Abo Arab *et al.*
Bulletin of the National Research Centre (2022) 46:192
https://doi.org/10.1186/s42269-022-00894-x

Bulletin of the National Research Centre

RESEARCH

Open Access

Potential of selected plant essential oils in management of *Sitophilus oryzae* (L.) and *Rhiyzopertha dominica* (F.) on wheat grains

Raafat Badr Abo Arab, Nariman Mohamed El-Tawelah, Ahmed Mohamed Abouelatta* and Amal Moustafa Hamza

Abstract

Background: Two plant essential oils, basil (*Ocimum basilicum* L.) and petitgrain mandarin (*Citrus reticulate* L.), and one pyrethroid chemical insecticide, lambda-cyhalothrin, were evaluated against two of the most important stored product insect pests, *Sitophilus oryzae* and *Rhyzopertha dominica*, on wheat grains under laboratory conditions using mixing with feeding method. The effect of the tested materials was studied on F_1 progeny of the tested insects. Chemical components of the oils and side effects on protein content percentage, total carbohydrates of wheat grain and germination were investigated.

Results: Results obtained showed that the two oils had a good insecticidal effect on the tested insects. Petitgrain mandarin oil was the premier. The two tested essential oils reduced the F_1 progeny. In addition, the progressive of periods after storage (0–180 days) significantly reduced protein content (%) and total carbohydrates compared to control. Nearly, there were no significant differences between treatments (LC_{50} and LC_{95}) of basil and (petitgrain) mandarin on the studied parameters. Germination percentages from 0 to 180 days post-storage had slight differences between control and treatments for oils. Lambda-cyhalothrin significantly reduced germination, especially with the LC_{95} from 60 to 180 days. Chemical analysis demonstrated that the main components of basil oil were linalool, eugenol, methyl chavicol and cani, while the main components of petitgrain mandarin oil were dimethyl panthenalate, α-terpinene, β-cinem and citral accounting for 71.1 and 95% of the two oils, respectively.

Conclusions: The results obtained proved that the two tested plant essential oils had an obvious role in suppressing the activity of the two tested insects and can be used in an integrated pest management program. The two tested essential oils can be used as green pesticides and can be effective alternatives for chemical pesticides.

Keywords: Petitgrain mandarin oils, Basil oil, *Sitophilus oryzae*, *Rhyzopertha dominica*, Essential oils, Lambda-cyhalothrin, Germination

Background

The rice weevil *Sitophilus oryzae* (L.) and the lesser grain borer, *Rhyzopertha dominica* (F.), are major pests of stored grains in Egypt. Both adults and larvae feed in whole grains. They cause extensive losses in the quality and quantity of commercial products as well as deterioration of seeds (Owalade et al. 2008; Dars et al. 2001). It is estimated that approximately 7% to 50% of all crops are destroyed by pests yearly (Pimentel and Rattan 2009; Sallam 2013; Calliney et al. 2014; Oliveira et al. 2014). Worldwide, the usage of pesticides has increased, reaching 48,000 tons of active ingredients in Germany, 24,000 tons in Poland, more than 18,000 tons in Great Britain, 62,000 tons in Italy and as much as 1.7 million tons in China (FAO 2015). Insects are the most important crop

*Correspondence: ahmedabouelatta2@gmail.com

Plant Protection Research Institute, Agriculture Research Center, Kafr El-Sheikh Sakha, Egypt

pests, and they can destroy crops and food products or contaminate them, making food unfit for human consumption. Insecticides are often non-specific and also affect non-target organisms (Spochacz et al. 2018). In this context, the use of insecticides based on botanical extracts is attracting considerable interest both among researchers and consumers. Among botanical extracts used as insecticides, essential oils (Eos) are a promising alternative because of worldwide availability and relative cost-effectiveness (Campolo et al. 2018). Essential oils are secondary metabolites synthesized by plants, and they play a very important role in plant defense (both against biotic and abiotic stresses) (Smith et al. 2006; Walters 2010; Zuzarte and Salgueiro 2015). Plant species that produce essential oils are called aromatic plants and are distributed worldwide; these plants (over 17,000 species) belong to a limited number of families: Asteraceae, Cupressaceae, Lamiaceae; Lauraceae, Rutaceae, Myrtaceae, Piperaceae and Poaceae (Svoboda and Greenway 2003; Bruneton 1999). Essential oils are mainly constituted by monoterpenes and sesquiterpenes synthesized in the cytoplasm and plastids (Zebec et al. 2016). Stored product sector seems to be a perfect candidate for the development of new essential oils-based alternative pest control strategies. Therefore, the objectives of this study aimed to evaluate the insecticidal activity of two plant oils (basil and petitgrain mandarin) and one pyrethroid insecticide, lambda-cyhalothrin, against *S. oryzae* and *R. dominica* using mixing with medium methods. In addition, determine the effect on F_1 offspring and reduction of progeny. The side effects of the tested oils and the chemical insecticide were evaluated on the protein content, total carbohydrate and germination of wheat grain.

Methods

Test insects

Rice weevil Sitophilus oryzae (L.)

The adults of rice weevil, *S. oryzae* (L.) 1–2 weeks old, used in this study were obtained from laboratory colony, established and reared on wheat grain (*Triticum aestivum*) under laboratory constant conditions of 26 ± 1 °C and (65 ± 5 R.H.). New adults 2–3 weeks old were selected for toxicity evaluation test (Feng et al. 2009).

Lesser grain borer Rhyzopertha dominica (F.)

The adults of lesser grain borer, *R. dominica* (F.), were collected from Kafr El-Sheikh Rice and Wheat Mills Companies and reared on wheat grain (*T. aestivum*) under laboratory constant conditions of 26 ± 1 °C and 65 ± 5 R.H. in dark. New adults of 2–3 weeks old were used for the next experiments (Teodoro et al. 2012).

Wheat samples

Wheat grain samples (*Triticum vulgare* L.), Sakha 69, were taken from the untreated area, Field Crops Research Institute, Agricultural Research Center.

Plant oils

Basil oil, *Ocimum basilicum* L.

Petitgrain mandarin oil, *Citrus reticulate* L.

Both oils were purchased from Hashem Brothers Company for Essential Oils and Aromatic Products (69 Abdel Moneim Riad St., Giza, Egypt).

Chemical insecticide

Common name: Lambda-cyhalothrin
Trade name: Lambda
Chemical name: 1, 1 mixture of (S)-α-cyano-3-phenoxybenzyl-(Z)-(1R, 3R)-3-(2chloro-3,3,3-trifluroprop-1-enyl-2,2-dimethyl cyclopropane carboxylate
Formulation: Powder
Produced by: Chema Industrial for Chemical.

Analysis of essential oils

Chemical analyses were performed on a gas chromatography (Hewlett Packard 5890)/mass spectrometry (Hewlett Packard 5989B) (GC–MS) apparatus. Essential oils were diluted in diethyl ether, and a sample amount of 0.5 μl was injected. The GC column was a 30 m (0.25 mm i.d., film thickness 0.25 um) HP-5MS (5% diphenyl) dimethylpolysiloxane capillary column. The GC conditions were as follows: injector temperature, 240 °C; column temperature, isothermal at 70 °C and held for 2 min, then programmed to 280 °C at 6 °C/min and held at this temperature for 2 min; ion source temperature, 200 °C; detector temperature, 300 °C. Helium was used as the carrier gas at the rate of 1 ml/min. The effluent of the GC column was introduced directly into the ion source of the MS. Spectra were obtained in the El mode with 70 eV ionization energy. The sector mass analyzer was set to scan from 40 to 400 amu for 5 s. The oil components were identified by comparison of their retention indices and mass spectra with the NIST Mass Spectral Library.

Bioassay procedures

Insecticidal bioassay (mixing with feeding medium)

Plant oils and lambda-cyhalothrin insecticide Twenty grams of wheat grains was placed in a glass jar 250 ml and was replicated three times. The two plant oils (*O. basilicum* and *C. reticulata*) were diluted in acetone and added to the wheat grains at rates of 50, 75, 100, 125, 150, 175, 200 mg/kg for oils, and seven levels of 1, 10, 50, 100, 200, 400, 800 mg/kg of lambda-cyhalothrin were weighed and admixed with grains at required doses. Jars were mechanically shaken for adequate and fixed time (15 min.) to ensure complete mixing. The treated grains were allowed to dry at room temperature. Twenty unsexed adults of both tested insects (2–3 weeks old) for *S. oryzae* and *R. dominica* were separately transferred to each jar. The same numbers of insects were transferred to glass jar containing acetone-treated wheat grains (untreated control) (Ragaa et al. 2012). Mortality was recorded after 7, 14 and 21 days for all tested compounds. Results were recorded and corrected by Abbott's formula (Abbott 1925). LC_{50} and LC_{95} values were calculated by the method of Finney (Finney 1952). This method was described by Harein and Soderstorm (Harein et al. 1966) and Davis and Bry (Davis et al. 1985).

Effect on progeny

A laboratory experiment was established to evaluate the affection of the tested toxicants on the progeny of *S. oryzae* and *R. dominica*. Batches (50 g) of wheat grain were placed in small jars and treated with the considerable concentrations, for oils (1000, 2000, 4000, 6000, 8000, 10,000 and 20,000 ppm) and (1, 10, 50, 100, 200, 400 and 800 ppm), and then were infested with 20 adults for each jar. After two weeks, all insects were removed. Jars were held in an incubator at 26 + 1 °C and 65 + 5% R.H. The untreated grains were used as control. The treatments (treated and control) were repeated three times. The newly emerged adults were recorded for two weeks, and adult reduction % was calculated according to the following equation:

$$\%\ \text{Reduction} = \frac{\text{MNEC} - \text{MNET}}{\text{MNEC}} \times 100$$

MNEC—Mean number of those which emerged in the control.

MNET—Mean number of those which emerged in the treatment.

Determination of carbohydrates

Total carbohydrate content in wheat grains was determined. The procedure was carried out according to Smith et al. (1964). Carbohydrates were determined colorimetrically using a Hunter colorimeter (Hunter Lab.D 25L) by the phenol–sulfuric acid**.** 0.5 g of fine dry powder was placed in a tube, and 10 mL of 1 N from H_2SO_4 was added. The tube was boiled and condensed in a boiling water bath for 60 min and traced of barium carbonate (0.1 g). The solution was filtered into a measuring flask (100 mL) by Whatman No. 1 filter paper. The residue was washed several times with distilled water. The total sugar was determined calorimetrically. A known volume (1 mL) of sugar solution was quantitatively transferred in a test tube and (1 mL) of 5% aqueous phenol solution was added followed by 9 mL of concentrated sulfuric acid, and the tube was then left to cool at room temperature. Measurement of the intensity of the yellow-orange color was carried out by spectrophotometer (Shimadzu UV–Vis spectrophotometer Model UV-240) at 490 nm. A standard curve was prepared by the known concentration of glucose. The blank was distilled water (1 mL) instead of the sugar solution. Total carbohydrates were expressed as g/100 g dry weight.

Determination of nitrogen and crude protein

Kjeldahl method as described by A.O.A.C. (1980) was used. Briefly, 0.5 gm of sample was weighed and placed on free filter paper, then folded and dropped into a Kjeldahl digestion tube, and 3.0 gm of digesting mixed catalyst ($CuSO_4 \pm Na_2SO_4$) and 25 mL of conc. Na_2SO_4 were added to sample in the digestion tube. The mixture was transferred to the Kjeldahl digestion apparatus. The heater was regulated at a temperature below the boiling point of the acid. The mixture was boiled vigorously as the temperature was increased, until the green color was obtained. The digests were allowed to be cooled and then 10 cm^3 transferred into volumetric flasks and diluted with distilled water to make up 100 cm^3, and 10 ml of digests was introduced into the distillation jacket of the microsteam distillation apparatus. 20 mL of 40% NaOH was added to each digest in the distillation jacket, 50 mL of 40% boric acid was measured into two 250 mL, and four drops of methyl red indicator was added. The conical flasks containing the mixture were placed into the distillation apparatus, and NH_3 was collected through the condenser. The distillation continued till 25 mL of the distillate was trapped into the boric acid solution, and the color changes from red to yellow. The distillates were then titrated with 0.02 m HCl, and the titer value was recorded. The percentage of nitrogen and crude protein was calculated by multiplying nitrogen percent by a factor 6.25.

Seed germination

Untreated sterilized wheat grains were mixed with the tested, plant oils, basil oil and petitgrain mandarin oil and pesticide, lambda. All tested materials were at concentration of LC_{50} and LC_{95}. After ensuring mixing 20 seeds from each treatment was allowed to germinate on medical cotton on Petri dishes (9 cm diameter), according to the technique stated by International Seed Testing Association (1976). All treatments are stored at 20 °C. Germination was made after treatment at zero time up to

180 days. Samples were taken after 0, 15, 30, 60, 90, 120, 150 and 180 days. Successful germination was noticed after the appearance of more than 3 mm of the radical.

Statistical analysis

All data were analyzed using the procedure (SAS, 2008) program of the version 9.2 to determine single or interaction effects of factors, according to Duncan's multiple range test (Duncan 1955).

Results

Laboratory experiments were conducted to evaluate the tested plant's oils (basil oil and petitgrain mandarin oil) against *S. oryzae* and *R. dominica*.

Toxicity

Toxicity of the tested plant oils

LC_{50} data obtained in Table 1 showed that petitgrain mandarin was stronger than basil oil with the two tested insects at all times post-treatment except that of 7 days for *S. oryzae*. In addition, *R. dominica* was more susceptible than *S. oryzae* with the two tested oils at all exposure times from 7 to 21 days. Results represented that the toxicity increased with the increase of exposure time, and LC_{50} reduced from 132.75 to 108.08 and from 135.30 to 104.45 with basil oil and petitgrain mandarin, respectively, for *S. oryzae*. For *R. dominica*, LC_{50} decreased from 129.10 to 91.44 and from 125.17 to 89.36 mg/kg from 7 to 21 days post-treatment for both the two tested insects.

Toxicity of the tested insecticides

Unlike the results presented in Table 1, data in Table 2 cleared that *S. oryzae* adults are more susceptible than *R. dominica* in response to lambda-cyhalothrin. The toxicity in Table 2 had the same trend as that in Table 1, where the effectuation increased with the increase of exposure period. The different impacts between oils and chemical insecticides may be due to the composition of each, the physiology and the behavior of the two tested insects.

Results in Table 2 demonstrated that lambda-cyhalothrin recorded LC_{50} of 48.56 mg/kg and 45.28 mg/kg after 24 and 48 h, respectively.

Effect of the tested plant oils and lambda on emerging adults and reduction percentages of *S. oryzae* and *R. dominica*

S. oryzae

Effect of basil and petitgrain mandarin oils

Data in Table 3 cleared that basil oil had a greater effect than petitgrain mandarin oil on emergence of *S. oryzae* where the concentration of 20,000 mg/kg reduced the emerged progeny from 144 in control to 14 and 27 adults with basil and petitgrain mandarin oil, respectively.

In addition, basil oil significantly reduced the reduction of progeny to 90.72% as compared to petitgrain mandarin oil which achieved 81.25%. In general, the two tested oils significantly reduced the number of emerged adults and increased the reduction of progeny with all of the tested concentrations of the two tested oils.

Table 1 Toxicity of the tested plant oils against adults of and *R. dominica* at the indicated times post-treatment

Time in day	Basil oil			Petit mandarin grain		
	LC_{50} mg/kg	C.L	S.V	LC_{50} mg/kg	C.L	S.V
	S. oryzae					
7	132.75	111.94–158.04	5.62	135.30	112.01–160.88	7.35
14	125.24	104.66–148.35	5.49	120.22	100.05–140.62	6.27
21	108.08	91.75–124.17	4.88	104.45	89.46–118.45	5.61
	R. dominica					
7	129.10	113.58–146.06	5.99	125.17	102.07–151.30	5.58
14	109.17	93.59–124.63	4.94	104.19	89.57–118.12	5.21
21	91.44	76.95–104.23	5.21	89.36	78.28–99.16	5.57

Table 2 Toxicity of lambda-cyhalothrin against adults of *S. oryzae* and *R. dominica* at the indicated times post treatment

Time in day	*S. oryzae*			*R. dominica*		
	LC_{50} mg/kg	C.L	S.V	LC_{50} mg/kg	C.L	S.V
24	48.56	12.92–172.02	0.89	59.98	19.97–143.34	0.98
48	45.28	14.46–102.88	1.01	29.27	8.45–64.44	1.01

Table 3 Effect of basil oil and petitgrain mandarin oil on number of emerged progeny and reduction percentages of *S. oryzae*

	Concentration (mg/kg)	Mean of emerged progeny ± SE	% Reduction
Basil oil	1000	106 ± 4.61 bc	26.38
	2000	93 ± 2.88 bcd	35.41
	4000	77 ± 7.79 de	46.52
	6000	53 ± 1.73 efg	63.19
	8000	25 ± 2.88 h	82.63
	10,000	21 ± 1.73 h	85.41
	20,000	14 ± 2.30 h	90.72
Petitgrain mandarin oil	1000	119 ± 6.35 ab	17.36
	2000	103 ± 8.6bcd	28.47
	4000	91 ± 6.35 cd	36.80
	6000	79 ± 79.0 de	45.13
	8000	54 ± 2.3 ef	62.50
	10,000	36 ± 3.46 fgh	75.00
	20,000	27 ± 2.88 gh	81.25
Control		144 ± 7.50 a	

Effect of lambda insecticide

S. oryzae Data in Table 4 summarized the influence of lambda insecticide on emerged progeny which significantly inhibited the newly emerged adults of *S. oryzae* at all tested concentrations; for example, concentration 400 mg/kg scored 68 insects compared to control 187 by 63.3% reduction. Generally, the tested insecticide achieved a significant reduction in emerged adults number and increasing in % reduction of progeny with all tested concentrations.

Data summarized in Table 4 indicated that increasing the concentration of lambda-cyhalothrin significantly decreased the number of progeny and increased the reduction percentage, where the mean number of progeny ranged from 206 to 76 with 8.03% to 66.07%, of reduction at the concentrations from 1 to 800 mg/kg as compared to control which produced 224 individual of *R. dominica* adults.

R. dominica

Effect of basil and petitgrain mandarin oils

Data in Table 5 cleared that basil oil has more influence than petitgrain mandarin oil at all concentrations on the two tested parameters.

For example, the highest concentration 200 mg/kg produced 38 and 46 adults and increased reduction of progeny to 82.15% and 78.40% with basil and petitgrain mandarin oils, respectively. All tested concentrations of both basil and petitgrain mandarin oils significantly reduced the number of progeny which ranged from 173 to 38 and from 191 to 46 as compared to control which produced 213 adults.

Side effects

On protein and carbohydrates

An experiment was conducted to study the effect of the tested, basil, petitgrain mandarin oils and lambda-cyhalothrin on the total crude protein, total carbohydrates and germination of wheat grain at LC_{50} and LC_{95} concentrations when stored for 180 days. Samples of treated wheat grain were withdrawn at different intervals (zero, 15, 30 till 180 days).

Protein content

Effect of basil and petitgrain mandarin oils

Results obtained in Table 6 cleared that there were no significant differences between the treatments of LC_{50} and LC_{95} compared to control at all periods of storage except that of LC_{95} at 150 and 180 days. Meanwhile, periods of storage had an obvious effect on the protein content percentage throughout the duration of the experiment, whether treatment or control samples. For

Table 4 Effect of lambda-cyhalothrin on number of emerged progeny and reduction percentages of *S. oryzae* and *R. dominica*

	Concentration (mg/kg)	Mean of emerged progeny ± SE		% Reduction	
		S. oryzae	*R. dominica*	*S. oryzae*	*R. dominica*
Lambda-cyhalothrin	1	176 ± 8.08 ab	206 ± 7.5 ab	5.87	8.03
	10	141 ± 6.92 bc	191 ± 4.04 abc	24.59	14.73
	50	137 ± 8.66 c	173 ± 10.39 bc	26.73	22.76
	100	112 ± 2.30 cd	167 ± 6.92 c	40.10	25.44
	200	93 ± 6.35 de	114 ± 8.66 d	50.26	49.10
	400	68 ± 9.23 ef	91 ± 4.04 d	63.36	59.37
	800	54 ± 5.77 f	76 ± 10.39 d	71.12	66.07
Control		187 ± 8.08 a	224 ± 7.5 a		

In the same column, means followed by the same letters are not significantly different at 0.05 level according to Duncan multiple range test

Table 5 Effect of basil and petitgrain mandarin oils on number of emerged progeny and reduction percentages of *R. dominica*

	Concentration (mg/kg)	Mean of emerged progeny ± SE	% Reduction
Basil oil	50	173 ± 9.81 bc	18.77
	75	152 ± 4.61 cde	28.63
	100	118 ± 2.88 f	44.60
	125	86 ± 6.35 g	59.62
	150	67 ± 4.04 gh	68.54
	175	49 ± 2.88 h	76.99
	200	38 ± 4.61 h	82.15
Petitgrain mandarin oil	50	191 ± 4.61 ab	10.32
	75	163 ± 8.66 bcd	23.47
	100	141 ± 1.73 def	33.80
	125	129 ± 6.35 ef	39.43
	150	83 ± 8.66 g	61.03
	175	61 ± 4.61 gh	71.36
	200	46 ± 3.46 h	78.40
Control		213 ± 5.77 a	

In the same column, means followed by the same letters are not significantly different at 0.05 level according to Duncan multiple range test

example, the protein content decreased from 12.33 at zero time to 11.19 and 11.18 and 11.09% at 180 days post-storage for basil oil with the control and treatments. For petitgrain mandarin, the protein content inhibited from 12.15 to 11.26, 11.23 and 11.19% at the same times and treatments.

Effect of lambda-cyhalothrin

Likewise, data obtained in Table 7 had the same trend of oils, where the period of storage dramatically affects the percent of protein content. There is no significant difference between control and LC_{50} levels till 120 days, while a significant effect is shown at 120 and 150 days. For LC_{95}, the protein content (%) significantly differed from 60 to 180 days.

Table 7 Effect of lambda-cyhalothrin on crude protein content % of wheat grains during storage (0–180 days)

Time (day)	Lambda-cyhalothrin		
	Control	LC_{50}	LC_{95}
0	12.34 a	12.34 a	12.34 a
15	12.19 b	12.13 bc	12.07 bc
30	12.01 c	11.91 c	11.89 c
60	11.97 d	11.68 cd	11.37 e
90	11.68 e	11.43 ef	11.19 g
120	11.41 ef	11.29 f	11.03 gh
150	11.23 f	11.06 g	10.91 h
180	11.07 g	10.92 h	10.75 i

In the same column, means followed by the same letter are not significantly different at 0.05 level according to Duncan multiple range test

Total carbohydrates

Effect of oils and insecticides

Similarly, data obtained in Tables 8 and 9 had the same trend with protein content since the progressive of storage time significantly inhibited the content of carbohydrates in wheat grain both each treatment (basil, petitgrain and lambda) or the control with the two levels of LC_{50} and LC_{95}. For example, total carbohydrates content (%) declined from 73.51 at zero time to 70.76 and to 70.73 and 70.69 with LC_{50} and LC_{95} of basil oil at 180 days. For lambda, the inhibition ranged from 73.51 to 70.01 and 69.91 through the time of storage (0–180 days). In addition, the findings obtained clarified that no significant changes were found between control and (LC_{50} and LC_{95}) of oils and insecticide concerning the effect on carbohydrates content except for LC_{90} of lambda at 90–180 days.

In the same column, means followed by the same letter are not significantly different at 0.05 level according to Duncan multiple range test.

Table 6 Effect of both basil and petitgrain mandarin oils on crude protein content (%) of wheat grains during storage (0–180 days)

Time (day)	Basil oil			Petitgrain mandarin oil		
	Control	LC_{50}	LC_{95}	Control	LC_{50}	LC_{95}
0	12.33 a	12.33 a	12.33 a	12.15 a	12.15 a	12.15 a
15	12.30 b	12.30 b	12.29 b	12.12 b	12.11 b	12.11 b
30	12.03 c	12.05 c	12.01 c	12.07 c	12.08 c	12.01 c
60	11.86 c	11.84 d	11.79 d	11.94 d	11.91 d	11.86 d
90	11.63 e	11.67 e	11.58 e	11.72 e	11.69 e	11.60 e
120	11.50 f	11.52 f	11.43 f	11.61 e	11.52 f	11.46 f
150	11.31 g	11.30 g	11.28 g	11.47 g	11.38 g	11.28 h
180	11.19 h	11.18 h	11.09 h	11.26 h	11.23 h	11.19 i

In the same column, means followed by the same letter are not significantly different at 0.05 level according to Duncan multiple range test

Table 8 Effect of basil and petitgrain mandarin oils on total carbohydrates contents in wheat grains during storage (0–180 days)

Time (day)	Basil oil			Petitgrain mandarin oil		
	Control	LC_{50}	LC_{95}	Control	LC_{50}	LC_{95}
0	73.51 a	73.51 a	73.51 a	73.64 a	73.64 a	73.64 a
15	73.01 b	73.02 b	73.00 b	73.11 a	73.11 a	73.10 a
30	72.74 c	72.73 c	72.72 c	72.72 c	72.70 c	72.68 c
60	72.59 c	72.58 c	72.56 d	72.23 d	72.11 d	72.09 d
90	72.26 d	72.21 d	72.13 d	71.93 d	71.87 e	71.74 f
120	71.98 e	71.94 e	71.87 e	71.27 f	71.18 f	71.15 g
150	71.27 e	71.21 f	71.20 f	70.71 g	70.62 g	70.55 g
180	70.76 g	70.73 g	70.69 g	70.12 h	70.01 n	69.91 h

Table 9 Effect of lambda-cyhalothrin on the total carbohydrates content in wheat grains during storage (0–180 days)

Time (day)	Lambda-cyhalothrin		
	Control	LC_{50}	LC_{95}
0	72.97 a	72.97 a	72.97 a
15	72.86 a	72.77 b	72.67 b
30	72.46 c	72.39 c	72.31 c
60	72.37 c	72.21 d	72.18 d
90	71.98 d	71.91 d	71.87 e
120	71.53 e	71.41 e	71.20 f
150	71.10 f	71.02 f	70.86 f
180	70.63 f	70.58 g	70.31 g

On germination percentages

A laboratory experiment was conducted to study the induction of the used materials on germination percentages of wheat grains using two levels of concentration, LC_{50} and LC_{95}, at intervals of zero to 180 days post-treatment.

Effect of basil and petitgrain mandarin oils

Results given in Table 10 illustrated fluctuation in the germination percentage with the control and plants oils at LC_{50} and LC_{95} through the intervals of the experiment from 0 to 180 days. There were slight significant differences like LC_{50} and LC_{95} of basil at 60 and 150 days, but the remainder values were nearly equal. For petitgrain mandarin, the germination percentage significantly differed from 60 to 180 days with the two levels of concentration LC_{50} and LC_{95}. Concerning the mode of action that may be due to monoterpenes, it is well known to have phytotoxic effects or cause their effect by inhibition of respiratory.

Effect of lambda-cyhalothrin

There were no significant differences in control from the beginning to the end of experiment (Table 11). In the same column, means followed by the same letter are not significantly different at 0.05 level according to Duncan multiple range test. Except the percent of germination of LC_{50} from 0 to 30 days, there were significant differences between the effect of LC_{50} and LC_{95} on the germination percentage. Likewise, the control of lambda had the same trend of plant oils where the time did not affect the percent of germination (0–180 days). This decrement of germination percentages may be attributed to the effect of the tested pesticide metabolites which penetrated inside wheat grains.

Chemical composition of essential oils

Basil oil

The chemical composition of *Ocimum basilicum* essential oil by GC–MS is presented in Table 12. Fifty-seven

Table 10 Effect of basil oil and petitgrain mandarin oil on wheat grain germination percentage (%) during storage (0–180 days)

Time (day)	Basil oil			Petitgrain mandarin oil		
	Control	LC_{50}	LC_{95}	Control	LC_{50}	LC_{95}
0	100 a	100 a	95 ab	95 ab	100 a	95 ab
15	100 a	90 bc	100 a	100 a	95 ab	100 a
30	90 bc	90 bc	90 bc	100 a	100 a	95 ab
60	100 a	90 bc	80 de	100 a	90 bc	80 de
90	95 ab	90 bc	90 bc	95 ab	90 bc	75 ef
120	90 bc	80 de	85 cd	100 a	100 a	90 bc
150	100 a	90 bc	80 de	90 bc	90 bc	85 cd
180	90 bc	95 ab	85 cd	95 ab	85 cd	85 cd

In the same column, means followed by the same letter are not significantly different at 0.05 level according to Duncan multiple range test

Table 11 Effect of lambda-cyhalothrin on wheat grain germination percentages during storage (0–180 days)

Time (day)	Lambda-cyhalothrin		
	Control	LC_{50}	LC_{95}
0	100a	95 ab	90 bc
15	95 ab	90 bc	80 de
30	100 a	95 ab	85 cd
60	95 ab	80 de	80 de
90	95 ab	85 cd	75 ef
120	100 a	90 bc	90 bc
150	95 ab	80 de	85 cd
180	100 a	80 de	70 fg

Table 12 Chemical composition of *Ocimum basilicum* essential oil

Compounds	Retention time R.T. (min)	Area percentage
Linalool	12.600	50.6
Eugenol	10.377	9.9
Methyl chavicol	23.787	5.5
Canio	20.453	5.1

Table 13 Chemical composition of *Citrus reticulata* essential oil

Compounds	Retention time R.T. (min)	Area percentage
Dimethyl anthenalate	31.457	55.8
α-Terpinene	18.360	22.6
β-cinem	11.017	9.0
Limonene	17.210	7.6

compounds represent 100% of the oil. The major compounds were linalool (50.6%), eugenol (9.9%), methyl chavicol (5.5%) and canio (5.1%).

Petitgrain mandarin oil

The results in Table 13 showed the chemical analysis of *Citrus reticulata*. The major components of the oil were dimethyl anthenalate (55.8%), terpinenes (22.6%), β-cinem (9.0%) and citral (7.6%).

Discussion

In agreement with the current study, basil oil showed insect repelling for insects (Dube et al. 1989). Cosimi et al. 2009 reported that extracts from tested oil are very toxic to mosquitoes; also, it was repellent to adults of *S. zeamais*. Repellency was dependent on insect species and oil origin. Petitgrain mandarin oil has insecticidal activity against insect pests, where *C. reticulate* showed more toxicity at 48 h exposure against adults of *S. oryzae* (Bhuwan and Tripathi 2011; Stefanazzi et al. 2011; Mumtaz et al. 2013). In the light of previous studies, plant materials extracts, oil and powders have deterrent effects against stored product pests. Kampouzia et al. 2009 reported that toxicity of 42 essential oil extracts from Moraceae was tested against *S. oryzae*. Also, essential oils toxicities are used as fumigants from Iranian *Moraceae* species (Lee et al. 2004). Worthily, the essential oil of plants is less harmful to human and environment (Yegen et al. 1998). Many essential oils and their constituents may have potential as alternative compounds to currently used compounds as fumigants (Huang et al. 2000; Tunc et al. 2000; Lee et al. 2001; Chayengia et al. 2010). All of those authors reported the toxicity effect of some plant oils. Also, Rutaceae family has important fruits and many essential oils products, and it has been widely used in many fields such as flavoring, perfume and pharmaceutical applications. In the current study, the results cleared that petitgrain mandarin oil and basil oil had good toxicity against the tested stored grain insect pests by contact toxicity. Essential oils from *C. reticulate* may be recommended as easily available for former level, low mammalian toxicity and alternative to synthetic insecticides. It could reduce the application of insecticides (Bhuwan and Tripathi 2011). Dhram et al. 1998; Golob and Hanks 1990 reported that organophosphorus compounds are insufficiently effective against *S. oryzae*, whereas pyrethroids are very good efficacy. So, pyrethroids compounds are recommended to *S. oryzae* and other pests such as lambda-cyhalothrin. Wohlgemuth et al. 1993; Samson et al. 1989; El-Lakwah et al. 2000 observed the efficacy of lambda against *S. oryzae* and *R. dominica*. Our results are agreed with Umoetok and Gerard 2003; Khalequzzaman and Nazeenm 2010. In this investigation, all treatments with insecticide gave good protection for stored grain under testing. Lambda-cyhalothrin was effective against *S. oryzae* and *R. dominica*. Current results agreed with Dhram et al. 1998). Golob and Hanks 1990 showed that lambda-cyhalothrin applied at 7 ppm was completely successful against *S. oryzae* for 3 months. After this time, a rapid decrease in efficiency occurred. Many plant volatile essential oils and their constituents have been studied to possess potential as alternative compounds and gaining tremendous importance for the management of stored products, and these are ecologically safe and biodegradable (Cosimi et al. 2009; Rajendran and Sriranjini 2008; Bareth 1989). *Eucalyptus globulus* (Myrtaceae) and *O. basilicum* (Lamiaceae) are two important medicinal plants. The essential oils of different species of both plants leaves and their constituents have pesticide properties against insect pests (Nagassoum et al. 2007), Mishra 2012 stated that *E. globulus* and *O. basilicum* had repellent activity against *S. oryzae* and *T. castaneum* and the effect increased with the increase in concentration. Eos from the peels of *C. reticulate* are known to have contact, fumigation and feeding deterrent activities on various insects that attack stored products (Mishra et al. 2011). Bounoua-Fraoucene and Debras 2019 reported that *O. basilicum* oil using fumigation and repellency tests at four doses and different exposure times under laboratory conditions on durum wheat grain was more toxic to *R. dominica* than *S. oryzae*. Current findings are in agreement with Nath et al. 2019 stating that *Citrus reticulate* (Peel) extract had significant insecticidal activity against *T. castaneum*. Also, they claimed that due to cheap and easy availability of this plant, its extract or powder can be the promising substitutes of chemical insect ides in pest management programs. Abouelatta et al. 2020 studied the chemical composition of geranium essential oils and studied the fumigant and repellent and contact toxicity of geranium essential oils against *R. dominica* and found that all tested essential oils had fumigant and repellent effect against *R. dominica.* Mode of action for the essential oils against insects may be due to inhibition of acetyl-cholinesterase (AChE) (Ryan and Byrene 1988) by determined five monoterpenes which inhibited AChE activity. The obtained results are in agreement with Bhuwan and Tripathi 2011 and Ragaa et al. 2012. Ahmad et al. 2006; Lopez et al. 2008 studied the effect of basil oil and other oils on emerged and reduction percentages of adults of *S. oryzae* and *R. dominica* and stated high effects of basil on reduction percentage for *R. dominica*. The two commercialized basil and orange oils showed stored fumigant and contact activities against *S. zeamais* and *T. castaneum* (Kim and Lee 2013). These results demonstrated that lambda-cyhalothrin had strong effect on the tested insects (Abo-Arab et al. 2014; Salem et al. 2015). These results of lambda are in agreement with (Afridi et al. 2009; Sayed and Shaker 2010).

These results are in agreement with Nagi 1979 who found that crude protein content in wheat grains was gradually decreased when pirimiphos methyl was used as protectant. Furthermore, Magdoline 1985 observed that insecticide concentration as well as storage period significantly affected the total nitrogen in wheat grains. The major components of *O. basilicum* oil were reported by Lopez et al. 2008; Ogendo et al. 2008. Similar to those previously described by Ahmad et al. 2006; Tandorost and Karimpour 2012. The constituents of the basil oil were linalool (21.83%), estragole (74.29%) and α-humulene (2.17%) (Kim and Lee 2013). These results are in disagreement with our study. These differences may be due to the date of harvest, analysis method and location of collected plant.

Conclusions

The results obtained proved that the two tested plant essential oils had an obvious role in suppressing the activity of the two tested insects and can be used in integrated pest management program. The two tested essential oils can be used as green pesticides and can be effective alternatives for chemical pesticides.

Abbreviations

LT_{50}: Is the time that will kill 50 percent of the sample population under scrutiny,; LC_{50}: Is the concentration of a chemical that will kill 50 percent of the sample population under scrutiny.; C.L.: Confidence limits; S.V.: Slope value; S.E.: Standard error; Mg: Milligram; Kg: Kilogram.

Acknowledgements

We would like to thank Hashem Brothers Company for Essential oils and Aromatic Products for their support.

Author contributions

R.B.A. contributed to visualization, data curation, writing—original draft, and supervision. N.M.E. was involved in validation and formal analysis and provided software. A.M.A. contributed to writing, reviewing, editing and conceptualization. A.M.H. was involved in investigation and methodology. All authors read and approved the final manuscript.

Funding

This study had no fund.

Availability of data and materials

Yes, in the main manuscript.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

On behalf of all authors, the corresponding author states that there is no competing interests.

Received: 18 February 2022 Accepted: 29 June 2022
Published online: 05 July 2022

References

Abbott WS (1925) A method of the effectiveness of an insecticides. J Econ Entomol 18:265–270

Abo-Arab RB, Hamza, AM, Hashem AS (2014) Comparative bioactivity of aluminum dioxide (Al_2O_3), titatnium dioxide (TiO_2) nano-particles and malathion in *Sitophilus oryzae* (L.) and *Sitophilus zeamais* (Motsch.). Global J Agric Food Saf Sci 1(2): 25–37

Abouelatta AM, Keratum AY, Ahmed SI, El-Zun HM (2020) Repellent, contact and fumigant activities of geranium (Pelargonium graveolens L.'Hér) essential oils against Tribolium castaneum (Herbst) and Rhyzopertha dominica (F.). Int J Trop Insect Sci. https://doi.org/10.1007/s42690-020-00161-4

Afridi IAK, Parveen Z, Masud SZ (2009) Stability of organophosphorus and pyrethroids pesticides on wheat in storage. J Stored Prod Res 37:199–204

Ahmad MM, Ur-Rehman S, Iqbal Z, Anum FM, Sultan JI (2006) Genetic variability to essential oil composition in four citrus fruit species. Pak J Bot 38:319–324
AOAC (1980) Official Methods of Analysis. In: W. Horwitz, Pub. Benjamin Franklin Station (ed) Association of official analytical chemists, 12th edn. Washington D.C., USA, pp 1–832
Bareth SS (1989) Gupta HC (1989) Efficacy of gunny bag and seed treatment on the natural infestation of *Rhyzopertha dominica* on stored wheat. Seed Res 172(2):178–181
Bhuwan B, Tripathi C (2011) Contact toxicity of essential oil of Citrus reticulate against stored grain pests *Sitophilus oryzae* (L.) and *Tribolium castaneum* (Herbest). World J Zool 6(3):307–311
Bounoua-Fraoucene Kellouchem A, Debras JF (2019) Toxicity of four essential oils against two insect pests of stored grains, *R dominica* (Coleoptera: Bostrychidae) and *S. oryzae* (Coleoptera: Curculionidae). African Entomol 27(2):344–359
Bruneton J (1999) Pharmacognosy, phytochemistry, medicinal plants, laboisier tec & Doc., Paris, France 2nd edition
Calliney TW (2014) Crop losses to arthropods. In: Pimentel D, Peshin R (eds) Integrated pest management. Springer, New Delhi, pp 201–225
Campolo O, Giunit G, Russo A, Palmeri V, Zapalla L (2018) Essential oils in stored product insect pests control. J of Food Qual. https://doi.org/10.1155/2018/6906105
Chayengia B, Patgiri P, Rahman Z, Sarma S (2010) Efficacy of different plant products against *Sitophilus oryzae* (Linn.) (Coleoptra: Curculionidae) infestation on stored rice. J Biopestic 3(3):604
Cosimi SE, Rossi E, Cioni PL, Canale A (2009) Bioactivity and qualitative analysis of some essential oils from Mediterranean plants against stored-product pests evaluation of repellency against *Sitophilus zeamais* Motschulsky, *Cryptolestes errugineus* (Stephens) and *Tenebrio molitor* (L.). J. Stored Products Res. 45(2):125–132
Dars F, Rustaman MA, Khuro RD, Baloch HB (2001) Effect of wheat grain moisture on infestation of red flour beetle, *Tribolium castaneum* (Herbst). Pakistan J Zool 33:189–200
Davis R, Bry RE (1985) *Sitophilus granaries, Sitophilus oryzae*, *Sitophilus zeamais, Tribolium castaneum* and *Tribolium confusum*. In: Singh P, More RF (eds) Handbook of insect rearing, vol I. Elsevier, Amsterdam, Oxford, New York, Tokyo, pp 287–293
Dhram S, Yadav T, Singh D (1998) Efficacy of deltamethrin, etrimfos, chlorpyrifos-methyl and malathion dusts on wheat seed against *Sitophilus oryzae* and *Trogoderma granarium*. Indian J Entomol 60(3):262–268
Dube SP, Upadhyay PD, Tripathi SC (1989) Antifungal physiochemicals and insects repelling activity of the essential oil of *Ocimum basilicum*. Can J Bot 67(7):2085–2092
Duncan DB (1955) Multiple range and multiple F. test. Biometrics 11:1–42
El-Lakwah FA, Zewer MM, Mahgoub SM, Mohamed SM (2000) Evaluation of rock phosphate, pirimiphos-methyl and their mixture as grain protectant against some products, insects. Annals Agric Sci Moshtohor 38(1):573–581
FAO (2015) faostat3.fao.org/browse/Q/QC/E
Feng LY, Guany WL, Yi IX, Yong YL (2009) Diatomaceous earth enhance the toxicity of garlic, *Allium sativum*, essential oil against stored product pests. J Stored Prod Res 46:118–123
Finney S (1952) Probit analysis, 2nd edn. Cambridge Univ. Press, London
Golob P, Hanks C (1990) Protection of stored farm maize against infestation by *Prostephanous truncates* (Horn) and *Sitophilus* species in Tanzania. J Stored Prod Res 26:187–198
Harein CR, Soderstorm EI (1966) Coleoptera infesting stored product. In: Smith CN (ed) Insect colonization and mass production. Academic Press, New York and London, pp 241–257
Huang Y, Chen SX, Ho SH (2000) Bioactivities of methyl allyle disulfide and diallyle trisulfide from essential oil of garlic to two species of stored product pests. J Econ Entomol 93:537–543
International Seed Testing Association (1976) International rules for seed testing. Seed Sci Technol 4:3–49
Kampouzia I, Negahban M, Maharramipour S (2009) Fumigant toxicity of *Eucalyptus leucoxylan* against stored products insects. Am Eurasian J Sustain Agric 3(2):229–233
Khalequzzaman M, Nazeenm S (2010) Toxicity of pirimiphos-methyl and three essential oils alone in combination against *Callosobruchus maculatus* (Fab.). Univ J Zool Raishahi Univ 28:01–05
Kim S, Lee D (2013) Toxicity of basil and orange essential oils and their components against two coleopteran stored products insects pests. J Asia-Pacific Entomology 17(1):13017
Lee SE, Lee BH, Choi WS, Park BS (2001) Fumigant toxicity of essential oils and their constituents compounds toward the rice weevil, *Sitophilus oryzae* (L.). Crop Prot 30:317–320
Lee BH, Annis PC, Tumaalii F, Choi WS (2004) Fumigant toxicity of essential oils from the myrtaceae family and 1, 8-cineol against 3 major stored grain insects. J Stored Prod Res 40:553–564
Lopez MD, Jordan MJ, Puscual-Villalobos MJ (2008) Toxic compounds in essential oils of cordiander, caraway and basil active against stored rice pests. J Stored Prod Res 44(3):273–278
Magdoline AS (1985) The effect of permethrin residues on the chemical constituents of wheat stored grains. Agric., Cairo Univ
Mishra BB (2012) Repellent effect of leaves essential oils from *Eucalyptus globulus* (Mirtaceae) and *Ocimum basilicum* (Lamiaceae) against to major stored grain insect pests of coleopterans. Nat Sci 10(2):50–54
Mishra BB, Tripathi SP, Tripathi CMP (2011) Contact toxicity of essential oil of citrus reticulate fruits peels against store grain pests *Sitophilus oryzae* (Linnaeus) and *Tribolium castaneum* (Herbst). World J of Zool 6(3):307–311
Mumtaz A, Muhammad A, Abu Bakkar R, Muhammad L, Chaudhary N (2013) Repellent effects of certain plant extracts against rice weevil, *Sitophilus oryzae* (L.) (Coleoptera: Curclionidae). Int J Agric Appl Sci 5(1):114–129
Nagassoum MB, Tinkeu LSN, Ngatanko L, Tapondjou LA, Lognay G, Malaisse F, Hance T (2007) Chemical composition, Insecticidal effect and repellent activity of combination towards Sitophilus oryzae (Coleoptera: Curculionidae). Nat Prod Comm 2(12):1229–1232
Nagi AS (1979) Effect of some insecticides on the chemical constituents of the stored wheat and its penetration through the kernel. Agric., Zagazig Univ
Nath R, Singh G, Deep G (2019) Efficacy of some botanical extracts against *T. castaneum*. Coleoptera (Tenebrionidae). Plant Cell Biotech Mol Biol 20(15–16):660–666
Ogendo JO, Kastyukovsky M, Ravid U, Matasyoh JC, Deng AL, Omolo EO, Karuki ST, Shaaya E (2008) Bioactivity of *Ocimum basilicum* L. oil and two of its constituents against five insects attacking stored food products. J Stored Prod Res 44:328–334
Oliveira C, Auad A, Mendes S, Frizzas M (2014) Crop losses and the economic impact of insect pests on Brazilian agriculture. Crop Prot 56:50–54
Owalade OF, Ogunleti DO, Adenekan MO (2008) Titanium dioxide affect disease development and yield of edible cowpea. Elect J Environ Agri Food Chem 7(50):2942–2947
Pimentel D (2009) Pest control in world agriculture. In: Rattan L (ed) Agricultural Science. Eolss Publishers/ UNESCO, Singapore, pp 272–293
Ragaa KAH, Ahmed SMS, Abotaleb AOB, Bahira E-S (2012) Efficacy of certain plant oils as grains protectants against the rice weevil, *Sitophilus oryzae* (Coleoptera: Curculionidae) on wheat. J Biolog Sci 5(2):49–53
Rajendran S, Sriranjini V (2008) Plant products as fumigants for stored product insect control. J Stored Prod Res 43(2):126–135
Ryan MF, Byrene O (1988) Plant insects coevaluation and inhibition of acetylcholinesterase. J Chem Ecol 14:1965–1975
Salem A, Hamza MH, El-Taweelah NM (2015) Aluminum and zinc oxide nanoparticles as a new method in controlling the red flour beetle, *Tribolium castaneum* (Herbest) compared to malathion insecticide. Int J Sci Res Agric Sci Proc 2:1–6
Sallam MN (2013) Insect damage on post-harvest. FAO. Roma
Samson PR, Paker RJ, Jones AL (1989) Laboratory studies on protection for control of *S. oryzae* and *Rhizopertha dominica* in paddy rice. J Stored Prod Res 25(1):39–48
SAS (2008) SAS/STAT Q.Z version users guide. As Institute Inc., Gary, North Calorina, USA
Sayed FM, Shaker S (2010) Synthetic pyrethroids multi residue in grapes from southern India. Kathamadu Univ Sci Eng Technol 6(11):104–110
Smith T, Gills KA, Hamilton JK, Herbers FA, Dubois M (1964) Colorimetric method for determination of sugar and related substance. Anal Chem 28:550
Smith SE, Barker SJ, Zhu YG (2006) Fast moves in arbuscular mycorrhizal symbiotic signaling. Trends Plant Sci 11(8):369–371
Spochacz M, Chowanski S, Walkowiake K, Szymczak M, Adamski Z (2018) Plant-derived substances used against beetles-pests of stored crops and food-and their mode of action. Compr Rev Food Sci Food Saf 17:1339–1366

Stefanazzi N, Teodoro S, Ferrero A (2011) Composition and toxic, repellent and feeding deterrent activity of essential oils against the stored-grain pests *Tribolium castaneum* (Coleoptera: Tenebrionidae) and *Sitophilus oryzae* (Coleoptera: Curculionidae). Pest Managl Sci 67:639–646
Svoboda K, Greenway R (2003) Investigation of volatile oil glands of *Satureja hortensis* L. (summer savory) and phytochemical comparison of different varieties. Int J Aromather 13(4):196–202
Tandorost R, Karimpour Y (2012) Evaluation of fumigant toxicity of orange peel citrus sinensis product insects in laboratory condition. Mun Ent Zool 7:352–358
Teodoro S, Micaela D, David K, Stephens S (2012) Comaprative toxicity of nano-structured alumina and commercial inert dusts for *Sitophilus oryzae* (L.) and *Rhizopertha dominica* (F.) at varying ambient humidity levels. J Stored Prod Res 48:81–90
Tunc I, Berger BM, Erler F, Dagli F (2000) Ovicidal activity of essential oils from five plants against two stored products insects. J Stored Prod Res 36(2):161–168
Umoetok SBA, Gerard MB (2003) Comparative efficacy of *Acarus calamus* and two synthetic insecticides for control of three major insect pests of stored cereal grains. Global J Agric Sci 2(2):94–97
Walters DR (2010) Plant defense: warding off attach by pathogens, herbivores and parasitic plants. Wiley, Hoboken, N.J., USA
Wohlgemuth R, Piarra R, Harnisch R (1993) Comparing tests in the control and long-term action of insecticides against stored products under hot-humid tropical conditions. Deutsche Gesellschaft für technische Zusammenarbeit (GTZ) GmbH Eschborn, Germany, p 401
Yegen O, Unlu A, Berger BM (1998) Einstaz und Nebenwirkungen auf bodenmikrobiel aktivitaten des etherischen ols aus bei der bekanpfung der vurzelhal skrankheit a paprika *Phytophthora capsici*. Zeitschrift Für Pflanzenschutz 105(6):602–610
Zebec Z, Wilkes J, Jervis AJ, Scrutton NS, Takano E, Breiitling R (2016) Towards synthesis of monoterpenes and derivatives using synthetic biology. Curr Opin Chem Biol 34:37–43
Zuzarte M, Salgueiro L (2015) Essentnial oils chemistry. In: Bioactive essential oils and cancer. Springer Cham, Switzerland, pp 18–61

Publisher's Note