Chemistry and Insecticidal Activity of Essential Oils against *Trogoderma granarium* Larvae

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ABSTRACT

The essential oils from five plants, *Mentha spicata*, *Ocimum basilicum*, *Cymbopogon schoenanthus*, *Juniperus phonicea* and *Matricaria chamomilla* were obtained by hydrodistillation and their chemical composition was identified based on spectral analysis of chromatography/mass spectrometry (GC/MS). The insecticidal potential of oils against the larvae of *Trogoderma granarium* was tested using contact and fumigant toxicity bioassays. Based on GC/MS analysis, the main compounds of essential oils were carvone (66.17 %) in *M. spicata*, methyl cinnamate (44.28 %) in *O.basilicum*, piperitone (63.35%) in *C. schoenanthus*, α-pinene (44.57 %) in *J. phonicea*and bisabolol oxide A (56.71 %) in *M. chamomilla*. It was also clear that the essential oils are rich with monoterpenes, either oxygenated or non-oxygenated ones except the essential oil of *M. chamomilla* which contains a high concentration of oxygenated sesquiterpenes. The oil of *M. spicata* displayed the highest fumigant toxicity against *T. granarium* as, it induced 71.67 and 91.67% larval mortality at 50 and 100 µl/l, respectively, while the essential oil of *J. phonicea* revealed a weakest toxicity. Among the five tested oils, *M. spicata* (LC_{50} = 0.07 mg/cm^2), *O. basilicum* (LC_{50} = 0.08 mg/cm^2) and *C. shoenanthus* (LC_{50} = 0.09 mg/cm^2) essential oils showed a remarkable contact toxicity against *T. granarium*. The values of LC_{50} it is almost half of deltamethrin (0.04 mg/cm^2), as one of the recommended insecticides to control stored insect pests. The essential oils of *M. chamomilla* and *J. phonicea* displayed moderate and weak contact toxicity, respectively. It was obvious that the essential oils were more active as contact toxicants than as fumigant toxicants. Therefore, *M. spicata, O. basilicum*and *C. shoenanthus* essential oils could be implemented in *T. granarium* management programs.

Keywords: Essential oils; Chemical constituents; insecticidal activity; Khapra beetle

INTRODUCTION

Grains are a highly important source not only as food for humans but also as feed for animals. Unluckily, insects induce 10% losses of stored grains, particularly in developing countries. In the case of high infestation, the loss may reach up to 50% of the total production worldwide (De Lira *et al.,* 2015). As results of feeding on stored grains, insects reduce grain germination and nutritional values. Furthermore, if the insect infestation is high, several changes such as, mold, contamination and odor, may occur and lead to the grains become not acceptable for consumption (Weaver and Petroff, 2004).

Khapra beetle, *Trogoderma granarium* Everts (Coleoptera: Dermestidae) is a key insect pest in stored commodities in several parts of the world, particularly in tropical and subtropical zones (Hagstrum & Subramanyam, 2009; Eliopoulos, 2013; Athanassiou *et al.*, 2019 and Kavallieratos *et al.*, 2019). This insect is native to India. The larvae are a harmful stage and heavy feeders that attack whole or cracked grains resulting in a massive loss in quality, weight and germination (Athanassiou *et al.*, 2015; Rajput *et al.*, 2015 and EPPO, 2018).

Control of stored product insects, including *T. granarium*, is primarily depending on the application of insecticides and fumigants. Despite their effectiveness, the frequent use for long periods induces several drawbacks, such as disruption of ecosystem by killing natural enemies, outbreak of some insect pests, widespread insect resistance in addition to detrimental consequences on non-target organisms and ecology (Tadesse and Subramanyam, 2018). These problems have stressed on the necessity for new alternatives with selective effects for the control of stored product insects. Among the available alternatives, plants-based products, such as essential oils, may offer a reliable tool for the management of stored product insects (Saad *et al.*, 2017).

Essential oils are highly volatile plant products and consist of mixtures of several terpenes and oxygenated terpenes. However, hydrocarbon and oxygenated monoterpenes and sesquiterpenes are mainly the main componontes of most essential oils (Cowan, 1999). Essential oils have the ability to interact with pest biochemical functions due to their chemical nature which characterized by high lipophilicity and low molecular weight. It has been reported that essential oils

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DOI: 10.21608/asejaiqjsae.2023.307402

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Received, May30, 2023, Accepted, June 30, 2023.

may offer an excellent source of ecofriendly insect control products (Isman, 2006). Several biological activities for the essential oils against stored product insects have been reported, including repellent, antifeedant, insecticidal, growth inhibitory and ovicidal propertiesz (Hamdani *et al.*, 2015 and Abdelgaleil *et al.*, 2016).

Our ongoing research is to seek for new plant natural products with promising insect control potential. The essential oils from five plants, namely *Mentha spicata*, *Ocimum basilicum*, *Cymbopogon schoenanthus*, *Juniperus phonicea* and *Matricaria chamomilla* were isolated and identified by GC/MS. The contact and fumigant toxicities of the essential oils were examined against the larvae of *T. granarium*.

MATERIAL AND METHODS

Test insect

A colony of khapra beetle was reared in our laboratory on whole wheat grains for several years at 30±2˚C and 70% ±5 R.H. in darkness. The third larval instar (2-4 mm length) was used in bioassay experiments.

Insecticide

A technical grade of deltamethrin (95 %) was obtained from Egyptchem Company, Egypt.

Plant materials

Aerial parts of *Mentha spicata* L. and *Ocimum basilicum* L. were collected from Alexandria University farm, Abis, Alexandria, Egypt in June, 2019. *Cymbopogon schoenanthus* (L.) Spreng (whole plant), *Juniperus phonicea* L. (fruits) and *Matricaria chamomilla* L. (aerial parts) were purchased from Asala Company, Maady, Cairo, Egypt. Plant materials were recognized by a taxonomist at Faculty of Agriculture, Alexandria University.

Essential oil extraction

Essential oils have been extracted by hydrodistillation for three hours. The oils were run over anhydrous sodium sulfate to insure full removing of water and stored at 4°C.

Essential oils analysis

Gas chromatography (Hewlwett Packard 5890)/mass spectrometry Hewlwett Packard 5989B) was used for essential oils analysis. Oils analysis and identification of oil components were run as reported by Mohamed and Abdelgaleil (2008).

Contact toxicity

The isolated essential oils were tested for their direct contact toxicity on *T. granarium* larvae (Abdelgaleil *et al.*, 2009). The essential oils solutions of were prepared in hexane. Then 1 ml of essential oil solution was carefully placed in each Petri dish (9 cm diameter). The essential oils were tested at a series of concentrations (0.01- 0.5 mg/cm^2). The solvent were allowed to evaporate for 2 min before releasing 20 third instar larvae into each Petri dish. The control dishes were treated with hexane alone. Each treatment was replicated four times. After 7 days of treatment, mortality percentages were recorded and subjected to probit analysis (Finney, 1971) to obtain LC$_{50}$ values for essential oils.

Fumigant toxicity

Fumigant toxicity of essential oils on larvae of *T. granarium* was tested at three concentrations, 10, 50 and 100 µl/L (Abdelgaleil *et al.*, 2009). One liter glass jar was used as fumigant unit. The essential oil volumes (µl) were applied on filter paper pieces (2 × 3 cm^2) attached to inner side of caps of fumigation jars. Then the jars containing 20 third larval instar of *T. granarium* were tightly covered with their screw caps. In the control treatment, jars were covered with their screw caps without essential oils. After 7 days of exposure, the numbers of dead larvae were counted and mortality percentages were calculated.

Data analysis

The essential oil LC$_{50}$ values were obtained by subjecting mortality data to probit analysis (Finney, 1971). Mortality percentages in fumigant toxicity assay were subjected to ANOVA using Duncan's New Multiple Range Test (DMRT) at a significance level < 0.05 to obtain the differences between treatments.

RESULTS AND DISCUSSION

Chemical constituents of essential oils

Percentages of chemical constituents of the five essential oils as identified by GC-MS are shown in Tables (1-5). Twenty-six compounds accounting for 99.65% of *Ocimum basilicum* essential oil were identified (Table 1). The chief compounds of the oil were methyl cinnamate (44.28 %) , camphor (16.04 %) , linalool (9.25 %) , 1,8-cineole (8.26 %) , *trans*-caryophyllene (3.83 %) , 4-terpineol (2.89 %) and germacrene D (2.32 %). Oxygenated monoterpenes, sesquiterpene hydrocarbons and monoterpene hydrocarbons were present in the oil at concentrations of 37.72, 10.95 and 3.96 %, respectively. The results of chemical composition studies on *O. basilicum* oils collected from Bulgaria and Colombia declared that the major compounds were methyl cinnamate and linalool, respectively (Sajjadi, 2006). Abdel-Azim *et al.* (2015) reported that linalool (33.9%) as major compound of essential oil of *O. basilicum* collected from Egypt, followed by eugenol (8.31%) and 2,6-dimethyl-6-(4-methyl-3-pentenyl)-bicyclo [3.1.1] hept-2-ene (8.04%).

Table (2) shows the composition of *Matricaria chamomilla* essential oil. The results showed that 31 compounds were detected and represented 99.75 % of total *M. chamomilla* essential oil. The main compounds of the oil were bisabolol oxide A (56.71 %), dl-limonene (11.55 %), bisabolone oxide (7.89 %), α-bisabolol oxide B (7.19 %), (E)- α-famesene (3.02 %) and (-)-spathulenol (2.43 %). This oil is largely consisting of monoterpene hydrocarbons (12.61%), sesquiterpene hydrocarbons (5.46 %) and oxygenated monoterpenes (4.39%). In a previous study, α-bisabolol oxide A (58.18%), α-bisabolone oxide A (7.88%) and α-bisabolol oxide B (6.57%) were the key compounds in the essential oils of chamomile flowers, whereas α-bisabolol oxides A (27.94%) and α-bisabolol oxides B (23.65%) were the major compounds in the chamomile teabags essential oil (Lopez and Blazquez, 2016). Stanojevic *et al.* (2016) reported that sesquiterpene hydrocarbons (57.2 %) and oxygen-containing sesquiterpenes (25.3 %) were the major classes of compounds in *M. chamomilla* essential oil with (E)-β-farnesene (29.8 %), (E,E)-α-farnesene (9.3 %) and α-bisabolol oxide A (7.0 %) being the most dominant components.

The chemical constituents of the *Mentha spicata* essential oil are shown in Table (3). Twenty four compounds representing 99.61 % of the total *M. spicata* essential oil were detected. The main compounds of the oil were carvone (66.17 %), dl-limonene (12.48 %), eucalyptol (7.43 %), α-pinene (3.07 %) and *trans*-caryophyllene (2.16%). The oil is mainly consisting of oxygenated monoterpenes (76.59%), monoterpene hydrocarbons (17.16%) and sesquiterpene hydrocarbons (5.26 %). In accordance with our results, Bardaweel *et al.* (2018) reported that carvone (49.5%) was the predominating component in the essential oil of *M. spicata*, followed by limonene (16.1%), and 1,8-cineole (8.7%). Snoussi *et al.* (2015) mentioned that carvone (40.8%), limonene (20.8%) and 1,8-cineole (17.0%) were main constituents in the oil of *M. spicata*.

The chemical constituents of the *Juniperus phonicea* essential oil are shown in Table (4). Twenty nine compounds accounting for 99.50 % of the total *J. phonicea* essential oil were known. The most dominant compounds of the oil were α-pinene (44.57 %), dl-limonene (12.83 %), α-cedrol (10.33 %), α-myrcene (5.93 %) and *trans*-pinocarveol (3.76 %). The oil is primarily consisting of monoterpene hydrocarbons (68.76 %), oxygenated monoterpenes (17.83 %) and oxygenated sesquiterpenes (11.63 %). Medini *et al.* (2011) reported that the chief components of the oil of *J. phonicea* were α-pinene, camphene and δ-3-carene. In the study of Ramdani *et al.* (2013), α-pinene, terpinolene and Δ3-carene were detected as major compounds in the EOs of *J. Phoenicea*.

The chemical components of the *Cymbopogon schoenanthus* essential oil are shown Table (5). The results showed that 23 compounds could be detected and represented 99.11 % of the total *C. schoenanthus* essential oil. The compounds with the highest concentration in the oil were piperitone (47.61 %), α-terpinene (35.62 %), elemol (4.80 %), dl-limonene (2.72 %) and α-eudesmol (2.40 %).

Table 1. Chemical constituents (%) of *Ocimum basilicum* essential oil

Compound	RT (min)	%	Compound	RT (min)	%
α-Pinene	4.26	1.38	*trans*-Caryophyllene	22.17	3.83
Camphene	4.67	1.04	Calarene	22.81	0.37
Sabinene	5.22	0.26	α-Humulene	23.68	0.61
dl-Limonene	6.87	0.78	Germacrene D	24.74	2.32
1,8-Cineole	6.98	8.26	Bicyclogermacrene	25.31	1.08
γ-Terpinene	7.85	0.35	Guaiene	25.55	0.43
trans-Sabinene hydrate	8.35	0.20	γ-Muurolene	26.09	0.97
α-Terpinene	8.79	0.15	(-)-Caryophyllene oxide	28.82	0.35
Linalool	9.39	9.25	Cubenol	30.16	0.27
Camphor	11.35	16.04	Cadinol	31.26	2.12
endo-Borneol	12.32	0.28	Monoterpene hydrocarbons		3.96
4-Terpineol	12.63	2.89	Oxygenated monoterpenes		37.72
p-Menth-1-en-8-ol	13.40	0.51	Sesquiterpene hydrocarbons		10.95
Piperitone	15.95	0.29	Oxygenated sesquiterpenes		2.74
α-Elemene	20.99	1.34	Others		44.28
Methyl cinnamate	21.60	44.28	Total identified		99.65

Table 2. Chemical constituents (%) of *Matricaria chamomilla* essential oil

Compound	RT (min)	%	Compound	RT (min)	%
α-Pinene	4.26	0.66	Bicyclogermacrene	25.32	0.30
Camphene	4.68	0.29	γ-Muurolene	26.12	0.16
Yomogi alcohol	5.84	0.44	Cadinene	26.29	0.12
Sabinene	6.51	0.11	(-)-Spathulenol	28.72	2.43
dl-Limonene	6.88	11.55	Salvial-4(14)-en-1-one	29.35	0.16
Artemisia ketone	7.88	1.67	*cis*-Lanceol	30.27	0.33
Artemisia alcohol	8.65	0.21	(-)-spathulenol	30.90	0.22
Camphor	11.37	0.22	α-Cadinol	31.28	0.75
1-Borneol	12.35	0.41	α-Bisabolol oxide B	31.67	7.19
4-Terpineol	12.79	0.96	Santalol	32.01	1.36
p-Menth-1-en-8-ol	13.65	0.11	Bisabolone oxide	32.73	7.89
p-Menth-1-en-8-ol acetate	19.56	0.37	α-Bisabolol	33.23	0.25
α-Copaene	20.37	0.10	Bisabolol oxide A	35.16	56.71
Berkheyaradulene	20.87	0.13	Monoterpene hydrocarbons		12.61
trans-Caryophyllene	22.17	0.46	Oxygenated monoterpenes		4.39
(E)- α-Famesene	23.83	3.02	Sesquiterpene hydrocarbons		5.46
Germacrene D	24.75	0.44	Oxygenated sesquiterpenes		77.29
α-Selinene	25.11	0.73	Total identified		99.75

Table 3. Chemical constituents (%) of *Mentha spicata* essential oil

Compound	RT (min)	%	Compound	RT (min)	%
α-Pinene	4.26	3.07	α-Elemene	20.99	0.26
Sabinene	5.23	0.64	*trans*-Caryophyllene	22.16	2.16
α-Myrcene	5.71	0.60	γ-Muurolene	23.19	0.12
α-Terpinene	6.50	0.15	(+)-epi-Bicyclosesquiphellandrene	23.98	0.17
dl-Limonene	6.87	12.48	Germacrene D	24.75	1.09
Eucalyptol	6.97	7.43	Bicyclogermacrene	25.32	0.29
Delta-3-Carene	7.88	0.22	Hedycaryol	27.73	0.31
trans-Sabinene hydrate	8.39	0.29	Cubenol	30.20	0.10
Isoborneol	12.35	0.22	• α-Eudesmol	31.89	0.19
4-Terpineol	12.69	1.21	Monoterpene hydrocarbons		17.16
α-Terpineol	13.49	0.20	Oxygenated monoterpenes		76.59
Dihydrocarvone	13.62	0.35	Sesquiterpene hydrocarbons		5.26
trans-Carveol	14.50	0.72	Oxygenated sesquiterpenes		0.60
Carvone	15.46	66.17	Total identified		99.61
α-Bourbonene	20.67	1.17			

Table 4. Chemical constituents (%) of *Juniperus phonicea* essential oil

Compound	RT (min)	%	Compound	RT (min)	%
Tricyclene	4.04	0.42	4-Terpineol	12.62	0.92
Thujene	4.09	0.49	Myrtenal	13.34	2.03
α-Pinene	4.29	44.57	l-Verbenone	13.85	2.27
Camphene	4.67	0.81	*trans*-Carveol	14.45	0.54
Verbenene	4.77	1.91	Bornyl acetate	16.79	0.72
γ-Terpinene	5.23	0.61	Cedrene	22.00	0.52
α-Myrcene	5.63	5.93	γ-Elemene	25.97	0.45
Delta-3-Carene	6.18	1.19	ε-Cadinene	26.28	0.31
dl-Limonene	6.86	12.83	Elemol	27.65	0.37
α-Campholenal	10.53	1.67	Caryophyllene oxide	28.81	0.33
trans-Pinocarveol	11.00	3.76	Veridiflorol	29.43	0.60
Verbenol	11.21	0.85	α-Cedrol	29.94	10.33
Camphor	11.34	0.52	Monoterpene hydrocarbons		68.76
p-Mentha-1,5-dien-8-ol	11.45	2.78	Oxygenated monoterpenes		17.83
trans-3-Pinanone	11.85	0.63	Sesquiterpene hydrocarbons		1.28
Pinocarvone	11.94	0.28	Oxygenated sesquiterpenes		11.63
1-Borneol	12.31	0.86	Total identified		99.50

Table 5. Chemical constituents (%) of *Cymbopogon shoenanthus* essential oil

Compound	RT (min)	%	Compound	RT (min)	%
α-Pinene	4.27	0.26	α-Cedrene	24.77	0.15
Spiro[4.5]dec-6-ene	4.68	0.27	Junipene	25.14	0.10
m-Cymene	5.26	1.05	Cuparene	26.02	0.13
Carveol	5.72	0.26	ε-Cadinene	26.31	0.17
α-Terpinene	5.91	35.62	Elemol	27.73	4.80
dl-Limonene	6.94	2.72	Caryophyllene oxide	28.86	0.16
α-Thujone	9.07	0.26	γ-Eudesmol	30.95	0.72
p-Menth-2-en-1-ol	10.57	0.44	α-Eudesmol	31.87	2.40
1-Terpineol	11.35	0.13	Monoterpene hydrocarbons		39.65
5-Methyl-1,5-hexadien-3-ol	12.77	0.12	Oxygenated monoterpenes		49.54
6,9,12-Octadecatrienoic acid, methyl ester	12.83	0.22	Sesquiterpene hydrocarbons		1.35
α-Terpineol	13.55	0.72	Oxygenated sesquiterpenes		8.08
Piperitone	15.91	47.61	Others		0.49
α-Elemene	21.02	0.62	Total identified		99.11
trans-Caryophyllene	22.20	0.18			

The oil is mostly consisting of oxygenated monoterpenes (49.54 %), monoterpene hydrocarbons (39.65 %) and oxygenated sesquiterpenes (8.08 %). Hellali *et al.* (2016) reported that the major component of *C. schoenanthus* essential oil was piperitone (63.35%). Also, they found oxygenated monoterpenes (65.36 %) were the most dominant class of compounds. It has been also reported that piperitone, cyclohexanemethanol, beta-elemene, alpha-eudesmol (11.5%) and elemol (10.8%) were detected as major components in *C. schoenanthus* essential oil (Hashim *et al.*, 2017).

Fumigant toxicity of essential oils against larvae of *T.granarium*

Fumigant toxicity of five essential oils (*O. basilicum, M. chamomilla, M. spicata, J. phonicea* and *C. schoenanthus*) against *T. granarium* larvae is shown in Table (6). The essential oil of *M. spicata* displayed the highest toxicity with mortality of 71.67 and 91.67% at 50 and 100 µl/l, respectively, followed by *C. schoenanthus*. In contrary, the essential oil of *J. phonicea* showed a weak or no fumigant toxicity. The fumigant toxicity of the five essential oils was not reported before against *T. granarium*. However, some essential oils have shown fumigant toxicity against *T. granarium*. For instance, Ghanem *et al.* (2013) tested the fumigant toxicity of *Foeniculum vulgare* essential oil against the larvae of *T. granarium* and found that the oils is highly toxic as the LC$_{50}$ and LC$_{90}$ values were 38.4 and 84.6 µl/l, respectively, after 24 h. of exposure. Mohamed and Abbas (2017) examined fumigant toxicity of essential oils of *Eucalyptus camaldulensis* and *Artemisia herba alba* against third instar larvae and adults of *T. granarium*. They concluded that adult mortality rates were higher than those of larvae after different duration of exposure.

Contact toxicity of essential oils against larvae of *T. granarium*

Contact toxicity of the five essential oils (*O. basilicum, M. chamomilla, M. spicata, J. phonicea and C. shoenanthus*) against *T. granarium* larvae in terms of LC$_{50}$ values is presented in Table (7). The tested essential oils showed variable toxicities against *T. granarium* larvae. Based on LC$_{50}$ values, the essential oils *M. spicata*, *O. basilicum* and *C. shoenanthus* revealed strong contact toxicity with LC$_{50}$ values of 0.07, 0.08 and 0.09 mg/cm^2, respectively. The LC$_{50}$ values of the three essential oils were close to the LC$_{50}$ of deltamethrin (0.04 mg/cm^2), as one of the recommended insecticides to control stored insect pests. While, the essential oil of *J. phonicea* (LC$_{50}$ = 0.42 mg/cm^2) was less toxic one. The contact toxicity of the five essential oils was not reported before against *T. granarium* insect. It has been reported that some essential oils had contact toxicity against *T. granarium*. For example, Gadir and Ehsan (2017) evaluated the toxicity of *Artemisia sieberi* Besser essential oil on 4th instar larvae of *T. granarium*. They concluded that the larvae were sensitive to the oil and LC$_{50}$ values were 44.3 µg/cm^2 and 33.5 µL/L air for contact and fumigant assays, respectively. Janaki *et al.* (2018) calculated the LC$_{50}$ values of *Cyperus rotundus* essential oil on the adults *Callosobruchus maculatus*, *Oryzaephilus surinamensis*, and *T. granarium* using contact toxicity assay and the values were 0.36, 0.51, and 0.2 µL/cm^2, respectively.

Table 6. Fumigant toxicity of essential oils against 3rd larval instar of *Trogoderma granarium* after 7 days of treatment

Essential oil	**% of Mortality (mean ±SE) at concentration (µl/l)**		
	10	**50**	**100**
Control	0.0±0.0a	0.0±0.0d	0.0±0.0d
Ocimum basilicum	5.0±1.67a	16.67±0.96c	20.0±2.88c
Matricaria chamomilla	3.33±1.92a	5.0±1.67d	15.0±1.67c
Mentha spicata	8.33±1.92a	71.67±3.47a	91.67±2.54a
Juniperus phonicea	0.0±0.0a	0.0±0.0d	1.67±0.96d
Cymbopogon shoenanthus	8.33±1.92a	40.0±1.67b	46.67±0.96b

Mean values within a column sharing the same letters are not significantly different at the 0.05 probability level

Table 7. Contact toxicity of essential oils against 3rd larval instar of *T. granarium* after7 days of exposure

Essential oil	LC$_{50}$(mg/cm^2)^a (95% CL)	LC$_{95}$(mg/cm^2)^b (95% CL)	Slope ± SE^c	Intercept ± SE^d	(χ^2)^e	*P*^{f}
Ocimum basilicum	0.08 (0.07 – 0.28)	0.21(0.18 – 0.28)	3.78±0.40	4.18±0.44	1.379	0.240
Matricaria chamomilla	0.14 (0.13-0.15)	0.27 (0.24-0.31)	5.94±0.54	5.03±0.44	0.120	0.729
Mentha spicata	0.07 (0.05-0.07)	0.11 (0.10-0.13)	8.05±1.87	9.52±2.04	0.713	0.398
Juniperus phonicea	0.42 (0.38-0.46)	1.02 (0.77-1.86)	4.23±0.83	1.62±0.35	2.047	0.152
Cymbopognshoenanthus	0.09 (0.07-0.11)	0.69 (0.48- 0.88)	1.89±0.42	3.95±0.41	2.850	0.092
Deltamethrin	0.04(0.03-0.06)	7.84(3.55-24.33)	0.73± 0.07	1.00±0.10	2.218	0.528

[a] The concentration causing 50% mortality.
[b] The concentration causing 95% mortality.
[c] Slope of the concentration-mortality regression line ± standard error.
[d] Intercept of the regression line ± standard error.
[e] Chi square value.
[f] Probability value.
CL = Confidence limits

It is well-known that the bioactivities of essential oils including their insecticidal activity are attributed to their monoterpenod contents. Indeed, some monoterpenes, limonene, α-pinene and 1,8-cineole, which have been detected as major compounds in the tested essential oils in the current study have been reported as fumigant and contact toxicants against *S. oryzae* and *T. castaneum* (Abdelgaleil *et al.*, 2009; Kim *et al.*, 2013; Saad *et al.*, 2018 and 2019). However, the toxicity of essential oils towards insects may be enhanced due to the presence of other minor constituents in the essential oils.

In conclusion, this study demonstrates the chemical composition, fumigant and contact toxicity of five essential oils against the larvae of *T. granarium*. Among the tested oils, *M. spicata*, *O. basilicum* and *C. shoenanthus* essential oils showed strong contact toxicity. Our findings indicated that these three oils could be promising in the control of *T. granarium*. However, further studies on formulation and safety are need before large scale application.

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الملخص العربي

كيمياء والنشاط الابادى الحشرى للزيوت الطيارة ضد يرقات حشرة الخابرا

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تم استخلاص الزيوت العطرية من خمسة نباتات عن طريق التقطير hydro-distillation وهي النعناع المدبب والريحان والبابونج الألماني وعشب الجمل (الحلفا بر) والعرعر الفينيقي و تم تحليلها بواسطة كروماتوجرافيا الغاز / مطياف الكتلة (GC / MS). وتم تقييم كفاءة الزيوت العطريه المعزولة كمبيدات حشرية بطريقتي الملامسة والتبخير ضد العمر الثالث ليرقات خنفساء الخابرا *Trogoderma granarium.* . أظهر تحليل GC / MS أن المركبات الرئيسية كانت carvone (66.17%) في زيت النعناع ، methyl cinnamate (44.28%) في زيت الريحان، (63.35 %) piperitone في عشب الجمل، α-pinene (44.57%) في العرعر و bisabolol oxide A (56.71%) في زيت البابونج. كما أوضحت النتائج أن الزيوت العطرية غنية بهيدروكربونات المونوتربين والمونوتربينات المؤكسدة باستثناء الزيت العطري للبابونج والذي يحتوي على نسبة عالية من السيسكوتربين المؤكسدة. أظهر الزيت العطري للنعناع أعلى سمية ضد يرقات خنفساء الخابرا بطريقة التبخير حيث بلغت نسبة موت اليرقات ٧١,٦٧ و ٩١,٦٧% عند تركيز ٥٠ و ١٠٠ ميكرولتر / لتر على التوالي، بينما أظهر الزيت العطري للعرعر اقل سمية. كما أظهرت الزيوت العطرية الخمسة المختبرة بطريقة الملامسة أن التركيز القاتل لـ ٥٠ % من اليرقات بلغ ($LC_{50} = 0.07$ mg / cm^2) لزيت النعناع و ($LC_{50} = 0.08$ mg / cm^2) لزيت الريحان و (LC50 = 0.09 mg / cm^2) لزيت عشب الجمل حيث كانت قيم LC50 للزيوت الثلاثة قريبة من قيمة الـLC50 للدلتامثرين (٠,٠٤ مجم / سم^{٢})، كأحد المبيدات الحشرية الموصى بها لمكافحة الآفات الحشرية في المخازن. وأظهرت الزيوت العطرية لكل من البابونج و العرعر سمية محسوسة اومنخفضة عن طريق الملامسة على التوالي. كما أظهرت النتائج أن الزيوت العطرية كانت أكثر كفاءة عن طريق الملامسة مقارنة بسميتها كمدخنات. لذلك قد يكون للزيوت العطرية لكل من النعناع و الريحان وعشب الجمل أهمية في مكافحة خنفساء الخابرا.