Aromatic plant odours of *Anethum graveolens* and *Coriandrum sativum* repel whitefly, *Bemisia tabaci* in tomato

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We studied the behavioural responses of female whitefly, *Bemisia tabaci* (Gennadius) towards headspace volatiles of tomato in the presence of aromatic intercrops, namely coriander (*Coriandrum sativum* L.) and dill (*Anethum graveolens* L.) using olfactometer bioassays, electrophysiological techniques and field experimentation. Olfactometer studies revealed the repellent nature of dill and coriander. Multiple-choice olfactometer studies revealed less residence time in tomato with coriander (T + Co; 1.33 ± 0.20 min) and tomato with dill (T + D; 1.97 ± 0.30 min) treated arms compared to sole tomato volatile treated arm (3.18 ± 0.35 min). Field studies also supported this trend, where significantly less whitefly incidence was recorded in treatment T + Co (2.34 ± 0.39 per three leaves) or T + D (3.33 ± 0.51 per three leaves) compared to sole tomato crop (5.71 ± 0.75 per three leaves). In coupled gas chromatography-electro-antennodetection (GC-EAD) studies, whitefly antenna responded to several compounds of dill and coriander. This study suggests that aromatic plants such as dill and coriander can be used as potential intercrop components in tomatoes to manage *B. tabaci* and the GC-EAD-identified compounds of dill and coriander will help formulate futuristic semiochemical-based pest management strategies against the whitefly.

Keywords: Aromatic intercrops, *Bemisia tabaci*, headspace volatiles, pest management strategies, tomato.

CULTIVATING two or more crops together known as intercropping, is an age-old traditional agronomic practice in the often diversified food-production systems of tropical regions spread across Asia, Africa and Latin America[1,2]. Unlike existing input-intensive popular monocropping systems, intercropping is credited with several impressive ecological and economic benefits like efficient utilization of abiotic resources, greater crop diversity and reduced insect-pest attack.

Incorporation of intercrop components not only increases the diversity of the agroecosystem, but also reduces insect attack (= herbivore attack) on the target crop[3]. Intercropping with non-host plants is often considered the best alternative to control herbivores and it has been successfully demonstrated in several crops[4,5]. Incorporation of coriander, marigold and mint as intercrops along with maize or cowpea in brinjal decreased the incidence of herbivores and increased the occurrence of natural enemies[6]. Intercropping with aromatic plants such as fennel, dill, coriander and marjoram in sugarbeet resulted in less incidence of tortoise beetle *Cassida vittata* Villers and increased the population of predatory species like *Coccinella* spp., *Chrysoperla carnea* (Stephens), *Paederus alfierii* Koch, *Scymnus* spp., spiders, etc.[7]. Intercropping of aromatic plants with kidney bean *Phaseolus vulgaris* L. not only decreased the whitefly incidence, but increased the parasitoids[8]. There are different ways by which an intercrop reduces the pest load on the target crop; the intercrop might affect the host plant-searching behaviour of insect pests of the target crop by acting as a repellent or masking the host plant odours[9,10]. Additionally, intercrop components may emit volatile organic compounds (VOCs) which attract the natural enemies of insect pests of the main crop[11]. Thus, intercropping systems provide cost-effective sustainable pest management options to small and marginal farmers. However, the scientific basis of combining the different intercrops with a particular main crop remains to be worked out for specific herbivores. Since herbivores locate their host plants through their VOCs[12], their host-finding behaviour amidst the odours of intercrops is worth exploring. The objective of the present study was to evaluate the potential of aromatic plants such as coriander (*Coriander sativum* L., family: Apiaceae) and dill (*Anethum graveolens* L., family: Umbelliferae) on the herbivores in the main crop, viz. tomato (*Solanum lycopersicum*).

Silver leaf whitefly, *Bemicia tabaci* (Gennadius) (Hemiptera: Aleyrodidae) is a major pest of several economically important crops worldwide causing significant yield losses[13]. It is highly polyphagous[14]. Currently, synthetic insecticides are extensively used to manage whiteflies across crops. However, they pose health and environmental risks[15]. Further, whiteflies have developed resistance to several insecticides and thus, other methods such as biological

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control involving predators/parasitoids[16], using living ground covers and other cultural practices[17] have been explored.

Using *B. tabaci* and its host plant *S. lycopersicum* as a model system, behavioural responses of the whitefly were explored towards the main crop (tomato) in the presence of aromatic intercrops, namely coriander and dill using olfactometer bioassays, electrophysiological assays and field experimentation.

Materials and methods

Plants

Tomato seeds (Arka Vikas) were procured from ICAR-Indian Institute of Horticultural Research Institute (ICAR-IIHR), Bengaluru, Karnataka, India. Seeds of dill, and coriander were procured from the local market in Bengaluru. In the case of coriander and dill, the direct seed sowing method was used, whereas in the case of tomato, the seedling transplantation method was followed. Tomato seeds were sown in plastic protrays containing cocopeat and were watered regularly following all standard agronomic practices. The 20-day-old seedlings were used for main field transplantation.

Insects

Whiteflies were reared on four-weeks-old tomato seedlings (Arka Vikas) in a greenhouse (26° ± 1°C temperature and 60–65% relative humidity) at the Division of Entomology and Nematology, ICAR-IIHR. Before experimentation, male and female whiteflies were separated based on body size/genitalia structures under a stereomicroscope (Leica M205A). In the experiment only females were used for all the bioassays.

Field experiment

The study was carried out in the experimental blocks of ICAR-IIHR (12°58′N; 77°35′E) during 2020–21. Three treatments, namely tomato intercropped with coriander (T + Co), tomato intercropped with dill (T + D) and tomato as a sole crop (T) were raised using a randomized block design in the area of 850 sq. m with each plot size of 8.4 m × 8.4 m. The individual intercrop components, namely coriander and dill were sown 15 days prior to tomato transplantation (in a single row after every two rows of tomatoes). Tomato seedlings were transplanted in the field between the rows of coriander and dill at a distance of 0.4 and 1.2 m within a row and between rows respectively. All the treatments were replicated four times. Standard agronomic practices were followed to maintain the crops. During the experiment, no insecticidal spray was done. Observations were recorded on the number of adult whiteflies/three leaves/plant by randomly counting from ten plants in each replication at weekly intervals from one week after transplantation (WAT) till six WAT of tomato.

Headspace volatile collection and analysis

Headspace volatile collection from healthy crop plants (tomato (4 WAT), coriander and dill (6 WAT)) was done according to an earlier described procedures[18], using battery-operated portable volatile collection unit in the field itself. The Porapak Q elutes of headspace volatiles collected in the solvent (diethyl ether, Merck, 99.97%) were analysed to identify specific compounds using Gas Chromatography-Mass Spectrometry (GC-MS) (Agilent 7890B GC system apparatus equipped with mass spectrophotometry; Agilent 5977 MSD), as described earlier[19].

Olfactometer bioassays

Circular perspex four-arm olfactometer (8 cm diameter) was used for studying the behavioural responses of *B. tabaci* towards headspace volatiles of plants, as described earlier[20]. For each treatment, 12 fresh adult female whiteflies ($n = 12$, starved for 1 h) were used. We conducted a total of three sets of olfactometer bioassays: (a) single-choice bioassays with individual plant volatiles (tomato, coriander, dill); (b) dual-choice bioassays with volatiles of tomato and its intercrop components (tomato versus coriander and tomato versus dill) and (c) multiple-choice bioassays with tomato plant volatiles versus a mixture of tomato + coriander (T + Co) and tomato + dill (T + D) plant volatiles to compare the whitefly preference behaviour towards sole and combined volatiles of tomato and its intercrop components.

Gas chromatography–electroantennogram detection

The gas chromatography–electroantennogram (GC–EAD) detection recordings ($n = 3$) for *B. tabaci* were made according to the procedure described earlier[20].

Statistical analysis

The data from single-choice olfactometer bioassays were analysed through an independent *t*-test to compare the means of residential time and the number of visits. The data from dual-choice as well as multiple-choice assays were analysed using one-way ANOVA to compare the means of residential time and number of visits with Tukey's HSD ($\alpha = 0.05$). Two-way ANOVA was used to analyse field data and the means were compared with Tukey's HSD ($\alpha = 0.05$). Principal component analysis (PCA) was performed to determine the variations among the main crop (tomato) and two intercrops (coriander and dill) volatile components. For all the statistical analyses and graphical representation, GraphPad prism (9.0 version) software was used.

Results

Single choice olfactometer bioassays

Tomato: Whiteflies showed a significant preference for the arm treated with tomato plant volatiles and stayed for more time (residence time) in the treatment arm compared to the control ($t = 7.037$, d$f = 11$, $P < 0.0001$; Figure 1 *a*). Further, the whiteflies made a significantly greater number of visits to the tomato volatiles-treated arm region ($t = 5.86$, d$f = 11$, $P = 0.0001$; Figure 1 *b*).

Coriander: The residence time of whiteflies was significantly low in the coriander volatiles-treated arm compared to the control ($t = 5.510$, d$f = 11$, $P = 0.0002$; Figure 1 *c*). Similarly, the whiteflies made significantly lesser number of visits to the coriander volatiles-treated arm compared to the control ($t = 3.988$, d$f = 11$, $P = 0.0021$; Figure 1 *d*).

Dill: Olfactometer bioassays using dill volatiles revealed that whitefly residence time was significantly lower in the treated arm compared to the control ($t = 4.534$, d$f = 11$, $P = 0.0009$; Figure 1 *e*). However, there was no significant difference with respect to total number of visits between the arms of the dill-treated odour region and the control ($t = 1.058$, d$f = 11$, $P = 0.3126$; Figure 1 *f*).

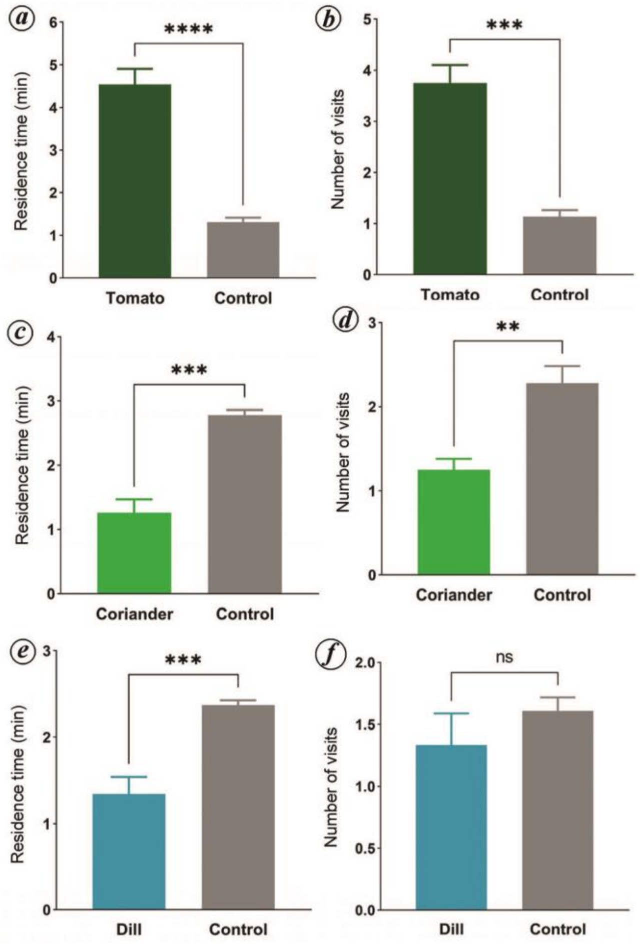

Figure 1. ***a–f***, Behavioural response of female whitefly, *Bemisia tabaci* to individual volatiles of tomato and its intercrop components in a four-arm olfactometer ($n = 12$). '*' indicates significant difference between treated and control arms; 'ns' Non-significant in independent *t*-test.

Dual-choice olfactometer bioassays

Tomato plant volatiles versus coriander/dill plant volatiles: Results of dual-choice olfactometer bioassays using volatiles of tomato and coriander showed that there was significant difference between the treatments as the whiteflies spent significantly more time ($F_{(2,33)} = 7.459$, $P = 0.0005$; Figure 2 *a*) and made significantly more number of visits ($F_{(2,33)} = 9.723$, $P = 0.0021$; Figure 2 *b*) to the arm treated with tomato plant volatiles (residence time: 3.35 ± 0.60 min; number of visits: 3.16 ± 0.53) compared to coriander plant volatiles (residence time: 1.11 ± 0.32 min; number of visits: 1.08 ± 0.22). In the bioassay using tomato and dill plant volatiles, significantly higher residence time ($F_{(2,33)} = 31.24$, $P < 0.0001$; Figure 2 *c*) and greater number of visits ($F_{(2,33)} = 12.68$, $P < 0.0001$; Figure 2 *d*) were observed in the tomato-treated arm (residence time: 3.46 ± 0.31 min; number of visits: 0.94 ± 0.18). These olfactometer assays indicate the repellent nature of both coriander and dill plant volatiles against *B. tabaci* compared to tomato.

Tomato plant volatiles versus a combination of tomato + coriander/dill plant volatiles: When whiteflies were given a choice between sole tomato plant volatiles (T) and a combination of tomato + coriander plant volatiles (T + Co)

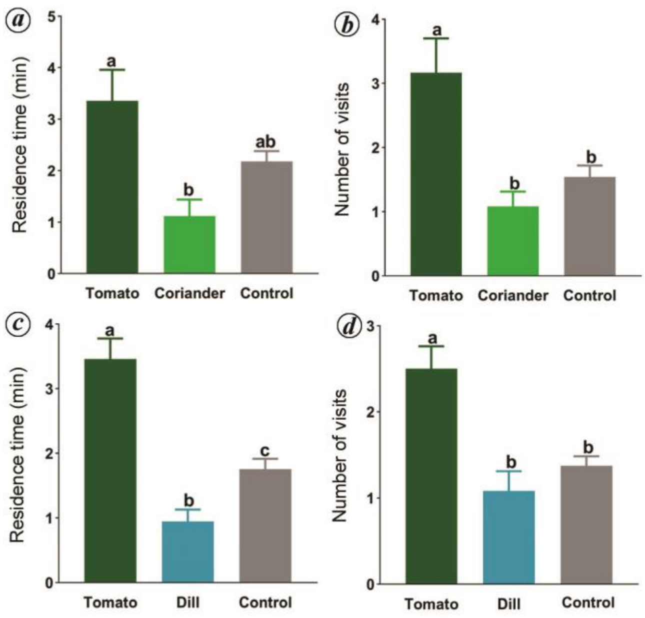

Figure 2. ***a–d***, Behavioural response of female *B. tabaci* to volatiles of tomato and its intercrop components in the four-arm olfactometer ($n = 12$). Bars with different letters are significantly different (Tukey's test: $P < 0.05$).

in a dual-choice assay, they spent significantly more time ($F_{(2,33)} = 13.48$, $P < 0.0001$, Figure 3 *a*) in the arm treated with sole tomato plant volatiles (2.76 ± 0.24 min) compared to that treated with a mixture of tomato and coriander volatiles (1.32 ± 0.20 min). In case of total number of visits also, whiteflies made significantly more visits ($F_{(2,33)} = 5.615$, $P = 0.0080$; Figure 3 *b*) to the arm treated with sole tomato volatiles (2.25 ± 0.17) compared to that treated with a mixture of tomato and coriander plants volatiles (1.33 ± 0.22). In the dual-choice bioassay between the sole tomato volatiles (T) and a combination of tomato and dill plant volatiles (T + D), there was a significant difference ($F_{(2,33)} = 21.33$, $P < 0.0001$; Figure 3 *c*) for residence time observed between sole tomato-treated arm (T: 3.49 ± 0.25 min) and a mixture of tomato and dill-treated arm (T + D: 1.84 ± 0.26 min). Here, the whiteflies spent significantly more time in the arm treated with T compared to T + D. However, no significant difference was observed in the total number of visits between these treatments ($P = 0.0708$; Figure 3 *d*).

Multiple-choice olfactometer assays

When choice was given among the various treatments in three different arms, residence time of whiteflies was found to be significantly more in the sole tomato-treated arm (3.18 ± 0.35 min; $F_{(3,44)} = 7.847$, $P = 0.0003$; Figure 3 *e*). There was no significant difference between the treatments T + Co (1.33 ± 0.20 min) and T + D (1.97 ± 0.30 min) ($P = 0.389$) for time spent by the whiteflies. Similarly, the number of visits was also higher for the sole tomato-treated arm (1.83 ± 0.24) compared to the other treatments (T + Co: 1.00 ± 0.12; T + D: 1.17 ± 0.16; $F_{(3,44)} = 4.451$, $P = 0.0081$; Figure 3 *f*). However, there was no significant difference between T + Co and T + D for the number of visits made by the whiteflies ($P = 0.90$).

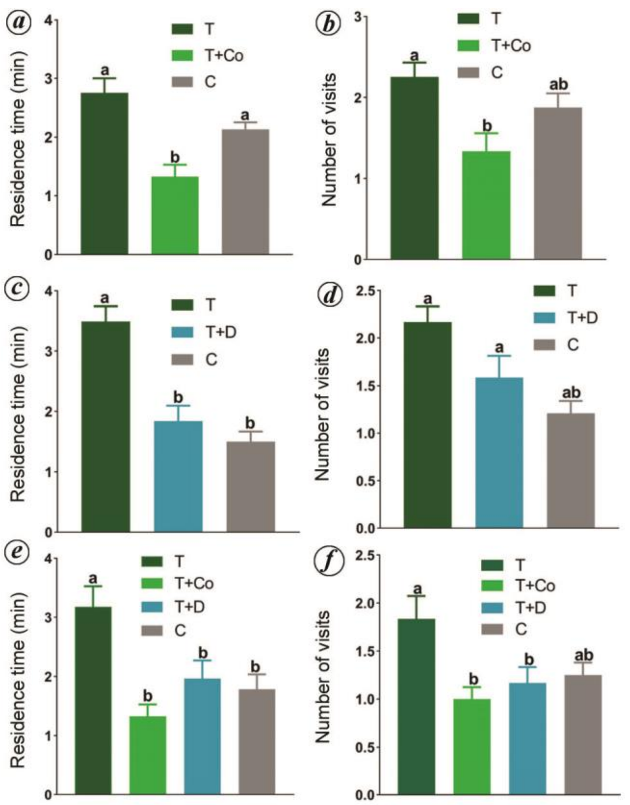

Figure 3. ***a–f***, Behavioural response of female *B. tabaci* to volatiles of tomato and a mixture of tomato volatiles with the intercrop component volatiles in the four-arm olfactometer ($n = 12$). Bars with different letters are significantly different (Tukey's test: $P < 0.05$).

GC-MS analysis of headspace volatiles

GC-MS analysis showed significant differences in the emission of VOCs among the three crop plants, i.e. tomato, coriander and dill. In case of tomato, *n*-undecane was the abundant compound followed by 2-methyl-*n*-tridecane, *n*-decane, 2,6,11-trimethyldodecane, 2-allylphenyl acetate and *n*-pentadecane. In coriander, 2-decen-1-ol, (E) was the most abundant compound followed by 2-methoxy-1,3-dioxolane, linalool, 3-ethylhexane, ethanone, 1-(4-ethylphenyl) and Farnesane. In case of dill, dill ether was the abundant compound followed by 3-carene, α-phellandrene, γ-terpinene and D-sylvestrene (Supplementary Table 1).

PCA revealed significant differences among the VOCs associated with the three crop plants, namely tomato, coriander and dill. Total variance (100%) was derived from the first two principal components (i.e. PC1 and PC2), which explained 55.21% and 44.79% variance respectively (Table 1 and Figure 4 *a*). PC1 was majorly represented by dill plant volatiles, namely dill ether, 3-carene, α-phellandrene, γ-terpinene, D-sylvestrene and *o*-cymene, which contributed positively (Table 1 and Figure 4 *b*). The principal component loadings of coriander volatiles (2-decen-1-ol, (*E*)-, linalool, ethanone 1-(4-ethylphenyl), 3-ethylhexane, 2-methylpentadecane, 2-methoxy-1,3-dioxolane, cyclofenchene, 2-decenal, (*Z*)- and 3-methyl-5-propylnonane) majorly contributed (negatively) to both PC1 and PC2 (Table 1 and Figure 4 *b*). The tomato volatiles contributed negatively to PC1 and positively to PC2. The volatile compounds 2-methyl-*n*-tridecane, 2-allylphenyl acetate, *n*-decane, 2,6,10-trimethyltetradecane, benzoic acid 4-ethoxy-ethyl ester, *n*-undecane, decane 2,3,5,8-tetramethyl, 3,7-dimethyldecane, 6-methylhydrocoumarin, 2,6-dimethyldecane, 2,6,11-trimethyldodecane, *n*-tridecane and *n*-pentadecane were the major contributors to both PC1 and PC2 (Table 1 and Figure 4 *b*).

GC-EAD study

In GC-EAD, antenna of whitefly responded to nine chemicals in tomato volatiles, viz. 2-methoxy-1,3-dioxolane, cyclofenchene, sabinene, *n*-decane, 5,6-dimethyldecane, ethyl benzoate, 2,6,11-trimethyldodecane, 6-methylhydrocoumarin and benzoic acid, 4-ethoxy-, ethyl ester (Supplementary

Figure 1 *a*). Among these, compounds like *n*-decane, 5,6-dimethyldecane, ethyl benzoate and 6-methylhydrocoumarin were completely absent in coriander as well as dill, and found to be exclusively present in tomato. Methoxy-1,3-dioxolane, which was found to be present in all three crop plants, could elicit antennal response only in tomato and dill but not in coriander. In case of coriander, compounds such as linalool oxide, (E)-ocimenone, farnesane, 2,6,10-trimethyltetradecane, 4-ethyltetradecane, 2-methylpentadecane and 2-methylheptadecane elicited an antennal response in whiteflies (Supplementary Figure 1 *b*). Among these, linalool oxide, (E)-ocimenone, 4-ethyltetradecane and 2-methylheptadecane were found to be specific to coriander and were absent in the main crop, viz. tomato. The other chemicals, namely farnesane, 2,6,10-trimethyltetradecane and 2-methylpentadecane though found in tomatoes, did not elicit any antennal response. Whereas, in dill volatiles, 2-methoxy-1,3-dioxolane, 3-carene, 8,9-dehydrothymol, *p*-cymene-2,5-diol and 8-methylheptadecane elicited an antennal response in whitefly. Among these, except 2-methoxy-1,3-dioxolane, all the other chemicals were found to be specific to dill (Supplementary Figure 1 *c*).

Field assessment

Incidence of whitefly in all the three treatments, i.e. T + Co, T + D and T started from the first WAT of tomato and reached peak population by third and fifth WAT across all treatments. There was significant difference ($F_{(2,9)} = 308.6$, $P < 0.0001$) in the whitefly population between the treatments, particularly between tomato sole crop and intercropped tomato. The highest mean whitefly population was observed in tomato sole crop (mean ± SE, 5.71 ± 0.75) and the lowest mean whitefly population was observed in tomato + coriander treatment (mean ± SE, 2.34 ± 0.39) followed by tomato + dill treatment (mean ± SE, 3.33 ± 0.51). The reduction in whitefly population between the intercropping treatments T + Co and T + D ranged from 56.00% to 72.00% (mean ± SE: 59.93 ± 2.47%) and 33.00% to 58.00% (mean ± SE: 42.75 ± 3.65%) respectively, when compared to tomato as a sole crop (Table 2).

Discussion

Intercropping ensures several benefits such as enhancing the population of predators/parasitoids of herbivores, thereby supporting greater ecosystem services[21]. In the present study, the response of whitefly to individual plant volatiles revealed that tomato is highly preferred, indicating that the host plant volatiles solely helps whiteflies while locating their preferred host plant. Earlier studies also proved that olfactory cues act as a primary stimulus in whitefly host plant selection[22]. Nevertheless, when whiteflies were tested against coriander and dill plant volatiles, they preferred tomato plant volatiles. This might be due to the presence of repellent compounds in coriander and dill plant volatiles, which might have manipulated the whitefly behaviour, thus leading to less residence time spent when tomato volatiles were mixed with aromatic plant volatiles. Essential oil from coriander was demonstrated to have repellency against citrus psyllid, *Diaphorina citri* Kuwayama[23]. Similarly, fumigant action of essential oils from dill has been demonstrated against greenhouse whitefly *Trialeurodes vaporariorum* (Westwood)[24].

The volatiles of aromatic plants (dill and coriander) in the present study, when presented along with tomato volatiles during olfactory bioassays revealed that whiteflies preferred sole tomato plant volatiles, indicating their odour-masking ability. Similar results have been demonstrated in other studies, with a higher response of *B. tabaci* to humidified air over a combination of leaves of tomato/coriander, tomato/basil and tomato/citronella grass[25,26].

PCA revealed a high degree of variation in the quantity and quality of VOCs among tomato, coriander and dill plants. It is well known that different species of plants produce characteristic volatiles[27]. Compounds like dill ether, 3-carene, α-phellandrene, γ-terpinene, D-sylvestrene and *o*-cymene solely represent dill crop volatiles. Among these, α-phellandrene, γ-terpinene, 3-carene and *p*-cymene are

Table 1. Principal component (PC) loadings of PC1 and PC2

Volatile compounds	PC1	PC2	Crop
2-Methoxy-1,3-dioxolane	–0.45	–0.94	Coriander
3-Ethylhexane	–0.58	–1.28	Coriander
Cyclofenchene	–0.49	–0.87	Coriander
α-Pinene	0.32	–1.07	Coriander
α-Phellandrene	2.06	0.19	Dill
3-Carene	2.77	0.26	Dill
o-Cymene	0.97	0.09	Dill
D-sylvestrene	1.49	0.14	Dill
γ-Terpinene	1.79	0.17	Dill
3-Methyl-5-propylnonane	–0.32	–0.70	Coriander
n-Decane	–0.80	1.13	Tomato
Linalool	–0.71	–1.56	Coriander
n-Undecane	–0.69	1.08	Tomato
2,6-Dimethyldecane	–0.19	0.91	Tomato
3,7-Dimethyldecane	–0.55	0.78	Tomato
Dill ether	2.87	0.27	Dill
2-Decenal, (Z)-	–0.41	–0.89	Coriander
2-Decen-1-ol, (E)-	–0.95	–2.08	Coriander
2,6,11-Trimethyldodecane	–1.26	0.07	Tomato
Ethanone, 1-(4-ethylphenyl)-	–0.56	–1.23	Coriander
n-Tridecane	–0.78	0.15	Tomato
Decane, 2,3,5,8-tetramethyl	–0.55	0.77	Tomato
2-Methyl-n-tridecane	–0.90	1.27	Tomato
2-Allylphenyl acetate	–0.79	1.11	Tomato
6-Methylhydrocoumarin	–0.50	0.70	Tomato
n-Pentadecane	–1.23	0.14	Tomato
Benzoic acid, 4-ethoxy-, ethyl ester	–0.66	0.94	Tomato
2-Methylpentadecane	–0.45	–0.98	Coriander
2,6,10-Trimethyltetradecane	–0.80	1.12	Tomato
Eigenvalue	47.21	38.31	
Proportion of variance (%)	55.21	44.79	
Cumulative proportion of variance (%)	55.21	100.00	

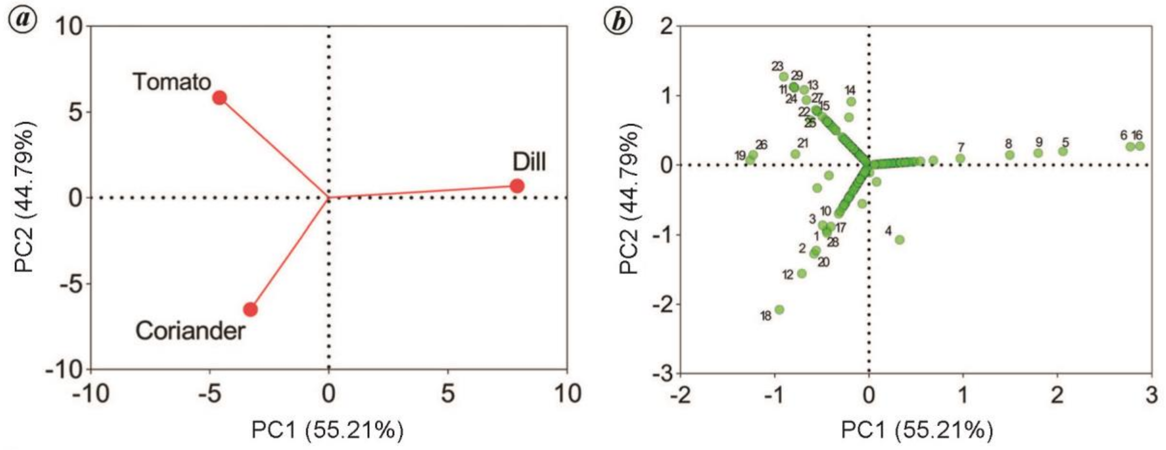

Figure 4. Principal component analysis of headspace volatile compounds from tomato, coriander and dill. ***a***, Score plot showing differences in volatile profile among three crop plants based on the first two principal components (PCs) with explained variance in parenthesis. ***b***, Loading plot with codes indicating the magnitude and direction of correlation of volatile compounds with the first two PCs. Compounds codes: 1, 2-Methoxy-1,3-dioxolane; 2, 3-Ethylhexane; 3, Cyclofenchene; 4, α-Pinene; 5, α-Phellandrene; 6, 3-Carene; 7, *o*-Cymene; 8, D-sylvestrene; 9, γ-Terpinene; 10, 3-Methyl-5-propylnonane; 11, *n*-Decane; 12, Linalool; 13, *n*-Undecane; 14, 2,6-Dimethyldecane; 15, 3,7-Dimethyldecane; 16, Dill ether; 17, 2-Decenal, (Z)-; 18, 2-Decen-1-ol, (E)-; 19, 2,6,11-Trimethyl-dodecane; 20, Ethanone, 1-(4-ethylphenyl)-; 21, *n*-Tridecane; 22, Decane, 2,3,5,8-tetramethyl; 23, 2-Methyl-*n*-tridecane; 24, 2-Allyl-phenyl acetate; 25, 6-Methylhydrocoumarin; 26, *n*-Pentadecane; 27, Benzoic acid, 4-ethoxy-, ethyl ester; 28, 2-Methylpentadecane and 29, 2,6,10-Trimethyltetradecane.

Table 2. Whitefly (mean ± SEM) incidence in tomato intercropped with coriander (T + Co), dill (T + D) and tomato sole crop (T)

Treatment	Number of weeks						Overall mean	Percentage reduction compared to sole crop
	1	2	3	4	5	6		
T + Co	1.65 ± 0.19^{a}*	2.1 ± 0.12^{a}	3.45 ± 0.19^{a}	3.00 ± 0.21^{a}	3.00 ± 0.12^{a}	0.9 ± 0.12^{a}	2.34 ± 0.39^{a}	59.93 ± 2.47
T + D	2.4 ± 0.2^{a}	3.3 ± 0.32^{a}	4.35 ± 0.20^{b}	3.97 ± 0.14^{b}	4.57 ± 0.22^{b}	1.35 ± 0.19^{a}	3.33 ± 0.51^{a}	42.75 ± 3.65
T	3.75 ± 019^{b}	6.07 ± 0.14^{b}	7.87 ± 0.23^{c}	6.52 ± 0.28^{c}	6.82 ± 0.23^{c}	3.22 ± 0.14^{b}	5.71 ± 0.75^{c}	–

*Means within a column followed by different letters are significantly different (Tukey's test: $P < 0.05$).

reported as repellents in a previous study against *B. tabaci* in wild tomato *Solanum pennellii*[28]. In the GC-EAD study, whitefly antenna responded to *p*-cymene-2,5-diol. Similarly, compounds related to the ocimene group (monoterpenes; (*Z*)-(β)-ocimene) and terpene alcohols (linalool) were known repellents against greenhouse whitefly *Trialeurodes vaporariorum* Westwood[29]. The toxicity and repellant action of linalool have been reported earlier in *Dinoderus bifloveatus*[30]. In the present study also, the aromatic intercrop coriander was observed to have closely related functional groups like ocimene and terpene alcohol compounds (*cis*-β-ocimene (1.14%); (*E*)-ocimenone (1.62%); linalool oxide (0.23%); linalool (8.82%)). Among these, (*E*)-ocimenone and linalool oxide elicited a response in GC-EAD studies, which might be the reason for their repelling nature against *B. tabci* in the present study. This can be further established through systematic bioassays involving synthetic fractions of these compounds.

Field studies also strongly supported the behavioural assays, where the whitefly population was significantly higher in tomato when raised as a sole crop compared to tomato intercropped with either coriander or dill plants. Many field and greenhouse studies showed that tomato intercropped with coriander had less pest incidence compared to tomato sole crop[25,26]. This might be due to the fact that the host location ability of generalist herbivores such as the whiteflies has been reported to be lowered when exposed to intercropping or mixed-cropping systems compared to specialist herbivores[31,32]. In Costa Rica, a low population of *B. tabaci* was observed on tomato intercropped with coriander along with other living ground covers such as perennial peanuts and whitesnow[33]. Reports also suggested that coriander is effective in minimizing the incidence of whiteflies in tomato–coriander intercropping system[34]. Aromatic plants like coriander and dill, were explored as intercrop components for controlling *B. tabaci* in cantaloupe, where the researchers found a significant reduction in the whitefly population[35].

The detailed GC-EAD and GC-MS identification of VOCs from intercrop components, namely dill and coriander in the present study gives the clear idea of the volatile cues to manipulate *B. tabaci* behaviour. This study also reveals the diverse volatile profiles of tomato, coriander and dill which influence the *B. tabaci* orientation behaviour to its host plant. The volatiles of dill as well as coriander not only repelled *B. tabaci*, but also offset its attraction towards tomato. Further, field studies also revealed that when coriander and dill crops were raised as intercrop components with tomato, whitefly incidence was significantly reduced over tomato when raised as a sole crop. This study emphasizes the potential use of dill as well as coriander as intercrop components with tomato to reduce whitefly incidence. Further, whitefly being a potential vector for a wide array of plant viruses (persistent/semi-persistent/circulative/non-circulative)[36], the repellency of dill as well as coriander plants observed in the present study can be exploited as a potential 'push stimuli' to formulate push–pull strategies. The synthetic version of GC-EAD-active VOCs identified in dill and coriander will be helpful as push stimuli while devising semiochemical-based pest management strategies against *B. tabaci*.

Conclusion

In the present study, we analysed the behavioural response of *B. tabaci* towards tomato in the presence of two aromatic intercrop components, namely coriander and dill using olfactometer bioassays, electrophysiological techniques and field experimentation. Results revealed the repellent nature of coriander and dill against *B. tabaci*. Hence, aromatic plants such as dill and coriander can be used as intercrop components in tomato to control *B. tabaci*. Further, studying the *B. tabaci* behaviour towards synthetic GC-EAD-active compounds of dill and coriander will be useful in designing eco-friendly pest management strategies against the whitefly.

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