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Reducing infestions of *Bemisia tabaci* (Hemiptera: Aleyrodidae) in cantaloupe using intercropping with non-host aromatic plants

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Abstract:

To manage and reduce the severity of damage caused by *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae) in the field, there is an enormous demand for safe and potential alternative strategiesto the use of chemical control. Trials were performed to determine the impact that the intercropping three aromatic plants garlic, *Allium sativum* (Amaryllidaceae), dill, *Anethum graveolense* (Umbelliferaeae) and coriander, *Coriandrum sativum* (Apiaceae) with cantaloupes has on the eggs and nymphs of *B. tabaci.* . The study was conducted during nili of the two successive growing seasons of 2015 and 2016 by intercropping these aromatic plants with cantaloupe in alternating rows. It was found that, intercropping cantaloupe with garlic, dill and coriander reduced infestations of *B. tabaci* and recorded highly significant differences between the intercropped and the cantaloupe monoculture. The mean numbers of *B. tabaci* eggs were 4.1, 4.4 and 4 eggs /leaf, respectively, compared to 13.7 eggs /leaf in cantaloupe monoculture during 2015 and 0.1, 0.07 and 0.02 eggs/leaf, respectively, compared to 14.6 eggs/leaf in cantaloupe monoculture during 2016]. Intercropping also markedly reduced the number of*B. tabaci* nymphs in 2015 and 2016 with garlic, dill and coriander to 20.7, 26.3 and 21.7 and 16.98, 15.5 and 16.8 nymphs /leaf, respectively compared to 61.8 and 55.6

nymphs /leaf, respectively in cantaloupe monoculture plots. We suggest that, intercropping non - hosts garlic, dill and coriander promotes the reduction of *B. tabaci* infestations in cantaloupe by insect repellency due to volatiles which may affect preference of *B. tabaci* as compared with cantaloupe. These plants appear to be good candidates for intercropping schemes and may be recommended in Integrated Pest Management programs as a safe and effective method in controlling *B. tabaci*. The tested aromatic plants have short life cycles, and are easy to be established and removed from the field

Introduction

Cantaloupe, *Cucumis melo* L. (Cucurbitaceae) is among the most important tasty, nutritional and exportable cucurbitaceous vegetable crops, that are cultivated in Egypt. Cantaloupe adapted to be cultivated in different types of soils and climates (FAO, 2006). In Egypt, cultivated areas of cantaloupe in old and new land reaches about 42,037 feddans and produces 475,817 tons in summer plantations (Qalyubia Governorate produced 26 tons of cantaloupe from the total production) while winter plantation resulted in about 24,254 feddans producing 370,115 tons (Anonymous**,** 2015). Azab *et al.* (1971) reported that whitefly damage generally includes a reduction of plant vigor due to adults and nymphs feeding on the plant phloem, the development of disorders including silver leaf, irregular ripening of fruit and excretion of honey-dew which promotes sooty mold. The most destructive and widely distributed *B. tabac*i biotypes are B and Q. Demichelis *et al.* (2000) reported that biotype Q is distributed in the Mediterranean region. *B. tabaci* is an extremely polyphagous pest that causes significant damage and can act as a vector of plant viral diseases. Jones (2003) found that *B. tabaci* transmits more than 100 species of viruses. Azevedo and Bleicher (2003) reported that *B. tabaci* has become the most important pest for melon crop in several countries, causing losses of millions of dollars /years. The worldwide spread of *B. tabaci* continues to cause severe crop losses which forces producers to use pesticides on many crops (such as tomato, cucurbits, beans, cotton, potatoes and sweet potatoes). In conjunction to this the biological and behavioral characteristics of the whitefly fast development, high fecundity and capacity for wide dispersion increase the probability of selecting individuals resistant to the most used insecticides (Byrne *et al.*, 2003).The strategy most commonly used to control B. tabaci continue to be the use of chemical pesticides, but this practice is becoming problematic and is considered high risk for beneficial arthropods and the environment. Metwally *et al*. (2013) demonstrated that cantaloupe is liable to be infested by numerous pests throughout seedling, flowering and fruiting stages of plant development. Among these are the cotton whitefly (also called tomato whitefly) *B. tabaci*. Many investigations have been carried out to estimate biocontrol agents as biological and safe control methods to manage the population of *B. tabaci* (Castle *et al*. 1996 and Faria and Wraight 2001). Li *et al*. (2001) and Hata *et al.* (2016) suggested that, mixed cropping or intercropping plays an important role in agriculture. This is due to the effective utilization of resources and improve crop productivity compared to that of monocultured crop. Letourneau *et al*. (2011) found extensive support for models with intercropping schemes in 552 experiments published in scientific papers concerning plant diversity in agroecosystems. Togni *et al*. (2010) suggested that intercropping prevent *B. tabaci* from becoming established in the tomato crop. In Egypt, garlic, (Allium *sativum*, Amaryllidaceae), dill (*Anethum graveolense*, Umbelliferaeae) and coriander, (*Coriandrum sativum*, Apiaceae) haven’t been recorded as hosts of *B. tabaci*, in addition, these plants are easy to be cultivated, lost cost and each has short crop cycle.

This current investigation was aimed to testing the effect of intercropping these aromatic plants as a safe control method in reducing populations of *B. tabaci* attacking cantaloupe plants in the field.

Materials and Methods

1. Intercropping cantaloupe with aromatic plants:

1.1. Study site and aromatic plants used:

A field trial was carried out on the Experimental Farm of Plant Protection Research Institute at Qaha region, southeast of Qalyubia Governorate (30° 17'00 "N, 31° 12'00 "E) in Egypt during two successive growing seasons, 2015 and 2016 of cantaloupe. Aromatic plants used in the experiment garlic, dill and coriander.

1.2. Seedlings preparation:

Seeds of cantaloupe (cv. Darvina) were obtained from the Horticultural Research Institute (Agricultural Research Center). Cantaloupe were seeded in a greenhouse on August 30 in 2015 and on August 28 in 2016. The seedlings were watered and maintained for growth but plants didn't receive any insecticidal treatments. The cantaloupe seedlings were transplanted in the field on September 29 during both years.

2. Experimental design and cultivation method:

An experimental area of 1026 m^2 (27 x 38m) was divided into four equal plots (254.75$m^2$of each) that were 2.5 m apart and each plot was arranged longitudinally to the others. Three of the plots were intercropped with the experimental aromatic plants. Each treatment plot was established with one aromatic plant interplanted with cantaloupe to determine the effect of each aromatic plant alone without interfering their volatiles or any other effect. One plot as control (monoculture or monocrop) of only cantaloupe. Each experimental plot was divided equally to represent three parts. Eeach part was represented as a replicate was 84.91 m^2 and consisted of six planting rows. The rows were designed as 7 plants 0.30 m apart spacing between rows. Intercrop of aromatic plants was established in alternating rows in the southern edges of single rows facing cantaloupe plants which were planted in the eastern edges. A space of 20 cm was provided between aromatic plants and cantaloupe (Figure,1). The total number of plants per replicate was 42 plants (21 aromatic plants and 21 as cantaloupe plants). A total of 126 plants were established per plot [(n = 7 plants) x 6 rows x 3 replicates]. The same plot design was established in the cantaloupe monoculture plot. Seeds for the intercrop aromatic plants were sown in the field two weeks before the cantaloupe was seeded because these aromatic plants require more time to grow than cantaloupe.All the standard agricultural practices for cantaloupe cultivation in Egypt were adopted, and the entire experimental area remained free from any chemical control of pests and diseases.

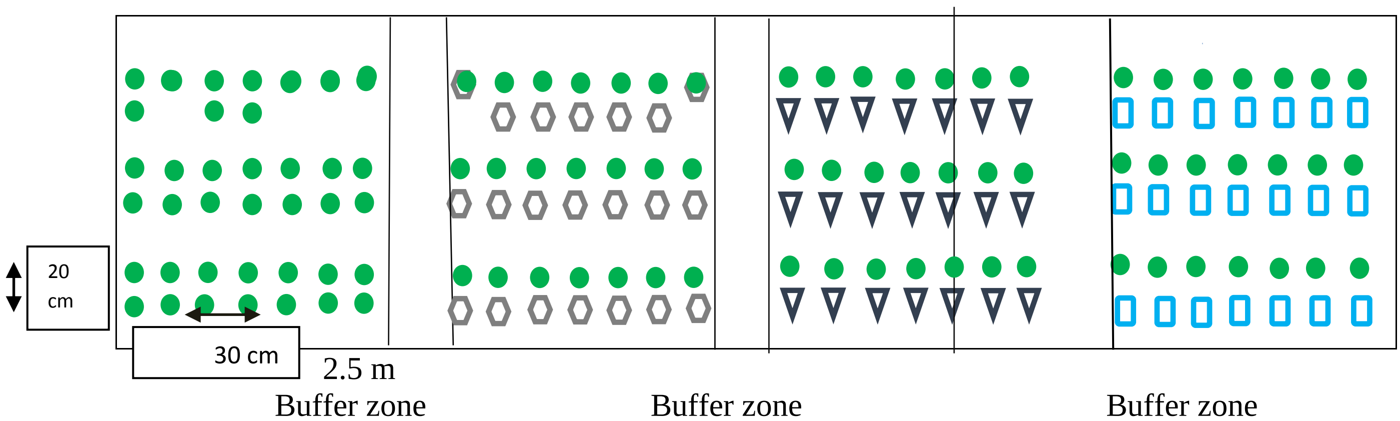

Figure (1): Design of one replicate of cantaloupe intercropping with garlic, dill and coriander or cantaloupe monoculture in th e field (cantaloupe, garlic, dill, coriander).

3. Sampling technique:

During the two growing seasons (2015 and 2016), samples were taken 15 days after crops were seeded and sampling continued weekly for 10 weeks. A sample of 120 leaves of canatloupe (10 leaves x 3 replicates x 4 plots) were randomly picked from three levels of plants (upper, middle and lower levels) during the morning of each sample date. Leaves that were sampled form each plot were kept separately in tightly closed polyethylene bags and they were then transferred to the laboratory. The presence of whitefly (*B. tabaci*) eggs and nymphs were examined by aid of a binocular stereomicroscope. The number of eggs and nymphs were assessed on the abaxial leaf surface. The number of eggs and nymphs per the three replicates in each treatment and the monoculture were estimated.

4. Statistical analysis:

Data for the intercropped cantaloupe and cantaloupe monoculture were subjected to analysis of variance. Mean separation was conducted according to the Duncan's multiple range test (Snedecor and Cochran,1971) to arrange any treatments in groups according to their infestation levels by *B. tabaci* population. The data were statistically analyzed by using SAS (SAS Institute Inc., 1988) program.

Results and discussion

1 .Effects of intercropping cantaloupe on *Bemisia tabaci* eggs:

Generally, B. tabaci showed oviposition preference to cantaloupe in monoculture as compared with cantaloupe intercropped with either garlic, dill or coriander. The females deposited eggs on cantaloupe leaves in all plots (intercropped or monoculture), during the study from 13 October through 14 December during 2015 (Table, 1). The data showed that, the number of B. tabaci eggs in cantaloupe plots intercropped with garlic, dill or coriander ranged from 0 to 24.7, 0 to 25.3 and 0 to 19.3 eggs/30 leaves (10 leaves in each replicate), respectively (Figure, 2). However, the egg counts in cantaloupe monoculture ranged from 0.3 to 55 eggs/30 leaves. Our study revealed that, all intercropped plots had lower seasonal mean number of whitefly eggs than cantaloupe monoculture. This pattern was observed in plots of cantaloupe intercropped with garlic (4.1±1.5), dill (4.4±1.5) and coriander (4±1.1) (mean ± SD) compared to 13.7±3.8 in the plot of monoculture cantaloupe. After the first three weeks of sampling, the counts of whitefly eggs were very low in all plots. Although there were no significant differences among the aromatic plant treatments in reducing *B. tabaci* laying eggs ($P < 0.05$), there was a significant difference in whitefly oviposition between intercropped cantaloupe and monoculture cantaloupe ($P=0.0001$). Infestation with *B. tabaci* eggs was observed on the first sample date of 12 October and eggs were observed through the last sample date of 14 December (Table, 2). The number of eggs ranged from 0 to 0.3, 0 to 0.3, 0 to 0.1 eggs /30 leaves in cantaloupe + garlic, cantaloupe + dill and cantaloupe + coriander, respectively. However, the number of eggs in the monoculture plot. of cantaloupe ranged between 0 to 142.5 eggs/30 leaves. The presence of whitefly eggs on leaves was low (a mean of less than 3 eggs per 30 leaves) on cantaloupe in all plots regardless of intercrop or monoculture). Cantaloupe intercropped with garlic, dill or coriander had mean numbers of eggs of 0.1±0.03, 0.07 ±0.02 and 0.02±0.01eggs, respectively versus a mean of 14.6±7.9 eggs in cantaloupe monoculture across the season. The obtained data are in accordance with the data of the previous season without significant different in reduction of B. *tabaci* eggs.

Table (1): Mean number of *Bemisia tabaci* eggs on cantaloupe plants intercropped with garlic, dill or coriander versus monoculture of cantaloupe during the nili plantation of 2015.

Sample Date	Mean number of *B. tabaci* eggs /30 leaves			
	Garlic	Dill	Coriander	Cantaloupe monoculture
October,13	7.9	4	5.9	51.4
21	24.7	25.3	10.3	55
27	7.8	14.3	19.3	12.4
November,2	0.3	0.3	0.6	1.1
9	0.1	0	0.5	0.6
16	0.2	0.1	2.4	5.9
23	0	0.1	0.8	3.1
30	0	0.03	0.03	0.3
December,7	0	0	0.1	5.2
14	0	0	0	2.2
Seasonal mean ±SE	4.1 ±1.5b	4.4±1.5b	4 ±1.1b	13.7 ± 3.8a
F value	16.4			
P	0.0001			
LSD	4.1			

Means within a row followed by the same letter do not differ significantly (Duncan's test: $P<.0.05$). LSD= Least significant difference.

Table (2): Mean number of *Bemisia tabaci* eggs on cantaloupe plants intercropped with garlic, dill or coriander versus monoculture of cantaloupe during the nili plantation of 2016.

Sample date	Mean number of *B. tabaci* eggs/ 30 leaves			
	Garlic	Dill	Coriander	Cantaloupe monoculture
October,12	0.2	0.03	0	142.5
19	0.03	0.2	0.1	0
26	0	0	0	0
November,2	0	0.3	0.1	2.5
9	0	0	0	0.03
16	0.2	0.2	0.05	0.63
23	0.3	0	0	0.1
30	0	0	0	0
December,7	0.3	0	0	0
14	0	0	0	0
Seasonal mean±SE	0.1 ± 0.03 b	0.07 ± 0.02b	0.02 ± 0.01b	14.6 ± 7.9a
F value	3.8			
P	0.0001			
LSD	10.1			

Means within a row followed by the same letter do not differ significantly (Duncan's test:$P<.0.05$)
LS D = Least significant difference.

2 .Effects of intercropping cantaloupe on Bemisia tabaci nymphs:

The data in Table (3) from October 13 through 14 December in 2015 indicated that, the counts of B. *tabaci* nymphs ranged between 0 to 66.7, 0 to 68.3 and 0.8 to 50.4 nymphs per 30 leaves in plots intercropped with garlic, dill or coriander, respectively (Table, 3). However, the count ranged between 5.3 to 146.4 nymphs per 30 leaves in cantaloupe monoculture (Figure, 4). Additionally, the lower incidence of *B. tabaci* adults in intercropped plots with garlic, dill or coriander was reflected by lower number of nymphs per leaf (20.7 ±4.5, 26.3±4.8 and 21.7±3.4), respectively) across the sampling period. The colonization of cantaloupe monoculture by B. tabaci adults was apparently reflected by higher mean number of B. tabaci nymphs (61.8±9.4) than all intercropped cantaloupe plots. There were no significant differences in counts of nymphs among the treatments with aromatic plants. However, there was a significant reduction in number of nymphs between the treatment of aromatic plants and cantaloupe monoculture.

A similar pattern was observed in 2016 (Table, 4) as was observed in 2015. The mean number of *B. tabaci* nymphs ranged from 0.4 to 56.2, 0 to 55.3 and 0.1 to 53.6 nymphs/30 leaves in plots intercropped with garlic, dill or coriander, respectively (from 12 October through 14 December) in 2016. On the other hand, the mean number of nymphs in cantaloupe monoculture ranged between 5.2 to 127 nymphs/30 leaves. The populations of whitefly nymphs were clearly reduced in intercropped plots with garlic (16.98±2.9), dill (15.5±3.2) or coriander (16.8±2.9) as compared the plot of cantaloupe monoculture which harboured higher number of B. tabaci nymphs (55.6 ±7.98). There was a highly significant reduction reduction in the number of nymphs in all intercropped plots as compared to the plot monoculture cantaloupe which suffered from highest infestation level (P=0.0001).

Table (3): Mean number of *Bemisia tabaci* nymphs on cantaloupe plants intercropped with garlic, dill or coriander versus monoculture of cantaloupe during the nili plantation of 2015

Sample date	Mean number of *B. tabaci* nymphs / 30 leaves			
	Garlic	Dill	Coriander	Cantaloupe
October,13	5.9	4.6	0.8	5.3
2 1	14.6	27.2	8	146.4
27	66.7	68.3	27.3	122.1
November,2	22.6	62.4	46.5	106.3
9	63.5	52.9	43.2	107.6
16	26.9	29.2	50.4	38.8
23	6.3	16.2	18.9	27.2
30	0	0.1	12.1	24.1
December,7	0	2.3	2.9	32.5
14	0	0	6.5	7.7
Seasonal mean ±SE	20.7 ± 4.5b	26.3 ±4.8b	21.7 ± 3.4b	61.8 ± 9.4a
F value	22.8			
P	0.0001			
LSD	10.5			

Means within a row followed by the same letter do not differ significantly (Duncan's test : $P<.0.05$). LSD= Least significant difference.

Table (4): Mean number of *Bemisia tabaci* nymphs on cantaloupe plants intercropped with garlic, dill or coriander versus monoculture of cantaloupe during the nili plantation of 2016

Sample date	Garlic	Dill	Coriander	Cantaloupe monoculture
October,12	18.5	0	0.1	41.6
19	10.2	15.9	23.3	120
26	30.7	8.9	14.5	62.8
November,2	11.5	24	25	88.3
9	10.8	35.5	22.5	62.9
16	56.2	55.3	53.6	127
23	15.3	9.6	17.9	29.4
30	8.6	1.7	5	9
December,7	7.4	1.3	2.5	9.8
14	0.4	2.7	3.2	5.2
Seasonal mean ±SE	16.98 ±	15.5 ±	16.8 ±	55.6 ± 7.98a
F value	26.8			
P	0.0001			
LSD	8.3			

Means within a row followed by the same letter do not differ significantly (Duncan's test: $P<.0.05$). LSD= Least significant difference

Our findings demonstrated that intercropping garlic, dill or coriander plants of cantaloupes can result r in reduction in B. *tabaci* infestation during the growing season. This work supports the hypothesis that *B. tabaci* has strong repellent behavior to intercropped areas with each of the tested aromatic plants. This was apparent when cantaloupes intercropped with the aromatic plants under investigation had lower number of eggs and nymphs than cantaloupe monoculture. It is known that, *B. tabaci* avoids plant species which contain aromatic oils, such as ginger oil but repellence or deterrence of plant volatiles to *B. tabaci* is not well established.

It is quite evident from the obtained results that, the infestation levels of both eggs and nymphs were significantly reduced in cantaloupe that was intercropped with either garlic, dill or coriander as compared with cantaloupe monoculture. It is noteworthy that in some instances, only records for nymphs were observed on cantaloupe monoculture and no records of eggs. Hongtao and Yuchuan (2017) stated that, intercropping cucumber with different celery (Apium *graveolens)* varieties showed repellent effects and oviposition deterrent effects in *B. tabaci* and thus acted as a good repellent against *B. tabaci*. The volatiles of celery, asparagus (*Asparagus officinalis*), lettuce, Malabar spinach (Basella *alpa*), and edible amaranth (Amaranthus *tricolor*) have also been shown to strongly repel *B. tabaci* biotype B in a Y-tube assay, however, the repellency was different among plants (Zhao *et al*., 2014). In addition, Ying *et al*. (2003) demonstrated that, *B. tabaci* biotype B is attracted by host plant volatiles.

The same pattern of reduction in number of nymphs of *B. tabaci* was observed when garlic, dill or coriander was added. The population of nymphs significantly declined for garlic, dill or coriander intercropping during 2015. The same trend was evident in 2016 and the population was significantly treatments in garlic, dill and coriander compared to the cantaloupe monoculture. Although the number of whitefly eggs tended to be more depressed in the 2016 experiment than in the 2015, the difference was statistically insignificant. However, the population of *B. tabaci* nymphs was lower in 2016 than 2015. El-Khayat *et al.* (2010) reported different *B. tabaci* infestations during two years of their study. Naranjo *et al*. (2004) attributed the mortality of *B. tabaci* in spring and fall cantaloupes as well as other crops to predation, parasitism, desiccation, weather factors and other factors besides control methods. It was apparent here that garlic, dill and coriander show strong and positive effect of similar force in helping to keep *B. tabaci* away from intercropped plots. The reduction in the number of nymphs *B. tabaci* was observed by Costa and Bleicher (2006) when melon (*C. melo* L). or watermelon (*Citrullus lanatus* Thumb), plants were intercropped with coriander in a greenhouse.

The suppression of *B. tabaci* populations in coriander plots may be explained here by aromatic volatiles which may have affected the preference of the insect to cantaloupe. Suppression could be due to different reasons, eg., Togni *et al*. (2010) found that, tomato intercropped with coriander reduced the population of *B. tabaci* attacking tomato plants as compared with tomato monoculture plots. They suggested that coriander produces a high amount of volatile secondary metabolites that had an odour that mask the odor tomato volatiles, and interfered in the host plant selection of *B. tabaci.* Also, coriander plant can be attractive to some natural enemies such as Coccinellidae, especially under organic management (Togni *et al*., 2009). Bickerton (2011) found that, intercropping dill, coriander or buckwheat with bell pepper (Capsicum annuum) attracted natural enemies of *Ostrinia nubilalis*. The same approach was previously reported when the South American tomato pinworm (*Tuta absoluta* Meyrick) (eggs and adults) were found in lower numbers in intercropped coriander and Gallant soldier (Galinsoga *parviflora*) with tomato compared to tomato alone in an organic cropping system. However, there were higher population of predators such as spiders and ladybeetles. Ladybeetles appeared at the flowering season of coriander (Medeiros *et al*., 2009). Hilje and Stansly (2008) stated that coriander *C. sativum* reduced the number of incoming whitefly adults, delayed the onset of *Tomato yellow mottle virus* (ToYMoV) and decreased disease severity, resulting in higher yields and profits in a field experiment in Costa Rica.

More recently, Sujayanand *et al.* (2015) reported that intercropping eggplant (*Solanum melongena* L.) with coriander, marigold or mint resulted in lower numbers of *B. tabaci* on eggplant versus sole eggplant. In addition, they found highest mean number of coccinellids in treatment had coriander as intercrop. They found 21 volatile compounds in coriander plants. Carvalho *et al*. (2017) assayed the behavior and population development of *B. tabaci* biotype B in the field (adults) and in the greenhouse (nymphs) on tomato plants alone and in tomato intercropped with aromatic plants. In Y-tube olfactometer assays coriander, Greek basil and citronella show strong repellency of similar magnitude to whiteflies characterizing their odors as repellents. In field tomato intercropped with coriander and basil adult populations of whiteflies were reduced by the same magnitude.

The reduction of *B. tabaci* in cantaloupe due to intercropping with garlic was less than that was previously reported. However, a recent study concluded that, garlic can be used effectively as a repellent crop under intercropping (Karavina *et al*., 2014). In that study, no significant difference in larval populations of the diamondback moth (Plutella *xylostella*) was observed between cabbage plots treated chemically versus cabbage intercropped with garlic. According to Hata *et al*. (2016), strawberry (*Fragaira ananassa*) intercropped with garlic plants reduced *Tetranychus urticae* Koch (two spotted spider mite) populations in the field. They suggested that interplanting garlic between rows may be a promising strategy to reduce T. *urticae* and attributed the mortality in mite population to the release of strong plant odor. Volatiles released from plants can act as toxins or repellents (Kant *et al*., 2009). Such volatiles could be responsible for reducing B. *tabaci* by garlic plants in the current investigation due to volatile bioactive compounds which can enter the insect body through the tracheal system (Isman, 2000). Intercropped with garlic has also been shown to reduce mites in the tomato field in Malawi (Mtambo and Zeledon, 2000). Garlic oil has oviposition deterrent and repellent effects on *B. tabaci* adults as well as affects the survival of larvae (Hussein, 2017). In cantaloupe intercropped with garlic the reduction effect on *B. tabaci* population may specifically be due to vinyl dithiin, diallyl disulfide and diallyl trisulfide, that have been identified in garlic essential oil (Attia *et al.* 2012). We suggested that releasing sulfur volatile compounds could play a role in keeping *B. tabaci* away from the cantaloupe fields intercropped with garlic according to Attia *et al.* 2012.

It is concluded that the developing whiteflies in plots intercropped with garlic, dill or coriander were apparently decreased because of repellency of plant volatiles to the adult whiteflies. Consequently, intercropping cantaloupe with aromatic plants reduced the incidence of *B. tabaci* in the open field. Particularly, intercropping with dill or coriander kept B. *tabaci* nymphs lower than cantaloupe monoculture during 10 weeks. This approach emphasize that garlic or dill and coriander could be good candidates in an integrated pest management programs due to their promising results in reducing *B. tabaci* populations in cantaloupe plants as safe alternative control methods to chemicals. Moreover, these plants have short life cycle, provide additional economic returns when sold and was easier to establish and remove.

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