recorded 147 host plants, 56 were new hosts of *A. dispersus*. The level of incidence of spiralling whitefly on various host plants ranged from 2.4 to 100.0%. *Gossypium hirsutum* L., *Morus alba* L., *Carica papaya* L., and *Manihot esculenta* Crantz had the highest incidence (100%). the least percent incidence was recorded on *Nephelium lappaceum* L. (2.4 ± 0.98). The characteristic pattern of spiral egg laying was observed throughout the reported host plants. The adult female preferred young apical leaves for oviposition. However, it was observed that the adult female occasionally oviposits on upper surface of leaves. Eggs were also noticed on fruit-parts of plants like eggplant, papaya and tomato. The most and least egg spiral/leaf were found on *Tectona grandis* L.f. (17.13 ± 2.13) and *Citrullus lanatus* (Thunb.) Matsum. and Nakai (0.13 ± 0.08), respectively. The adults were observed to be engaging in migratory flight especially for reproduction during the early morning hours (5.30 to 7.30 h). The spiralling whitefly preferred the lower and middle leaves for feeding. Teak had the highest spiralling whitefly nymph population (91.73 ± 11.14 leaf^{-1}) and adult population (76.60 ± 6.56 leaf^{-1}). Host plants such as *Vigna unguiculata* (L.) Walp., *Cucumis sativus* L., *C. lanatus*, *Plectranthus amboinicus* (Lour.) Spreng., *Butea monosperma* (Lam.) Taub., and *Ardisia elliptica* Thunb. had no nymphal stages. Similarly, in the host plants such as *Grevillea robusta* A.Cunn. ex R.Br., and *Cordia sebestena* L., the adult stage was not present. The highest density of population of spiralling whitefly was observed on teak (168.3 ± 14.2 leaf^{-1}), whereas the least density was found on *Brassica oleracea* L. (Capitata Group) (0.07 ± 0.07 leaf^{-1}).

Of the different host plants determined, 25% plant species (37) had >10 individuals per leaf, including *A. tricolor* L., *Acalypha hispida* Burm. f., *Achyranthes aspera* L., *Aleurites fordii* Hemsl., *Alternanthera triandra* Lam., *Amaranthus viridis* L., *C. capsularis* L., *Calotropis gigantean* (L.) W.T.Aiton, *Capsicum annuum* L., *Cassia* sp., *Cleome viscosa* L., *Commelina benghalensis* L., *Convolvulus arvensis* L., *Corchorus olitorius* L., *Datura metel* L., *E. geniculata* Ortega, *E. heterophylla* L., *E. hirta* L., *E. ingens* E.Mey. ex Boiss., *Euphorbia pulcherrima* Willd. ex Klotzsch, *M. esculenta*, *Jacaranda mimosifolia* D. Don, *Millettia pinnata* (L.) Panigrahi, *Moringa oleifera* Lam., *Musa paradisiaca* L., *Parthenium hysterophorus* L., *Ruellia tuberosa* L., *S. elaeagnifolium*

Table 2 Host plants of *Aleurodicus dispersus* and its incidence and population in India

Host plants	Family	Mean ± standard error*	
		Incidence (%)	Population (No. leaf^{-1})
a. Field crops			
Cotton, *Gossypium hirsutum* L.	Malvaceae	100.00 ± 0.00	3.80 ± 0.89
Castor, *Ricinus communis* L.	Euphorbiaceae	84.80 ± 2.65	2.07 ± 1.09
Pigeonpea, *Cajanus cajan* (L.) Millsp.	Fabaceae	98.40 ± 0.98	1.73 ± 0.37
Black gram, *Vigna mungo* (L.) Hepper	Fabaceae	70.40 ± 5.74	3.06 ± 0.87
Green gram, *Vigna radiata* (L.) R. Wilczek	Fabaceae	67.20 ± 5.12	2.07 ± 1.08
#Horse gram, *Vigna biflorus* (Lam.) Verdc.	Fabaceae	63.20 ± 5.99	0.33 ± 0.15
Cowpea, *Vigna unguiculata* (L.) Walp.	Fabaceae	82.40 ± 3.25	0.53 ± 0.20
Groundnut, *Arachis hypogaea* L.	Fabaceae	76.80 ± 2.65	2.46 ± 0.39
Mulberry, *Morus alba* L.	Malvaceae	100.00 ± 0.00	7.40 ± 0.29
#Napier grass, *Pennisetum purpureum* Schumach	Poaceae	9.60 ± 2.04	0.27 ± 0.19
b. Fruit crops			
Guava, *Psidium guajava* L.	Myrtaceae	99.20 ± 0.80	6.20 ± 1.21
Banana, *Musa paradisiaca* L.	Musaceae	97.60 ± 2.40	11.93 ± 3.00
Custard apple, *Annona squamosa* L.	Annonaceae	79.20 ± 6.62	2.67 ± 0.64
Pomegranate, *Punica granatum* L.	Lythraceae	93.60 ± 2.99	5.60 ± 0.97
Papaya, *Carica papaya* L.	Caricaceae	100.00 ± 0.00	8.67 ± 2.00
#Wood apple, *Limonia acidissima* L.	Rutaceae	60.00 ± 8.30	2.80 ± 0.67
#Ber, *Ziziphus jujuba* Mill.	Rhamnaceae	7.20 ± 3.88	0.53 ± 0.27
#Avacado, *Persea americana* Mill.	Lauraceae	72.00 ± 5.93	7.33 ± 1.09
Mango, *Mangifera indica* L.	Anacardiaceae	17.60 ± 3.49	2.13 ± 0.23
#Sapota, *Manilkara zapota* (L.) P.Royen	Sapotaceae	23.20 ± 6.74	3.53 ± 0.81
Jack fruit, *Artocarpus heterophyllus* Lam.	Moraceae	14.40 ± 6.40	6.07 ± 1.18
Cashew, *Anacardium occidentale* L.	Anacardiaceae	64.80 ± 6.12	4.53 ± 0.93
Grapes, *Vitis vinifera* L.	Vitaceae	51.00 ± 7.48	5.60 ± 1.01
Jamun, *Syzygium cumini* (L.) Skeels.	Myrtaceae	6.40 ± 4.67	2.93 ± 0.27
Almond, *Terminalia catappa* L.	Combretaceae	92.00 ± 2.83	22.08 ± 0.98
c. Vegetable crops			
Eggplant, *Solanum melongena* L.	Solanaceae	97.60 ± 1.60	52.20 ± 5.59
Tomato, *Solanum lycopersicum* L.	Solanaceae	95.20 ± 2.33	26.27 ± 3.22
Chilli, *Capsicum annuum* L.	Solanaceae	99.20 ± 0.80	44.80 ± 3.50
Capsicum, *Capsicum annuum* L.	Solanaceae	96.00 ± 3.10	8.47 ± 2.47
Okra, *Abelmoschus esculentus* (L.) Moench	Malvaceae	82.40 ± 2.99	4.47 ± 1.11
Pea eggplant, *Solanum torvum* Sw.	Solanaceae	88.00 ± 4.00	5.87 ± 0.86
#Garden lab-lab, *Lablab purpureus* (L.) Sweet	Fabaceae	63.20 ± 6.12	1.47 ± 0.57
#Field lab-lab, *Lablab purpureus* (L.) Sweet	Fabaceae	76.00 ± 4.90	3.93 ± 1.25
#Broad bean, *Vicia faba* L.	Fabaceae	37.60 ± 10.01	1.67 ± 0.30
#Pumpkin, *Cucurbita pepo var.styriaca*Greb.	Cucurbitaceae	31.20 ± 7.31	1.47 ± 0.53
#Cucumber, *Cucumis sativus* L.	Cucurbitaceae	44.00 ± 2.83	0.27 ± 0.13
Bitter gourd, *Momordica charantia* Descourt.	Cucurbitaceae	71.20 ± 4.27	1.40 ± 0.43
Bottle gourd, *Lagenaria siceraria* (Molina) Standl.	Cucurbitaceae	16.80 ± 3.88	1.80 ± 0.29
Ash guard, *Benincasa hispida* Thunb.	Cucurbitaceae	20.96 ± 5.98	1.53 ± 0.50
#Ridge gourd, *Luffa acutangula* (L.) Roxb.	Cucurbitaceae	63.20 ± 5.85	1.00 ± 0.26
#Water melon, *Citrullus lanatus* (Thunb.) Matsum. & Nakai	Cucurbitaceae	30.40 ± 4.83	0.13 ± 0.08

Table 2 (continued)

Host plants	Family	Mean ± standard error*	
		Incidence (%)	Population (No. leaf^{-1})
#Pointed gourd, *Trichosanthes dioica* Roxb.	Cucurbitaceae	74.40 ± 4.67	2.53 ± 0.44
#Cabbage, *Brassica oleracea L.* (Capitata Group)	Brassicaceae	12.80 ± 3.44	0.07 ± 0.07
#Cauliflower, *Brassica oleracea L.* (Botrytis cultivar)	Brassicaceae	44.80 ± 6.74	2.60 ± 1.18
d. Root crops and green vegetables			
Cassava, *Manihot esculenta* Crantz	Euphorbiaceae	100.00 ± 0.00	63.47 ± 2.13
Elephant yam, *Amorphophallus paeoniifolius* (Dennst.) Nicolson.	Araceae	32.00 ± 4.90	2.60 ± 1.13
#Dioscorea, *Dioscorea opposita* Thunb.	Dioscoreaceae	20.80 ± 4.80	1.33 ± 0.46
Sweet potato, *Ipomoea batatas* (L.) Lam.	Convolvulaceae	12.00 ± 2.83	1.07 ± 0.39
Colocasia, *Colocasia* sp.	Araceae	73.60 ± 3.71	2.80 ± 1.04
Moringa, *Moringa oleifera* Lam.	Moringaceae	66.40 ± 6.52	31.00 ± 2.70
Tampala, tandaljo or tandalja bhaji, *Amaranthus tricolor* L.	Amaranthaceae	30.40 ± 4.67	0.87 ± 0.25
European black nightshade, *Solanum nigrum* L.	Solanaceae	76.80 ± 3.20	3.73 ± 0.58
#Spinach, *Spinacia oleracea* L.	Amaranthaceae	38.40 ± 3.25	2.07 ± 0.45
Slender or green amaranth, *Amaranthus viridis* L.	Amaranthaceae	20.80 ± 2.94	28.20 ± 0.97
#Chinese spinach, *Amaranthus dubius* Mart. ex Thell.	Amaranthaceae	19.20 ± 2.94	1.87 ± 0.356
e. Medicinal and aromatics plants			
Turmeric, *Curcuma longa* L.	Zingiberaceae	9.60 ± 3.71	1.00 ± 0.37
Curry tree, *Murraya koenigii* (L.) Sprengel	Rutaceae	16.80 ± 4.63	4.20 ± 1.49
#Cinnamon, *Cinnamomum verum* J.Presl	Lauraceae	16.80 ± 2.33	1.93 ± 0.78
#Insulin plant, *Costus igneus* N.E.Br.	Costaceae	34.40 ± 7.44	2.80 ± 0.79
Purple Fruited Pea Eggplant, *Solanum trilobatum* L.	Solanaceae	76.80 ± 8.89	9.73 ± 2.34
#Indian mint or Indian borage, *Plectranthus amboinicus* (Lour.) Spreng.	Lamiaceae	8.80 ± 3.88	0.33 ± 0.11
Great basil or Saint-Joseph's-wort, *Ocimum basilicum* L.	Lamiaceae	39.20 ± 4.63	6.80 ± 1.29
Holy basil, *Ocimum sanctum* L.	Lamiaceae	64.80 ± 6.25	1.73 ± 0.68
#Clove basil, African basil, *Ocimum gratissimum* (L.)	Lamiaceae	86.40 ± 4.12	3.93 ± 0.45
Balloon plant, *Cardiospermum halicacabum* L.	Sapindaceae	28.80 ± 4.63	5.20 ± 0.52
Henna, *Lawsonia inermis* L.	Lythraceae	45.60 ± 8.64	7.60 ± 1.103
#Avaram senna, *Senna auriculata* (L.) Roxb.	Fabaceae	12.80 ± 1.50	5.60 ± 0.68
Yellow fruit night-shade, *Solanum surattense* Burm. F.	Solanaceae	52.80 ± 3.44	1.60 ± 0.40
#Desert thorn-apple, *Datura discolor* Bernh.	Solanaceae	80.80 ± 3.44	8.40 ± 1.36
#Noni, *Morinda citrifolia* L.	Rubiaceae	10.40 ± 3.92	2.00 ± 0.32
Ban basil or tulasi, *Croton sparsiflorus* Morong	Euphorbiaceae	6.40 ± 2.04	9.00 ± 0.32
#Common Leucas, thumba, *Leucas aspera* (Willd.)	Lamiaceae	12.80 ± 4.63	5.00 ± 0.71
f. Flowers and ornamentals			
Rose, *Rosa* sp.	Rosaceae	58.40 ± 9.00	4.27 ± 0.89
#Peruvian zinnia, *Zinnia peruviana* (L.) L.	Asteraceae	16.16 ± 4.46	2.20 ± 0.82
#Globe amaranth or bachelor button, *Gomphrena globosa* L.	Amaranthaceae	14.40 ± 2.71	1.60 ± 0.72
Indian Jasmine, *Jasminum auriculatum* Vahl	Oleaceae	16.80 ± 2.33	2.00 ± 0.94
#River Jasmine, *Jasminum flexile* L.	Oleaceae	26.40 ± 5.46	4.00 ± 1.41
Chinese hibiscus or Chinese rose, *Hibiscus rosasinensis* L.	Malvaceae	38.40 ± 5.31	4.47 ± 1.13
Firecracker flower, *Crossandra infundibuliformis* (L.) Nees (Orange)	Acanthaceae	8.80 ± 1.50	4.00 ± 1.09
Lollipop or golden shrimp plant, *Pachystachys lutea* Nees	Acanthaceae	3.20 ± 1.50	1.07 ± 0.41
#Trumpet bush, *Tecoma stans* (L.) Juss. ex Kunth	Bignoniaceae	76.80 ± 3.20	19.87 ± 1.46
#*Golden pothos*, *Epipremnum aureum* (L.) Engl.	Araceae	17.60 ± 2.99	2.80 ± 0.79

Table 2 (continued)

Host plants	Family	Mean ± standard error*	
		Incidence (%)	Population (No. leaf^{-1})
Bamboo/areca palm, *Dypsis lutescens* (H.Wendl.) Beentje & J.Dransf.	Arecaceae	12.00 ± 4.20	4.60 ± 2.08
#Spotted or Japanese laurel, *Aucuba japonica* Thunb.	Garryaceae	16.00 ± 3.80	0.60 ± 0.07
Variegated croton, *Codiaeum variegatum* (L.) A.Juss.	Euphorbiaceae	10.40 ± 2.04	0.73 ± 0.36
Chenille plant or red-hot cat's tail, *Acalypha hispida* Burm. f.	Euphorbiaceae	86.40 ± 5.31	22.47 ± 3.82
#Oleander, *Nerium oleander* L.	Apocynaceae	66.40 ± 5.74	5.53 ± 1.13
Poinsettia, *Euphorbia pulcherrima* Willd. ex Klotzsch	Euphorbiaceae	99.20 ± 0.80	36.20 ± 2.75
#Christmas candle, *Euphorbia amygdaloides* L.	Euphorbiaceae	25.60 ± 2.04	3.20 ± 0.49
#Pandal Malli, *Jasminum calophyllum* Wall. & G.Don.	Oleaceae	49.60 ± 3.25	5.20 ± 0.37
g. Plantation crops and forest trees			
Coconut, *Cocos nucifera* L.	Arecaceae	76.00 ± 8.49	1.93 ± 0.93
#Cocoa, *Theobroma cacao* L.	Malvaceae	54.40 ± 4.31	4.93 ± 1.61
Teak, *Tectona grandis* L.f.	Lamiaceae	96.80 ± 1.50	168.33 ± 14.25
Indian beech, *Millettia pinnata* (L.) Panigrahi	Fabaceae	94.40 ± 2.99	11.87 ± 1.95
#Sandalwood, *Santalum album* L.	Santalaceae	13.60 ± 2.99	1.33 ± 0.44
Paradise tree or bitter wood, *Simarouba glauca* DC.	Simaroubaceae	88.80 ± 4.08	12.33 ± 2.12
#Mimosa, *Jacaranda mimosifolia* D.Don	Bignoniaceae	48.80 ± 4.63	11.20 ± 1.95
#Pink shower tree, *Cassia grandis* L.	Caesalpiniaceae	48.80 ± 7.10	2.53 ± 0.62
Neem, *Azadirachta indica* A.Juss.	Meliaceae	7.20 ± 2.65	1.67 ± 0.49
Portia tree, *Thespesia populnea* (L.) Sol. ex Corrêa	Malvacea	14.40 ± 3.71	8.53 ± 0.76
Butterfly tree, *Bauhinia purpurea* L.	Fabaceae	56.80 ± 6.62	3.53 ± 0.47
Jatropha or nettlespurge, *Jatropha* sp.	Euphorbiaceae	48.00 ± 4.90	5.27 ± 0.87
#Bael, *Aegle marmelos* (L.) Corr.Serr.	Rutaceae	6.40 ± 2.40	0.27 ± 0.07
Flame of the forest, *Butea monosperma* (Lam.) Taub.	Fabaceae	4.00 ± 2.53	0.20 ± 0.08
#Tung oil tree, *Aleurites fordii* Hemsl.	Euphorbiaceae	95.20 ± 1.50	87.53 ± 9.38
#Silky oak, *Grevillea robusta* A.Cunn. ex R.Br.	Proteaceae	52.80 ± 5.12	0.80 ± 0.40
#Scarlet *cordia or* orange geiger tree, *Cordia sebestena* L.	Boragninaceae	48.00 ± 7.27	0.53 ± 0.08
#Shoe button ardisia, *Ardisia elliptica* Thunb.	Myrsinaceae	27.20 ± 3.44	0.13 ± 0.08
Cassia, *Cassia* sp.	Fabaceae	72.80 ± 2.65	12.80 ± 1.11
Sacred fig or peepal, *Ficus religiosa* L.	Moraceae	14.40 ± 6.40	3.80 ± 0.80
Indian mast tree, *Polyalthia longifolia* (Sonn.) Thwaites	Annonaceae	64.80 ± 6.20	4.40 ± 0.51
h. Weed plants			
Indian acalypha, *Acalypha indica* L.	Euphorbiaceae	88.00 ± 4.20	5.60 ± 0.40
#Aal or Indian Mulberry, *Morinda tinctoria* Roxb.	Rubiaceae	31.20 ± 4.27	3.80 ± 0.86
Crown flower, *Calotropis gigantean* (L.) W.T. Aiton	Asclepiadoideae	46.40 ± 4.31	31.40 ± 1.36
#Yellow berried nightshade, *Solanum xanthocarpum* Schrad. and Wendl.	Solanaceae	48.00 ± 4.56	11.20 ± 1.32
#Prickly chaff flower, *Achyranthes aspera* L.	Amaranthaceae	12.00 ± 2.83	12.80 ± 0.97
Indian abutilon or mallow, *Abutilon indicum* (Link) Sweet	Malvaceae	63.20 ± 3.44	5.00 ± 1.18
Spiny headed sida, *Sida acuta* Burm. f.	Malvaceae	22.40 ± 5.15	21.40 ± 1.66
#Common sowthistle, *Sonchus oleraceus* L.	Asteraceae	10.40 ± 4.83	4.00 ± 0.95
Coat buttons or tridax daisy, *Tridax procumbens* L.	Asteraceae	76.80 ± 3.20	6.40 ± 0.98
Asthma plant or garden spurge, *Euphorbia hirta* L.	Euphorbiaceae	87.20 ± 3.88	19.80 ± 1.16
Fiffler's spurge, *Euphorbia geniculata* Ortega	Euphorbiaceae	54.40 ± 5.74	22.00 ± 1.55
Minnie root or fever root, *Ruellia tuberosa* L.	Acanthaceae	41.60 ± 2.71	14.80 ± 1.02
Devil's trumpet and metel, *Datura metel* L.	Solanaceae	80.80 ± 3.44	37.00 ± 1.52

Table 2 (continued)

Host plants	Family	Mean ± standard error*	
		Incidence (%)	Population (No. leaf^{-1})
#Erigeron or fleabane, *Erigeron* sp.	Asteraceae	5.60 ± 2.04	4.80 ± 0.58
#Frog fruit orturkey tangle, *Phylanodi flora* (L.) Greene	Verbenaceae	4.80 ± 2.94	2.80 ± 0.97
Santa maria feverfew, *Parthenium hysterophorus* L.	Asteraceae	91.20 ± 4.08	77.40 ± 4.71
#Candelabra tree, *Euphorbia ingens* E.Mey. ex Boiss.	Euphorbiaceae	29.60 ± 2.99	17.40 ± 1.33
#Asian spider flower, *Cleome viscosa* L.	Cleomaceae	48.80 ± 3.44	10.00 ± 1.27
#Spider plant, or pink queen, *Cleome hassleriana* Chodat	Cleomaceae	16.80 ± 4.63	5.40 ± 0.68
Fire plant or desert poinsettia, *Euphorbia heterophylla* L.	Euphorbiaceae	69.60 ± 4.83	18.80 ± 1.36
Nalta jute or tussa jute, *Corchorus olitorius* L.	Tiliaceae	92.00 ± 3.35	16.80 ± 0.74
Jute, *Corchorus capsularis* L.	Tiliaceae	7.20 ± 2.65	21.40 ± 1.29
#False daisy, *Eclipta prostrate* (L.) L.	Asteraceae	4.00 ± 2.19	5.60 ± 0.81
Ironweed, *Vernonia cinerea* (L.)	Asteraceae	24.80 ± 2.33	11.60 ± 1.12
Banjauri, *Vicoa indica* (L.) DC.	Asteraceae	5.60 ± 2.99	6.00 ± 1.10
Creeping Rungia, *Rungia repens* (L.)Nees	Acanthaceae	44.00 ± 2.83	5.60 ± 0.87
Benghal dayflower, *Commelina benghalensis* L.	Commelinaceae	18.40 ± 5.15	21.40 ± 0.93
Tangle mat or sessile joyweed, *Alternanthera triandra* Lam.	Amaranthaceae	38.40 ± 3.71	11.20 ± 1.16
Bhaji, *Amaranthus tricolor* L.	Amaranthaceae	21.60 ± 5.15	21.00 ± 1.38
Corn sow thistle or, dindle, *Sonchus arvensis* L.	Asteraceae	58.40 ± 6.01	6.40 ± 0.98
#Bindweed, *Convolvulus arvensis* L.	Convolvulaceae	4.00 ± 1.27	11.00 ± 0.84
Birthworts or pipe vines, *Aristolochia bracteata* Retz.	Aristolochiaceae	5.60 ± 0.98	7.20 ± 1.07
Desert horse purslane, *Trianthema portulacastrum* L.	Aizoaceae	46.40 ± 2.99	8.80 ± 1.43
Silver-leaved nightshade, *Solanum elaeagnifolium* Cav.	Solanaceae	35.20 ± 2.33	29.40 ± 1.69
Lettuce/cabbage tree, *Pisonia alba* Span.	Nyctaginaceae	4.80 ± 1.96	3.60 ± 0.81
Rambutan, *Nephelium lappaceum* L.	Sapindaceae	2.40 ± 0.98	3.00 ± 0.63

*Means separated with a standard error (SE) at $P \leq 0.01$ (n = 10). #new host plants recorded during current investigation. See the materials and methods for further clarification of the experiment

Cav., *S. lycopersicum* L., *S. xanthocarpum* Schrad. and Wendl., *Sida acuta* Burm. f., *Simarouba glauca* DC., *Solanum melongena* L., *T. grandis*, *Tecoma stans* (L.) Juss. ex Kunth., *Terminalia catappa* L., and *Vernonia cinerea* (L.). *A. fordii*, *A. hispida*, *Abelmoschus esculentus* (L.) Moench, *Acalypha indica* L., *Annona squamosa* L., *Arachis hypogaea* L., *C. annuum, C. olitorius*, *C. papaya*, *Cajanus cajan* (L.) Millsp., *Cocos nucifera* L., *D. metel*, *Datura discolor* Bernh., *E. hirta*, *E. pulcherrima*, *Gossypium hirsutum* L., *J. mimosifolia*, *Lablab purpureus* (L.) Sweet, *M. alba*, *M. esculenta*, *M. paradisiaca*, *M. pinnata*, *Ocimum gratissimum* (L.), *P. hysterophorus*, *P. guajava*, *Punica granatum* L., *Ricinus communis* L., *S. glauca*, *S. lycopersicum*, *S. melongena*, *S. nigrum* L., *S. torvum* Sw., *S. trilobatum* L., *T. catappa*, *T. grandis*, *T. stans*, *Tridax procumbens* L., and *V. unguiculata* are highly preferred host plants by spiralling whitefly in India based on percentage incidence (> 75%).

Spiralling whitefly infested fifty-three (53) plant families (Table 3). Thirty-three plant families were found to be a susceptible host plants for spiralling whitefly. The highest number of host plants infested by the spiralling whitefly in the plant families *viz*., Euphorbiaceae (14), Fabaceae (14), Solanaceae (12), Asteraceae (9), Amaranthaceae (8), Cucurbitaceae (8), Malvaceae (7) and Lamiaceae (6) which contributed >50% of host species. The percentage distribution of plant families due to the spiralling whitefly incidence ranged from 0.68 to 9.46%. The highest percentage distribution of plant families due to the spiralling whitefly incidence was recorded from Euphorbiaceae and Fabaceae (9.46).

Fig. 2 Pictorial illustration of various host plants of *Aleurodicus dispersus* in India

25. *Benincasa hispida* Thunb.

26. *Solanum torvum* Sw.

27. *Brassica oleracea* L. (Capitata Group)

28. *Brassica oleracea* L. (Botrytis Group)

29. *Lablab purpureus* (L.) Sweet

30. *Vicia faba* L.

31. *Trichosanthes dioica* Roxb.

32. *Abelmoschus esculentus* (L.) Moench

33. *Amaranthus tricolor* L.

34. *Spinacia oleracea* L.

35. *Moringa oleifera* Lam.

36. *Amorphophallus paeoniifolius* (Dennst.)

37. *Solanum nigrum* L.

38. *Murraya koenigii* (L.) Sprengel

39. *Cinnamomum verum* J. Presl

40. *Solanum trilobatum* L.

41. *Costus igneus* N.E.Br.

42. *Ocimum basilicum* L.

43. *Ocimum sanctum* L.

44. *Ocimum gratissimum* (L.)

45. *Plectranthus amboinicus* (Lour.) Spreng.

46. *Lawsonia inermis* L.

47. *Cardiospermum halicacabum* L.

48. *Rosa* sp.

Fig. 2 (continued)

49. *Jasminum flexile* L.

50. *Jasminum auriculatum* Vahl

51. *Crossandra infundibuliformis* (L.) Nees

52. *Crossandra* sp.

53. *Hibiscus rosa-sinensis* L.

54. *Nerium oleander* L.

55. *Zinnia peruviana* (L.) L.

56. *Tecoma stans* (L.) Juss. ex Kunth

57. *Epipremnum aureum* (L.) Engl.

58. *Dypsis lutescens* (H.Wendl.) Beentje & J.Dransf.

59. *Acalypha* sp.

60. *Plumeria acuminata* Air.

61. *Canna* sp.

62 *Euphorbia pulcherrima* Willd. ex Klotzsch

63. *Tectona grandis* L.f.

64. *Millettia pinnata* (L.) Panigrahi

65. *Cocos nucifera* L.

66. *Santalum album* L.

67. *Azadirachta indica* A.Juss.

68. *Jacaranda mimosifolia* D.Don

69. *Thespesia populnea* (L.) Sol. ex Corrêa

70. *Jatropha* sp.

71. *Bauhinia purpurea* L.

72. *Bombax ceiba* L.

Fig. 2 (continued)

73. *Cordia sebestena* L.

74. *Grevillea robusta* A.Cunn. ex R.Br.

75. *Cassia grandis* L.

76. *Ardisia elliptica* Thunb.

77. *Simarouba glauca* DC.

78. *Ficus religiosa* L.

79. *Aegle marmelos* (L.) Corr.Serr.

80. *Aleurites fordii* Hemsl.

81. *Theobroma cacao* L.

82. *Butea monosperma* (Lam.) Taub.

83. *Morinda tinctoria* Roxb.

84. *Parthenium hysterophorus* L.

85. *Erigeron* sp.

86. *Phyla nodiflora* (L.) Greene

87. *Cassia* sp.

88. *Acalypha indica* L.

89. *Calotropis gigantea* (L.) W.T.Aiton

90. *Croton sparsiflorus* Morong

91. *Abutilon indicum* (Link) Sweet

92. *Sida acuta* Burm. f.

93. *Euphorbia ingens* E.Mey. ex Boiss.

94. *Sonchus oleraceus* L.

95. *Achyranthes aspera* Linn.

96. *Tridax procumbens* L.

Fig. 2 (continued)

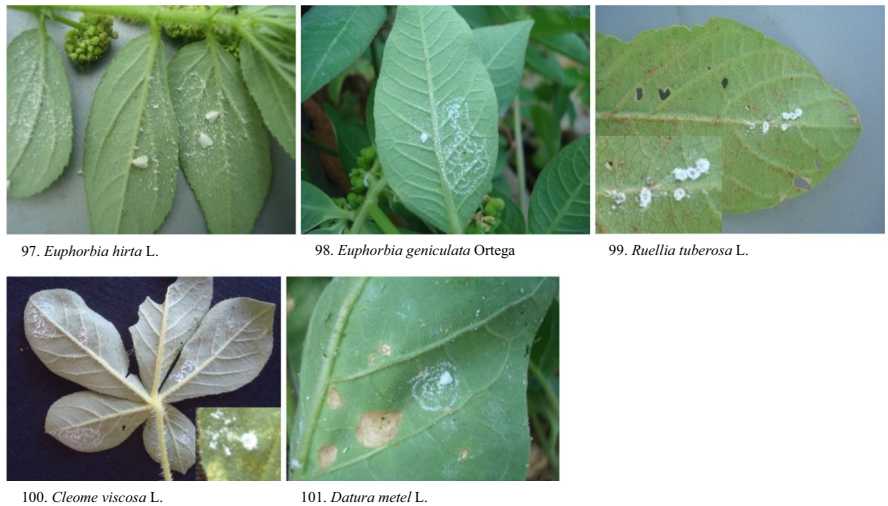

Fig. 2 (continued)

Natural enemies of Aleurodicus dispersus Survey was carried out to investigate the abundance of natural enemies (parasitoids and predators) of spiralling whitefly (Fig. 3).

Arthropod predators Surveys conducted to study the distribution and occurrence of arthropod predators feeding on spiralling whitefly in seven geographic regions of India as well as on 15 host species confirmed the occurrence of 28 species of arthropod predators such as 16 coccinellid species, 5 chrysopid species, 2 drosophilid species and one species of each cybocephalid, lycaenid, mantodea, reduviid and oxyopid species.

Among the seven geographical regions of India, the total population of predators was found to be highest in Coimbatore, Tamil Nadu (134.8 ± 14.76/10 plants) compared to other geographical regions. Tiruchirappalli, Tamil Nadu (23.0 ± 1.64/10 plants) and Tiruppur, Tamil Nadu (24.75 ± 1.78/10 plants) recorded the lowest population of predators. Among the 15 predators, *Cybocephalus* sp. (111.0 ± 21.57/10 plants) and *Mallada astur* (Banks) (100.5 ± 23.80/10 plants) were the most abundant predators reported. Less abundant was found to be *Acletoxenus indicus* Malloch (5.0 ± 2.86/10 plants). There were statistically significant differences in population density of *Cryptolaemus montrouzieri* Muls., *Axinoscymnus puttarudriahi* Kapur & Munshi, *Anegleis cardoni* (Weise), *Micraspis* sp., *Jauravia* sp., *Cybocephalus* sp., *M. astur*, *Mallada desjardinsi* (Navas), *Chrysoperla zastrowi sillemi* (Esben-Petersen), *A. indicus*, praying mantis (Mantodea: Mantidae) and spiders (Arachnida: Araneae) from seven geographical locations of India. However, there were no significant differences in the population of *Cheilomenes sexmaculata* (F.), *Scymnus coccivora* Ayyar and *Chilocorus nigrita* (F.) in seven geographic regions of India. Interestingly, *M. astur*, *Cybocephalus* sp., and *A. puttarudriahi* were fund to be more prevalent throughout the study period in Bengaluru, Coimbatore, Erode, Namakkal, Salem, Tiruppur, and Trichy (Fig. 4). In Namakkal (Tamil Nadu), *Cybocephalus* sp., *A. puttarudriahi*, *C. montrouzieri* and *S. coccivora* were more abundant. *M. astur*, *C. sexmaculata*, *Micraspis* sp., *S. coccivora*, praying mantis and spiders were found in more numbers at Coimbatore. *A. indicus* and *M. desjardinsi* were recorded only in Bengaluru, Karnataka.

Of the 15 host species, guava, cassava, mulberry and teak had the highest total predator population than other host species. The total population of predators was lowest in banana and custard apple. *M. astur* (483.7 ± 16.75/10 plants) and *Cybocephalus* sp. (462.7 ± 2.21/10 plants) were the most abundant of the 15 predators. *Acletoxenus indicus* was found to be the less abundant one (13.0 ± 3.06/10 plants). There were significant variations in the population density of *A. cardoni*, *A. indicus*, *A. puttarudriahi*, *C. montrouzeiri*, *C. nigrata*, *C. zastrowi sillemi*,

Table 3 Percent distribution of plant families on which incidence of *Aleurodicus dispersus* is reported in India

S. no.	Family	No. of host plants	% distribution	S. no.	Family	No. of host plants	% distribution
1.	Euphorbiaceae	14	9.46	28.	Apocynaceae	1	0.68
2.	Fabaceae	14	9.46	29.	Aristolochiaceae	1	0.68
3.	Solanaceae	12	8.11	30.	Asclepiadoideae	1	0.68
4.	Asteraceae	9	6.08	31.	Boragninaceae	1	0.68
5.	Amaranthaceae	8	5.41	32.	Caesalpiniaceae	1	0.68
6.	Cucurbitaceae	8	5.41	33.	Caricaceae	1	0.68
7.	Malvaceae	7	4.73	34.	Combretaceae	1	0.68
8.	Lamiaceae	6	4.05	35.	Commelinaceae	1	0.68
9.	Acanthaceae	4	2.70	36.	Costaceae	1	0.68
10.	Araceae	3	2.03	37.	Dioscoreaceae	1	0.68
11.	Moraceae	3	2.03	38.	Garryaceae	1	0.68
12.	Oleaceae	3	2.03	39.	Meliaceae	1	0.68
13.	Rutaceae	3	2.03	40.	Moringaceae	1	0.68
14.	Anacardiaceae	2	1.35	41.	Musaceae	1	0.68
15.	Annonaceae	2	1.35	42.	Myrsinaceae	1	0.68
16.	Arecaceae	2	1.35	43.	Nyctaginaceae	1	0.68
17.	Bignoniaceae	2	1.35	44.	Poaceae	1	0.68
18.	Brassicaceae	2	1.35	45.	Proteaceae	1	0.68
19.	Cleomaceae	2	1.35	46.	Rhamnaceae	1	0.68
20.	Convolvulaceae	2	1.35	47.	Rosaceae	1	0.68
21.	Lauraceae	2	1.35	48.	Santalaceae	1	0.68
22.	Lythraceae	2	1.35	49.	Sapotaceae	1	0.68
23.	Myrtaceae	2	1.35	50.	Simaroubaceae	1	0.68
24.	Rubiaceae	2	1.35	51.	Verbenaceae	1	0.68
25.	Tiliaceae	2	1.35	52.	Vitaceae	1	0.68
26.	Sapindaceae	2	1.35	53.	Zingiberaceae	1	0.68
27.	Aizoaceae	1	0.68		Total	147	100.00

Cybocephalus sp., *Jauravia* sp., *M. astur*, *M. desjardinsi*, *M. sexmaculata*, *Micraspis* sp., praying mantis, *S. coccivora*, and spiders from 15 host species (Table 4). *Axinoscymnus puttarudriahi*, *C. sexmaculata*, *Cybocephalus* sp. and *Micraspis* sp. were found to have the highest density in cassava when compared to other host plants. In comparison with other host plants, highly dense populations of *A. cardoni*, *C. montrouzeiri*, *Jauravia* sp., *M. desjardinsi* and praying mantis were found in guava. Populations of *C. nigrata* and *M. astur* were highest in teak when compared to other plants in the host. The densest population of *A. indicus*, *C. zastrowi sillemi*, *S. coccivora*, and spider were found on acalypha, cotton, mulberry and chilli, respectively.

Parasitoids In order to identify the parasitoids attacking *A. dispersus*, seven geographic regions and 15 host plants were surveyed. Two species of parasitoids, *E. meritoria* and *E. guadeloupae*, were confirmed to occur.

Coimbatore, Tamil Nadu (58.8 ± 5.76/5 plants) recorded the highest population of parasitoids among the seven geographical regions of India. At Tiruchirappalli, Tamil Nadu (8.8 ± 1.32/5 plants), the total population of parasitoids was found to be least. Among the two parasitoids, *E. guadeloupae* (110.8 ± 14.23/5 plants) was the most abundant parasitoid in all geographical regions than *E. meritoria* (79.55 ± 2.72/5 plants). There were significant variations in the parasitism (%), parasitoid emergence (%)

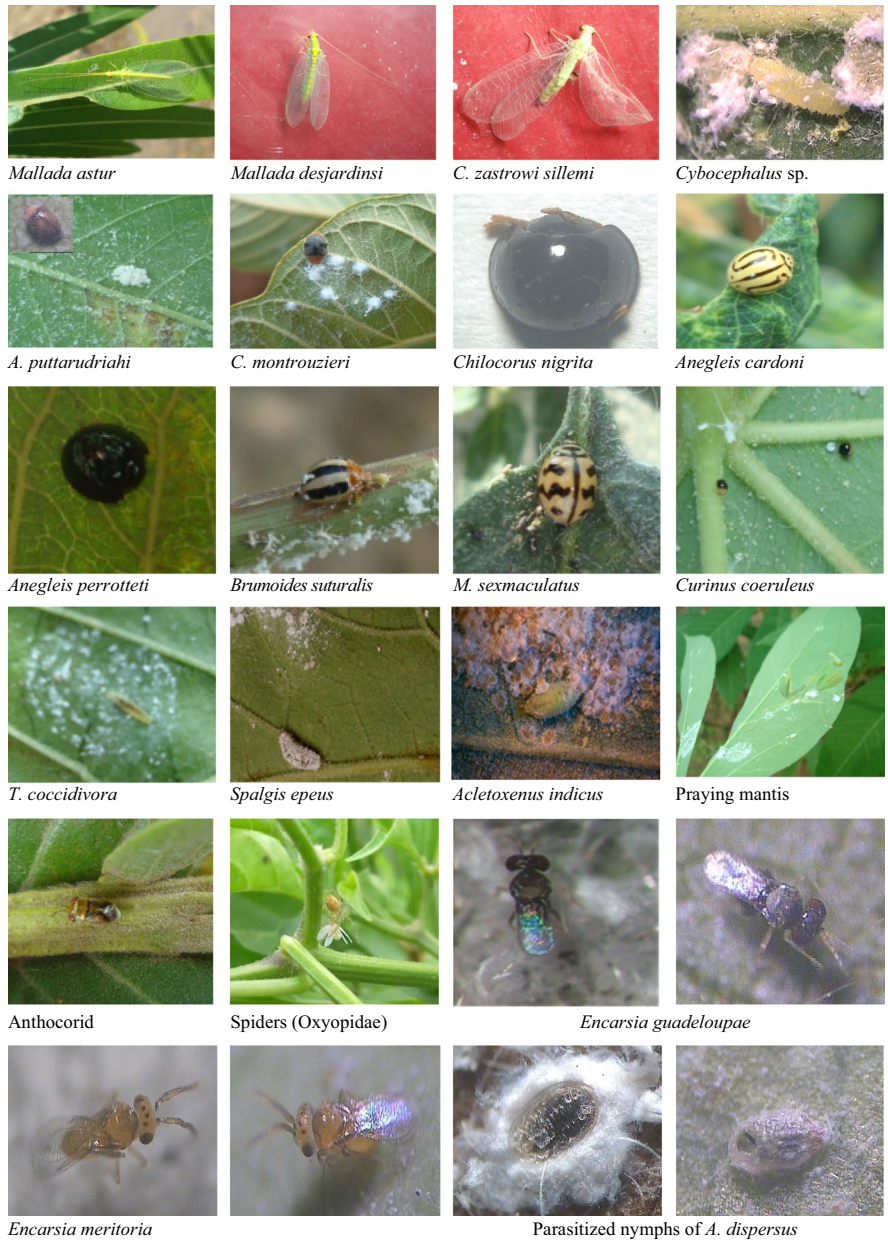

Fig. 3 Natural enemy complex of *Aleurodicus dispersus* in India

and populations of *E. meritoria* and *E. guadeloupae* from seven geographic locations of India (Fig. 5). Bengaluru (54.2%) and Tiruchirappalli (12.8%) recorded the highest and lowest parasitism. At Coimbatore (89.3) and at Tiruppur (35.2) the percentage of parasitoid emergence was highest. The most abundant parasitoids in Coimbatore were *E. guadeloupae* (27.0/5 plants) and *E. meritoria* (28.3/5 plants) when compared to other geographic regions.

Of the 15 host plants, cassava (56.3 ± 0.88/5 plants) recorded the highest total population of parasitoids when compared to other host plants. In pigeon pea (3.7 ± 1.76/5 plants) the total population of parasitoids was found to be least. Among the two parasitoids, *E. guadeloupae* (187.3 ± 17.57/5 plants) was the most abundant parasitoid on all host plants than *E. meritoria* (145.7 ± 15.07/5 plants). There were significant variations in the parasitism (%), parasitoid

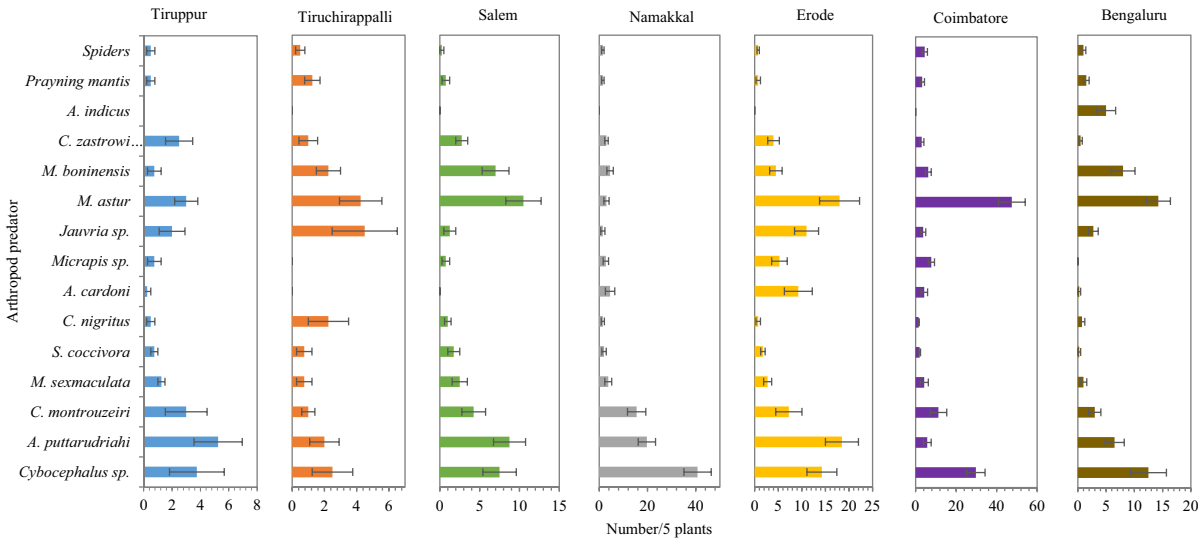

Fig. 4 Distribution of arthropod predators of *Aleurodicus dispersus* in seven geographical regions of India. Means separated with a standard error (SE) at $P \leq 0.01$ (n = 5)

emergence (%) and populations of *E. meritoria* and *E. guadeloupae* from 15 host plants (Fig. 6). The highest and lowest level of parasitism were documented from acalypha (58.4%) and banana (6.4%), respectively. The percentage of parasitoid emergence was highest on acalypha (89.7) and almond (89.0). The most abundant parasitoids in cassava were *E. guadeloupae* (26.7/5 plants) and *E. meritoria* (29.7/5 plants).

Discussion

A severe incidence of spiralling whitefly was observed in most of the surveyed states in southern India (Kerala, Karnataka, Tamil Nadu, and Maharashtra except Andhra Pradesh) and in northeastern states (Mizoram and Meghalaya). In India, this pest was first reported during 1993 in Thiruvananthapuram (Kerala, India) (Palaniswami et al. 1995). It was then reported from multiple places of Tamil Nadu (David and Regu 1995), Kerala (David and Regu 1995; Ranjith et al. 1996), Karnataka (Mani et al. 2000), Andhra Pradesh (Charati et al. 2003), Maharashtra (Charati et al. 2003), Mizoram (Boopathi 2008), and Meghalaya (Boopathi et al. 2014c) were reported later. This pest might have got introduced to India from the neighboring countries such as Sri Lanka (Ranjith et al. 1996), Maldives (Muniappan 1996), and Myanmar (Burma) (Boopathi 2008; Boopathi et al. 2014c). The spiralling whitefly is reported for the first time from Andaman and Nicobar and Himachal Pradesh, which were both on guava. Currently, the spiralling whitefly is emerging as a major and economically important insect pest of many food crops in India. Host availability and climate certainly play a significant role in assessing the spiralling whitefly incidence, but accidental spread is a key factor in the latest outbreaks of this pest.

In the present investigation, as many as 147 crop species belonging to 53 families were reported as host plants of spiralling whitefly in India. Out of these, 56 host plants are new host records in India. The host range includes vegetables, fruits, flowers, ornamentals, shade trees, perennial trees, shrubs, annuals and alternative weed hosts. Reports are being made from several countries where the occurrence of this pest has been reported on a broad range of host species. *A. dispersus*, as already reported, is highly polyphagous and capable of attacking around 500 plants in various countries (Srinivasa 2000). This pest was first noticed on coconut in Florida (Russell 1965). Palaniswami et al. (1995) first reported the pest on cassava in India. The number of host species infested by spiralling whitefly were recorded by several authors in the past, and the numbers ranged from 22 to 128

Table 4 Distribution of arthropod predators of *Aleurodicus dispersus* in 15 host plants

Host plants	Arthropod predators (number per 5 plants)[#]														
	Ac	*Ai*	*Ap*	*Cs*	*Cn*	*Czs*	*Cm*	*C.* sp.	*J.* sp.	*Ma*	*Md*	*M.* sp.	Pm	*Sc*	Spider
Cassava	6.7	0.0	45.7	17.3	4.7	4.7	38.0	83.7	4.3	62.0	37.7	11.3	13.0	7.0	14.3
Eggplant	6.0	0.0	1.0	12.3	0.0	9.3	4.7	38.0	1.7	31.3	5.0	2.3	3.0	7.0	7.3
Guava	11.0	0.0	26.7	7.3	9.0	2.0	71.0	31.7	26.7	63.3	72.0	6.0	17.7	15.0	24.3
Chilli	1.3	0.0	1.3	2.3	0.0	12.7	1.0	14.3	3.3	57.7	1.3	0.0	9.7	3.3	27.0
Mulberry	0.0	0.0	9.0	1.3	6.3	2.3	63.0	66.7	7.3	71.3	34.0	0.0	6.7	21.3	4.3
Papaya	1.3	0.0	0.0	0.0	1.0	0.0	37.3	13.3	0.0	15.7	7.7	0.0	7.7	1.3	5.3
Almond	0.0	4.3	38.0	0.0	2.0	0.0	4.7	68.0	0.0	21.3	4.7	1.3	2.0	0.0	5.7
Banana	1.3	0.0	0.0	0.0	5.3	0.0	2.3	4.3	0.0	4.3	1.0	0.0	1.3	2.0	3.3
Pigeon pea	0.0	0.0	0.0	11.3	1.3	0.0	11.0	2.7	1.3	8.0	0.7	1.0	0.0	0.0	5.0
Cotton	0.0	2.3	7.3	14.3	0.0	16.7	5.7	24.3	5.3	14.3	1.0	0.0	6.0	0.0	11.3
Tomato	0.0	0.0	0.0	9.7	0.0	3.3	5.7	4.3	2.3	10.7	0.7	1.0	2.7	0.0	2.3
Custard apple	0.0	0.0	3.0	0.0	1.3	0.0	1.0	4.3	0.0	8.7	6.3	0.0	4.7	1.0	0.0
Acalypha	0.0	6.3	4.3	1.3	0.0	0.0	36.7	0.0	3.0	38.3	12.3	0.0	1.0	0.0	4.3
Teak	0.0	0.0	35.7	9.0	12.0	11.7	31.3	70.7	1.7	74.0	6.7	1.0	11.0	11.0	12.3
Coconut	1.0	0.0	12.3	0.0	3.7	0.0	3.3	36.3	0.0	2.7	2.7	0.0	1.3	1.0	6.3
df	14,28	14,28	14,28	14,28	14,28	14,28	14,28	14,28	14,28	14,28	14,28	14,28	14,28	14,28	14,28
F value	11.70	13.12	31.07	10.37	8.05	13.78	27.69	28.60	18.10	20.05	60.73	9.60	7.14	16.70	15.01
P value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

[#]Data in interaction analyzed by Tukey's post-doc test at $P \leq 0.001$ (n = 3). *Ac*: *Anegleis cardoni*, *Ai Acletoxenus indicus*, *Ap*: *Axinoscymnus puttarudriahi*, *Cs*: *Cheilomenes sexmaculata*, *Cn*: *Chilocorus nigritus*, *Czs*: *Chrysoperla zastrowi sillemi*, *Cm*: *Cryptolaemus montrouzieri*, *C.* sp.: *Cybocephalus* sp., *J.* sp.: *Jauravia* sp., *Ma*: *Mallada astur*, *Md*: *Mallada desjardinsi*, *M.* sp.: *Micrapis* sp., Pm: Preyning mantis, *Sc*: *Scymnus coccivora*, Spider: Spider, *Oxyopus* sp.

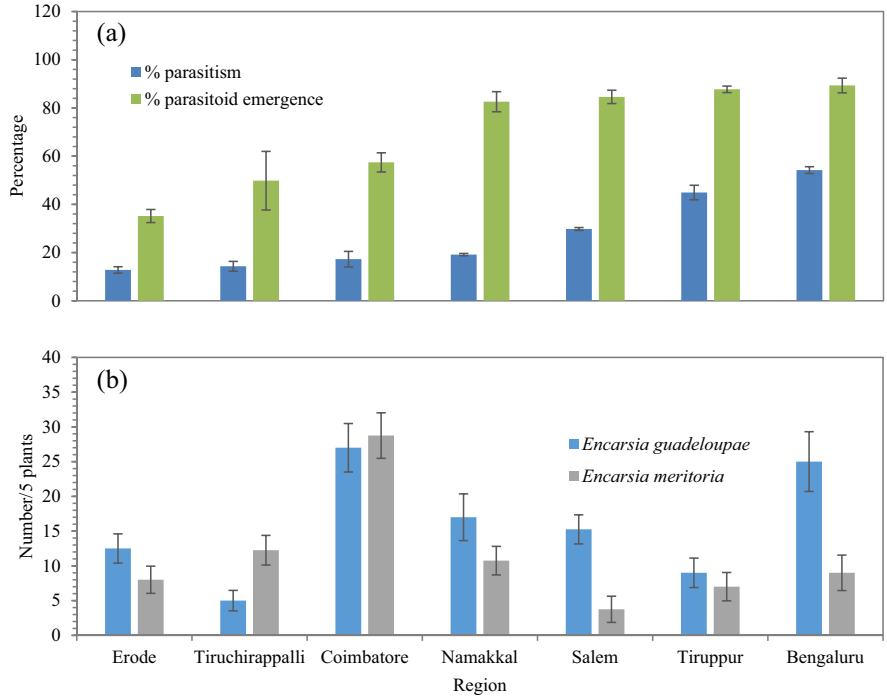

Fig. 5 (a) Percent parasitism and parasitoid emergence and (b) distribution of parasitoids of *Aleurodicus dispersus* in seven geographical regions of India. Means separated with a standard error (SE) at $P \leq 0.01$ (n = 5)

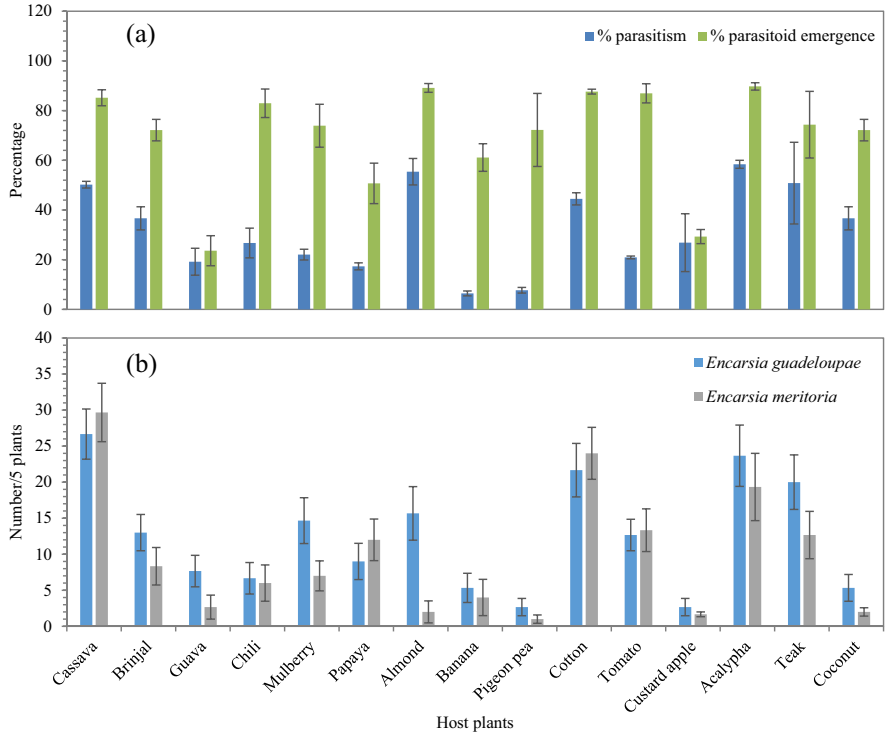

Fig. 6 (a) Percentage of parasitism, percentage of parasitoid formation and (b) distribution of the parasitoids of *Aleurodicus dispersus* in 15 host plants. Means separated with a standard error (SE) at $P \leq 0.01$ (n = 3)

(David and Regu 1995; Prathapan 1996; Ranjith et al. 1996; Gajendra Babu and David 1999; Mani and Krishnamoorthy 1999a; Muralikrishna 1999; Asia Mariam et al. 2000; Mallappanavar 2000; Ramani

2000; Srinivasa 2000; Geetha and Swamiappan 2001; Aiswariaya et al. 2007). The current investigation is a major update to this data, which reported 147 crop species, as infested by spiralling whitefly. This may suggest that not all available host species in India have been overwhelmingly colonized by the spiralling whitefly. The pest affected about 80–90% of the crops examined, with losses ranging from 2.4% to 100%. A few of the host species reported in the present survey have been identified previously in other parts of the world as host plants.

In the current investigation, 37 plant species (25%) had >10 individuals of *A. dispersus* per leaf. Montiero (2004) reported earlier that 45% of host plants *viz*., *A. wilkesiana* var. *musaica* Müll. Arg., *M. paradisiaca*, *M. esculenta*, *E. pulcherrima*, *Hibiscus rosasinensis* L., *Hymenocallis senegambica* Kunth & Bouché, *Malvastrum cordifolium* Rojas Acosta, *C. papaya*, *Parietaria debilis* G.Forst. and *S. nigrum* (L.) had more than 10 individuals per cm^2. These 58 species are preferred hosts based on the spiralling whitefly population (10 individuals per leaf), which may require additional management. About 38 plant species are highly preferred host plants by spiralling whitefly in India based on percentage incidence (> 75%). Palaniswarni et al. (1995), Mani and Krishnamoorthy (1999b) and Geetha et al. (1998, 1999) also reported the highest incidence of whitefly in annona, banana, cassava, cassia, citrus, chilli, coconut, eggplant, fig, guava, jasmine, *Leucinia*, mango, *Ocimum sanctum* L., *O. basilicum* L., okra, rose and sapota. Breeding and feeding hosts of spiralling whitefly are host species such as banana, cashew, castor, chilli, citrus, cocoa, coconut, eggplant, guava, jackfruit, okra, papaya, pigeon pea, pepper, sapota, and tomato (Ranjith 1998). In Tamil Nadu (India), this pest was also found to feed on wild cassava and rubber (David and Regu 1995).

Majority of host plants belonged to Euphorbiaceae (9.46%), Fabaceae (9.46%), Solanaceae (8.11%), Asteraceae (6.08%), Amaranthaceae (5.41%), Cucurbitaceae (5.41%), Malvaceae (4.73%) and Lamiaceae (4.05%). Earlier, Monteiro (2004) reported that the majority of host plants were in the Fabaceae (23%), Euphorbiaceae (23%), Malvaceae (13%), and Solanaceae (12%) families. Francis et al. (2016) reported that Arecaceae (22%), Burseraceae (16%), Clusiaceae (10%), Lauraceae (9%), Combretaceae (4%) and Anacardiaceae (3%) were the host families affected by the rugose spiralling whitefly (*Aleurodicus rugioperculatus* Martin). Plant families such as Euphorbiaceae, Fabaceae and Solanaceae were more susceptible to spiralling whitefly incidence in the present investigation. The findings are similar to those of Asia Mariam (1999) who reported plant species belonging to Euphorbiaceae, Solanaceae and Fabaceae were more susceptible to infestation with *A. dispersus* in earlier studies.

Spiralling whitefly nymphs and adults gathered and heavily infested the lower leaf surface of all plant varieties (Boopathi et al. 2014c). When the spiralling whitefly infestation was severe, yellow speckling, curling, and crinkling of the leaves was observed (Palaniswami et al. 1995). Damage in young plants by spiralling whitefly would result in reduced growth. Tree species may have escaped death, but would have significantly reduced vigor (Ranjith 1998). Wen et al. (1995) estimated that spiralling whitefly could result in an 80% loss of fruit yield in guava through four months of infestation. David and Regu (1995) reported that this insect's occurrence and spread was alarming on rubber and the infestation caused unseasonal leaf collapse and consequent yield reduction as a result of reduced latex flow. Banana production decreased as a result of the spiralling whitefly attack (Ranjith 1998). Some of the host species reported are likely to be minor host plants that are unable to sustain *A. dispersus* populations for long-time and therefore need minimum or no control measures. However, 58 host species are preferred hosts based on host frequencies, incidence (>75%) and most dense population (10 individuals/leaf), which may require additional control. The spiralling whitefly had a drastic detrimental impact on the agricultural sectors (Alam et al. 1998). Considering the wide spread and severe incidence of spiralling whitefly on a variety of plants in India, it is likely that this species may soon pose a threat to cultivation of economically important field and plantation crops in India.

Extensive survey was conducted in the present study to find out natural enemies of this introduced pest. In Tamil Nadu and Karnataka, 28 predators belonging to the families of Cybocephalidae, Coccinellidae, Chrysopidae, Drosophilidae, Lycaenidae, Anthocoridae, praying mantis and spiders and two hymenopteran parasitoids species were observed as natural enemies of *A. dispersus*. These natural enemies have a vital role to play in *A. dispersus*

population regulation. Several workers in many countries have previously documented the natural enemy complex of *A. dispersus* (Nechols 1982; Kumashiro et al. 1983; Waterhouse and Norris 1989; Blanco-Metzler and Laprade 1998; Geetha 2000). In India (Karnataka, Kerala, Maharashtra, Tamil Nadu, Lakshadweep Islands, and Andhra Pradesh), 45 predators, 3 parasitoids, and 2 pathogens of *A. dispersus* were reported (Mani 2010). Seventeen Coleopteran, five Neuropteran, two Dipteran and one in each of the lycaenid, anthocorid, mantid and spider groups were found in Tamil Nadu and Karnataka (India). A total 45 predators were reported in India, mostly generalists and a few species are host specific (Mani 2010). Known to attack *A. dispersus* were predators numbering 22 from Karnataka (Mani et al. 2004), 15 from Tamil Nadu (Geetha 2000) and 40 from Karnataka and Lakshadweep (Ramani 2000). The current study showed that the predominant predator of *A. dispersus* on cassava was *Cybocephalus* sp. Previously, *Cybocephalus* sp. was first recorded from Minicoy (Ramani 2000) and was later discovered to occur frequently in Bangalore (Karnataka, India), notably at highest densities (PDBC 2000; Mani and Krishnamoorthy 1999a). Geetha (2000) have recorded higher numbers of *Cybocephalus* sp. on cassava.

Axinoscymnus puttarudriahi, *C. montrouzieri*, *C sexmaculata*, *C. nigrita* and *S. coccivora* were the commonly found coccinellids on cassava in colonies of *A. dispersus*. *A. puttarudriahi* is found to be specific to *A. dispersus* and occurs all year round. *A. puttarudriahi* presence was previously recorded as a potential predator on *A. dispersus* in Sri Lanka (Wijesekera and Kudagamage 1990) and in Karnataka, India (Mani 2010). *C. montrouzieri* was found to be praying on *A. dispersus* and found to decrease in large numbers the population of *A. dispersus* to some extent. Mani and Krishnamoorthy (1997), Asia Mariam (1999) and Geetha (2000) found that in many areas of India, *C. montrouzieri* preyed on whitefly almost all year round. The abundance of *C. nigrita* on guava was reported earlier by Mani and Krishnamoorthy (1999b) and Geetha (2000).

Among the two parasitoids recorded, the most abundant parasitoids in Coimbatore were *E. guadeloupae* and *E. meritoria*. These two parasitoids might have been accidentally entered in India with the host insect (*A. dispersus*). They were found in Tamil Nadu and Karnataka parasitising *A. dispersus* nymphs on several host species. Earlier in Kerala (Beevi et al. 1999) and Karnataka (Srinivasa et al. 1999), similar parasitoid activity was reported. These two parasitoids are exotic and have never been reported in India on other whiteflies. The study of relative abundance of parasitoids in various locations of Tamil Nadu and Karnataka revealed that Coimbatore recorded more numbers of parasitoids and the least was documented from Tiruchirappalli. This variation in parasitoid abundance at a location may be due to local climate conditions and availability of host food. Host plants also affected parasitoid abundance. Parasitoids harbored more in cassava (56.7), cotton (45.7) and acalypha (43.0), while pigeon pea had less parasitoids (3.7). Survey in Thrissur (Kerala, India) found high levels of parasitism on banana, balsam, chilli, eggplant, guava, rubber, and tapioca (PDBC 2002). In this study, parasitism level was up to 58.8% and parasitoid emergence on acalypha was up to 89.7%. Earlier, Mani and Krishnamoorthy (2006) recorded *E. guadeloupae* parasitism in rose to 96%, *Hibiscus* to 86.45%, Poinsettia to 90.4% and *Acalypha* to 39.86%.

Given the widespread and severe incidence of exotic spiralling whitefly on a variety of host plants in India, this species is likely to pose a threat to the cultivation of economically important crops in India in the near future. Arthropod predators, *Cybocephalus* sp. and *M. astur* were the predominant predators of *A. dispersus*. *E. guadeloupae* and *E. meritoria* are expected to spread to even more places, resulting in a major decline in the *A. dispersus* population in India. In order to prevent further spread of *A. dispersus*, these four natural enemies, *Cybocephalus* sp., *M. astur*, *E. guadeloupae* and *E. meritoria* can be included in the IPM program for regulating the population of *A. dispersus*.

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Declarations

Conflict of Interest The authors declare they have no conflicts of interest.

Ethical Approval This article does not contain any studies with human participants performed by any of the authors.

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