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Effectiveness of monoterpenes against *Sitophilus oryzae* (L.) and *Tribolium castaneum* (Herbst) in stored wheat

Sailan A. A. El-arami[a], Magdy I. E. Mohamed[b], Samir A. M. Abdelgaleil[c,*]

[a]Department Plant Protection, Faculty of Agriculture, Sanaa University, Sanaa, Yemen
[b]Department of Stored Product Pests, Plant Protection Research Institute, Agricultural Research Center, Sabahia, Alexandria, Egypt
[c]Department of Pesticides Chemistry, Faculty of Agriculture, Alexandria University, 21545-El-Shatby, Alexandria, Egypt

ABSTRACT

A study was conducted to evaluate the efficacy of eight monoterpenes namely (-)-carvone, 1-8-cineole, cuminaldehyde, (L)-fenchone, geraniol, (-)-limonene, (-)-linalool and myrcene against two major stored-grain insects on wheat seeds in the laboratory. Insect species tested were the rice weevil, *Sitophilus oryzae* (L.), and the rust red flour beetle, *Tribolium castaneum* (Herbst). Wheat seeds were treated with monoterpenes at 0.5, 1 and 5 mg/g for controlling the two insect species. Out of the eight monoterpenes, (-)-carvone was the most toxic compound against both insects at the three tested application rates after one and two weeks of treatment. Geraniol and cuminaldehyde were among the most effective compounds against both insects. Four of the tested monoterpenes (carvone, cuminaldehyde, geraniol and (-)-linalool) caused complete mortality to the adults of *S. oryzae* after one week at the rate of 5mg/g, while all of the tested monoterpenes except myrcene and (-)-linalool caused complete mortality of *T. castaneum* adults at the same application rate. Comparing the toxicity of monoterpenes toward the two insects indicated that, (-)-limonene, (L)-fenchone and cuminaldehyde had approximately the same activity on both insects. On the other hand, myrcene, geraniol, (-)-carvone and 1-8-cineole were more toxic against *T. castaneum* than *S. oryzae*, while (-)-linalool was more toxic towards *S. oryzae* than *T. castaneum*. All of the tested compounds except for myrcene showed significant reduction in progeny production of *S. oryzae* after 6 and 12 weeks of treatment compared with control. (-)-Carvone was the most effective in reducing the progeny production at the three tested application rates, followed by geraniol, cuminaldehyde and (-)-linalool. These four monoterpenes provided complete suppression of progeny production at the rate of 5 mg/g after 12 weeks. At the rates of 1 and 5mg/g, the majority of monoterpenes significantly reduced weight loss of treated wheat and complete protection was observed in wheat treated with (-)-carvone, geraniol, cuminaldehyde and (-)-linalool at 5 mg/g. These strong insecticidal activities of monoterpenes particularly (-)-carvone, geraniol, cuminaldehyde and (-)-linalool indicate that these monoterpenes can used for control *S. oryzae* and *T. castaneum* in stored wheat.

Keywords: Monoterpenes; insecticidal activity; *Sitophilus oryzae*; *Tribolium castaneum*; stored wheat

INTRODUCTION

Losses of grain in storage due to insects are main components of the insect damage in agricultural production. These losses can exceed those incurred while growing the crop. Insects damage stored grain directly by consuming kernels and reducing the weight and feed value of the infested commodity. Additionally, insects infesting stored grain produce heat and moisture that contribute to mold growth and spoilage (Evans, 1987). Worldwide losses in stored products, caused by insects, have been estimated to be between five and ten percent. Heavier losses occurring in the tropics may reach 30% (Larry, 2000).

Insect control in stored grain at present relies heavily upon the use of fumigants (methyl bromide and phosphine) and protectants (synthetic insecticides). However, the intensive use of these chemicals may led to some environmental and health problems as well as the development of insect resistance (Collins *et al.*, 1993). For this reason, alternative control means are necessary. Plant secondary metabolites may provide potential alternatives to currently used insect control agents. The plant materials have several advantages over traditional pest control agents; such as specificity, biodegradability and low mammalian toxicity (Wink, 1993; Mohan and Fields, 2002).

One of the most promising secondary metabolites in the field of pest control is monoterpenes which are common constituents of plant essential oils. They are biosynthesized from geranyl pyrophosphate, the ubiquitous acyclic C_{10} intermediate of the isoprenoid pathway (Windholz *et al.*, 1983). Monoterpenes can be classified into two major groups: monoterpene hydrocarbons and oxygenated monoterpenes. The later group includes alcohols, aldehydes, ketones, ethers and acids (Templeton 1969).

Monoterpenes have been considered as potential pest control agents. This includes their insecticidal activity (Waliwitiya *et al.*, 2005; Choi *et al.*, 2006; Kordali, *et al.*, 2006; Samarasekera *et al.*, 2008), herbicidal activity (Kohli *et al.*, 1998; Isman 2000; Romagni *et al.*, 2000), repellent activity (Mason, 1990; Watanabe *et al.*, 1993), antifeedant activity (Hough-Goldstein, 1990; Hummelbrunner and Isman, 2001; Argandoña *et al.*, 2002) and development and growth inhibitory activity (Gunderson *et al.*, 1985; Karr and Coats 1992). The wide spectrum of the biological activities of monoterpenes is attributed to their physical-chemical properties such as lipophilicity and low vapour pressure.

Although, the fumigant and contact toxicities of some monoterpenes have been studied on the rice weevil, *Sitophilus oryzae* (Lee et al. 2001, 2003 and 2004, Kim and Ahn 2001; Park *et al.*, 2003) and the rust red flour beetle, *Tribolium castaneum* (Rice and Coats, 1994; Partes *et al.*, 1998; Lee *et al.*, 2003, 2004), there were no reported studies on the effectiveness of monoterpenes for the control of both insects on the stored wheat. Therefore, the present study was conducted to investigate the potential use of monoterpenes for the control of these two important stored product insects in stored wheat. The effect of the monoterpenes on the progeny production of *S. oryzae* and weight loss of wheat seeds was also investigated.

MATERIALS AND METHODS

Monoterpenes: The monoterpenes, (-)-carvone (98%), 1-8-cineole (99%), cuminaldehyde (98%), (L)-fenchone (98%), geraniol (98%), (-)-limonene (96%), (-)-linalool (95%) and myrcene (90%) were purchased from Sigma-Aldrich Chemical Co., Steinheim, Germany. The chemical structures of the tested monoterpenes are shown in (Figure 1).

Insects and commodity: *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae) adults were taken from culture that was kept on whole hard wheat in the laboratory at 26±1°C and 65± 5% R.H. *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) adults were taken from a culture kept on wheat flour mixed with yeast (10:1, w/w) under the same conditions. The colonies of both insects were maintained in our laboratory over 10 years without exposure to insecticides. The adults used in the tests were 2 weeks post-emergence. Untreated, clean, sterilized and infestation-free Egyptian wheat with 13.6% moisture content was used in the tests for two insect species.

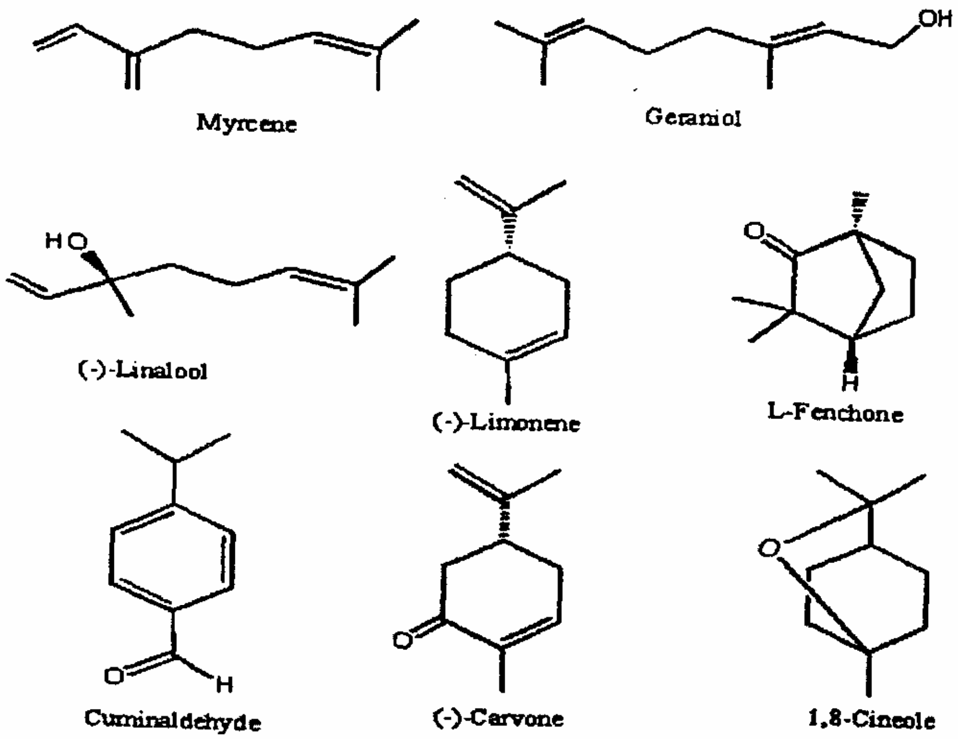

Figure 1. The chemical structures of the tested monoterpenes

Bioassay: Stock solutions of the tested monoterpenes were prepared in acetone. Fifty grams of wheat were placed in 300 ml glass jars. Wheat in glass jars were treated with 1 ml of the stock solution of the tested monoterpenes. The application rates were 0.5, 1 and 5 mg/g. The jars were shaken manually for 3 minutes to achieve distribution of the compounds throughout the grains. The control grains were treated with acetone only. The jars were left for 30 minutes for complete evaporation of the solvent. Twenty adults of *S. oryzae* and *T. castaneum* were separately introduced into each jar. Three replicates were used for each treatment and control. The jars were covered with cheese cloth fastened by rubber bands to prevent escape of insects and to ensure proper ventilation. The jars were kept at 26±1°C and 65±5% R.H. The adult mortality was done at one week from the initial treatment date at which time all dead insects were counted and removed. After another week, adult mortality was assessed again giving a cumulative 2 weeks mortality assessment, with all remaining adults being removed from the treatment. In the assessment of adult mortality, insects were recorded as dead if they were unable to move after gentle prodding with a fine-haired brush or/and unable to move or walk during a 2 minutes observation period. After the last mortality count, all jars were retained under the same conditions as above. After 6 and 12 weeks later, the number of emerged adults of *S. oryzae* were counted and expressed as progeny production. The following formula was used to determine the reduction percentage in the number of progeny after 6 and 12 weeks of treatment: $\% = 1 - x/y \times 100$, where x = the number of adults emerging in the treatment; y = the number of adults emerging in the control. The grains were sieved and the powder was discarded. The weight of remaining grains in treatments and control was recorded. The weight loss percentage was calculated from the following formula:

% Weight loss = Wu –Wi/Wu × 100, where Wu = weight of uninfested grain; Wi = weight of infested grain of control and treatment.

Grain germination: In order to assess the effect of tested monoterpenes on the viability of grains, grains germination was tested using 100 randomly picked grains from each jar treated with the higher application rate (5 mg/g). This test was done on six monoterpenes which showed the highest or/and complete protection of the grains. The seeds were placed on a moistened filter paper in glass Petri dishes and the number of germinated grains was recorded after one week.

Statistical analysis: Statistical analyses were conducted using the statistical package SPSS version 12.0 (Statistical Package for Social Sciences, USA). The mortality, progeny and weight loss data were submitted to a one-way analysis of variance (ANOVA). Mean separations were performed by Student-Newman-Keuls (SNK) test and differences at $P = 0.05$ were considered as significant.

RESULTS AND DISCUSSION

Effect of monoterpenes on mortality of *S. oryzae* and *T. castaneum*: The effect of different monoterpenes on the mortality of *S. oryzae* adults after one and two weeks of treatment is presented in Table 1.

Table1. Effect of monoterpenes against *Sitophilus oryzae* exposed for 1 and 2 weeks on treated wheat.

Monoterpene class	Monoterpene	Application rate (mg/g)	Cumulative mortality (% ± SE)	
			1 Week	2 Weeks
	Control	0	0.0 ± 0.0^{g}	3.3 ± 1.67^{ef}
Hydrocarbon	(-)-Limonene	0.5	0.0 ± 0.0^{g}	1.7 ±1.67^{f}
		1	10.0.± 2.89^{fg}	13.7 ±1.67^{def}
		5	88.3 ± 4.41^{ab}	91.7 ±1.67^{a}
	Myrcene	0.5	0.0 ± 0.0^{g}	1.7 ±1.67^{f}
		1	0.0 ± 0.0^{g}	1.7 ±1.67^{f}
		5	5.0 ± 2.89^{fg}	8.3 ±1.67^{def}
Alcohol	Geraniol	0.5	26.7 ± 4.41^{c}	51.7 ± 4.41^{b}
		1	85.0 ± 2.89^{b}	93.3 ± 4.41^{a}
		5	100.0 ± 0.0^{a}	100.0 ± 0.0^{a}
	(-)-Linalool	0.5	8.3 ± 3.34^{fg}	10.0 ± 2.89^{def}
		1	46.7 ± 3.34^{c}	46.7 ± 3.34^{b}
		5	100.0 ± 0.0^{a}	100.0 ± 0.0^{a}
Ketone	(-)-Carvone	0.5	36.7 ± 1.67^{d}	36.7 ±1.67^{c}
		1	96.7 ± 3.34^{a}	96.7 ± 3.34^{a}
		5	100.0 ± 0.0^{a}	100.0 ± 0.0^{a}
	(L)-Fenchone	0.5	5.0 ± 0.0^{fg}	11.7 ±1.67^{def}
		1	5.0 ± 2.89^{fg}	11.7 ±1.67^{def}
		5	91.7 ± 4.41^{ab}	91.7 ± 4.41^{a}
Aldehyde	Cuminaldehyde	0.5	15.0 ± 2.89^{f}	16.7 ± 3.34^{d}
		1	88.3 ± 3.34^{ab}	90.0 ± 2.89^{a}
		5	100.0 ± 0.0^{a}	100.0 ± 0.0^{a}
Oxide	1-8-Cineole	0.5	0.0 ± 0.0^{g}	3.3 ±1.67^{ef}
		1	6.7 ±1.67^{fg}	15.0 ± 2.89^{de}
		5	50.0 ± 5.0^{c}	51.7 ± 4.41^{b}

Means in a column with same letters are not-significant ($p < 0.05$) compared to the control.

The results showed that there were significant effects between monoterpenes and among the concentrations of each monoterpene on the percentage adult mortality. At the application rate of 0.5 mg/g, (-)-carvone showed the highest mortality (36.7%) followed by geraniol (26.7%) while the rest of monoterpenes displayed a weak or no mortality after one week. (-)-Carvone, cuminaldehyde and geraniol caused the highest mortality at the rate of 1 mg/g with mortality percentages of 96.7, 88.3 and 85.0, respectively. At the rate of 5 mg/g, four of the tested monoterpenes (carvone, cuminaldehyde, geraniol and (-)-linalool) caused complete mortality to the adults of *S. oryzae* after one week. Despite their weak effect on the adult mortality at the rates of 0.5 and 1 mg/g after one week, (L)-fenchone and (-)-limonene showed a strong mortality of the rate of 5 mg/g with percentages of 91.7 and 88.3, respectively. In general,

(-)-carvone, cuminaldehyde, geraniol and (-)-linalool had a strong effect on the mortality of *S. oryzae* on treated wheat after one week of treatment. In contrast, myrcene and 1-8-cineole were the least effective monoterpenes on adult mortality. The results of *S. oryzae* adult mortality after two weeks indicated that there was a slight increasing in the mortality percentages comparing with those after one week.

In the case of *T. castaneum*, (-)-carvone was the only compound which caused a significant mortality (61.7%) at the rate of 0.5 mg/g., while the other monoterpenes showed a weak or no effect on mortality after one week of treatment (Table 2). (-)-carvone, cuminaldehyde and geraniol were the most toxic at the rate of 1 mg/g. All of the tested monoterpenes except myrcene and (-)-linalool caused complete mortality of *T. castaneum* adults after one week at the rate of 5 mg/g. The mortality of *T. castaneum* adult caused by myrcene, geraniol, (-)-linalool and cuminaldehyde was significantly increased after two weeks comparing with that of one week. The toxicity results of monoterpenes on the adults of *S. oryzae* and *T. castaneum* revealed that (-)-limonene, (L)-fenchone and cuminaldehyde had approximately the same activity on both insects. Myrcene, geraniol, (-)-carvone and 1-8-cineole were more toxic towards *T. castaneum* than *S. oryzae*. In contrary, (-)-linalool was more toxic towards *S. oryzae* than *T. castaneum*. The different response of these two insects to monoterpenes has been stated (Lee et. al., 2003 and 2004).

The investigation of a relationship between the toxicities of the test monoterpenes and their structures revealed some interesting correlations. For examples, (-)-carvone, a ketone, showed the highest toxicity against the two tested insects. Cuminaldehyde, an aldehyde, and geraniol, an alcohol, were more toxic than other oxygenated and non-oxygenated monoterpenes. On the other hand, 1-8-cineole, an ether, and (-)-limonene, a hydrocarbon, showed a moderate toxicity against both insects. Myrcene, a hydrocarbon, was the less effective monoterpene among the test compounds against both insects. These findings are in agreement with Lee *et al.*, (2003) who stated that the two ketones, (-)-carvone and (L)-fenchone, were more effective fumigants than the alcohols, (-)-linalool and geraniol, and with Rice and Coats (1994) who found that some ketones were more effective fumigants than alcohols.

Table 2. Effect of monoterpenes aganist *Tribolium castaneum* exposed for 1 and 2 weeks on treated wheat.

Monoterpene class	Monoterpene	Application rate (mg/g)	Cumulative mortality (% ± SE)	
			1 Week	2 Weeks
	Control	0	0.0 ± 0.0^{h}	0.0 ± 0.0^{g}
Hydrocarbon	(-)-Limonene	0.5	0.0 ± 0.0^{h}	1.7 ± 2.11^{g}
		1	6.7 ± 2.11^{fgh}	13.3 ± 2.11^{f}
		5	100.0 ± 0.0^{a}	100.0 ± 0.0^{a}
	Myrcene	0 5	0.0 ± 0.0^{h}	16.7 ± 2.11^{ef}
		1	3.3 ± 2.11^{fgh}	21.7 ± 2.11^{de}
		5	61.6 ± 3.34^{c}	63.3 ± 2.11^{b}
Alcohol	Geraniol	0.5	10.0 ± 0.0^{f}	31.7 ± 2.11^{c}
		1	48.3 ± 2.11^{d}	63.3 ± 2.11^{b}
		5	100.0 ± 0.0^{a}	100.0 ± 0.0^{a}
	(-)-Linalool	0.5	5.0 ± 0.04^{fgh}	21.7 ± 3.34^{de}
		1	16.7 ± 3.34^{e}	21.7 ± 2.11^{de}
		5	51.7 ± 3.34^{d}	63.3 ± 4.41^{b}
Ketone	(-)-Carvone	(.5	61.7 ± 3.34^{c}	65.0 ± 2.89^{b}
		1	100.0 ± 0.04^{a}	100.0 ± 0.0^{a}
		5	100.0 ± 0.0^{a}	100.0 ± 0.0^{a}
	(L)-Fenchone	0.5	1.7 ± 2.11^{gh}	3.3 ± 2.11^{g}
		1	8.3 ± 2.11^{fg}	11.7 ± 2.11^{f}
		5	100.0 ± 0.0^{a}	100.0 ± 0.0^{a}
Aldehyde	Cuminaldehyde	0.5	16.7 ± 2.11^{e}	25.0 ± 2.89^{d}
		1	76.7 ± 3.34^{b}	96.7 ± 3.34^{a}
		5	100.0 ± 0.0^{a}	100.0 ± 0.0^{a}
Oxide	1-8-Cineole	0.5	0.0 ± 0.0^{h}	1.7 ± 2.11^{g}
		1	8.3 ± 2.11^{fg}	21.7 ± 2.11^{de}
		5	100.0 ± 0.0^{a}	100.0 ± 0.0^{a}

Means in a column with same letters are not-significant ($p < 0.05$) compared to the control.

Effect of monoterpenes on progeny production of *S. oryzae*: The results of the progeny production and the reduction percentage of *S. oryzae* after 6 and 12 weeks of treatment are presented in Table 3. In general, all of the tested compounds except for myrcene showed significant reduction in progeny compared with control. (-)-Carvone was most effective in reducing the progeny production at the three tested application rates, followed by geraniol, cuminaldehyde and (-)-linalool. No progeny emerged on wheat treated with these four monoterpenes at the highest application rate of 5 mg/g. Two monoterpenes ((L)-fenchone and (-)-limonene) revealed a strong reduction in progeny at 5 mg/g, while 1-8-cineole showed a moderate progeny reduction. In contrast, myrcene was the less effective compound;

there were no significant differences in progeny reduction at the three tested rates of this compound compared with control.

Table 3. Effect of monoterpenes on the progeny production (±SE) of *Sitophilus oryzae* on treated wheat.

Monoterpene	Application rate (mg/g)	6 weeks		12 weeks	
		Progeny production	Reduction	Progeny production	Reduction
Control	0	165.0±5.23^{ab}		561.3±6.18^{b}	
(-)-Limonene	0.5	163.0±4.05^{ab}	1.2±2.43	521.3±6.39^{c}	7.1±1.16
	1	131.0±1.53^{d}	20.6±0.92	336.0±10.98^{g}	40.1±1.95
	5	14.7±1.20^{gh}	91.1±0.72	43.7±1.33^{m}	92.2±0.23
Myrcene	0.5	170.3±5.21^{a}	-0.83±3.85	580.04.93^{a}	-3.3±0.90
	1	164.0±7.01^{ab}	0.6±4.26	562.0±4.05^{b}	-0.1±0.69
	5	161.3±7.23^{ab}	2.4±3.68	559.0±3.61^{b}	0.43±0.66
Geraniol	0.5	127.0±4.05^{d}	23.0±2.46	265.0±4.62^{i}	52.8±0.81
	1	13.0±2.0^{gh}	92.1±1.20	31.0±3.06^{m}	94.4±0.49
	5	0.0±0.0^{h}	100.0±0.0	0.0±0.0^{n}	100.0±0.0
(-)-Linalool	0.5	139.0±3.79^{cd}	15.8±2.30	395.0±7.10^{f}	29.6±1.27
	1	53.0±7.20^{f}	67.9±4.40	195.0±5.04^{k}	65.3±0.89
	5	0.0±0.0^{h}	100.0±0.0	0.0±0.0^{n}	100.0±0.0
(-)-Carvone	0.5	85.7±7.27	48.1±4.53	246.7±5.85^{j}	56.0±1.23
	1	3.3±0.34^{gh}	98.0±0.20	30.0±0.58^{m}	94.7±0.08
	5	0.0±0.0^{h}	100.0±0.0	0.0±0.0^{n}	100.0±0.0
(L)-Fenchone	0.5	153.0±5.04^{bc}	7.2±3.06	506.7±9.85^{cd}	9.7±1.77
	1	132.0±3.0^{d}	20.0±1.80	495.0±3.47^{de}	11.8±0.64
	5	4.0±0.58^{gh}	97.6±0.35	28.3±3.52^{m}	95.0±062
Cuminaldehyde	0.5	149.0±3.06^{bc}	10.5±1.44	487.7±6.97^{e}	13.1±1.25
	1	19.0±0.58^{g}	88.5±0.35	79.7±5.931	85.8±1.07
	5	0.0±0.0^{h}	100.0±0.0	0.0±0.0^{n}	100.0±0.0
1-8-Cineole	0.5	139.0±4.17^{cd}	15.7±2.53	397.0±8.63^{f}	29.3±1.54
	1	130.3±4.49^{d}	21.0±3.32	380.0±6.09^{f}	32.3±1.10
	5	95.7±1.86^{e}	42.0±1.11	297.0±4.41^{h}	46.6±1.14

Means in a column with same letters are not-significant ($p < 0.05$) compared to the control.

Progeny production in the treated substrate is perhaps more important than parental mortality, because a grain protectant should protect the grain for a long storage period (Athanassiou *et al.*, 2005). In our work, progeny production of *S. oryzae* was significantly low on wheat treated with 1 and 5 mg/g of the tested monoterpenes except for myrcene, which suggest that long-term protection for the treated wheat.

Effect of monoterpenes on weight loss of wheat: All of the tested monoterpenes except myrcene reduced significantly weight loss of treated wheat particularly at the higher rates of 1 and 5 mg/g (Table 4). Complete protection was observed at the application rate of 5 mg/g in wheat treated with (-)-carvone, geraniol, cuminaldehyde and (-)-linalool. At the application rate of 1 mg/g, (-)-carvone, cuminaldehyde and geraniol showed a strong reduction of weight loss with percentages of loss of 0.8, 1.9 and 4.9%, respectively. The reduced percentage of grain damage observed in the treated grains with the application rates of 1 and 5 mg/g can be attributed to high mortality of adults after treatment with the tested monoterpenes.

Table 4. Effect of monoterpenes on weight loss (%± SE) of treated wheat.

Monoterpene	Application rate (mg/g)	Weight loss (gm)	Monoterpene	Application rate (mg/g)	Weight loss (gm)
Control	0	34.1 ± 1.22^{ab}	(-)-Carvone	0.5	16.3 ± 1.24^{f}
(-)-Limonene	0.5	36.0 ± 1.80^{a}		1	0.8 ± 0.0^{g}
	1	28.5 ± 1.10^{cde}		5	0.0 ± 0.0^{g}
	5	2.4 ± 0.69^{g}	(L)-Fenchone	0.5	35.6 ± 1.47^{a}
Myrcene	0.5	33.5 ± 2.06^{abc}		1	31.3 ± 0.78^{abcd}
	1	33.3 ± 1.15^{abc}		5	1.3 ± 0.30^{g}
	5	32.0 ± 0.95^{abc}	Cuminaldehyde	0.5	29.9 ± 0.34^{bcde}
Geraniol	0.5	24.6 ± 0.35^{e}		1	4.7 ± 1.41^{g}
	1	1.9 ± 0.71^{g}		5	0.0 ± 0.0^{g}
	5	0.0 ± 0.0^{g}	1-8-Cineole	0.5	26.6 ± 1.68^{e}
(-)-Linalool	0.5	25.1 ± 1.54^{e}		1	27.1 ± 1.21^{de}
	1	16.9 ± 2.31^{f}		5	24.9 ± 1.65^{e}
	5	0.0 ± 0.0^{g}			

Means in a column with same letters are not-significant ($p < 0.05$) compared to the control.

Effect of monoterpenes on seed germination of treated wheat: Seed germination results revealed that the tested monoterpenes had no and/or slight effect on germination percentage at the highest rate of 5 mg/g after 12 weeks of treatment (Figure 2). The untreated seeds (control) were completely destroyed therefore no seed germination was observed. Cuminaldehyde and (-)-linalool had no effect on seed germination with germination percentage of 100 % for each one, while (-)-carvone and (L)-fenchone had slight effect on seed germination with germination percentages of 95.0 and 93.3%, respectively. In contrary, (-)-limonene and (-)-limonene showed significant effect on seed germination with seed germination percentages of 76.7 and 83.3, respectively.

The fumigant and contact toxicities of monoterpenes against *S. oryzae* and *T. castaneum* have been investigated (Lee et al. 2003, 2004; Park *et al.*, 2003; Abdelgaleil et al. 2009). However, there were no reported studies, to the best of our knowledge, on the effectiveness of monoterpenes for control of these two insects on the stored wheat or other stored products. The results of the present work revealed that some of the tested monoterpenes had a potential as seed protectants. Since, they caused high mortality, reduced progeny and protected wheat seeds free of infestation for 12 weeks.

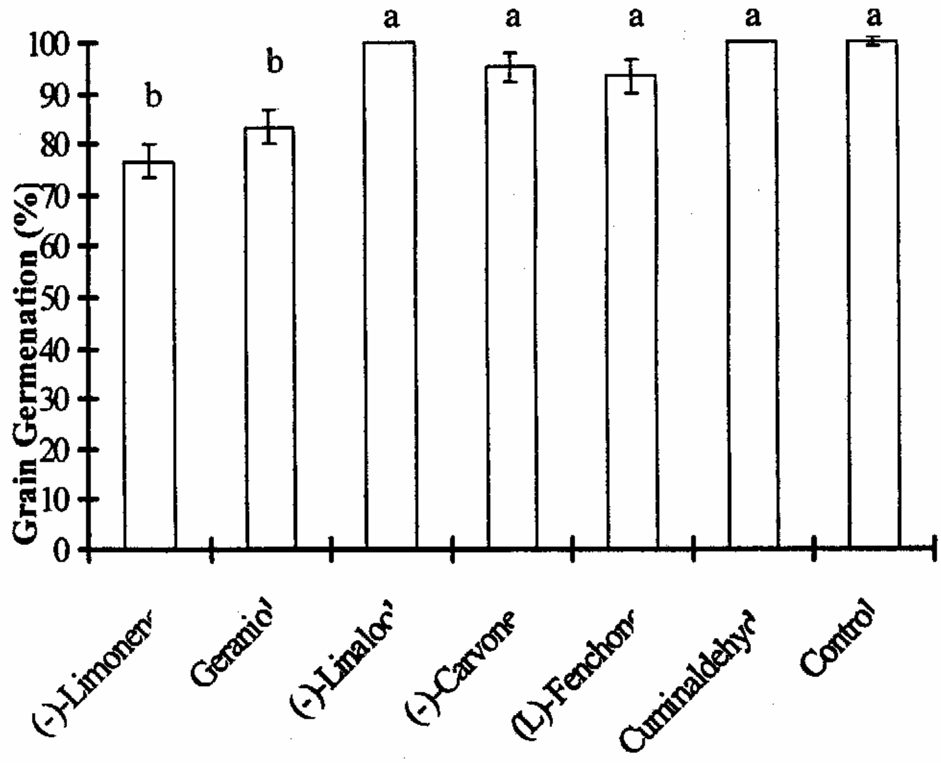

Figure 2. Effect of monoterpenes on grain germination of wheat treated with the application rate of 5 mg/g,12 weeks after treatment.

Although synthetic insecticides and/or fumigants are the most widely used methods for managing stored-product insects, there are some limitations for their use in control such as the development of resistance, residues in stored products and environmental pollution (Brun and Attia, 1983; Collins *et al.*, 1993; Lorini and Galley, 1999; Zettler and Arthur, 2000). Replacement of methyl bromide, the most effective fumigant for insect disinfestation in storage facilities, is essential because it depletes the ozone layer (UNEP, 1995) and thus searching for new compounds with new mode of action and environmentally safe are required. It should be noted that biologically active compounds of food plants such as monoterpenes are assumed to be environmentally more acceptable and less hazardous than others to humans. The results of the present study demonstrated that some of tested monoterpenes such as (-)-carvone, geraniol, cuminaldehyde and (-)-linalool had remarkable toxicity against *S. oryzae* and *T. castaneum*. Moreover, these monoterpenes drastically reduced the progeny *S. oryzae* and the damage of wheat seeds. Based on these results, these monoterpenes could be used as safer pest control agents against *S. oryzae* and *T. castaneum*.

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فاعلية المونوتربينات فى مكافحة حشرتى سوسة الأرز وخنفساء الدقيق الصدئية فى القمح المخزون

سيلان أحمد العرامى – مجدى إبراهيم الدسوقى – سمير عبد العظيم عبد الجليل

تم إجراء هذه الدراسة لتقييم فاعلية ثمانية من المونوتربينات وهى carvone-(-) و1-8-cineole وcuminaldehyde و (L)-fenchone وgeraniol و -(-)-limonene وlinalool و myrcene ضد حشرتين رئيسيتين من حشرات الحبوب المخزونة على حبوب القمح معملياً. الحشرات التى تمت الدراسة عليها هى سوسة الأرز وخنفساء الدقيق الصدئية. تم معاملة حبوب القمح بالمعدلات 0.5 و 1 و 5 مجم/جم لمكافحة الحشرتين تحت الإختبار. الـ carvone-(-) كان أكثر المركبات سمية ضد الحشرتين على كل المعدلات المستخدمة بعد اسبوع واسبوعين من المعاملة. الـ geraniol و cuminaldehyde كانا ضمن أكثر المركبات فاعلية ضد الحشرتين. أربعة من المونوتربينات المختبرة وهى الـ carvone-(-) و geraniol وcuminaldehyde و linalool -(-) قد سببت موت كامل لحشرة سوسة الأرز بعد اسبوع من المعاملة على معدل 5 مجم/جم فى حين كل المونوتربينات المختبرة عدا myrcene و linalool -(-) سببت موت كامل لحشرة خنفساء الدقيق الصدئية على نفس معدل الإستخدام. بمقارنة سمية المونوتربينات ضد الحشرتين تحت الدراسة وجد أن الـ fenchone -(L) و limonene-(-) وcuminaldehyde لهما نفس الفاعلية ضد الحشرتين تقريباً. على الجانب الأخر geraniol و myrcene و -(-) carvone و 1-8-cineole كانت أكثر فاعلية على خنفساء الدقيق الصدئية من سوسة الأرز بينما الـ linalool-(-) كان أكثر سمية ضد سوسة الأرز من خنفساء الدقيق الصدئية. كل المونوتربينات المختبرة عدا الـ myrcene سببت خفض معنوى فى أعداد حشرات سوسة الأرز الناتجة بعد 6 و12 أسبوع من المعاملة مقارنة بالكنترول. الـ carvone-(-) كان أعلى المركبات فاعلية فى خفض أعداد الحشرات الناتجة على الثلاث معدلات المستخدمة يليه الـ geraniol و cuminaldehyde و -(-) linalool . المركبات الأربعة السابقة منعت تماماً وجود حشرات على معدل 5 مجم/جم بعد 12 أسبوع. على معدلات 1 و5 مجم/جم غالبية المونوتربينات قللت الفقد فى الوزن لحبوب القمح المعاملة وكذلك أظهرت مركبات الـ carvone-(-) و geraniol وcuminaldehyde و -(-) linalool وقاية كاملة للحبوب على معدل 5 مجم/جم. هذا النشاط الإبادى القوى للمونوتربينات خاصة الـ carvone-(-) و geraniol وcuminaldehyde و linalool -(-) يدل على أن هذه المونوتربينات يمكن أن تستخدم فى مكافحة حشرتى سوسة الأرز و خنفساء الدقيق الصدئية فى القمح.