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ARTICLE

Acaricidal and insecticidal properties of *Coriandrum sativum* oils and their major constituents extracted by three different methods against stored product pests

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Abstract Essential oils of *Coriandrum sativum* were extracted by three different methods, including steam distillation (SDE), solvent (SE) and supercritical fluid extraction (SFE), to determine their acaricidal and insecticidal properties against *Plodia interpunctella*, *Sitotroga cerealella* and *Tyrophagus putrescentiae*. The fumigant bioassay against *P. interpunctella*, *S. cerealella* and *T. putrescentiae* revealed the strongest activity (LD_{50} 9.38, 18.76 and 4.19 μg/cm^3) of oil obtained via SDE, followed by extraction via SE (LD_{50} > 75.20, 21.11, and > 75.20 μg/cm^3) and SFE (LD_{50} > 75.20, 27.36, and > 75.20 μg/cm^3). The contact bioassay against *T. putrescentiae* revealed the most potent activities of oil obtained via SDE (LD_{50} 19.29 μg/cm^2), followed by oil via SE and SFE. The chemical composition of *C. sativum* oils obtained by SDE, HE and SFE was analyzed by GC–MS. The *C. sativum* oil obtained by SDE contained linalool (66.80%) compared with oils obtained by SE and SFE (70.67–70.80%). However, camphor (6.46%) was detected in SDE but not in the other two extracts. Based on the LD_{50} values of six major compounds derived from the three *C. sativum* oils against *P. interpunctella*, *S. cerealella* and *T. putresceentiae*, camphor was considered the most active (2.32, 19.31 and 3.24 μg/cm^3, respectively) insecticide. The three values were about real camphor concentration in the oil via SDE. These results indicate that camphor contributes to the acaricidal and insecticidal activities of oil extracted via SDE of *C. sativum* seeds.

Keywords Acaricidal activity · *Coriandrum sativum* · Extraction method · Insecticidal activity · *Plodia interpunctella* · *Sitotroga cerealella* · *Tyrophagus putresceentiae*

Introduction

Agricultural products and stored harvest grains incur substantial losses and damage because of insect pests [1, 2]. *Plodia interpunctella*, *Sitotroga cerealella* and *Tyrophagus putrescentiae* are distributed globally and are serious economic pests infesting stored products such as grains, flours, feeds, dried nuts and fruits [3–5]. The Indian meal moth, *P. interpunctella*, continuously produces silken web on the food surface. The food products contaminated with *P. interpunctella* are covered by their silken web [3]. The *S. cerealella* larvae invade grains and complete their larval and pupal stages within the grains. This pest feeding on the stored grain decreases its weight and nutritional value [4]. *T. putrescentiae* is a major species commonly contaminating stored products. Furthermore, these mites disseminate toxic fungi and induce allergic reactions among workers engaged in agriculture and food industries [5, 6].

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Management of insect pests infesting stored products is generally accomplished via application of various chemical insecticides. However, chemical insecticides may be harmful to humans and result in outbreaks of environmental contamination, toxic residues and resistance. Therefore, safe insecticides are needed to decrease the adverse effects associated with the use of stored foods [1, 2]. Essential oils and plant-derived products exhibiting acaricidal and insecticidal effects represent potential pest control agents [2, 7, 8]. The essential oils or plant extracts are generally obtained by various extraction methods such as hydrodistillation, steam distillation, solvent and supercritical fluid methods [8]. Variations in the chemical composition of essential oils have been observed depending on not only the plant part used in the extraction, and other local conditions, but also the various extraction methods [8–10]. Therefore, extraction methods play an important role in the isolation of bioactive compounds from plant extracts [11].

Coriandrum sativum (Coriander) is distributed in the Mediterranean region and belongs to family Apiaceae [12]. The medicinal properties of *C. sativum* have been exploited in the pharmaceutical industry against rheumatism and indigestion [13]. Furthermore, the *C. sativum* extract and essential oils have been used as a flavoring in food products and beauty industry [14, 15]. A wide range of therapeutic effects including antimicrobial, antioxidant and insecticidal properties of the essential oil of *C. sativum* seeds have been reported [16]. This study was carried out to assess the acaricidal and insecticidal activities of the essential oil and its aromatic constituents derived from *C. sativum* seeds using the three extraction methods.

Materials and methods

Chemicals and plant material preparation

Camphor, geranyl acetate, linalool, α-pinene and terpinene derived from the three extracted oils were purchased from Sigma-Aldrich (St. Louis, MO, USA), while limonene was obtained from Tokyo Chemical Industry (Tokyo, Japan). All chemicals are analytical grade. The *Coriandrum sativum* seeds (5 kg) were bought from a herbal market (Jeonju, South Korea). The *C. sativum* fresh seeds (200 g) were washed and machine-ground to a powder prior to steam distillation extraction (SDE), solvent extraction (SE) and supercritical fluid extraction (SFE).

Steam distillation extraction (SDE)

The *C. sativum* seeds were processed at the Jeollanam-do Institute of Natural Resources Research (Jangheung, Korea) by steam distillation for 4 h at 100 °C using an essential oil extractor device (EM-250, Micro, Korea). The extraction was performed by a steam extractor containing the seeds and distilled water. As the water heated, the water vapor was produced by steam extractor and the steam passed to the condenser and collected on the receiving flask.

Solvent extraction (SE)

Dried *C. sativum* seeds were pulverized and placed in a 5-L Erlenmeyer flask with 100% hexane (Hexane, 1500 mL × 2). The extraction was performed on a shaking incubator at 200 rpm and 25 °C for 48 h. The extract of *C. sativum* seeds was filtered and concentrated using a rotary vacuum evaporator at 35 °C.

Supercritical fluid (CO_2) extraction (SFE)

The *C. sativum* seeds were ground and powdered at the Jeollanam-do Nano Bio Research Center (Jangsung, Korea) using a SCFE-0500 supercritical fluid extractor (Ilshin autoclave, Daejeon, Korea). Extraction and separation were conducted at pressures of 400 and 40 bar and temperatures of 50 and 40 °C for 120 min, respectively. The supercritical CO_2 flow rate was approximately 60 mL/min.

Mite and insect colonies

T. putrescentiae were reared on artificial diet including protein (46.0%), fiber (4.0%), phosphate (2.0%), lipid (3.0%) and calcium (1.1%) and stored in plastic containers (15 × 12 × 6 cm) under controlled conditions (26 ± 1 °C, 70 ± 5% relative humidity). The artificial diet was purchased from Korea Special Feed Meal Co. (Jeonju, Korea). *P. interpunctella* (larvae and adults) and *S. cerealella* (adults) were obtained from the insect-rearing room of a laboratory at 27 ± 1 °C and 40–60% relative humidity under darkness. They were reared on rice bran and barley in an acrylic growth cage (40 × 40 × 40 cm^3) [5].

Chemical analysis of *C. sativum* seed oil

The chemical composition of the three essential oils of *C. sativum* seeds was determined using GC–MS. The GC–MS analysis of the volatile constituents present in the three oils was performed using an Agilent HP-6890 gas chromatography coupled to an Agilent 5973IV mass spectrometer (Agilent Technology, Santa Clare, CA, USA) with helium as the carrier gas on a DB-5 column (0.25 mm i.d. × 30 mL × 0.25 μm film thickness) at a flow rate of 0.8 mL/min. In all cases, the analytic conditions were as follows:

ion source temperature, 220 °C; injector temperature, 210 °C; sample temperature 20 °C for 15 min; and programmed to increase by 2 °C/min–220 °C. The MS detector operated in the electron ionization mode at 70 eV.

Bioassays

The acaricidal activities of the essential oils of *C. sativum* seeds and all compounds against *T. putrescentiae* were evaluated in contact and fumigant bioassays, as modified by Yang et al. [6]. In the contact bioassay, the filter papers were moistened evenly with 50 µL of *C. sativum* oil and its constituents added at different concentrations (75.20–1.00 µg/cm^3). The base formulation, methanol, was used as a solvent and negative control. After drying for 10 min, the treated filter paper was placed at the bottom of a Petri dish (35 mm diameter) followed by addition of 20 mites and sealed with parafilm. In the fumigant bioassay, the essential oils and compounds were dissolved in acetone in order to obtain 75.20–1.00 µg/cm^3 concentrations. The fabric disks (8 mm diameter and 1 mm thick) were treated with test solutions (10 µL) and dried for 10 min. The fabric disks were placed at the top of a microtube. Twenty adult mites were added to the microtubes. Acetone was used as the negative control. Treatments in the contact and fumigant bioassays were repeated three times at 26 ± 1 °C for 24 h.

Contact and fumigant bioassays were used to evaluate the insecticidal toxicity of the essential oils and their constituents against *P. interpunctella* and *S. cerealella*. Using a contact bioassay, different doses (75.2–1.0 µg/cm^2) of each sample were suspended in methanol and applied to filter paper. The filter paper was placed at the bottom of a Petri dish after solvent evaporation for 10 min. Twenty *P. interpunctella* larvae were moved in the Petri dish, and the lid was sealed. To determine the fumigation of the samples against adults of *P. interpunctella* and *S. cerealella*, the filter paper was treated with an appropriate concentration (75.2–1.0 µg/cm^3) of the test samples in methanol. The impregnated filter paper (90 mm diameter) was then placed inside the lids of a glass jar (90 mm diameter, 80 mm height). In order to prevent evaporation of the tested samples, the lids were sealed. Acetone was used to treat the control jars. Twenty adults were released individually at the bottom of the glass jar and exposed for 48 h. These jars were maintained at 27 ± 1 °C and 40–60% relative humidity for 48 h. After the experiment, the mortality of adults was recorded after treatment. All experimental procedures were performed in triplicate.

Statistical method

Lethal doses (LD_{50} and LD_{90}) of the three essential oils and their major constituents were calculated by probit analysis using SPSS version 12.0 for Windows (SPSS Inc., Chicago, IL, USA). The LD_{50} and LD_{90} values of the tested samples considered vary significantly from one another when 95% confidence limits did not overlap.

Results and discussion

The acaricidal and insecticidal activities of the three *C. sativum* oils extracted by SDE, SE and SFE against *T. putrescentiae*, *P. interpunctella* and *S. cerealella* were tested using contact and fumigant bioassays (Table 1). In the contact and fumigant bioassays against adults of *T. putrescentiae*, the most active oils were SDE oil (19.29 and 4.19 µg/cm^3), followed by SE oil (29.25 and 9.38 µg/cm^3) and SFE oils (31.57 and > 75.20 µg/cm^3), respectively. In the contact and fumigant bioassays against the larvae of *P. interpunctella*, none of the SED, SE and SFE oils exhibited insecticidal activity, while the SED oil showed only insecticidal activity (LD_{50} 9.38 µg/cm^3) against *P. interpunctella* adults in the fumigant bioassay. Based on the LD_{50} values of three *C. sativum* oils against *S. cerealella* in the fumigant bioassay, the most active oil was SDE oil (LD_{50} 18.76 µg/cm^3), followed by SE oil (LD_{50} 21.11 µg/cm^3) and SFE oil (LD_{50} 27.36 µg/cm^3). At a dosage of 0.08 µg/mL in the fumigant bioassay, treatment with the essential oil of *C. sativum* resulted in 100% mortality of larvae, pupae and adults of *Tribolium castaneum* [12]. In the laboratory studies of Zoubiri et al. [13], the essential oil derived from *C. sativum* at an atmospheric concentration of 10 µL/L caused 70% mortality of *Sitophilus granarius* after 120 h. In this regard, many studies reported that the acaricidal and insecticidal activities of *C. sativum* may be due to contact and fumigant bioassays against stored product pests. Furthermore, our studies showed differences in the degree of acaricidal and insecticidal activity of *C. sativum* oils against *P. interpunctella*, *S. cerealella* and *T. putrescentiae*. Similar studies suggested that the *Tanacetum parthenium* oil extracted by hydrodistillation against *Spodoptera littoralis* was more active (LD_{50} 0.05 µL/larvae, and LD_{90}, 0.18 µL/larvae, respectively) than the other oil extracted by SFE [16]. Pavela et al. [17] found that the *Satureja hortenisis* oil extracted by hydrodistillation and supercritical extractions (extracted with pure CO_2 at 12 MPa and 50 °C) exhibited the most insecticidal activities against *Leptinotarsa decemlineata*, *Spodoptera littoralis*, *Musca domestica* and *Culex quinquefasciatus*. Chiasson et al. [10] demonstrated that among the essential oils of *Artemisia absinthium* and *Tanacetum vulgare*

Table 1 Acaricidal and insecticidal activities of *Coriandrum sativum* seed oils extracted by three different methods against *Tyrophagus putrescentiae* and *Plodia interpunctella* using contact and fumigant bioassays[a]

Plant	Extract method	Insect	Stage	Contact (μg/cm^2)			Fumigant (μg/cm^3)		
				LD_{50} (95% CI)[b]	Slope ± SE	χ^2 (*df*, *p*)	LD_{50} (95% CI)[c]	Slope ± SE	χ^2 (*df*, *p*)
C. sativum	Steam	*T. putrescentiae*	Adults	19.29 (17.31–24.09)	2.06 ± 0.22	4.659 (4, 0.324)	4.19 (2.89–5.63)	2.14 ± 0.37	1.673 (4, 0.796)
		S. cerealella	Adults	NT[c]	–	–	18.76 (15.97–20.42)	3.96 ± 0.61	2.426 (5, 0.788)
		P. interpunctella	Larvae	> 75.20	–[d]	–	> 75.20	–	–
			Adults	NT[c]	–	–	9.38 (6.53–12.32)	2.21 ± 0.45	6.045 (5, 0.196)
	Solvent	*T. putrescentiae*	Adults	29.25 (26.13–33.47)	1.60 ± 0.20	2.819 (4, 0.589)	> 75.20	–	–
		S. cerealella	Adults	NT[c]	–	–	21.11 (18.13–24.77)	3.96 ± 0.61	2.426 (5, 0.788)
		P. interpunctella	Larvae	> 75.20	–	–	> 75.20	–	–
			Adults	NT[c]	–	–	> 75.20	–	–
	Supercritical	*T. putrescentiae*	Adults	31.57 (28.96–36.35)	1.64 ± 0.20	1.207 (4, 0.877)	> 75.20	–	–
		S. cerealella	Adults	NT[c]	–	–	27.36 (23.66–33.98)	3.47 ± 0.53	4.369 (5, 0.498)
		P. interpunctella	Larvae	> 75.20	–	–	> 75.20	–	–
			Adults	NT[c]	–	–	> 75.20	–	–

[a]Adults; exposed for 24 h, larvae; exposed for 48 h

[b]LD_{50} is the average of 3 assays in triplicate with 20 insects per assay

[c]Not tested

[d]No activity

Table 2 GC-MS analyses of essential oils derived from *C. sativum* seeds via three different extraction methods

No.	Compounds	RI[a]	Relative amount (%)		
			Steam distillation extraction	Hexane extraction	Supercritical fluid extraction
1	α-Pinene	939	7.79	3.05	9.84
2	Camphene	953	1.51	–[b]	–
3	Myrcene	992	1.01	–	–
4	Cymene	1027	2.94	–	–
5	Limonene	1033	3.79	–	–
6	Terpinene	1074	3.97	–	–
7	Terpinolene	1084	1.15	–	–
8	Linalool	1100	66.80	70.67	70.80
9	Camphor	1139	6.46	–	–
10	α-Terpineol	1195	0.37	–	–
11	Linalool oxide	1212	0.50	–	–
12	Citronellyl acetate	1357	–	0.79	–
13	Geranyl acetate	1382	3.17	24.31	18.40
14	Myristic acid	1720	–	–	0.96
Major compound groups					
Acid			–	–	0.96
Monoterpene alcohol			67.17	70.67	70.80
Monoterpene esters			3.17	25.10	18.40
Monoterpene ether			0.50	–	–
Monoterpene ketone			6.46	–	–
Monoterpene hydrocarbons			22.16	3.05	9.84
Total (%)			99.46	98.82	100
Yield (%)			0.29	2.22	3.43

[a]RI: The retention indices were determined on DB-5 column

[b]–: Not detection

extracted by microwave-assisted process, distillation in water and direct steam, the oil obtained via direct steam distillation was the most toxic against *Tetranychus urticae*. These studies demonstrated that the acaricidal and insecticidal activities against various types of insects showed significant differences with methods of plant extraction. Therefore, our results indicate that the *C. sativum* oil obtained by SED was more effective in controlling the pests infesting stored products than the oils obtained by two other extraction methods.

The relative amounts (%) of *C. sativum* oil components obtained by the three extraction methods vary according to the results of GC–MS (Table 2). Essential oils derived from the seeds of *C. sativum* isolated by SDE, SE and SFE showed a yield of 0.25, 2.22 and 3.43%, respectively. Fourteen compounds in the *C. sativum* oils have been identified and comprise mainly monoterpenoids: 1 acid (myristic acid), 2 monoterpene alcohols (linalool, α-terpineol), 1 monoterpene ether (linalool oxide), 2 monoterpene ester (citronellyl acetate, geranyl acetate), 1 monoterpene ketone (camphor) and 7 monoterpene hydrocarbons (α-pinene, camphene, myrcene, cymene, limonene, terpinene and terpinolene). The main components of the *C. sativum* oil obtained by SDE were linalool (66.80%), α-pinene (7.79%), camphor (6.46%), terpinene (3.97%), limonene (3.79%), geranyl acetate (3.17%), cymene (2.94%), camphene (1.51%), myrcene (1.01%), linalool oxide (0.50%) and terpineol (0.37%). The major composition of the *C. sativum* oil obtained by SE included linalool (70.67%), geranyl acetate (24.31%), α-pinene (3.05%) and citronellyl acetate (0.79%). The main constituents of the *C. sativum* oil obtained by SFE were linalool (70.80%), geranyl acetate (18.40%), α-pinene (9.84%) and myristic acid (0.96%). In the *C. sativum* oils, linalool was the major component obtained with all the three extraction methods. Our result was consistent with previous studies that reported linalool as the major compound occurring in the *C. sativum* oil [13, 15, 18]. Benelli et al. [19] demonstrated

Table 3 Acaricidal and insecticidal activities of major components derived from *C. sativum* seed oil against *T. putrescentiae* and *P. interpunctella* in the contact bioassay[a]

Compounds	Insects	Stage	Contact (μg/cm^2)			
			LD_{50} (95% CI)[b]	LD_{90} (95% CI)	Slope ± SE	χ^2 (*df*, *p*)
α-Pinene	*T. putrescentiae*	Adults	> 75.20	–[c]	–	–
	P. interpunctella	Larvae	> 75.20	–	–	–
Limonene	*T. putrescentiae*	Adults	22.87 (18.79–27.93)	60.70 (46.14–93.74)	3.02 ± 0.42	2.704 (5, 0.746)
	P. interpunctella	Larvae	> 75.20	–	–	–
Terpinene	*T. putrescentiae*	Adults	> 75.20	–	–	–
	P. interpunctella	Larvae	> 75.20	–	–	–
Linalool	*T. putrescentiae*	Adults	4.39 (3.59–5.41)	11.67 (8.73–19.01)	3.02 ± 0.45	2.126 (5, 0.831)
	P. interpunctella	Larvae	> 75.20	–	–	–
Camphor	*T. putrescentiae*	Adults	2.81 (2.30–3.44)	7.64 (5.75–12.23)	2.95 ± 0.44	3.010 (5, 0.698)
	P. interpunctella	Larvae	> 75.20	–	–	–
Geranyl acetate	*T. putrescentiae*	Adults	> 75.20	–	–	–
	P. interpunctella	Larvae	> 75.20	–	–	–

[a]Adults; exposed for 24 h, larvae; exposed for 48 h

[b]LD_{50} is the average of 3 assays in triplicate with 20 insects per assay

[c]No activity

the presence of linalool (83.60%) in the *C. sativum* oil. The main constituents of the *C. sativum* oil obtained by SDE, SE and SFE are mostly similar, whereas the identified compounds apparently varied. The *C. sativum* oil obtained by SDE contains camphor (6.46%), which is also the main acaricidal and insecticidal ingredient in the *C. sativum* oil [20, 21]. Thus, the highest percentage of active acaricidal and insecticidal ingredients in the *C. sativum* oil extracted by SDE containing linalool together with camphor was obtained.

The content of camphene, citronellyl acetate, cymene, linalool oxide, myrcene, myristic acid, terpinolene and α-terpineol in the *C. sativum* oils extracted by SDE, SE and SFE was relatively small (0.50–2.94%), suggesting limited toxicity. Therefore, the acaricidal and insecticidal activities of six compounds (camphor, geranyl acetate, limonene, linalool, α-pinene and terpinene, constituting 3% of the total composition) derived from the *C. sativum* oils extracted by SDE, SE and SFE were determined using contact and fumigant bioassays against *P. interpunctella* (larvae and adults), *S. cerealella* (adults) and *T. putrescentiae* (adults) (Tables 3, 4). In the contact and fumigant actions against *T. putrescentiae* (Tables 3, 4), the most toxic compound was camphor (2.81 and 3.24 μg/cm^3), followed by linalool (4.39 and 5.49 μg/cm^3) and limonene (22.87 and 43.72 μg/cm^3), respectively. Geranyl acetate, α-pinene and terpinene against *T. putrescentiae* showed no acaricidal effect at the tested concentrations (> 75.20 μg/cm^2 and μg/cm^3). In the fumigant bioassay against *S. cerealella* (Table 4), the most toxic compound was linalool (11.80 μg/cm^3), followed by camphor (19.31 μg/cm^3) and terpinene (30.49 μg/cm^3). Limonene, geranyl acetate and α-pinene showed no insecticidal activity against *S. cerealella* (> 75.20 μg/cm^3) at the tested concentrations in the contact and fumigant bioassays. In the case of *P. interpunctella* larvae, none of the tested compounds showed any insecticidal activity in the contact and fumigant bioassays. Based on the LD_{50} against *P. interpunctella* adults in fumigant bioassay, the most toxic compound was camphor (2.32 μg/cm^3), followed by terpinene (4.62 μg/cm^3), while limonene, linalool, geranyl acetate and α-pinene did not manifest insecticidal activity against *P. interpunctella* adults. In our study, among the six compounds tested, camphor (monoterpene ketone) was the most active against stored product insects tested. The higher potencies of SDE oil compared with SE and SFE oils were attributed to their chemical composition. Camphor constituted 6.46% of the oil composition obtained via SDE and was absent in the other two oils. Similar trends regarding acaricidal and insecticidal activities of camphor against various insect species have already been reported [21, 22]. Papachristos et al. [22] suggested that monoterpene ketones were generally more toxic than monoterpene alcohols, and both showed higher activity compared with monoterpene hydrocarbons. Therefore, the acaricidal and insecticidal activities may be related to the presence of camphor. Certain plant essential oils and plant-derived compounds may manifest either synergistic or antagonistic efficacy in

Table 4 Acaricidal and insecticidal activities of major components derived from *C. sativum* seed oil against *T. putrescentiae*, *S. cerealella* and *P. interpunctella* in the fumigant bioassay[a]

Compounds	Insect	Stage	Fumigant (μg/cm^3)			
			LD_{50} (95% CI)[b]	LD_{90} (95% CI)	Slope ± SE	χ^2 (*df*, *p*)
α-Pinene	*T. putrescentiae*	Adults	> 75.20	–[c]	–	–
	S. cerealella	Adults	> 75.20	–	–	–
	P. interpunctella	Larvae	> 75.20	–	–	–
		Adults	> 75.20	–	–	–
Limonene	*T. putrescentiae*	Adults	43.72 (36.96–51.44)	95.75 (77.41–132.42)	3.76 ± 0.50	4.169 (5, 0.527)
	S. cerealella	Adults	> 75.20	–	–	–
	P. interpunctella	Larvae	> 75.20	–	–	–
		Adults	> 75.20	–	–	–
Terpinene	*T. putrescentiae*	Adults	> 75.20	–	–	–
	S. cerealella	Adults	30.49 (24.91–35.92)	65.82 (53.25–95.00)	3.83 ± 0.65	4.314 (4, 0.365)
	P. interpunctella	Larvae	> 75.20	–	–	–
		Adults	4.62 (3.43–6.30)	16.72 (11.04–34.49)	2.29 ± 0.37	4.140 (4, 0.387)
Linalool	*T. putrescentiae*	Adults	5.49 (4.55–6.65)	13.85 (10.56–21.93)	3.19 ± 0.48	1.194 (5, 0.945)
	S. cerealella	Adults	11.80 (9.95–14.02)	27.59(21.70–40.69)	3.47 ± 0.49	2.372 (5, 0.796)
	P. interpunctella	Larvae	> 75.20	–	–	–
		Adults	> 75.20	–	–	–
Camphor	*T. putrescentiae*	Adults	3.24 (2.66–3.91)	8.46 (6.50–12.92)	3.07 ± 0.44	3.078 (5, 0.688)
	S. cerealella	Adults	19.31 (15.64–23.68)	54.70 (41.25–85.75)	2.83 ± 0.40	4.151 (5, 0.528)
	P. interpunctella	Larvae	> 75.20	–	–	–
		Adults	2.32 (1.73–3.03)	8.43 (5.89–15.17)	2.28 ± 0.34	3.760 (5, 0.584)
Geranyl acetate	*T. putrescentiae*	Adults	> 75.20	–	–	–
	S. cerealella	Adults	> 75.20	–	–	–
	P. interpunctella	Larvae	> 75.20	–	–	–
		Adults	> 75.20	–	–	–

[a]Adults; exposed for 24 h, larvae; exposed for 48 h

[b]LD_{50} is the average of 3 assays in triplicate with 20 insects per assay

[c]No activity

terms of biological activity [10]. The toxicity of *C. sativum* oil is attributed to the composition of camphor and linalool and their combination.

In conclusion, the oils extracted from *C. sativum* seeds via SDE, SE and SFE, and their constituents represent potential acaricides and insecticides targeting *T. putrescentiae*, *P. interpunctella* and *S. cerealella*. Different extraction methods play an important role in extracting specific bioactive compounds from plants. Therefore, the choice of the extraction method dictates the type of bioactive chemicals desired.

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