Egypt. J. Plant Prot. Res. Inst. (2020), 3 (2): 794 - 803

Egyptian Journal of Plant Protection Research Institute

www.ejppri.eg.net

Potential toxicity of some essential oils on mealybug, *Maconellicoccus hirsutus* (Hemiptera: Pseudococcidae)

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ARTICLE INFO

Article History

Received: 14/ 4/ 2020

Accepted: 25/6/ 2020

Keywords

Essential oils, mealybug, *Maconellicoccus hirsutus*, alternative insecticides and control.

Abstract:

The present work was conducted to evaluate the efficiency of some essential oils on the populations of the *hibiscus mealybug Maconellicoccus hirsutus* (Green) (Hemiptera: Pseudococcidae) under Laboratory and field conditions. The essential oils were ginger (*Zingiber officinale*), garlic (*Allium sativum*), lemone (*Citrus aurantiifolia*) and mint (*Menth* sp.) . One compound insecticide (Actara) was used as control measure for the essential oils. LC_{50} of each treatment were established after 24, 48 and 72 hours the alive of mealybugs and the obtained results revealed that the lemone was the most effective. Ginger and garlic, also, was more effective than mint which has very low effect on mealybug. LC_{50} was 0.78, 3.07, 0.02 and 57.94; 0.47, 2.29, 0.01 and 41.80 and 0.32, 1.51, 0.01 and 24.39 0.32, 1.51, 0.01 and 24.39 ppm, for ginger, garlic, lemone e, mint, after 24, 48 and 72 hrs., respectively. Mortality percentages were calculated after 7, 15 and 21 days post treatment. The results indicated that the average mortality percentages of mealybugs were 63.92, 51.89, 72.72, 29.67 and 87.38 for 2018 year and 61.49, 54.46, 73.77, 31.75 and 88.55 for 2019 year by ginger, garlic, lemone e, mint and actara, respectively. The efficacy of ginger, garlic, mint, lemone and actara in all treatments can be useful for development safe elements for an IPM strategy to mealybugs. So, it prefers to use the essential oils for controlling the insect in IPM program and more studies should be carried on ginger and garlic to improve their efficiency for control insect pests to minimize the environmental pollution with pesticides.

Introduction

Grapevine is considered as one of the most important fruit crops in Egypt not only as popular fruit but also used for many agricultural industries. Egypt ranks fourth worldwide in the global production volume of table grapes and has shown impressive growth in the past 5 to 10 years. In Egypt, grapes are one of the most widely grown fruit crops, second only to citrus. In 2016, production of grapes in Egypt amounted to 1 691 194 tones on 184 254 feddans of cultivated land (FAOSTAT, 2019).

The hibiscus mealybug *Maconellicoccus hirsutus* (Green) (Hemiptera: Pseudococcidae) is one of the most important mealybugs insect infesting grapevine in Egypt. It recorded with heavily infestation on trunk, bunches, leaves and roots of grapevine, the sever infestations of *M. hirsutus* affected greatly on bunches resulting poor crop with poor quality and quantity. The hibiscus mealybug *M. hirsitus* has wide range of host plants include many agricultural crops e.g. hibiscus, citrus, coffee, sugarcane, annonas, plums, guava, mango, okra, pigeon pea, peanut, grapevine, maize, asparagus, chrysanthemum, beans, cotton, soybean, cocoa, and many other plants (Williams, 1996 and Abd-Rabou, 2000). Chemical pesticides pollute the tissues of almost every form of life on earth, air, lakes, oceans, the fish they inhabit and the birds that feed on fish and the application of pesticides cause serious problems such as the accumulation of resistant pests, disturbance of natural balance and dangers to the environment (Hurley *et al*., 1998 and Abd-Rabou, 2008). Essential oil (EO) products are natural compounds that have insecticide properties, and their use in crop protection is as old as agricultural practices (Bakkali *et al*., 2008). It may provide potential alternatives to currently used pest control agents, and essential oils are complex natural metabolites that are characterized by strong odor and volatility and have generally lower density than water. Because of its volatility, essential oils are environmentally unstable. Recent research has reported the nature of insecticides for many essential oils (Bell *et al*., 1990).

Mode of action of the use of EO and their principal compounds for mealybug control, as these lipophilic compounds can penetrate the waxy cuticle and may thus more effectively kill these insects. In fact, as botanical products impair lipid synthesis, they lower the lipid content of the insect cuticle, thereby making the mealybugs more sensitive to pesticides and chemical action (Patil *et al*., 2010).

So, the present work was conducted to evaluate the efficiency of some essential oils on the populations of the *hibiscus mealybug M. hirsutus* under Laboratory and field conditions

Materials and methods

1. Laboratory tests:

1.1. Bioassy experiment:

The experiments were carried out in the laboratory of Organic agriculture center laboratory, Agricultural Research Center, Giza, collected of *M. hirsutus* by cutting leaves in fasted it from hibiscus tree then transferred to potato sprouts in laboratory with 23±2 ºC and 65±5 RH.%. The following four plant extract oils were tested: Ginger (*Zingiber officinale*), garlic (*Allium sativum*), lemone (*Citrus aurantiifolia*) and mint (*Menth* sp.) oils used at aerate of five concentration (0.5, 1, 3, 5 and 7 ml. /Lw of water then dipping hibiscus leaves into each concentration for five seconds, has been moved plant leaf treatments to clean wide plastic dishes, which were then covered with muslin cloth held in position by rubber bonds. Mealybugs transferred to plastic dishes, mealybugs individuals were divided into three replicates, each replicate contains it 10 from mealybugs. Addition to water used in untried cheek. After 24, 48 and 72 hours the alive of mealybugs.

1.2.Statistical analysis:

The mortality percentages were calculated and corrected for natural mortalities by **Abbott´s formula (1925).** The corrected percent mortalities were statistically computed according to **Finney (1971)** and plotted on probity analysis paper. The tested oils according to their Lc_{50} , Lc_{90} , slopes and relative potency of the toxicity lines.

2. Field tests:

Field evaluation of the tested essential oils on populations of the hibiscus *mealybug M. hirsutus* infested grapes. Four compounds of plant extract oils, ginger, garlic, lemone and mint oils used recommended concentration and actara® 25 WG **(**Thiamethoxam) evaluation carried out in July 2018 and 2019 at Atfih, Giza Goverorate under field conditions for controlling the *M. hirsutus*. The evaluated compounds were:

A. Ginger (*Zingiber officinale*): This group was presented with one Mineral compound Super Misrona oil 95% EC Mayonnaise: Formulated by Misr Company for Petroleum Egypt, used with rate of 2.5%.

B. Garlic (*Allium sativum*), an entomopathogenic fungi (3200 viable spore/mg), containing the fungus *Beauveria bassiana* applied at a rate 2ml/liter of water.

C. Lemone (*Citrus aurantiifolia*) an entomopathogenic fungi (32×10^2 viable spore/ ml), containing the fungus *Metarrhizium anisoplae* applied at a rate 2ml/liter of water.

D. Mint (*Menth* sp.), applied at rate of 2.5g/ liter of water.

E. Actara® 25 wg **(**Water Dispersible Granules) **(**Thiamethoxam) **compound**: This group was presented with one insectide compound *i.e.* Malathion 57%EC formulated by Sumitomo Company, used with rate of 1%. This compound was used as control measure for the four alternatives groups. The grapevine orchard kept away from any control measures before and during the investigation. Five treatments were applied in four replications, each replicate contain four grapes orchards besides other four trees were left as control (untreated check) . Spraying was accomplished by motor sprayer with diluted solution of 15 liter/tree. Random samples of 80 infested leaves were picked up from each replicate, i.e. 240 leaves for each treatment immediately before spraying application. The leaves samples were put in polyethylene bags and transferred to the laboratory. The population of *M. hirsutus* was sorted to different stages i.e. eggs, nymphs, and adults.

The reduction percentages were estimated according to Henderson and Tilton (1955) equation. Reduction percentage of the insect populations was transferred to arc sine before conducting analysis of variance (F test) and LSD values were used to separate the means. The statistical analysis of the present work was conducted using MSTATC computer Program.

Results and discussion

1. Laboratory experiments:

The data in Table (1) demonstrated that, although the extract concentrations were low, the mortality rate of *M. hirsutus* populations was low and when the concentrations increased, the total mortality increased. However, Table (2) demonstrated that, Our results from the study showed that LC_{50} was 0.78, 3.07, 0.02 and 57.94 **;** 0.47, 2.29, 0.01 and 41.80 and 0.32, 1.51, 0.01 and 24.39 ppm, for ginger, garlic, lemone e , mint, after 24, 48 and 72 hrs., respectively. While LC_{90} was 15.34, 47.59, 5.48 and 1239.46 **;** 12.04, 30.15, 1.15 and 1968.77 and 9.60, 84.23, 1.15 and 4397.08 ppm, for ginger, garlic, lemone e , mint, after 24, 48 and 72 hrs., respectively.

Table (1): Toxic effect of some essential oils against the mealybug *Maconellicoccus hirsutus* at different concentrations.

Treatment	Con. Ml/lw	Mortality %			Mean
		24 hours	48 hours	72 hours	
Zingiber officinale (Ginger)	0.5	43.3	50	53.3	
	1	56.6	63.3	73.3	
	3	63.3	73.3	76.5	
	5	80	83.3	83.3	
	7	86.6	86.6	90	
Allium sativum (Garlic)	0.5	23.3	26.2	40	
	1	26.6	30	43.3	
	3	46.6	56	53.3	
	5	56.6	56.3	56.3	
	7	70	79.3	80	
Citrus aurantiifolia (Lemone e)	0.5	73.3	86.6	86.6	
	1	86.6	86.6	96.6	
	3	86.6	96.6	96.6	
	5	90	96.6	100	
	7	90	100	100	
Menth sp. (Mint)	0.5	6.6	6.6	16.6	
	1	10	26.6	30	
	3	13.3	20	36.6	
	5	13.3	26.6	36.6	
	7	20	30	40	

Table (2): Efficiency of some essential oils on mealybug *Maconellicoccus hirsutus.*

Treatment	LC_{50}			LC_{90}		
	24h	48h	72h	24h	48h	72h
***Zingiber officinale* (Ginger)**	**0.78**	**0.47**	**0.32**	**15.34**	**12.04**	**9.60**
***Allium sativum* (Garlic)**	**3.07**	**2.29**	**1.51**	**47.59**	**30.15**	**84.23**
***Citrus aurantiifolia* (Lemone e)**	**0.02**	**0.01**	**0.01**	**5.48**	**1.15**	**1.15**
***Menth* sp. (Mint)**	**57.94**	**41.80**	**24.39**	**1239.46**	**1968.77**	**4397.08**

2. Field experiments:

2.1. Field evaluation of the tested alternative insecticides on population of the hibiscus mealybug *Maconellicoccus hirsutus* in 2018 year:

The initial effect of tested compounds on the populations after one week of population as well as the residual effect after two and three weeks of application were shown Table (3 and 4). The obtained results shown that the initial effect of tested insecticides after one week of application was varied on the egg population. The highest effective compound was actara (84.05%). While the moderate effective compound was lemone, ginger and garlic. They reduced the egg population to (62.51%, 57.35 and 49.14%, respectively). The less effective compounds on the egg populations was mint, it reduced the population to (27.98 %). The initial effect of the tested compounds on nymph populations showed that the highest effective compound was actara (82.39%). While the moderate effective compound was lemone, ginger and garlic. They reduced the nymph population to 61.18, 53.34 and 45.5%, respectively. The less effective compounds on the nymph populations was mint, it reduced the

population to 24.15 %. The same trend of the effect essential oils on adult populations showed that the highest effective compound was actara (79.29%). While the moderate effective compound was lemone, ginger and garlic. They reduced the egg population to 59.03, 49.69 and 43.01%, respectively. The less effective compounds on the egg populations was mint, it reduced the population to 21.85 %.

The residual effect of the tested compounds on the populations of *Maconellicoccus hirsutus* stages was appeared after 2 weeks, was varied on the egg population. The highest effective compound was actara (90.15%). While the moderate effective compound was lemone, ginger and garlic. They reduced the egg population to (77.4, 65.24 and 55.25, respectively). The less effective compounds on the egg populations was mint, it reduced the population to (33.49 %). The initial effect of the tested compounds on nymph populations showed that the highest effective compound was actara (87.7 %). While the moderate effective compound was lemone, ginger and garlic. They reduced the nymph population to 74.73, 66.16 and 52.86 %, respectively. The less effective compounds on the nymph populations was mint, it reduced the population to 30.8 %. The same trend of the effect essential oils on adult populations showed that the highest effective compound was actara (85.1%). While the moderate effective compound was lemone, ginger and garlic. They reduced the adult population to 70.23, 61.93 and 51.47 %, respectively. The less effective compounds on the adult populations was mint, it reduced the population to 26.16 %.

After 3 weeks of application, the residual effects of tested insecticides were varied was varied on the egg population. The highest effective compound was actara (95.38%). While the moderate effective compound was lemone, ginger and garlic. They reduced the egg population to (86.71, 77.23 and 59.27, respectively). The less effective compounds on the egg populations was mint, it reduced the population to (38.16 %). The initial effect of the tested compounds on nymph populations showed that the highest effective compound was actara (92.68 %). While the moderate effective compound was lemone, ginger and garlic. They reduced the nymph population to 83.58, 79.96 and 56.21%, respectively. The less effective compounds on the nymph populations was mint, it reduced the population to 34.83 %. The same trend of the effect essential oils on adult populations showed that the highest effective compound was actara (95.0%). While the moderate effective compound was lemone, ginger and garlic. They reduced the adult population to 79.13, 69.42 and 54.32 %, respectively. The less effective compounds on the adult populations was mint, it reduced the population to 29.66 %.

Table (3): Average numbers of the mealybug *Maconellicoccus hirsutus* after treatment with different compounds on grapes in Atfih (Giza) during 2018.

Treatment	Rate of Applic. /L.W.	Pre spraying count			Post spraying count after									Average number			
					7			14			21						
		E.	N.	A.	E.	N.	A.	E.	N.	A.	E.	N.	A.	E.	N.	A.	AV.
Ginger	10 ml	23.2	13.0	6.9	9.0	10.03	2.7	6.6	4.5	2.2	4.9	3.9	2.0	6.83	4.66	2.3	4.59
Garlic	10 ml	22.7	15.3	9.4	10.5	11.7	4.3	9.7	6.9	4.0	9.4	6.7	4.2	9.86	6.93	4.16	6.98
Lemone	2.5 gm	26.1	18.2	9. 1	8.9	13.2	2.9	8.5	4.4	2.3	5.63.1	3.1	1.8	7.66	4.53	2.33	4.84
Mint	5 ml	20.0	14.2	10.2	13.1	6.2	6.2	12.7	9.4	6.4	12.5	9.6	6.8	12.76	9.43	6.46	9.55
Thiamethoxam (Actara 25% WG)	2 gm	25.5	17.1	9.6	3.7	13.0	1.5	2.4	2	1.3	1.2	1.3	1.0	2.43	1.96	1.26	1.88
Control		24.3	16.1	15.3	22.1	16.1	11.9	23.2	15.4	13.0	24.7	16.7	14.5	23.33	15.33	13.13	17.26

E. Egg N. Nymphs A. Adult AV. Average

Table (4): Reduction percentage of different compounds on the mealybug *Maconellicoccus hirsutus* on grapes in Atfih (Giza) during 2018.

Treatment	Rate of Applic. /L.W.	%Reduction after:									Average %reduction			
		7			14			21						
		E.	N.	A.	E.	N.	A.	E.	N.	A.	E.	N.	A.	AV.
Ginger	10ml	57.35	53.34	49.69	65.24	66.16	61.93	77.23	79.96	69.42	67.27	64.15	60.34	63.92
Garlic	10ml	49.14	45.5	43.01	55.25	52.86	51.47	59.27	56.21	54.32	54.55	51.52	49.6	51.89
Lemone	2.5gm	62.51	61.18	59.03	77.4	74.73	70.23	86.71	83.58	79.13	75.54	73.16	69.46	72.72
Mint	5ml	27.98	24.15	21.85	33.49	30.8	26.16	38.16	34.83	29.66	33.21	29.92	25.89	29.67
Thiamethoxam (Actara 25% WG)	5ml	84.05	82.39	79.92	90.15	87.78	85.1	95.38	92.68	95.0	89.86	87.61	89.01	87.38

E. Egg N. Nymphs A. Adult AV. Average .

2.2. Field evaluation of the tested alternative insecticides on population of the *hibiscus mealybug Maconellicoccus hirsutus* in 2019 year:

The initial effect of tested compounds on the populations after one week of population as well as the residual effect after two and three weeks of application were shown Table (5 and 6). The obtained results showed that the initial effect of tested insecticides after one week of application was varied on the egg population. The highest effective compound was actara (85.56%). While the moderate effective compound was lemone, ginger and garlic. They reduced the egg population to (69.55%, 54.97 and 50.81%, respectively). The less effective compounds on the egg populations was mint, it reduced the population to (31.49 %). The initial effect of the tested compounds on nymph populations showed that the highest effective compound was actara (83.29%). While the moderate effective compound was lemone, ginger and garlic. They reduced the egg population to 66.94, 51.68 and 46.53%, respectively. The less effective compounds on the egg populations was mint, it reduced the population to 29.13 %. The same trend of the effect essential oils on adult populations showed that the highest effective compound was actara (81.27%). While the moderate effective compound was lemone, ginger and garlic. They reduced the egg population to 63.95, 48.41 and 42.86%, respectively. The less effective compounds on the egg populations was mint, it reduced the population to 25.55 %.

The residual effect of the tested compounds on the populations of *Maconellicoccus hirsutus* stages was appeared after 2 weeks, was varied on the egg population. The highest effective compound was actara (91.15%). While the moderate effective compound was lemone, ginger and garlic. They reduced the egg population to (77.19, 67.34 and 58.94, respectively). The less effective compounds on the egg populations was mint, it reduced the population to (34.5 %). The initial effect of the tested compounds on nymph populations showed that the highest effective compound was actara (89.27 %). While the moderate effective compound was lemone, ginger and garlic. They reduced the nymph population to 74.7, 62.1 and 54.4 %, respectively. The less effective compounds on the nymph populations was mint, it reduced the population to 31.1 %. The same trend of the effect essential oils on adult populations showed that the highest effective compound was actara (86.41%). While the moderate effective compound was lemone, ginger and garlic. They reduced the adult population to 70.01, 58.45 and 50.05 %, respectively. The less effective compounds on the adult populations was mint, it reduced the population to 28.85 %.

After 3 weeks of application, the residual effects of tested insecticides were varied was varied on the egg population. The highest effective compound was actara (96.18%). While the moderate effective compound was lemone, ginger and garlic. They reduced the egg population to (84.59, 74.95 and 66.53, respectively). The less effective compounds on the egg populations was mint, it reduced the population to (38.96 %). The initial effect of the tested compounds on nymph populations showed that the highest effective compound was actara (93.47%). While the moderate effective compound was lemone , ginger and garlic. They reduced the nymph population to 80.85, 71.36 and 62.75 %, respectively. The less effective compounds on the nymph populations was mint, it reduced the population to 34.46 %. The same trend of the effect essential oils on adult populations showed that the highest effective compound was actara (90.44%). While the moderate effective compound was lemone, ginger and garlic. They reduced the adult population to 76.5, 68.28 and 57.32 %, respectively. The less effective compounds on the adult populations was mint, it reduced the population to 30.13 %.

Table (5): Average numbers of the mealybug *Maconellicoccus hirsutus* after treatment with different compounds on grapes in Atfih (Giza) during 2019.

Treatment	Rate of Applic. /L.W.	Pre spraying count			Post spraying count after:									Average number			
					7			14			21						
		E.	N.	A.	E.	N.	A.	E.	N.	A.	E.	N.	A.	E.	N.	A.	AV.
Ginger	10 ml	22.9	15.3	7.4	8.4	6.0	4.2	7.1	5.8	3.8	6.3	5.3	3.1	7.26	5.7	3.7	5.55
Garlic	10 ml	27.2	18.2	9.14	10.9	7.9	5.2	10.6	8.3	5.0	10.0	8.2	4.8	10.5	8.13	5.0	7.87
Lemone	2.5 gm	25.4	16.4	10.4	6.3	4.4	4.6	5.5	4.2	4.3	4.3	3.8	3.7	5.36	4.13	4.2	4.56
Mint	5 ml	26.7	19.3	11.6	14.9	11.1	9.5	16.6	13.3	10.2	17.9	15.3	11.0	16.46	13.23	10.23	13.30
Thiamethoxam (Actara 25% WG)	2 gm	23.8	17.7	13.1	2.8	2.4	2.7	2.1	1.9	2.2	1	1.4	1.7	1.96	1.9	2.2	2.02
2.02Control		27.5	19.1	14.0	22.4	15.5	15.4	26.1	19.1	17.3	30.2	23.1	19.0	26.23	19.23	17.23	20.89

E. Egg N. Nymphs A. Adult AV. Average .

Table (6): Reduction percentage of different compounds on the mealybug *Maconellicoccus hirsutus* on grapes in Atfih (Giza) during 2019

Treatment	Rate of Applic. /L.W.	%Reduction after:									Average %reduction			
		7			14			21						
		E.	N.	A.	E.	N.	A.	E.	N.	A.	E.	N.	A.	AV.
Ginger	10ml	54.97	51.68	48.41	67.34	62.1	58.45	74.95	71.36	68.28	65.75	61.71	58.38	61.94
Garlic	10ml	50.81	46.53	42.86	58.94	54.4	50.05	66.53	62.75	57.32	58.76	54.55	50.07	54.46
Lemone	2.5gm	69.55	66.94	63.95	77.19	74.7	70.01	84.59	80.85	76.5	77.11	74.06	70.15	73.77
Mint	5ml	31.49	29.13	25.55	34.5	31.1	28.85	38.96	34.46	30.13	34.98	31.56	28.17	31.57
Thiamethoxam (Actara 25% WG)	5ml	85.56	83.29	81.27	91.15	89.27	86.41	96.18	93.47	90.44	90.96	88.67	86.04	88.55

E. Egg N. Nymphs A. Adult AV. Average.

Statistical analysis demonstrated in first highly significant differences between the different compounds (Ginger, garlic, lemone e, mint and actara) and control of population of eggs ,nymphs and adult of *M. hirsitus* during , 2018 (F=177.04, 186.99 and 225.79, and LSD=3.3536, 12.6136 and 2.7874) respectively. While, during 2019 (F=325.78, 359.71, 225.79 and LSD=2.38, 2.7252 and 2.7874) respectively (Table, 7).

Table (7) : Statistical analysis of the efficacy of different compounds against *Maconellicoccus hirsutus* populations.

Treatment	Rate of Applic. /L.W.	Average % reduction 2018			Average %reduction 2019		
		Egg	N	Adult	Egg	N	adult
Ginger	10ml	67.27b	64.15b	60.34b	65.75b	61.71b	58.38b
Garlic	10ml	54.55c	51.52c	49.6c	58.76c	54.55c	50.07c
Lemone	2.5gm	75.54a	73.16a	69.46a	77.11a	74.06a	70.15a
Mint	5ml	33.21d	29.92d	25.89d	34.98	31.56d	28.17d
Thiamethoxam (Actara 25% WG)	5ml	89.86	87.61	89.01	90.96	88.67	86.04
F test		177.04	186.99	225.79	325.78	359.71	225.79
L.S.D		3.3536	12.6136	2.7874	2.38	2.7252	2.7874

Essential oils are much preferable as green insecticides against different pest groups (Işık and Görür, 2009). They are volatile, natural, complex compounds characterized by a strong odor and are formed by plants as secondary metabolites (Sharaby *et al.*, 2012). In nature, essential oils seems to be important agents of interspecific communication as they are favour pollination by attracting insects, they also play an important role in protection of the plants as antibacterial, antiviral, antifungal, insecticides and also against herbivorous by reducing their appetite for such plants (Bakkali *et al.*, 2008). Peschiutta *et al*. (2017) showed the capacity of EO derived from plants as a potential tool for mealybug control, due to its insecticidal activity. This type of research contributes to the search of potential novel active compounds to environmentally friendly control of mealybug in vineyards.

Our results from the study showed that LC50 was 0.78, 3.07, 0.02 and 57.94 **;** 0.47, 2.29, 0.01 and 41.80 and 0.32, 1.51, 0.01 and 24.39 0.32, 1.51, 0.01 and 24.39 ppm, for ginger, garlic, lemone e , mint, after 24, 48 and 72 hrs., respectively. Mortality percentages were calculated after 7, 15 and 21 days post treatment. The results indicated that the average mortality percentages of mealybugs infested vineyards were 63.92, 51.89, 72.72, 29.67 and 87.38 for 2018 year and 61.49, 54.46, 73.77, 31.75 and 88.55 for 2019 year by ginger, garlic, lemone e , mint and actara, respectively. Overall results suggested that the essential oils tested may help for us in controlling *M. hirsutus* populations in various agroecosystems.

The repellency of ginger oil was attributed to its odor, effective at the concentrations used over a distance of 1-2 mm. Tomato leaf disks dipped in ginger oil repelled whiteflies at concentrations of 0.5, 0.75, and 1%, but not at concentrations <0.5%, in a dose-response experiment conducted in the olfactometer (Zhang *et al*.,2004). The results showed that, garlic oil was the best efficient in reducing the population of leafhoppers and planthoppers by a mean reduction percentage of 68.09% at 3% conc. However, in controlling aphids, also garlic surpasses again by a mean overall reduction 90.96 % (Mousa *et al*., 2013). Ahmadi *et al*. (2012) tested the effects of sirinol (garlic extract) with five doses (1000, 1500, 2000, 2500 and 3500 ppm) on citrus mealybug and found that the highest mortality with sirinol (3500 ppm) with 87.11% mortality, 72 h after spraying. The EOs of the aromatic plants of mint species (*Mentha* spp.) have adulticidal, larvicidal, and growth and reproduction inhibitory effects, as well as repellent activity against various stored product pests and vectors (Michaelakis *et al.*, 2012). They also exhibit strong fumigant toxicity against greenhouse pests such as *Trialeurodes vaporariorum* (Westwood) (Hemiptera: Aleyrodidae), *Tetranychus urticae* Koch (Acari: Tetranychidae) (Choi *et al.*, 2003 and 2004), and several aphids species (Kimbaris *et al*., 2010). Cloyd *et al.* (2009) reported that

a mixture of thyme and mint oil resulted in 89% mortality of citrus mealybugs 3 days after spraying.

The insecticidal activity of pure limonene has been shown against other mealybug species. Spray applications of limonene in 1% aqueous solution (together with a spray adjuvant as an emulsifier/surfactant and another agricultural surfactant) resulted in 44% mortality of 3rd and 4th instar nymphs of *Planococcus citri* (Risso) (Hemiptera: Pseudococcidae) on gardenia pot plants in the greenhouse. In addition, laboratory bioassays with the same limonene solution showed 95–100% mortality to the nymphs and adults of the coconut mealybug *Nipaecoccus nipae* (Maskell) (Hemiptera: Pseudococcidae), on sprayed coconut leaves, 92% mortality against 3rd and 4th instar nymphs of the long tailed mealybug, *Pseudococcus longispinus* (Targioni-Tozzetti) (Hemiptera: Pseudococcidae), when applied on green beans by dipping for 1 min, and 100% mortality of eggs of the root mealybug, *Rhizoecus* spp., on Gardenia roots by dipping in application for 1 min (Hollingsworth, 2005).

In conclusion, our results suggest that the essential oils tested in the present study may help in reducing *M. hirsutus* populations in different agroecosystems through their repellent, oviposition-deterrent and egg-hatching inhibitory effects. Furthermore, they appear to be environmentally safe because many of them, including those tested in the present study, are commonly used in the food and beverage industry as flavorings, in the cosmetic and perfume industry for fragrances and in the pharmaceutical industry for medicinal purposes. They also have the potential to be adopted on commercial scale. These results are promising for future research.

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