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ARTICLE

Acaricidal and insecticidal responses of *Cinnamomum cassia* oils and main constituents

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Abstract Insecticidal and acaricidal responses of *Cinnamomum cassia* oils made by organic solvent (OS), steam distillation (SD), and supercritical fluid (SF) and their components were examined in two bioassays (contact and fumigant bioassays) against *Plodia interpunctella*, *Sitophilus oryzae*, *S. zeamais*, *Tyrophagus putrescentiae*, and *Sitotroga cerealella* adults. Using the contact or fumigant bioassay against *T. putrescentiae* adults, OS oil exhibited the strongest toxicities (50% lethal dose [LD_{50}], 2.60 μg/cm^2 and 1.34 μg/cm^3), followed by SF and SD oils. Furthermore, using two bioassays, SD oil against *S. oryzae* and *S. zeamais* adults exhibited the strongest toxicities (LD_{50}, 102.25 μg/cm^2 and 68.62 μg/cm^3, 102.03 μg/cm^2 and 57.59 μg/cm^3), followed by SF and OS oils. Using the fumigant bioassay against *S. cerealella* and *P. interpunctella* adults, OS oil exhibited the strongest toxicities (LD_{50}, 1.17 μg/cm^3 and 0.79 μg/cm^3) followed by SF and SD oils. Cinnamaldehyde, cinnamyl acetate, and coumarin against *T. putrescentiae* adults showed no significant differences in the contact bioassay, but in the fumigant bioassay, cinnamaldehyde exhibited the highest toxicity (LD_{50}, 0.91 μg/cm^3) followed by cinnamyl acetate and coumarin. Against *S. oryzae*, *S. zeamais*, *S. cerealella,* and *P. interpunctella* adults, cinnamaldehyde using two bioassays exhibited the most potent toxicities (LD_{50}, 108.81 μg/cm^2 and 77.80 μg/cm^3, 104.72 μg/cm^2 and 36.48 μg/cm^3, 0.57 μg/cm^2 and 2.29 μg/cm^3), followed by coumarin and cinnamyl acetate in order. The results showed that cinnamaldehyde and the *C. cassia* oils could be effective values in the management of stored product pests.

Keywords Acaricidal responses · *Cinnamomum cassia* · *Plodia interpunctella* · *Sitotroga cerealella* · *Sitophilus oryzae* · *Tyrophagus putrescentiae*

Introduction

Protecting food crops against damage from stored product pests and storage pathogens is a major concern for public health organizations, the food industry, and environmental agencies. *Tyrophagus putrescentiae*, *Sitophilus oryzae*, *S. zeamais*, *Sitotroga cerealella,* and *Plodia interpunctella* are worldwide-distributed grave loss economic pests that infest stored products [1–3]. *Tyrophagus putrescentiae* is a major species often encountered infesting a large variety of stored foods and grains [4–6]. *S. oryzae* and *S. zeamais* are two of the most serious and destructive pests found in stored grains throughout the world [7, 8]. They cause widespread loss in grains and affect the quantity and quality of the grains and grain products [9]. The *S. cerealella* feeds on grains of the superficial layers of the stored crops and reduces both their weights and nutritional values [10]. *P. interpunctella* is a lepidopteran insect pest undergoing larvae diapause as a pre-pupa, and the larval stage gives great damage to the stored products by polyester, penetrating foil, and polypropylene film covering the stored foods [11]. The management of stored product pests is conducted via the application of pesticides. Synthetic chemicals (γ-benzene hexachloride, pirimiphos-methyl, and dichlorvos) have been instrumental thus far in the development of contemporary agriculture. Nevertheless,

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the misuse and overuse of pesticides have sometimes resulted in problems such as environmental pollution, poisoning, pest resurgence, and pesticide resistance. Therefore, consumers today demand environmentally safe pesticides with low toxicity and long-term control [12, 13]. Natural products exhibiting insecticidal based on plant essential oils may represent alternatives to synthetic insecticides. *Cinnamomum cassia* barks may be an alternative source of materials for stored product pests control because they contain a range of bioactive chemicals [14]. Furthermore, the extract derived from *C. cassia* barks shows antioxidant activities, and inhibitors against harmful bacteria are used in traditional medicine for anti-ulcer and analgesic effects [15]. The aim of our study was to assess the insecticidal and acaricidal responses of *C. cassia* oils made by three different methods, as well as their constituents.

Materials and method

Sample preparation and chemicals

The *C. cassia* barks (10 kg) were obtained from a local market (Jeonju, South Korea). Cinnamaldehyde (≥ 95%), cinnamyl acetate (99%), and coumarin (≥ 99%) were purchased from Sigma (St. Louis, MO, USA).

Steam distillation (SD)

Essential oils of *C. cassia* barks were prepared as follows: 300 g sample of 150 μm particle size was weighted into a 3000-mL glass distillation flask, 1500 mL distilled water was added and SD for 4.1 h at 101 °C using oil extraction equipment (Micro, Daejeon, South Korea). As the water is heated, the water vapor was produced by the steam extractor and the steam passed to the evaporative condenser and collected in the receiving glass flask.

Organic solvent (OS)

C. cassia barks were broken into shatters and placed in a 4.5-L glass flask (Erlenmeyer) with hexane (1500 mL × 2). The extraction was conducted on a shaking incubator (Edun, Seongnam, South Korea) at 210 rpm and 26 °C for 48 h. The *C. Cassia* bark oil was filtered.

Supercritical fluid (SF)

SF was performed using supercritical fluid extractor (Ilshin autoclave, Daejeon, South Korea). The *C. cassia* barks were broken into shatters and powdered. The control of the extraction process was performed at 300 bar and 50–40 °C for 123 min, in which the CO_2 flow rate was generally 61 mL/min.

Stored product pest colonies

S. oryzae, *S. zeamais*, *S. cerealella*, and *P. interpunctella* adults were reared from the insect-rearing room at 26.5 ± 1 °C and 60 ± 5% relative humidity (RH). They were reared on barley and rice bran in a cage (39 × 40 × 40 cm^3). *T. putrescentiae* was reared on fry feed including calcium (1.1%), fiber (4.0%), protein (45.0%), lipid (3.0%), phosphate (2.0%), and dried yeast and housed in circular plastic cage (15 × 12 × 6 cm, SPL, Pocheon, South Korea) under controlled conditions (25.5 ± 1 °C, 71 ± 4.5% RH). Fry feed was purchased from Korea Special Feed Meal Co. (Jeonju, South Korea).

Chemical analysis of *C. cassia* bark oils

Three oils of *C. cassia* barks were studied with GC/MS (HP 6890 and 5973 series; Santa Clara, CA, USA) and separated using a DB-5 fused silica column (30 ml × 0.25 mm I. d × 0.25 μm thickness, J&W Scientific, Folsom, CA, USA). GC/MS conditions were: flow rate of helium, 0.74 mL/min; injector temperature, 209 °C; ion source temperature, 201 °C; sample temperature initially at 20 °C for 16 min, then programmed to increase by 2 °C/min up to 221 °C. MS detector was controlled in the electron ionization mode at 71 eV with a scan portion of 20–401 amu. The major components of *C. cassia* oils were identified by comparing mass spectra to the Wiley Registry of Mass Spectral Data (8th edition) and the retention indices. The relative percentages (%) of the *C. cassia* oil components were measured by comparison with internal standards.

Bioassays

Contact or fumigant bioassay was studied in order to access the acaricidal activities of main compounds and *C. cassia* oils made by SD, OS, and SF against *T. putrescentiae.* Acaricidal activity against *T. putrescentiae* was observed with contact or fumigant bioassay [16, 17]. In the contact bioassay, differing concentrations from 1000 to 0.5 μg/cm^2 in 50 μL were added to filter papers (35 mm diameter, 55 μm thick, Chmlab, Terrassa, Spain). After being dried on the table for 10.5 min, the worked up filter paper was placed in a Petri dish (10 mm × 35 mm, Spl, Pocheon, South Korea). Twenty mites were transferred to each Petri dish, which was covered with a lid and completely sealed. In the fumigant bioassay, varying concentrations ranging from 1000 to 0.5 μg/cm^3 in acetone (10 μL) were added to paper disks (1 mm thick and 8 mm diameter). The paper

disk (Advantec, Tokyo, Japan) was dried on the table for 10 min and put in a microtube (Spl, Pocheon, South Korea). Treatments in the contact or fumigant method were repeated three times at 27 ± 2 °C with 70 ± 5% RH for 24 h. Acetone was used as the negative control.

The insecticidal effect of the main compounds and the *C. cassia* bark oil against *S. oryzae*, *S. zeamais*, *S. cerealella,* or *P. interpunctella* adults with contact or fumigant method was studied as previously described [18]. Several concentrations (1000–0.5 μg/cm^2) of the sample in the contact bioassay were suspended in methanol and dropped on to filter papers (55 μm thick, 60 mm diameter). Filter paper was placed in a Petri dish (60 mm × 15 mm) after being dried on the table for 15 min. Each of the four types of stored product pests was moved into the Petri dish; then, the dishes were covered with lids and completely sealed. In the fumigant bioassay, appropriate concentrations (1000–0.5 μg/cm^3) of the samples against stored product pests were treated on the filter paper after being dried on the table for 15 min. The impregnated filter paper was then put inside the lids and cotton fabric pieces (100 mm diameter) of a bottle (80 mm height, 90 mm diameter). These glass bottles were retained at 27 ± 1 °C with 60 ± 5% RH for 48 h. The mortality of twenty larvae and adults was written down after treatment.

Statistics

This study used probit analysis using SPSS version 12.0 for Windows (SPSS INC., Chicago, IL, USA). The mortality of each concentration was calculated after 24 h and 48 h as the means of three replicates. The values of LD_{50} and LD_{90} were studied to be different if their 95% confidence limits did not overlap with each other.

Result and discussion

Insecticidal and acaricidal responses of *C. cassia* oils made by three different methods

Essential oils of the *C. cassia* barks extracted by steam distillation (SD), organic solvent (OS), and supercritical fluid (SF) exhibited yields of 0.65, 4.06, and 7.61%, respectively. The acaricidal responses of three *C. cassia* oils made by SD, OS, and SF against *T. putrescentiae* adults were examined using contact or fumigant bioassay (Table 1). The LD_{50} values of SD, OS, and SF extracts against *T. putrescentiae* adults in the contact bioassay were 5.64, 2.60, and 3.10 μg/cm^2, respectively. The LD_{50} values of SD, OS, and SF extracts against *T. putrescentiae* adults in the fumigant bioassay were 2.29, 1.34, and 1.54 μg/cm^3, respectively. Acaricidal activities were not observed in the acetone (negative control) for *T. putrescentiae* adults. Based on the LD_{50} values, the OS oil was more sensitive than the other oils against *T. putrescentiae* adults. In a previous report, the acaricidal responses of *C. cassia* oils were shown to be influential by proportion and type of constituent from essential oil, detoxification enzyme effect, and the biological requirement conditions of mites [17].

The insecticidal responses of *C. cassia* oils made by SD, OS, and SF were studied by contact or fumigant bioassay against *S. oryzae*, *S. zeamais*, *S. cerealella,* and *P. interpunctella* adults (Table 1). Using the contact or fumigant bioassay against *S. oryzae* adults, SD oil (LD_{50}, 102.25 μg/cm^2 and 68.62 μg/cm^3, respectively) was found to have the most effective insecticidal activities, followed by SF oil (204.12 μg/cm^2 and 75.28 μg/cm^3, respectively) and SE oil (213.87 μg/cm^2 and 128.59 μg/cm^3, respectively). Using the contact and fumigant bioassays against *S. zeamais* adults, SD oil (LD_{50}, 102.03 μg/cm^2 and 57.59 μg/cm^3, respectively) had the most effective insecticidal activities. SE and SF oils were not significantly different from each other in the contact or fumigant method against *S. zeamais*. Using the fumigant bioassay against *S. cerealella* and *P. interpunctella* adults, SE oil (LD_{50}, 1.17 μg/cm^3 and 0.79 μg/cm^3, respectively) had the most potent insecticidal activities, followed by SF oil (LD_{50}, 1.47 μg/cm^3 and 1.07 μg/cm^3, respectively) and SD oil (LD_{50}, 1.95 μg/cm^3 and 1.31 μg/cm^3, respectively). Insecticidal activities were not observed in the methanol (negative control) against *S. oryzae*, *S. zeamais*, *S. cerealella,* or *P. interpunctella* adults.

Composition of *C. cassia* oils made by SD, OS, and SF

In order to study the acaricidal and insecticidal responses of the active component derived from *C. cassia* oils against *T. putrescentiae*, *S. oryzae*, *S. zeamais*, *S. cerealella,* and *P. interpunctella* adults, the components of *C. cassia* oils were analyzed through GC/MS (Table 2). Three oils comprised phenylpropanoid esters, phenylpropanoid hydrocarbons, sesquiterpene alcohol, sesquiterpene hydrocarbons, and sesquiterpene ketones. The components of the *C. cassia* oil extracted by SD were found to be the highest at cinnamaldehyde (83.19%), followed by at cinnamyl acetate (5.77%), coumarin (2.6%), α-copaene (2.3%), δ-cadinene (1.77%), muurolene (1.39%), cadinol (0.57%), α-cedrene (0.45%), cubinene (0.44%), β-caryophyllene 3-ethoxy-hexa-1,5-dienyl-benzene (0.40%), cyclosativene (0.32%), α-calacorene (0.22%), and α-humulene (0.19%). Main components of the *C. cassia* oil extracted by OS were in descending order cinnamaldehyde (75.94%), δ-cadinene (3.81%), coumarin (3.77%), α-copaene (3.77%), muurolene (3.75%), cinnamyl acetate (2.0%), cubinene (1.09%), cyclosativene (0.37%), 3-ethoxy-hexa-1,5-dienyl-benzene (0.29%), and α-cedrene

Table 1 Acaricidal[a] and insecticidal[b] activities of *Cinnamomum cassia* oils extracted through three different methods against stored product pests using the contact or fumigant bioassay

Insect	Bioassay	LD_{50} (95% CI)		
		Extraction methods		
		Steam distillation (SD)	Organic solvent (OS)	Supercritical fluid (SF)
T. putrescentiae	Contact	5.64	2.60	3.10
	(μg/cm^2)	(4.00–7.07)	(1.58–3.56)	(1.65–4.59)
	Fumigant	2.29	1.34	1.54
	(μg/cm^3)	(1.94–2.92)	(1.01–1.59)	(1.26–1.80)
S. oryzae	Contact	102.25	213.87	204.12
	(μg/cm^2)	(82.48–129.27)	(173.45–260.35)	(164.78–248.54)
	Fumigant	68.62	128.59	75.28
	(μg/cm^3)	(57.61–82.31)	(102.10–159.82)	(62.48–89.07)
S. zeamais	Contact	102.03	211.37	221.15
	(μg/cm^2)	(83.50–120.78)	(173.73–253.56)	(183.00–264.36)
	Fumigant	57.59	59.42	37.81
	(μg/cm^3)	(49.87–67.26)	(51.63–69.00)	(30.61–47.04)
S. cerealella	Fumigant	1.95	1.17	1.47
	(μg/cm^3)	(1.31–2.52)	(0.73–1.63)	(1.03–1.94)
P. interpunctella	Fumigant	1.31	0.79	1.07
	(μg/cm^3)	(1.06–1.63)	(0.55–1.09)	(0.79–1.41)

[a]Exposed for 24 h

[b]Exposed for 48 h

(0.2%). The main components of the *C. cassia* oil made by SF were in descending order cinnamaldehyde (72.36%), α-copaene (9.81%), coumarin (5.64%), δ-cadinene (3.58%), cinnamyl acetate (3.46%), muurolene (2.42%), β-caryophyllene (0.56%), α-humulene (0.29%), and cyclosativene (0.18%). Similar to a prior study [19], cinnamaldehyde was the major component of *C. cassia* oils extracted by the three extraction methods with only slight differences in content. Our study also showed that the components of the *C. cassia* oil extracted by SD, OS, and SF were mostly similar.

Insecticidal and acaricidal responses of major commercial components (cinnamaldehyde, cinnamyl acetate, and coumarin) derived from the SD, OS, and SF oils

The acaricidal activities of three major commercial components (cinnamaldehyde, cinnamyl acetate, and coumarin) derived from the SD, OS, and SF oils against *T. putrescentiae* adults were examined using the contact or fumigant bioassay (Table 3). The LD_{50} values of cinnamaldehyde, cinnamyl acetate, and coumarin against *T. putrescentiae* adults in the contact bioassay were 1.93, 1.85, and 1.54 μg/cm^2, respectively. The LD_{50} values of cinnamaldehyde, cinnamyl acetate, and coumarin against *T. putrescentiae* adults in the fumigant method were 0.91, 1.00, and 2.26 μg/cm^3, respectively. Based on the LD_{50} values against *T. putrescentiae* adults, cinnamaldehyde, cinnamyl acetate, and coumarin were not significantly different in the contact activities, but cinnamaldehyde was the most active in the fumigant bioassay. In a previous research, the acaricidal activities of cinnamaldehyde, which is the main component of *C. cassia*, were found to be potent against *T. putrescentiae* adults [20, 21].

The insecticidal activities of cinnamaldehyde, cinnamyl acetate, and coumarin against *S. oryzae*, *S. zeamais*, *S. cerealella,* and *P. interpunctella* adults were examined using the contact or fumigant method (Table 3). Using contact bioassay against *S. oryzae*, cinnamaldehyde (LD_{50}, 108.81 μg/cm^2) was found to have the most effective insecticidal activities. Cinnamyl acetate and coumarin showed no insecticidal activities in the contact bioassay against *S. oryzae* adults. Using the fumigant bioassay against *S. oryzae* adults, coumarin (LD_{50}, 38.03 μg/cm^3) was found to have the most effective insecticidal activities, followed by cinnamaldehyde (LD_{50}, 77.80 μg/cm^3). Cinnamyl acetate showed no insecticidal activities in the fumigant method against *S. oryzae* adults. Using the contact bioassay against *S. zeamais* adults, cinnamaldehyde (LD_{50}, 104.72 μg/cm^2) was found to have the most effective insecticidal activities, followed by coumarin (LD_{50}, 213.74 μg/cm^2). Cinnamyl acetate showed no insecticidal activities in the contact method against *S. zeamais* adults. Using the fumigant method against *S. zeamais* adults, cinnamaldehyde (LD_{50}, 36.48 μg/cm^3) was found to have

Table 2 GC/MS analyses of *Cinnamomum cassia* oils obtained through three different extraction methods

No.	Compounds	RI[a]	Relative amount (%)		
			Extraction methods		
			SD[c]	OS[d]	SF[e]
1	Cyclosativene	1125	0.32	0.37	0.18
2	Cinnamaldehyde	1283	83.19	75.94	72.36
3	Cinnamyl acetate	1367	5.77	2.0	3.46
4	α-Copaene	1377	2.30	3.77	9.81
5	Coumarin	1439	2.60	3.77	5.64
6	Cubinene	1440	0.44	1.09	–[b]
7	α-Humulene	1467	0.19	–	0.29
8	β-Caryophyllene	1494	–	–	0.56
9	3-Ethoxy-hexa-1,5-dienyl-benzene	1499	0.40	0.29	–
10	δ-Cadinene	1519	1.77	3.81	3.58
11	Muurolene	1523	1.39	3.75	2.42
12	α-Cedrene	1580	0.45	0.20	–
13	Cadinol	1676	0.57	–	–
14	α-Calacorene	1859	0.22	–	–
	Major grouped compounds				
	Phenylpropanoid esters		5.77	2.0	3.46
	Phenylpropanoid hydrocarbons		83.59	76.23	72.36
	Sesquiterpene alcohol		0.57	–	–
	Sesquiterpene hydrocarbons		7.08	12.99	16.84
	Sesquiterpene ketones		2.60	3.77	5.64
Total (%)			99.61	94.99	98.3
Yield (%)			0.65	4.06	7.61

[a]Retention indices determined on a DB-5 column

[b]Not detected

[c]Steam distillation

[d]Organic solvent

[e]Supercritical fluid

the most effective insecticidal activities, followed by coumarin (LD_{50}, 74.64 μg/cm^3). Cinnamyl acetate in the fumigant bioassay showed no insecticidal activities against *S. zeamais* adults. Cinnamaldehyde (LD_{50}, 0.57 μg/cm^3) in the fumigant method against *S. cerealella* adults was found to have the most potent insecticidal activities, followed by coumarin (LD_{50}, 9.36 μg/cm^3) and cinnamyl acetate (LD_{50}, 9.39 μg/cm^3). Using the fumigant bioassay against *P. interpunctella* adults, cinnamaldehyde (LD_{50}, 2.29 μg/cm^3) was found to have the most effective insecticidal activities. Cinnamyl acetate and coumarin showed no insecticidal activities in the fumigant bioassay against *P. interpunctella* adults. A previous research reported cinnamaldehyde to be the major component of *C. cassia*, and the component was shown to be important in controlling stored product pests [22]. The oils that contain high levels of cinnamaldehyde are potent against stored product pests [23]. The acaricidal and insecticidal responses of the *C. cassia* appear to be related to their composition. In a previous study, cinnamon oil was shown to have detrimental effects on the permeability of cell membrane and inhibit the growth caused by the disruption of intracellular enzymes [24]. Cinnamon oil is registered with the US Food and Drug Administration (FDA) and is exempt from US Environmental Protection Agency toxicological data requirements. Cinnamon shows a variety of pharmacological activities, including anti-allergy [25] and anti-bacterial [26] activities.

Our study examined the insecticidal and acaricidal responses of *C. cassia* oils made by three different methods and their constituents against *S. oryzae*, *S. zeamais*, *T. putrescentiae, S. cerealella,* and *P. interpunctella* adults. SD extraction has been compared to other extraction techniques (OS and SF) for the extraction of active compounds, and SD extraction provides better results. The *C. cassia* oil extracted by SD had the highest contents of

Table 3 Acaricidal[a] and insecticidal[b] activities of major components derived from three *Cinnamomum cassia* oils against stored product pests using the contact or fumigant bioassay

Compounds	Insect	Stage	Bioassay	LD_{50} (95% CI)	LD_{90} (95% CI)	Slope ± SE	χ^2 (*df*, *p*)
Cinnamaldehyde	*T. putrescentiae*	Adults	Contact (μg/cm^2)	1.93 (1.36–2.43)	6.23 (4.82–9.46)	2.52 ± 0.42	4.578 (5, 0.599)
			Fumigant (μg/cm^3)	0.91 (0.75–1.12)	2.30 (1.70–4.03)	3.19 ± 0.55	5.080 (4, 0.279)
	S. oryzae	Adults	Contact (μg/cm^2)	108.81 (88.69–130.72)	245.18 (193.99–360.10)	3.63 ± 0.57	3.189 (4, 0.527)
			Fumigant (μg/cm^3)	77.80 (58.04–104.97)	291.32 (195.39–562.98)	2.23 ± 0.33	2.648 (4, 0.618)
	S. zeamais	Adults	Contact(μg/cm^2)	104.72 (85.25–129.05)	241.79 (183.89–392.71)	3.52 ± 0.59	6.657 (4, 0.155)
			Fumigant (μg/cm^3)	36.48 (29.44–45.43)	97.14 (72.08–160.93)	3.01 ± 0.46	6.255 (4, 0.181)
	S. cerealella	Adults	Fumigant (μg/cm^3)	0.57 (0.43–0.77)	2.05 (1.39–3.90)	2.32 ± 0.35	6.676 (4, 0.154)
	P. interpunctella	Adults	Fumigant (μg/cm^3)	2.29 (1.71–2.98)	8.15 (5.72–14.75)	2.32 ± 0.36	2.767 (4, 0.597)
Cinnamyl acetate	*T. putrescentiae*	Adults	Contact (μg/cm^2)	1.85 (1.30–2.34)	5.91 (4.60–8.86)	2.55 ± 0.42	3.382 (4, 0.760)
			Fumigant (μg/cm^3)	1.00 (0.84–1.21)	2.27 (1.76–3.47)	3.64 ± 0.56	5.058 (4, 0.281)
	S. oryzae	Adults	Contact (μg/cm^2)	–	–	–	–
			Fumigant (μg/cm^3)	–	–	–	–
	S. zeamais	Adults	Contact (μg/cm^2)	–	–	–	–
			Fumigant (μg/cm^3)	–	–	–	–
	S. cerealella	Adults	Fumigant (μg/cm^3)	9.39 (8.33–10.72)	16.19 (13.58–21.76)	5.42 ± 0.83	2.197 (4, 0.700)
	P. interpunctella	Adults	Fumigant (μg/cm^3)	–	–	–	–
Coumarin	*T. putrescentiae*	Adults	Contact (μg/cm^2)	1.54 (1.12–1.97)	6.57 (4.75–11.04)	2.04 ± 0.31	6.317 (7, 0.503)
			Fumigant (μg/cm^3)	2.26 (1.96–2.60)	4.20 (3.47–5.77)	4.74 ± 0.72	5.477 (4, 0.242)
	S. oryzae	Adults	Contact (μg/cm^2)	–	–	–	–
			Fumigant (μg/cm^3)	38.03 (30.68–47.53)	102.61 (75.52–173.80)	2.97 ± 0.47	5.929 (4, 0.205)
	S. zeamais	Adults	Contact (μg/cm^2)	213.74 (172.60–261.12)	567.44 (428.61–921.98)	3.02 ± 0.48	5.536 (4, 0.237)
			Fumigant (μg/cm^3)	74.64 (172.60–261.12)	182.07 (137.66–296.44)	3.30 ± 0.53	5.004 (4, 0.287)
	S. cerealella	Adults	Fumigant (μg/cm^3)	9.36 (8.33–10.66)	15.85 (13.36–21.09)	5.61 ± 0.85	2.781 (4, 0.595)
	P. interpunctella	Adults	Fumigant (μg/cm^3)	–	–	–	–

[a]Exposed for 24 h

[b]Exposed for 48 h

[c]No activity

cinnamaldehyde (83.19%), which is the major insecticidal and acaricidal ingredient in *C. cassia*. Therefore, our results are potentiality helpful in the management of *T. putrescentiae, S. oryzae*, *S. zeamais*, *S. cerealella,* and *P. interpunctella* adults. *C. cassia* oil could aid in the development of effective natural acaricides and insecticides.

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