Volatile blooms of *Aleurodicus rugioperculatus* Martin infested coconut and banana leaves attracting parasitoid *Encarsia guadeloupae* Viggiani

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DOI: https://doi.org/10.36077/kjas/2023/v15i2.12142

Received date: 22/5/2023

Accepted date: 3/7/2023

Abstract

Invasive whitefly species in coconut plantations have become a matter of concern in the last half a decade as they cause direct and indirect infestation on the palms. The Rugose spiralling whitefly (RSW), *Aleurodicus rugioperculatus* Martin infestation was high on *Cocos nucifera* L. (coconut) followed by *Dypsis lutescens* (H. Wendl.) (Butterfly palm) and *Annona squamosa* L. (custard apple). The coconut varieties Malayan Yellow Dwarf and Chowghat Orange Dwarf were observed with higher infestation index while that of West coast tall was the lowest. Higher RSW parasitization levels were observed on *Musa paradisiaca* L. (banana) and *Canna indica* L. (Indian shot), with 85.96 and 71.59% parasitization, respectively. Identification of volatile organic compounds (VOCs) between healthy and RSW-infested coconut plants revealed the emission of 56 VOCs from the healthy coconut plant and 47 VOCs from RSW infested plant. 22 VOCs were common in both samples, and 25 VOCs were unique to RSW-infested coconut plants. The presence of 42 VOCs was identified from the headspace extracts of RSW-infested bananas. Differences in the VOCs emitted from RSW-infested banana and coconut plants revealed higher emission of terpenoids like β-Caryophyllene, (E, Z)-2,6-dimethyl-2,4,6-Octatriene, Humulene, α-Pinene, Farnesane, α-Copaene and β-cis-Ocimene from RSW infested banana plants that proved to be more attractive to the parasitoid. Identifying specific blends of volatile compounds influencing *Encarsia guadeloupae* Viggiani could help to augment the parasitotic for RSW management in coconut plantations.

Keywords: Rugose spiralling whitefly, *Cocos nucifera*, volatile organic compounds, tri-trophic interactions

Introduction

Invasive whiteflies top the list of exotic pests in Indian Agro-ecosystems and a total of 464 whitefly species from 68 genera are found to cause significant damage in a wide range of crop plants (28). The coconut ecosystem has experienced the invasion of five whitefly species which four of the species *viz*., *Aleurodicus rugioperculatus* Martin, *Paraleyrodes bondari* Peracchi, *P.minei* Iaccarini, and *Aleurotrachelus atratus* Hempel had recently invasions with significant damage (16, 19, 28 and 29). *Aleurodicus rugioperculatus* (Rugose Spiralling Whitefly- RSW) is a polyphagous pest native to Central America and its presence in the old world was reported from Kottayam, Kerala, and Pollachi, Tamil Nadu (29 and 30). It is the predominant coconut whitefly and has become a matter of concern in coconut plantations. A total of 118 host species of RSW were recorded in Florida (12) and 35 host species in Karnataka with severe infestation on coconut, banana, and Indian almond (22). Colonization and continuous feeding by nymphs and adult whiteflies on phloem saps result in nutrient and water loss of host plants. In addition, they honeydew released as a result of asap-feedings as a medium for sooty mould growth by the fungus, *Capnodium* sp. (1). Though there was no direct economic impact by the insect on coconut palms, it indirectly affects photosynthesis and nut production through sooty mould growth (7).

Management of RSW in coconut plantations is challenging due to plant height and the rapid development of resistance to insecticides in whiteflies (26). An Aphelinid parasitotic, *Encarsia guadeloupae* was reported as a potential natural enemy of RSW with higher parasitization record of 60.00% in Kerala (27), 60.75% in Kanyakumari district of Tamil Nadu (11) and 70.70% in Southern transition zone of Karnataka (22). Hence, managing RSW through non-insecticidal methods is essential to keep the pest under control and to boost yield in coconut plantations. Chemical cues from the host plant play a key role in the insect's host-finding process for feeding and oviposition. Thsemiochemical-based based approaches in pest management that offer advantages of specificity, safety, and efficacy are an effective way to address insect infestation of agriculturally important crops (20). The choice of host plant and herbivore location mainly depends on the volatile organic compounds released by host plants (31), while the parasitoids locate their hosts by herbivore-induced plant volatiles and host kairomones (17). Price *et al.* (23) proposed the theory of tri-trophic interactions which would play a pivotal role in maintaining a functional agroecosystem. When attacked by phytophagous insects, host plants emit a mixture of volatile organic compounds known as herbivore-induced plant volatiles (HIPVs), which attract natural enemies of the pest, especially their parasitoids. (14). Hence, the present study aimed to identify the HIPVs from coconut and other hosts due to RSW infestation and the volatile compounds attracting *E. guadeloupae* from its most preferred host plant.

Materials and Methods

Survey on RSW infestation

Survey and *in-situ* observation of RSW infestation on different host plants was conducted at Tamil Nadu Agricultural University (TNAU), Coimbatore, Tamil Nadu, and India. Nymphal and adult populations were used to assess the infestation range of RSW on different crops (4) along with number of parasitized and healthy nymphs and co-occurring whitefly species.

Parasitisation % =

$$\frac{\text{Number of parasitized whitefly nymphs}}{\text{Total number of nymphs observed}} * 100$$

Infestation index of different coconut varieties

The infestation index of different coconut varieties infested by RSW at three different Research stations *viz.*, Coconut Research Station (CRS), Aliyar Nagar, CRS, Veppankulam, TNAU, and Coimbatore was calculated using the damage rating scale developed by Srinivasan *et al.* (30). Palms in each variety were graded from 0 to 3 based on the level of infestation, no. of egg spirals and sooty mold encrustation – 0; Fewer than 10 egg spirals per leaflet; the presence of sooty mold encrustation in 5- 6 lower-most fronds – 1; Ten to 20 egg spirals per leaflet and presence of sooty mold encrustation in 10-12 fronds – 2; More than 20 egg spirals per leaflet and presence of sooty mold encrustation in more than 12 fronds – 3.

$$\text{Infestation indeX} = \frac{(\text{No. of palms under Scale 0 X 0}) + (\text{No. of palms under Scale 1 X 1}) + (\text{No. of palms under Scale 2 X 2}) + (\text{No. of palms under Scale 3 X 3})}{\text{Total no. of palms observed}}$$

Collection of host plant headspace volatiles

Headspace volatiles from healthy and RSW-infested coconut and banana plants were collected using a custom-designed field-based air entrainment device. A set-up consisting of polyvinyl acetate bags (150 cm x 75 cm in height x breadth) fitted with input and outflow silica tubes was designed to collect volatiles from host plants (21). After passing through a humidifier and a charcoal filter, air from an air compressor reached the entrainment chamber through the input tube. Volatile trapping tubes constructed of Porapak Q (50 mg, 60/80 mesh; Supelco, Sigma Aldrich St Louis, United States) were installed inside the air outlet. These tubes were connected to the vacuum pump, and the airflow was set to 500 mL min^{-1}. The equipment was inverter-powered, and each host plant's volatile collection lasted 16 hours. The volatile substances trapped in Porapak Q were eluted in glass vials with 500µL of diethyl ether (purity > 99.5% pure, Merck) and stored in a freezer (−20◦C) until further use (32).

Identification of volatile organic compounds

Porapak Q elutes of headspace plant volatiles from four samples (Healthy and RSW infested coconut and banana) collected in the solvent (Diethyl ether, Merck, 99.97%) was analyzed using GC-MS, Agilent 7890B GC system equipped with Mass Spectrometry, MS (Agilent 5977 MSD). The samples were examined using an Agilent (HP-5 MS UI) capillary column. The temperature setting was the same as indicated earlier. At a flow rate of 1 mL min^{-1}, helium was used as a carrier gas. The MS was set to full scan mode (70 eV) and the AMU range was set at 40-450. At a split less mode ratio of 40 mL min^{-1}, one microliter of the sample was injected at a temperature of 250°C. Individual volatile chemicals were identified by comparing the GC retention time and the MS spectra to the NIST 14 spectral database. Total volatile production was calculated as the sum of all GC-FID peak regions in the chromatogram, and specific compounds were quantified as a percentage of total volatile production (32) the proportion of compounds in the headspace extracts was calculated by the peak area of the compounds.

$$\text{Proportion of compound A (\%)} = \frac{\text{Area of compound A}}{\text{Total area}} \times 100$$

Statistical analysis

Analysis of variance (Way ANOVA) of the arcsine transformed percentage values was done using Statistical Analysis Software (SAS cloud-based version- On Demand for Academics) and the mean data was compared at a 5% significance level using Tukey's (HSD) test.

Results and Discussion

Field observations revealed very high infestation levels on *C. nucifera* by RSW and four other exotic whitefly species, followed by *D. lutescens*, *A. squamosa* and *M. paradisiaca* as demonstrated in Table (1).

Table 1. Host spectrum of RSW with infestation range on different host plants

Host	Family	Infestation Range	Co-occurring whitefly species
Annona reticulata	Annonaceae	Moderate	*Paraleyrodes bondari, P. minei*
A. squamosa	Annonaceae	High	*Aleurodicus dispersus, P. bondari, P. minei, Paelius sp.,*
Canna indica	Cannaceae	Low	-
Citrus medica	Rutaceae	Low	*Dialeurodes citri*
Cocos nucifera	Arecaceae	Very high	*A. dispersus, P. bondari, P. minei, Aleurotrachelus atratus*
Dypsis lutescens	Arecaceae	High	*P. bondari, P. minei, A. atratus*
Hibiscus rosa-sinensis	Malvaceae	Low	*A. dispersus, P. bondari*
Mangifera indica	Anacardiaceae	Low	-
Manilkara zapota	Sapotaceae	Low	*P. bondari, P. minei*
Musa paradisiaca	Musaseae	High	*A. dispersus, P. bondari*
Myristica fragrans	Myristicaceae	Low	-
Persea americana	Lauraceae	Low	*P. minei*
Psidium guajava	Myrtaceae	Moderate	*A. dispersus, P. bondari, P. minei, Aleurothrixus floccosus*
Roystonea regia	Arecaceae	Low	-

Syzigium cumini	Myrtaceae	Low	*A. dispersus, P. bondari, P. minei*
Terminalia catappa	Combretaceae	High	*P. bondari, P. minei*
Theobroma cacao	Malvaceae	Moderate	*P. bondari*

Low- (≤10 adults and nymphs/ 10cm^2); Moderate - (10 to 30 adults and nymphs/ 10cm^2); High - (31 to 50 adults and nymphs/ 10cm^2); Very high - (>50 adults and nymphs/ 10cm^2)

The data in Figure (1) gives the level of parasitisation of RSW on different hosts. Among the different hosts observed, the maximum parasitisation of 85.96 % was observed in *Musa paradisiaca* followed by 71.59 % in *Canna indica.* The low level of parasitisation was recorded in *Manilkara zapota* (32.18%) and *Terminalia catappa* (44.76 %). *Encarsia guadeloupae* was the major parasitoid observed to parasitize RSW nymphs, though *E. dispersa* was found to be present in field conditions, and no adult *E. dispersa* emerged from examined parasitized nymphs.

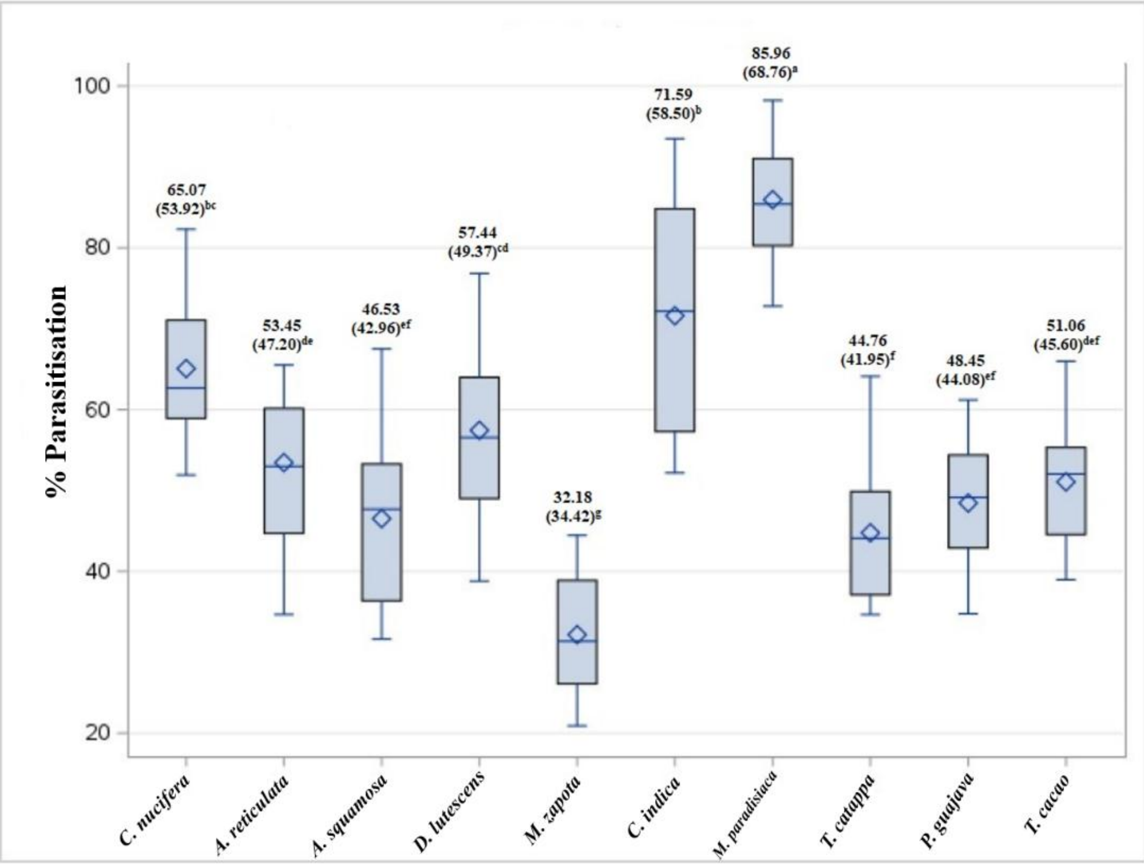

Figure 1. Parasitisation% of RSW on different host plants; Values in the parentheses are Arcsine transformed values; means followed by a common letter(s) are not significantly different by Tukey's HSD test at 5% level

Table (2) describes the whitefly infestation index of different coconut varieties. Higher infestation index was observed in the Coconut var. Malayan Yellow Dwarf in all the three Coconut Research Stations followed by var. Chowghat Orange Dwarf and var. Malayan Orange Dwarf. Coconut var. West Coast Tall and Arasampatti Tall recorded low infestation index. Infestation index of coconut varieties at CRS, Veppankulam, was relatively higher than the other two research stations. On var. Chowghat Orange dwarf Srinivasan *et al.* (30) and Elango *et al.* (11) recorded the highest infestation index of 2.55 and 2.28.

Table 2. Infestation index of different coconut varieties assessed at three different locations

Variety	Infestation Index			
	CRS, Aliyar Nagar	CRS, Veppankulam	TNAU, Coimbatore	Mean Infestation range
Arasampatti Tall (n=20)	0.7	0.95	0.95	Low
Chowghat Green Dwarf (n=15)	1.45	2.2	1.9	Medium
Chowghat Orange Dwarf (n=20)	2.25	2.7	2.35	High
East Coast Tall (n=20)	0.85	1.05	1.3	Medium
Gangabondam (n=15)	1.9	2.15	2.05	High
Kenthali Dwarf (n=20)	1.35	1.85	1.65	Medium
Malayan Green Dwarf (n=15)	1.75	2.35	2.15	High
Malayan Orange Dwarf (n=20)	2.1	2.55	2.3	High
Malayan Yellow Dwarf (n=20)	2.35	2.85	2.65	High
West Coast Tall(n=20)	0.55	0.8	0.7	Low

n- Number of palms observed; CRS- Coconut Research Station; TNAU- Tamil Nadu Agricultural University

Profiling of headspace extracts revealed the presence of 56 volatile organic compounds (VOCs) from healthy coconut plant and 47 VOCs from RSW infested coconut plant, 44 VOCs from healthy banana plant and 42 VOCs from RSW infested banana plant as indicated in the table (3). Figure (2) indicates the number of compounds present in different headspace extracts.

A total of nine volatile compounds were identified in all the headspace samples and the emission of 13 VOCs (α-Hydroxypropanoic acid; 2-Butyl-1-octanol; Phthalic acid,hept-4-yl isobutyl ester; 3,7-dimethylundecane; 7-methylhexadecane; 6-Methylpentadecane; 10-methyl-Eicosane; 2,3-Dimethylanisole; 2,6,10,14-Tetramethylhexadecane; 3,7,11-Trimethyl-1-dodecanol; 2-Methylnonadecane; Decenal and α-Copaene) from banana and 25 VOCs ((Z)-4-Tetradecene; 5-Methyltetradecane; 1-Tetradecene; (E)-2-Dodecene; 2,6-

Dimethyloctane; 4-Ethyltetradecane; 2-Methyltetradecane; 3-Ethyloctane; 4,5-dimethylnonane; 2,3,5,8-Tetramethyldecane; 2,7,7-trimethyl-3-oxatricyclo-octane; 7,7-Diethylheptadecane; 5-Methyltridecane; (Z)-3-Dodecene; 5-Ethyldecane; 2,2,4,6,6-Pentamethylheptane; 7-Methylheptadecane; Benzothiazole; 1,2,3,6-tetramethyl-bicyclo-octa-2,5-diene; 2,5-Dimethylnonane; Ascaridole; Octadecane; 3,6-dimethyldecane; 3-Methylundecane and 4-Ethyldecane) from coconut were triggered by RSW infestation further altering insect's host finding process and tri-trophic interactions.

Table 3. Volatile organic compounds and their proportion in Healthy and RSW infested coconut and banana plants

RT	Compound	Area %			
		Healthy coconut	Infested coconut	Healthy banana	Infested banana
3.35	2-Butanone, 3-hydroxy	3.56	4.15	-	-
3.52	α-Hydroxypropanoic acid	0.95	1.31	-	0.72
4.30	2,3-Butanediol	24.29	28.70	10.72	13.12
4.49	1,3,5-Trioxepane	10.79	8.18	6.4	-
4.51	3-Hexanol, 3-methyl	7.90	-	0.58	-
4.59	2-Ethyl-1,3-dioxolane	18.65	18.48	-	-
5.86	3-Hexanol, 3,5-dimethyl	0.06	0.07	-	-
6.13	1,3-Dioxolane, 2-propyl-	0.04	0.02	-	-
6.55	2,6-Dimethyloctane	-	0.45	-	-
6.58	α-Pinene	-	-	0.54	0.68
6.65	Methyl 2-hydroxy-2-methylbutanoate	0.49	-	-	-
7.16	m-Ethyltoluene	0.15	-	-	-
7.19	3-Ethyloctane	-	0.26	-	-
7.57	β-Pinene	-	-	2.31	-
7.58	psi. –Cumene	1.38	-	-	-
7.64	2,2,4,6,6-Pentamethylheptane	-	11.42	-	-
8.16	p-Dichlorobenzene	0.75	0.27	-	-
8.39	2-Ethyl-1-hexanol	2.75	-	3.22	4.03
8.41	2,5-Dimethylnonane	-	3.00	-	-
8.65	3,7-Dimethyl-1,3,7-octatriene	0.33	-	-	-
8.78	β-cis-Ocimene	-	-	0.67	0.84
8.85	4,5-Dimethylnonane	-	0.27	-	-
8.95	2-Methyldecane	-	-	2.87	3.59
9.26	o-Methylphenol	0.05	-	-	-
9.50	m-Cresol	0.29	-	-	-
9.54	2,7,7-Trimethyl-3-oxatricyclo-octane	-	0.24	-	-
9.65	Terpinolene	0.20	-	-	-
9.86	Undecane	-	-	3.34	4.18
9.91	Nonanal	1.54	0.72	-	-
9.96	2,6-Dimethyldecane	-	-	1.81	2.26
10.12	3,7-Dimethyldecane	-		1.64	2.05
10.20	3,6-Dimethyldecane	-	0.76	-	-

10.24	α-Ethylhexanoic acid	0.11	-	-	-
10.45	(E, Z)-2,6-Dimethyl-2,4,6-octatriene	-	-	0.72	0.9
10.71	5-Ethyldecane	-	0.41	-	-
10.76	1,3-Bis(1-methylethyl)-benzene	0.79	-	-	-
10.81	2,3-Dimethylanisole	-	-	-	4.2
10.87	4-Ethyldecane	-	0.37	-	-
10.96	1,2,3,6-Tetramethyl-bicyclo-octa-2,5-diene	-	0.91	-	-
10.98	1,4-Bis(1-methylethyl)-benzene	-	-	0.19	-
11.04	m-Xylene, 5-tert-butyl	1.00	-	3.35	-
11.16	1-(1,1-dimethylethyl)-4-ethyl-benzene	0.61	-	-	-
11.24	3-Methylundecane	-	2.31	-	-
11.42	p-Diisopropylbenzene	1.11	-	-	-
11.54	(Z)-3-Dodecene	-	0.27	-	-
11.66	(E)-2-Dodecene	-	0.65	-	-
11.83	Dodecane	1.02	4.44	2.3	2.87
11.96	Decanal	0.38	-	-	-
12.59	Benzothiazole	-	0.08	-	-
12.64	(E)-2-Decen-1-ol	-	-	0.36	-
12.72	Ascaridole	-	0.26	-	-
12.83	Decenal	-	-	-	0.45
13.31	2-Butyl-1-octanol	0.22	0.04	-	0.87
13.38	4-Methyldodecane	0.22	-	-	-
13.41	2-Methyldodecane	0.09	-	0.33	-
13.45	3,7-Dimethylundecane	-	-	-	0.41
13.49	2,6,11-Trimethyldodecane	-	-	3.19	3.99
13.79	n-Tridecane	0.20	0.57	8.33	0.97
13.97	2,3,5,8-Tetramethyldecane	-	0.31	3.24	0.75
14.16	Undecanal	2.26	-	-	-
14.48	4,6-Dimethyldodecane	-	-	1.63	10.43
14.68	Farnesane	-	-	0.21	2.06
14.79	5-Methyltridecane	-	0.07	-	-
15.11	3-Methyltridecane	0.46	1.68	0.24	0.61
15.39	(Z)-4-Tetradecene	-	0.18	-	-
15.45	α-Copaene	0.87	-	-	0.3
15.50	1-Tetradecene	-	0.20	-	-
15.65	Tetradecane	3.04	2.88	1.09	1.37
16.09	β-Longipinene	0.07	-	-	-
16.30	β-Caryophyllene	0.71	-	0.44	0.55
16.59	α-Himachalene	0.19	-	-	-
16.91	Humulene	0.07	-	0.4	0.51
17.02	5-Methyltetradecane	-	0.08	-	-
17.09	2,5-di-tert-Butyl-1,4-benzoquinone	0.17	-	-	-
17.27	2-Methyltetradecane	-	1.58	-	-
17.41	Pentadecane	0.27	-	17.8	22.29
17.63	2-Hexyl-1-decanol	-	-	0.31	0.49
17.72	2,4-Di-tert-butylphenol	1.12	1.08	0.22	-
18.04	4-Ethyltetradecane	-	0.10	-	-

18.30	2,6,10-Trimethyltetradecane	0.25	-	2.76	0.72
18.52	6-Methyloctadecane	0.22	-	-	-
18.61	2-Methylpentadecane	0.84	0.56	0.86	-
18.65	6-Methylpentadecane	-	-	-	0.28
18.75	5,8-Diethyldodecane	-	-	0.69	1
18.87	3,7,11-Trimethyl-1-dodecanol	0.07	0.05		3.46
19.10	Hexadecane	1.36	0.84	0.56	0.86
19.15	7-methylhexadecane	-	-	-	0.7
19.87	Geranyl isovalerate	0.02	-	-	-
20.08	3,3-Diethyltridecane	2.07	-	-	-
20.09	2,6,10-Trimethylpentadecane	-	-	10.51	-
20.87	Heptadecane	-	-	0.77	0.97
21.05	2-Hexadecanol	0.11	0.11	0.22	0.28
21.53	5,5,7,7-Tetraethylundecane	-	-	0.82	-
21.62	2-Methylheptadecane	-	-	0.19	1.03
21.78	3-Methylheptadecane	0.29	0.26	0.2	0.25
22.17	(Z)-9-Tetradecen-1-ol acetate	3.52	-	-	-
22.21	7-Methylheptadecane	-	0.25	-	-
22.31	Phytane	-	-	0.24	-
22.36	2,6,10,14-Tetramethylhexadecane	-	-	-	0.3
22.50	Octadecane	-	0.47	2.83	-
23.30	Butyl isobutyl phthalate	0.05	0.27	0.28	3.54
23.96	2-Heptadecanol	0.14	-	-	-
24.02	Nonadecane	-	-	0.2	-
24.24	2-Methylnonadecane	-	-	-	0.35
24.67	1,19-Eicosadiene	0.70	-	-	-
24.83	10-Methyl-Eicosane	-	-	-	0.25
25.02	Cyclopentadecanol	0.77	-	-	-
25.30	7,7-Diethylheptadecane	-	0.07	0.42	-
25.48	Phthalic acid, hept-4-yl isobutyl ester	-	-	-	0.52
26.29	1-Hexadecanol acetate	0.25	-	-	-
26.67	Heneicosane	0.17	0.35	-	-

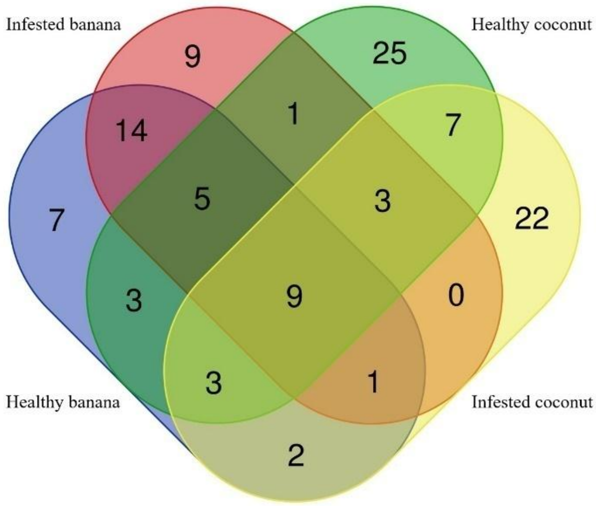

Figure 2. The number of volatile compounds present in the headspace extracts of healthy and RSW infested coconut and banana plants.

2-Ethyl-1-Hexanol and β-Caryophyllene which were reported to attract silverleaf whitefly *Bemisia tabaci* (8 and 24), was emitted from healthy coconut plant and were not present in infested plant sample whereas, in banana, the emission of 2-Ethyl-1-Hexanol and β-Caryophyllene were unaffected by RSW infestation.

Parasitisation of RSW was higher in bananas which corroborates with the report of Saranya *et al.* (25) that the parasitoid, *E. guadeloupae* was more highly attracted to banana plants than any other host plants studied. The ability to distinguish between different odor blends is probably influenced more by changes in the relative amount of distinct blends than by the presence or absence of specific compounds. Additionally, natural enemies like hymenopteran parasitoids have diverse volatile sensitivity and may not always react strongly to the most prevalent substances (18).

Green leaf volatiles (GLVs), terpenoid, aliphatic, and aromatic chemicals make up the majority of HIPVs; however, GLVs are not technically HIPVs because they are also emitted by healthy plants and plants that have been mechanically damaged, and the release is often not an induced response (10 and 15). Terpenoids are usually considered to be a major group of HIPVs, and the immense variability of terpenoids found in the emissions of various plant species and even different cultivars may act as a distinctive trait for parasitoids in identifying the proper host-infested plants. GC-MS analysis of the headspace extracts of RSW-infested coconut and banana plants revealed the presence of 47 and 42 VOCs, respectively. The volatile emission by RSW infested banana and coconut plants varied significantly, with 29 VOCs unique to banana (Fig. 2), the major being the terpenoids. Terpenoids such as β-Caryophyllene; (E, Z)- 2,6-dimethyl-2,4,6-Octatriene; Humulene; α-Pinene; Farnesane; α-Copaaene and β-cis-Ocimene present in the headspace extracts of RSW infested banana plant but absent in RSW infested coconut plants, were earlier reported to influence the activity of other parasitoids. A Hymenopteran parasitoid, *Closterocerus ruforum* was more attracted to the volatile blend of (E)- β-farnesene, (E)- βcaryophyllene, α-humulene, β-phellandrene and β-ocimene (5). Honeydew volatiles from *Trialeurodes vaporariorum* infested plants and terpenes like β-ocimene, 3-Carene, α-phellandrene and β-myrcene were highly attractive to *E. formosa* and these terpenes were utilized to attract the parasitoid, *E. formosa* (2 and 3).

The proportion of 2, 3-Butanediol was higher in all three plant volatiles (24.29% in healthy coconut, 28.70% in coconut infested, 10.75 in healthy banana, and 13.12% in banana infested). Soil application of 2, 3-Butanediol had the indirect attraction of the parasitoid, *Cotesia marginiventris* (9), and the compound was in relatively higher proportion among the blend of 21 VOCs that attracted *Aphdius colemani* (13).

Conclusion

HIPVs play a crucial role in host plant-herbivore-natural enemy interactions and have the potential to improve biological control and host plant resistance for integrated pest management. Enhanced emission of terpenoids along with other VOCs in the banana plant would have enhanced the parasitisation of RSW by *E. guadeloupae* more than any other host plant. Specific or blends of chemicals in the complex mixture attracting whiteflies and their natural enemies could be effectively identified by insect electrophysiological studies to broaden the research on whitefly olfaction. Further, the impact of one whitefly species on the co-occurring whitefly species can be easily adjudged with a broader investigation by correlating insect olfaction and volatile organic compounds.

Acknowledgment

The authors thank the Division of Entomology and Nematology, Indian Council of Agricultural Research- Indian Institute of Horticultural Research, Bengaluru, India.

Conflict of Interest

Authors have no conflict of interest.

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