International Journal of Entomology Research
www.entomologyjournals.com
ISSN: 2455-4758
Received: 20-08-2024, Accepted: 19-09-2024, Published: 04-10-2024
Volume 9, Issue 10, 2024, Page No. 42-48

Evaluation of insecticidal properties of cinnamaldehyde and cuminaldehyde against *Sitophilus zeamais*

Mukesh Kumar Chaubey[1*], Namita Kumar[2]
[1] Department of Zoology, National Post Graduate College, Barahalganj, Gorakhpur, Uttar Pradesh, India
[2] Department of Zoology, Mahatma Gandhi Post Graduate College, Gorakhpur, Uttar Pradesh, India

Abstract
Application of insecticides of synthetic nature in insect pest management programmes causes cancer, fetal deformities, mutation, and neurological disorders in non-target animals as well as depletion of ozone layer. These insecticides cause disturbances in food chains and changes pattern of food webs besides developing resistance in insects. These issues have forced the researchers to explore plant volatiles chemicals as insecticides in insect pest management. This study involves evaluation of two natural organic volatile chemicals viz., cinnamaldehyde and cuminaldehyde for its efficacy as insecticide for *Sitophilus zeamais* management. Cinnamaldehyde and cuminaldehyde have also been tested for its effect on oviposition, feeding potency and adult emergence of the insect. In fumigation toxicity assay, adults of *S. zeamais* were killed by the vapours of cinnamaldehyde and cuminaldehyde and median lethal concentrations (LC_{50}) were 0.462 and 0.302 µl/cm^3; and 0.423 and 0.286 µl/cm^3 air respectively for 24 and 48 hours exposure period. In contact toxicity assay, adults of *S. zeamais* were killed when come in contact with median lethal concentrations (LC_{50}) of 0.290 and 0.195 µl/cm^2; and 0.287 and 0.187 µl/cm^2 of area for cinnamaldehyde and cuminaldehyde when exposed for 24 and 48 hours respectively. Besides, reduction in acetylcholine esterase activity, oviposition, feeding and adult emergence was reduced by cinnamaldehyde and cuminaldehyde in *S. zeamais*. Therefore, cinnamaldehyde and cuminaldehyde can be used in designing cinnamaldehyde and cuminaldehyde based formulation in the management of insect pest under storage.

Keywords: Cinnamaldehyde, cuminaldehyde, insecticides, *Sitophilus zeamais*, oviposition inhibition, acetylcholine esterase

Introduction

Stored grain insect pests cause huge economic loss worldwide annually by damaging quality and quantity of grains under storage. Various insecticides have been synthesized, formulated and applied against a number of insect pests in the past. But, continuous and unlimited applications of these synthetic insecticides deplete ozone layer (WMO, 1991; UNEP, 2000) [54, 60]; as well as cause cancer, foetal deformities, mutations and neurological disorders in non-target animal species. These insecticides have developed various types of resistance in a variety of insects (Lu, 1995) [35]. These synthetic insecticides enter in human food chain and cause unintentional death annually (Alavanja and Bonner, 2012; EEA, 2013) [1, 17]. Organochlorines are the most persistant among these insecticides bioaccumulating in honey bees, carps, amphibious animals, aves and mammals (Kohler and Triebskorn, 2013; WHO, 2017) [29, 59]. Thus, researches have been searching natural plant based volatile molecules as substitute of synthetic insecticides in different insect pest management programmes. The volatile molecules are manofatured in a variety of aromatic plants of diverse families as metabolites for secondary function. A variety of factors like plants parts taken for isolation, process of isolation, plant age and genotype, month of year of collection of plant material and soil nature determine the composition of these volatiles (Atti-Santos *et al.* 2004; *Angioni et al.* 2006; Verma *et al.* 2011) [2, 3, 57]. These volatile chemicals affect viability, feeding, fecundity and development of a number on insects (Caballero-Gallardo *et al.* 2011; Isman *et al.* 2011; Liu *et al.* 2011; Stefanazzi *et al.* 2011; Chaubey, 2012a,b,c; Chaubey and Kumar, 2021) [5, 6, 7, 12, 13, 27, 34, 48].

Cinnamaldehyde is a phenylpropanoid compounds with a characteristic cinnamon odour (Gutzeit, 2014) [22] (Fig. 1). It is a viscous liquid of pale yellow colour constituting 90% of cinnamon bark oil (Kumar *et al.* 2012) [30]. It is used commercially in chewing gum, ice creams, candies and beverages production to add flavour. It shows repellent and lethal property against mosquito (Cheng *et al.* 2004; Ma *et al.* 2014) [15, 36]. It shows antimicrobial effects in several infectious bacterial and fungal species (Shen *et al.* 2015; Shreaz *et al.* 2016; Vasconcelos *et al.* 2018) [43, 44, 56]. It also shows anti-tumour and anti-inflammatory effects (Imai *et al.* 2002; Lee *et al.* 2004; Guo *et al.* 2006; Liao *et al.* 2012) [21, 26, 32, 33]. Cuminaldehyde, a monoterpenoid is a constituent of cumin volatile oils (Hajlaoui *et al.* 2010; Rihawy *et al.* 2014; Wei *et al.* 2015) [23, 40, 58] (Fig. 1). Due to its pleasant frangrance, it finds commercial role in preparation of perfumes and cosmetics. It has promising antimicrobial activities against different strains of bacteria (Sekine *et al.* 2007; Suleimana *et al.* 2009; Rasheehan *et al.* 2013; Khalil *et al.* 2018) [28, 39, 42, 49]. It shows anti-inflammatory, anti-cancer and anti-mutagenic effects (Medzhitov, 2008; Shu-meiang *et al.* 2016) [37, 45].

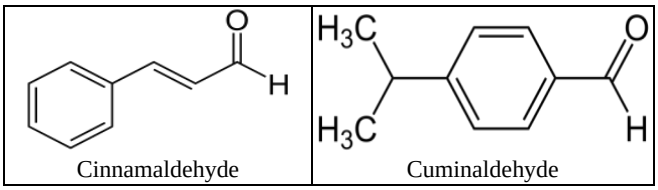

Fig 1: Structure of cinnamaldehyde and cuminaldehyde

Maize weevil, *Sitophilus zeamais*, a beetle (order: Coleoptera, family: Curculionidae) is a serious primary pest which infests previously undamaged grains. It is a polyphagus insect and both male and female adults infest intact grains of barley, maize, oats, rice, rye, wheat etc., consume whole grains and the larvae develop in grain kernel cryptically (Ileleji *et al.* 2007; Demissie *et al.* 2008) [16, 25] (Fig. 2). This weevil is found in those regions of the globe where human food contains maize in large. In the present study, different biological assays have been performed to evaluate efficacy of cinnamaldehyde and cuminaldehyde as insecticidal tool against against *S. zeamais*.

Fig 2: Adult of *Sitophilus zeamais*

Materials and methods

Compounds

Pure compounds viz. cinnamaldehyde (3-phenylprop-2-enal) and cuminaldehyde (4-Isopropylbenzaldehyde) were purchased from Sigma Chemical Company, USA.

Insects

Laboratory culture of different phases of *S. zeamais* was maintained on maize at temperature range 28±4^{0}C, relative humidity 50±5% and photoperiod 10:14h (Light:Dark). Insects from laboratory culture were used for different and biological assays.

Repellent activity

Repellent activity of cinnamaldehyde and cuminaldehyde was accessed using method developed by Tripathi *et al.* (2000) [53]. In this method, cinnamaldehyde and cuminaldehyde was dissolved in acetone to prepare experimental solution. Two equal halves of a filter paper disc were made by cutting and one half of the filter paper disc was impregnated with experimental solution and considered as treated, while other half of the filter paper disc was treated with acetone only and considered as control. Treated and control halves were dried in air to evaporate acetone completely and reattached using cellophane tape. Now, processed filter paper disc containing half treated and other half control portion was taken in petri dish (diameter 8.5 cm and height 1.2 cm) and adults of *S. zeamais* were introduced at the centre. Now petri disd was covered and kept in dark. After four hours of initiation of the assay, numbers of adults in treated and control filter paper half was recorded to calculate percent repellency (PR) and preference index (PI). In this assay, four different concentrations of each chemical were taken and six replications were set for each concentration of chemical. Percent repellency and preference index was estimated by calculated using the following relationships:

Percent repellency (PR) = [(C-T)/(C+T)] ×100

Where,
C = number of insects in the untreated halves
T = number of insect in treated halves.

Preference Index (PI) = $(N_T-N_{UT})/ (N_T+N_{UT})$

Where, N_T = % insects in treated halves
N_{UT} = % insects in untreated halves.

Fumigant toxicity

In fumigant toxicity assay, cinnamaldehyde and cuminaldehyde were dissolved in acetone to make experimental solutions. A whatmann's filter paper strip of 2 cm diameter was treated with experimental solution, air dried to evaporate solvent and pasted on undersurface of petri dish. Now, ten adults of *S. zeamais* and maize grains were taken in petri dish (diameter 8.5 cm and height 1.2 cm), covered with cover contain treated filter paper strip, sealed with parafilm and kept in conditions maintained for laboratory culture in dark. All the experimental conditions were similar to that applied for insect culture. After 24 and 48 hours of exposure period, number of insects dead was counted (Chaubey, 2012c) [7].

Contact toxicity

In contact toxicity assay, cinnamaldehyde and cuminaldehyde were dissolved in acetone to make experimental solutions. Poured experimental solution in petri dish (diameter 8.5 cm and height 1.2 cm), evaporated the acetone completely, released *S. zeamais* adults in petri dish and kept in dark. All the experimental conditions were similar to that applied for insect culture. After 24 and 48 hours of exposure period, number of insects dead was counted (Chaubey, 2012b) [6].

Acetylcholine esterase activity

Acetylcholine esterase activity was measured using method of Ellman *et al.* (1961) [18]. Adults of *S. zeamais* were fumigated with two sub-lethal concentrations of cinnamaldehyde and cuminaldehyde for 24 hours as was done in fumigant toxicity assay (Chaubey 2012a) [12]. The survived adults were collected, homogenized in buffer (50mM, pH8) and centrifuged for 30 minutes at 1000 rpm. The supernatant was collected and used as enzyme source. Now, in 0.1 ml of enzyme source, 0.1 ml of the substrate, acetylcholine iodide (ATChI) (0.5mM), 0.05 ml of 5,5-dithiobis 2-nitrobenzoic acid (DTNB) (0.33mM) and 1.45 ml of phosphate buffer (50mM, pH 8.0) were added and incubated at 25^{0}C for 3 min. Enzyme activity was measured by determining changes in the absorbency at 412 nm and expressed in terms of µmole of 'SH' hydrolyzed/min mg protein.

Oviposition inhibition

In oviposition inhibition assay, five pairs of *S. zeamais* adults were fumigated with two sub-lethal concentrations viz. 40 and 80% of 24h-$LC_{50}$of cinnamaldehyde and cuminaldehyde as was done in fumigant toxicity assay. After 24 hours of initiation of treatment, adults were reared in conditions used for insect culture for 10 days. After completion of fumigation, adults were removed, and newly emerged adults were counted till 45th day. For each concentration of compound as well as control group, six replications were set. Efficacy of tested volatile compounds was estimated in terms of percent oviposition deterrence using Vanmathi *et al.* (2012) [55] method.

Percent oviposition deterrence (POD) = $[(E_C-E_T)/E_C] \times 10$

Where,
E_C = number of adults emerged in control
E_T = number of adults emerged in test

Developmental inhibition

In this assay, five pairs of *S. zeamais* adults were taken along with maize grains in plastic box, and allowed to copulation and oviposition. Now, freshly laid eggs and emerged larvae were fumigated with cinnamaldehyde and cuminaldehyde till the emergence of adults. Six replications were set for treated as well as control group. Inhibition rate (IR) was measured by counting the number of adults emerged in treated as well as control groups using the formula developed ny Tapondju *et al.* (2002) [50].

Inhibition rate (IR) = $[(Cn-Tn)/Cn] \times 100$

Where,
Cn = number of adults emerged in control
Tn = number of adults emerged in test

Antifeedant Activity

In this assay, a suspension of maize flour was made by mixed it with water. Now, the suspension of maize flour was pipetted out onto a plastic sheet, develop the suspensions as discs by drying then at 25^0C for 1 day and then at 60^0 C for one hour. The dried flour discs were weighed after soaking cinnamaldehyde and cuminaldehyde. These flour discs were then placed in petri dish and released twenty five *S. zeamais* adults. The adult insects were allowed to feed for four days. After that, reweighed flour discs to estimate antifeedant activity cinnamaldehyde and cuminaldehyde. Antifeedant activity (AFA) was calculated by using formula developed by Sithisut *et al.* (2011) [46].

AFA = $[C-T/C] \times 100$

Where, C = consumption of flour disc in control group
T = consumption of flour disc in treated group

Statistical analysis

POLO programme was used median lethal concentration (LC_{50}) (Russel *et al.* 1977) [41]. To test the significancy of the data, analysis of variance (ANOVA), correlation and regression was perfomed (Sokal and Rohlf, 1973) [47].

Results

Repellent activity

Both cinnamaldehyde and cuminaldehyde repelled *S. zeamais* adults maximally at 0.8% concentrations. Increase in the concentrations of cinnamaldehyde and cuminaldehyde enhanced percent repellency (PR) and preference index (PI) (Table1).

Table 1: Repellent activity of cinnamaldehyde and cuminaldehyde against *S. zeamais* adults

Compound	Concentration (%)	Percent Repellency (PR)* Mean±SD	Preference Index (PI)**
Cinnamaldehyde	0.1	19.17	-0.19
	0.2	44.17	-0.44
	0.4	75.82	-0.75
	0.8	98.32	-0.98
Cuminaldehyde	0.1	16.67	-0.16
	0.2	38.32	-0.38
	0.4	66.67	-0.66
	0.8	92.92	-0.92

*Percent repellency (PR) was calculated using formula: PR = $[(C-T)/(C+T)] \times 100$, C = number of insects in the untreated halves and T = number of insect in treated halves; **Preference index (PI) was calculated using formula: PI = (percentage of insects in treated halves - percentage of insects in untreated halves)/ (percentage of insects in treated halves + percentage of insects in untreated halves). PI value between -1.0 to -0.1 indicates repellant, -0.1 to +0.1 neutral and +0.1 to +1.0 attractant

Fumigant toxicity

In fumigant toxicity assay, cinnamaldehyde and cuminaldehyde caused lethality in adults of *S. zeamais*. For cinnamaldehyde, LC_{50} values recorded were 0.462 and 0.302 µl/cm^3; while for cuminaldehyde, LC_{50} values recorded were 0.423 and 0.286 µl/cm^3 air when exposed for 24 and 48 hours respectively (Table 2). Mortality in insects was concentration-dependent.

Table 2: Fumigant and contact toxicity of cinnamaldehyde and cuminaldehyde against *S. zeamais* adults

Compound	Toxicity	Exposure period (h)	LC_{50}*	LCL-UCL**	g-value	Heterogeneity	t-ratio	Regression Equation	Correlation Coefficient***
Cinnamaldehyde	Fumigant toxicity	24	0.462	0.412-0.512	0.26	0.35	3.98	Y = - 7.95+5.52X	0.99
		48	0.302	0.279-0.325	0.23	0.32	4.23	Y = 5.29+7.42X	0.98
	Contact toxicity	24	0.290	0.272-0.308	0.25	0.36	4.33	Y = - 9.04+2.96X	0.98
		48	0.195	0.182-0.218	0.26	0.38	3.91	Y = 4.68+6.74X	0.97
Cuminaldehyde	Fumigant toxicity	24	0.423	0.364-0.482	0.24	0.32	3.67	Y = - 5.49+6.74X	0.98
		48	0.286	0.269-0.297	0.28	0.36	4.42	Y = 3.76+5.21X	0.98
	Contact toxicity	24	0.283	0.271-0.295	0.25	0.37	4.27	Y = - 6.97+4.97X	0.98
		48	0.187	0.176-0.198	0.29	0.34	3.64	Y = 5.70+5.74X	0.99

*µlcm^{-3} for fumigant toxicity and µlcm^{-2} for contact toxicity; **LCL and UCL= Lower confidence limit and Upper confidence limit; Significant at $P<0.05$ (df = 4, 25)

Contact toxicity

S. zeamais adults were killed when come in contact with cinnamaldehyde and cuminaldehyde. For cinnamaldehyde, LC_{50} values recorded were 0.290 and 0.195 µl/cm^2; while for cuminaldehyde, LC_{50} values recorded were and 0.283 and 0.187 µl/cm^2 area when insect adults were exposed for 24 and 48 hours respectively (Table 2). Mortality in insects was concentration-dependent.

Acetycholine esterase activity

Fumigation of *S. zeamais* adults with cinnamaldehyde and cuminaldehyde inhibited acetylcholine esterase activity. Activity of acetylcholine esterase in adult insect was reduced to 70.23 and 55.50%; and 77.01 and 53.49% of control group activity when fumigated with 40 and 80% of 24h-LC_{50} of cinnamaldehyde and cuminaldehyde respectively (For cinnamaldehyde, F=156.36; For cuminaldehyde, F = 141.91; P<0.05; Table 3).

Table 3. Effect of cinnamaldehyde and cuminaldehyde on acetylcholine esterase activity in *S. zeamais*

Compound	Concentration	Enzyme activity* (Mean±SD)	F-value
Cinnamaldehyde	Control	0.0944±0.0021(100)	156.36**
	40% of 24h-LC_{50}	0.0663±0.00019(70.23)	
	80% of 24h-LC_{50}	0.0524±0.0014(55.50)	
Cuminaldehyde	Control	0.0944±0.0021(100)	14.91**
	40% of 24h-LC_{50}	0.0727±0.0018(77.01)	
	80% of 24h-LC_{50}	0.050±0.0013(53.49)	

Values in parentheses indicate per cent change with respect to control taken as 100%; *mmol of 'SH' hydrolysed min^{-1}mg^{-1} protein; **Significant at P<0.05 (df = 2,15)

Oviposition inhibition

Cinnamaldehyde and cuminaldehyde reduced oviposition capacity of *S. zeamais* adults when fumigated (Table 4). Oviposition in *S. zeamais* adults was reduced to79.66 and 65.64%, and 78.78 and 59.17% of the control when fumigated with 40 and 80% of 24h-LC_{50} of cinnamaldehyde and cuminaldehyde respectively (For cinnamaldehyde, F = 21.86; For cuminaldehyde, F = 40.06; P<0.05; Table 4).

Table 4: Oviposition inhibitory activities of cinnamaldehyde and cuminaldehyde in *S. zeamais*

Compound	Conc.	No. of progeny emerged (Mean±SD)	POD*	F-value
Cinnamaldehyde	Control	92.66±3.03 (100%)	-	21.86**
	40% of 24h-LC_{50}	73.50±2.23 (79.32)	21.68	
	80% of 24h-LC_{50}	59.67±2.23 (65.64)	34.36	
Cuminaldehyde	Control	92.66±3.03 (100%)	-	40.06**
	40% of 24h-LC_{50}	73.00±2.09 (78.78)	21.22	
	80% of 24h-LC_{50}	54.83±1.96 (59.17)	40.83	

Values in parentheses indicate per cent change with respect to control taken as 100%; *Percent oviposition deterrence (POD) = [(E_C-E_T)/E_C] ×100; E_C = number of adults emerged in control and E_T = number of adults emerged in test; **Significant at P<0.05 (df = 2,15)

Developmental inhibition

Both cinnamaldehyde and cuminaldehyde reduced *S. zeamais* adult emergence when eggs and juveniles of *S. zeamais* were when fumigated with cinnamaldehyde and cuminaldehyde. Progeny emergence was 80.69, 58.59 and 43.05%; and 82.82, 55.22 and 41.31% of the control when fumigated with 0.2, 0.4 and 0.6 µlcm^{-3} of cinnamaldehyde and cuminaldehyde respectively (Table 5). (For cinnalmaldehyde, F = 47.15; for cuminaldehyde, F = 59.48; P<0.05; Table 5).

Table 5: Effect of cinnamaldehyde and cuminaldehyde on development of *S. zeamais*

Compound	Conc.	No. of adults emerged (Mean±SD)	IR*	F-value (df=3,20)
Cinnamaldehyde	Control	86.33±5.05 (100)	-	47.15**
	0.2 µlcm^{-3}	69.66±3.02 (80.69)	19.31	
	0.4 µlcm^{-3}	50.33±2.03 (58.59)	41.41	
	0.6 µlcm^{-3}	37.16±1.36 (43.05)	56.95	
Cuminaldehyde	Control	86.33±5.05 (100)	-	59.48**
	0.2 µlcm^{-3}	71.50±3.15 (82.82)	17.18	
	0.4 µlcm^{-3}	47.66±2.09 (55.22)	44.78	
	0.6 µlcm^{-3}	35.66±1.67 (41.31)	58.69	

Values in parentheses indicate per cent change with respect to control taken as 100%; *Inhibition rate (IR) = [(Cn-Tn)/Cn] ×100, Cn = number of adults emerged in control and Tn = number of adults emerged in test; **Significant at P<0.05 (df = 3,20)

Antifeedant activity

Feeding in *S. zeamais* adults was reduced by cinnamaldehyde and cuminaldehyde (Table 6). When *S. zeamais* adults were exposed to 40 and 80% of 96h-LC_{50} of cinnamaldehyde and cuminaldehyde, feeding was reduced to 54.70 and 29.05%, and 47.71 and 22.29% respectively. Reduction in feeding was significant and concentration-dependent (For cinnamaldehyde, F = 122.86; for cuminaldehyde, F = 170.87; P<0.05; Table 6).

Table 6: Antifeedant activity of cinnamaldehyde and cuminaldehyde against *S. zeamais*

Concentration	Cinnamaldehyde		Cuminaldehyde	
	Consumption of flour disc (mg) (Mean±SD)	AFA*	Consumption of flour disc (mg) (Mean±SD)	AFA*
Control	10.84±0.17 (100)	-	10.84±0.17 (100)	-
40% of 96h-LC_{50}	5.93±0.21 (54.70)	45.30	4.63±0.16 (47.71)	57.28
80% of 96h-LC_{50}	3.15±0.12 (29.05)	70.95	2.64±0.14 (22.29)	77.71
	F = 122.86**		F = 170.87**	

Values in parentheses indicate per cent change with respect to control taken as 100%; *Antifeedant activity was calculated using formula: AFA = [C-T/C] × 100; Where, C = consumption of flour disc in control group, and T = consumption of flour disc in treated group. Six replicates were set for each concentration of volatile chemical and control; **Significant at P<0.05 (df = 2, 15)

Discussion

Several plant volatile oils and its constituents have been evaluated for their insecticidal properties against insect pests of stored grains (Chaubey, 2012a, b, c; Chaubey, 2013) [6, 7, 8, 12]. These volatile chemicals act as oviposition, feeding and developmental inhibitors in a variety of coleopteran insects besides causing lethality in them. Mortality in insects has been reported due to inhibition in acetylcholine esterase enzyme activity (Chaubey, 2017a, b) [9, 10]. Several essential oils and its volatile compounds have been reported to exhibit repellent, lethal and affect oviposition behaviour, developmental processes in a variety of insects including maize weevil, *S. zeamais* (Ogendo *et al.* 2008, Ileleji *et al.* 2007; Chaubey, 2017a; Chaubey, 2022; Chaubey and Kumar, 2022) [9, 11, 14, 25, 38].

In this study, repellent and insecticidal properties of cinnamaldehyde and cuminaldehyde have been evaluated in *S. zeamais*. Both volatile compounds are found to show repellent activity against *S. zeamais* adults. These two volatile compounds inhibit acetylcholine esterase activity causing acute toxicity in *S. zeamais* adults which indicates that volatile chemical act on nervous system of the insects. Several other plant volatile oils and its volatile chemicals for their acute toxicity in insects by reducing activity of acetylcholine esterase enzyme (Chaubey, 2012a; Chaubey, 2017a, b) [6, 9, 10, 12]. The rapid mode of actions of the volatile compounds shows non-persistence nature which depends on nature and chemical properties of functional groups present (Kumbhar and Dewang, 2001) [31]. Some of the volatile oils and monoterpenoids interfere with functioning of gated ion channels (Enan, 2005; Tong and Coats, 2012) [19, 52]. Any interference in gating property of ion channels collapses the nervous co-ordination in insects (Hollingworth *et al.* 1984) [24]. Some of the volatile chemicals breakdown the structural integrity of cell wall and cell membrane causing leakage and release of cellular content (Tian *et al.* 2012; Bajpai *et al.* 2013) [4, 51].

Cinnamaldehyde and cuminaldehyde reduce oviposition and adult emergence in *S. zeamais*. This may probably be due to interference in communication between the two sexes and disruption in copulation processes in adults. These two volatile compounds reduce adult emergence probably by causing death egg or larvae due to disturbances in metabolic pathways or hormonal disorders. Similar to other volatile oils and its constituents, both cinnamaldehyde and cuminaldehyde reduce feeding which may be due to repellent property (Chaubey, 2013; Chaubey and Kumar, 2021, 2022) [8, 11, 13, 14].

Further studies should also been carried out to study the antagonistic as well as synergistic relationship among oil's constituents (Fields *et al.* 2010) [20]. The insecticidal role of the volatile chemicals must be for target insects only but not for beneficial insects. Human health as well as environmental issues must also be addressed in developing formulation involving natural volatile organic chemicals of plant origin.

Conclusions

This study concludes that cinnamaldehyde and cuminaldehyde work at different levels like oviposition, development and feeding of insects. This is helpful in reducing chances of resistance development in insects. Cinnamaldehyde and cuminaldehyde sources are commonly used in human food, accidental consumption of these will not cause harm. Thus, for the purpose of insect pests management of grains under storage, cinnamaldehyde and cuminaldehyde can play significant role.

Acknowledgement

Research and Development department of higher education, U.P. has been provided financial assistance [No. 46/2021/603/70-4-2021-4(56)/2020] under minor research project scheme.

Conflict of interest

All the authors have declared that there is no conflict of interest in existence.

References

1. Alavanja MCR, Bonner MR. Occupational pesticide exposures and cancer risk: a review. J. Toxicol. Environ. Health B,2012:15:238-263.
2. Angioni A, Barra A, Coroneo V, Dessi S, Cabras P. Chemical composition, seasonal variability and antifungal activity of *Lavandula stoechas* L. ssp. stoechas essential oils from stem/leaves and flowers. J. Agri. Food Chem,2006:54:4364-4370.
3. Atti-Santos AC, Pansera MR, Paroul N, Atti-Serafini L, Moyna PP. Seasonal variation of essential oil yield and composition of *Thymus vulgaris* L. (Lamiaceae) from south Brazil. J. Essential Oil Res,2004:16:294-295.
4. Bajpai VK, Sharma A, Baek KH. Antibacterial mode of action of *Cudrania tricuspidata* fruit essential oil, affecting membrane permeability and surface characteristics of food-borne pathogens. Food Control,2013:32(2):582-590.
5. Caballero-Gallardo K, Olivero-Verbel J, Stashenko EE. Repellent activity of essential oils and some of their individual constituents against *Tribolium castaneum* Herbst. J. Agri. Food Chem,2011:59:1690-1696.
6. Chaubey MK. Responses of *Tribolium castaneum* (Coleoptera: Tenebrionidae) and *Sitophilus oryzae* (Coleoptera: Curculionidae) against essential oils and pure compounds. Herba Polonica,2012b:58:33-45.
7. Chaubey MK. Biological effects of essential oils against Rice weevil *Sitophilus oryzae* L. (Coleoptera: Curculionidae). J. Essential Oil Bearing Plants,2012c:15:809-815.

8. Chaubey MK. Insecticidal effects of *Allium sativum* (Alliaceae) essential oil against *Tribolium castaneum* (Coleoptera: Tenebrionidae). J. Biol. Active Prod. Nature,2013:3:248-258.
9. Chaubey MK. Evaluation of insecticidal properties of *Piper nigrum* and *Cuminum cyminum* essential oils against *Sitophilus zeamais*. J. Entomol,2017a:14:148-154.
10. Chaubey MK. Study of insecticidal properties of *garlic, Allium sativum* (Alliaceae*)* and bel, *Aegle marmelos* (Rutaceae) essential oils against *Sitophilus zeamais* L. (Coleoptera: Curculionidae). J. Entomol,2017b:14:191-198.
11. Chaubey MK. Insecticidal properties of two terpenes against maize weevil, *Sitophilus zeamais* (Motschulsky). J. Biopest,2022:15(2):92-102.
12. Chaubey MK. Fumigant toxicity of essential oils and pure compounds against *Sitophilus oryzae* L. (Coleoptera: Curculionidae). Biol. Agri. Hort,2012a:28:111-119.
13. Chaubey MK, Kumar N. Role of *Piper cubeba* and *Zingiber officinale* volatile oils in maize weevil, *Sitophilus zeamais* management. Int. J. Green Herbal Chem,2021:10(4):404-417.
14. Chaubey MK, Kumar N. Insecticidal properties of *Allium sativum* and *Anethum graveolens* essential oils against maize weevil, *Sitophilus zeamais* (Motschulsky). Int. J. Green Herbal Chem,2022:11(1):60-74.
15. Cheng SS, Liu JY, Tsai KH, Chen WJ, Chang ST. Chemical composition and mosquito larvicidal activity of essential oils from leaves of different *Cinnamomum osmophloeum* Provenances. J. Agri. Food Chem,2004:52(14):4395-4400.
16. Demissie G, Tefera T, Tadesse A. Efficacy of SilicoSec, filter cake and wood ash against the maize weevil, *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) on three maize genotypes. J. Stored Prod. Res,2008:44:227-231.
17. EEA. Late lessons from early warnings: science, precaution, innovation. European Environment Agency, Report No 1/2013. EEA, Copenhagen, 2013.
18. Ellman GL, Courtney KD, Andres Jr. V, Featherstone RM. A new and rapid colorimetric determination of acetylcholinesterase activity. Biochem. Pharmacol,1961:7:88-95.
19. Enan EE. Molecular and pharmacological analysis of an octopamine receptor from American cockroach and fruit fly in response to plant essential oils. Arch. Insect Biochem. Physiol,2005:159:161-171.
20. Fields P, Woods SM, Taylor, W. Triterpenoid saponins synergize insecticidal pea peptides: effect on feeding and survival of the rice weevil, *Sitophilus oryzae*. Canad. Entomol,2010:142:501-512.
21. Guo SY, Guo JY, Huo HR, Zhao BS, Liu HB, Li LF, *et al*. Cinnamaldehyde reduces IL-1β-induced cyclooxygenase-2 activity in rat cerebral microvascular endothelial cells. Eur. J. Pharmacol,2006:537:174-180.
22. Gutzeit H. Plant Natural Products: Synthesis, Biological Functions and Practical Applications. Wiley, 2014, 19-21. ISBN. 978-3-527-33230-4
23. Hajlaoui H, Mighri H, Noumi E, Snoussi M, Trabelsi N. Chemical composition and biological activities of Tunisian *Cuminum cyminum* L. essential oil: a high effectiveness against *Vibrio* spp. strains. Food Chem. Toxicol,2010:48(8-9):2186-2192.
24. Hollingworth RM, Johnstone EM, Wright N. Pesticide Synthesis through Rational Approaches. ACS Symposium Series No. 255, American Chemical Society, Washington, DC, 1984, 103-125.
25. Ileleji KE, Maier DE, Woloshuk CP. Evaluation of different temperature management strategies for suppression of *Sitophilus zeamais* (Motschulsky) in stored maize. J. Stored Product Res,2007:43:480-488.
26. Imai T, Yasuhara K, Tamura T, Takizawa T, Ueda M, Hirose M, *et al*. Inhibitory effects of cinnamaldehyde on 4-(methylnitrosamino)-1-(3-pyridyl)-1- butanone-induced lung carcinogenesis in rasH2 mice. Cancer Let,2002:175:9-16.
27. Isman MB, Miresmailli S, Machial C. Commercial opportunities for pesticides based on plant essential oils in agriculture, industry and consumer products. Phytochem. Rev,2011:10:197-204.
28. Khalil N, Ashour M, Fikry S, Singab AN, Salama O. Chemical composition and antimicrobial activity of the essential oils of selected Apiaceous fruits, Future J. Pharmacol. Sci,2018:4:88-92.
29. Köhler HR, Triebskorn R. Wildlife ecotoxicology of pesticides: can we track effects to the population level and beyond? Science,2013:341:759-765.
30. Kumar S, Sharma S, Vasudeva N. Chemical compositions of *Cinnamaldehyde* oil from two different regions of India. Asian Pacific J. Trop. Dis, 2012, S761-S764.
31. Kumbhar PP, Dewang, PM. Monoterpenoids: The natural pest management agents. Frag. Flav. Assoc. India,2001:3:49-56.
32. Lee HS, Kim SY, Lee CH, Ahn AJ. Cytotoxic and mutagenic effects of *Cinnamomum cassia* bark-derived materials, J. Microbiol. Biotechnol,2004:14:1176-1181.
33. Liao JC, Deng JS, Chiu CS, Hou WC, Huang SS, Shie PH, *et al*. Anti-inflammatory activities of *Cinnamomum cassia* constituents *in vitro* and *in vivo*. Evid Based Comp. Alt. Med, 2012, 429320.
34. Liu ZL, Chu SS, Jiang GH. Insecticidal activity and composition of essential oil of *Ostericum sieboldii* (Apiaceae) against *Sitophilus zeamais* and *Tribolium castaneum*. Rec. Natural Prod,2011:5:74-81.
35. Lu FC. A review of the acceptable daily intakes of pesticides assessed by the World Health Organization. Reg. Toxicol. Pharmacol,1995:21:351-364.
36. Ma WB, Feng JT, Jiang ZL, Zhang X. Fumigant activity of 6 selected essential oil compounds and combined effect of methyl salicylate and trans-cinnamaldehyde against *Culex pipiens* pallens. J. Amer. Mosq. Con. Assoc,2014:30(3):199-203.
37. Medzhitov. Origin and physiological roles of inflammation. Nature,2008:454(7203):428-435.
38. Ogendo JO, Kostyukovsky M, Ravid U, Matasyoh JC, Deng AL, Omolo EO, *et al*. Bioactivity of *Ocimum gratissimum* L. oil and two constituents against five insect pests attacking stored food products. J. Stored Prod. Res,2008:44:328-334.
39. Rasheehan N, Iftikhar H, Abdul T, Muhammad T, Moazur R, Sohail H. Antimicrobial activity of the bioactive components of essential oils from Pakistani spices against Salmonella and other multi-drug resistant bacteria. BMC Alt. Comp. Med,2013:13:265.
40. Rihawy MS, Bakraji EH, Odeh A. PIXE and GC-MS investigation for the determination of the chemical composition of Syrian *Cuminum cyminum* L. Appl. Rad. Iso,2014:86:118-125.

41. Russel RM, Robertson JL, Savin SA. POLO: A new computer programme for probit analysis. Bull. Entomol. Res,1977:23:209-213.
42. Sekine T, Sugano M, Majid A, Fujii Y. Antifungal effects of volatile compounds from black zira (*Bunium persicum*) and other spices and herbs. J. Chem. Ecol,2007:33:2123-2132.
43. Shen S, Zhang T, Yuan Y, Lin S, Xu J, Ye H. Effects of cinnamaldehyde on *Escherichia coli* and *Staphylococcus aureus* membrane. Food Cont,2015:47:196-202.
44. Shreaz S, Wani WA, Behbehani JM, Raja V, Irshad M, Karched M, *et al*. Cinnamaldehyde and its derivatives, a novel class of antifungal agents. Fitoterapia,2016:112:116-131.
45. Shu-meiang, Kuen-daw T, Ho-Yiu W, Yi-Heng L, Ta-Wei C, Jonathan C, *et al*. Molecular Mechanism of *Cinnamomum verum* component cuminaldehyde inhibits cell growth and induces cell death in human lung squamous cell carcinoma NCI-H520 cells *in vitro* and *in vivo*. J. Cancer,2016:7(3):251-261.
46. Sithisut D, Fields PG, Chandrapathya A. Contact toxicity, feeding reduction and repellency of essential oils from three plants from the ginger family (Zingiberaceae) and their major components against *Sitophilus zeamais* and *Tribolium castaneum*. J. Stored Prod. Res,2011:104:1445-1454.
47. Sokal RR, Rohlf FJ. Introduction to Biostatistics. W.H. Freeman and Co, San Francisco, CA, USA, 1973, 185-207.
48. Stefanazzi N, Stadler TA, Ferrero A. 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 Manag. Sci,2011:67:639-646.
49. Suleimana MM, McGaw LJ, Naidoo V, Eloff JN. Detection of antimicrobial compounds by bioautography of different extracts of leaves of selected South African tree species. Afr. J. Trad. Alt. Comp. Med,2009:7(1):64-78.
50. Tapondju LA, Alder A, Fontem H, Fontem DA. Efficacy of powder and essential oil from the *Chenopodium ambrosioides* leaves as post-hervest grain protectants against six stored products beetles. J. Stored Prod. Res,2002:38:395-402.
51. Tian L, Liu S, Liu H, Li S. 20-hydroxyecdysone upregulates apoptoti genes and induces apoptosis in the *Bombyx* fat body. Arch. Insect Biochem. Physiol,2012:79(4-5):207-219
52. Tong, F. and Coats, J.R. Quantitative structure-activity relationship of monoterpenoid binding activities to the house flies GABA receptor. Pest Manag. Sci,2012:68:1122-1129.
53. Tripathi AK, Prajapati V, Aggarwal KK, Khanuja SPS, Kumar S. Repellency and toxicity of oil from *Artemisia annua* to certain stored product beetles. J. Econ. Entomol,2000:93:43-47.
54. United Nations Environment Programme (UNEP). The Montreal Protocol on substances that deplete the ozone layer. Nairobi (Kenya), 2000.
55. Vanmathi JS, Padmalatha C, Singh AJAR, Charman K. Effect of chosen botanicals on the oviposition deterrence and adult emergence of *Callosobruchus maculatus* (F.)(Coleoptera: Bruchidae). Elixir Biol. Technol,2012:51A:11120-11123.
56. Vasconcelos NG, Croda J, Simionatto S. Antibacterial mechanisms of cinnamon and its constituents: A review. Microb. Path,2018:120:198-203.
57. Verma RS, Verma RK, Yadav AK. Seasonal variation in essential oil content and composition of Thyme, *Thymus serpyllum* L. cultivated in Uttarakhand hills. Ind. J. Pharmacol. Sci,2011:341:233-235.
58. Wei J, Zhang X, Bi Y, Miao R, Zhang Z. Anti-Inflammatory effects of cumin essential oil by blocking JNK, ERK, and NF-kappa B signaling pathways in LPS-stimulated RAW 264.7 cells. Evid Based Comp. Alt. Med, 2015, 474509.
59. World Health Organization (WHO). Agrochemicals, health and environment: directory of resources, 2017.
60. World Meteorological Organization (WMO). Scientific assessment of ozone depletion. Geneva (Switzerland). Report No, 1991, 25.