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Evaluation of Insecticidal Properties of Artemisia absinthium via Induced and Topical Applications Against Storage Pests

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Abstract

Artemisia absinthium (L.) essential oil (1.2–1.6% yield) exhibited significant insecticidal activity against three major stored-grain pests: the rice moth, *Corcyra cephalonica*, the red flour beetle, *Tribolium castaneum*, and the pulse beetle, *Callosobruchus chinensis*. Fumigation assays (10–50 µl/L air) demonstrated dose- and exposure-dependent toxicity, with 48-h LC_{50} values of 18.23, 34.32, and 41.17 µl/L air for *C. cephalonica*, *T. castaneum*, and *C. chinensis*, respectively, indicating greater susceptibility of *C. cephalonica*. In topical contact bioassays (0.25–2.00 µl/insect), 72-h LD_{50} values were 1.34, 1.76, and 1.40 µl/insect, respectively. Under induced contact exposure (2.5–20.0 µl), 96-h LC_{50} values declined to 15.18, 12.82, and 11.12 µl, confirming increased toxicity with prolonged exposure. Across all bioassays, mortality increased significantly with both dose and exposure duration. Gas chromatographic analysis identified β-thujone (17.25%) as the predominant constituent, followed by *p*-cymene (13.94%), camphor (12.42%), α-terpineol (12.27%), eugenol (12.20%), terpinen-4-ol (10.10%), α-pinene (9.90%), farnesol (5.80%), myrcene (4.54%), α-thujone (1.62%), and β-pinene (0.54%). The insecticidal efficacy is primarily attributed to β-thujone and the synergistic action of these bioactive terpenoid constituents.

Highlights

• Essential oil obtained from showed marked toxicity against important stored grain insect pests.

• Toxic effects increased progressively with higher concentrations and longer exposure periods.

• Among the tested insects, exhibited maximum susceptibility to the essential oil treatment.

• GC analysis revealed as the predominant constituent along with several other biologically active compounds.

• The findings indicate the suitability of essential oil as a plant-derived alternative for stored product pest management.

INTRODUCTION

INTRODUCTION

The stored products in granaries and storehouses are infested by a number of insect pests which causes severe quantitative and qualitative losses throughout the world. Among these pests rice moth, *Corcyra cephalonica* (Stainton) (Lepidoptera: Pyralidae) is widespread and destructive pest of cereals in storage (Pathak and Tiwari, 2010; Shukla and Tiwari, 2011). The pulse beetle, *Callosobruchus chinensis* (Linnaeus) (Coleoptera: Bruchidae) is a major pest of economically important leguminous grains (Aslam et al., 2002) and the red flour beetle, *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) has long been associated with a wide range of commodities including grains, flour, peas, beans, nuts and dried fruits (Campbell and Runnion, 2003). The overall damage caused by stored grain pests accounts for 10–40 per cent of losses worldwide annually (Mathews, 1993). Inspite of improved storage structures and modern control techniques, 70–90 per cent of food grains is still stored for not more than six months to a year at farmer's level. Thus, to protect food grains synthetic pesticides have been considered the most effective and accessible means to control insect pests of stored products (Huang and Subramanyam, 2005). Their indiscriminate use, has given rise to many serious problems including development of resistance by pest species, pest resurgence, secondary pest outbreak, increasing cost of application, environmental pollution and their bioaccumulation (Gupta et al., 2001; Koul et al., 2008). The toxic residues of these pesticides are also a matter of concern due to their increased risk of neurotoxic, carcinogenic, teratogenic and mutagenic effects in non-target organisms (Bakkali et al., 2008; Ayaz et al., 2010). Fumigation of storage structures by synthetic pesticides played a very important role in the insect pest management of stored products (Zettler and Arthur, 2000). Phosphine and methyl bromide are the two major fumigants used worldwide for stored product protection (Rajendran and Muralidharan, 2005). In comparison to methyl bromide, phosphine was increasingly used for storage pest management primarily due to ease of formulation and lesser retention of residues. Now many pests have developed resistance to phosphine and therefore its continued use in future is a question (Bell and Wilson, 1995; Chaudhry, 1995; Benhalima et al., 2004; Collins et al., 2005; Pimentel *et al*., 2009). Also use of methyl bromide is being restricted and has been phased out by 2015 because of its ozone depleting properties (Bulter and Rodriguez, 1996). Many alternatives have been tested to replace methyl bromide fumigation for stored products and for quarantine uses. Over the past two decades, interest in botanical insecticides has increased as a result of increased public awareness regarding human safety, environmental concerns and insect populations becoming resistant to conventional chemicals. Botanical insecticides presently constitute 1 per cent of the world insecticide market (Rozman et al., 2007). Therefore, in the current scenario, there is an urgent need and worldwide interest to develop simple, safer, effective, biodegradable and eco-friendly alternatives that have potential to be comparable to synthetic pesticides which could be efficiently used in integrated pest management programme for sustainable biosecurity. In this search for alternatives to conventional synthetic pesticides, essential oils extracted from plants have been widely investigated. Their activities are manifold and may be contact, fumigant, antifeedant, ovicidal, larvicidal and repellent against various insect species. Due to their volatility, essential oils are environmentally non-persistent (Tripathi et al., 2009). Essential oils are generally recognized as safe by United States Food and Drug Administration (FDA) as they are neither hazardous to applicators nor leave toxic residues on food commodities. For this reason, they are regarded as a new class of ecological products for controlling insect pests.

Kashmir like rest of the country also suffers high storage losses due to insect pests. Keeping in view the global ban on synthetic fumigants and losses during storage, there is an urgent need to identify an essential oil that proves an efficient alternative to synthetic fumigants and other insecticides used against stored grain pests. In current preliminary observation, we have observed that some indigenously growing plants of Kashmir

viz. *Artemisia absinthium* (Linneaus) and *Juglans regia* (Linneaus) have exhibited insecticidal activity against these pests. Therefore, it was though pertinent to isolate essential oils from these plants to exploit them for use against stored grain pests as contact, fumigants or as antifeedants.

2. MATERIALS AND METHODS

2.1. Sampling and Extraction of essential oil from *A. absinthium*

The leaf/flower samples of *A. absinthium* (L.) (Family: Asteraceae; also known as common wormwood, mugwort or madder wort and locally known as 'Tethwan') were collected from four different locations viz., Tangmarg, Pattan, Raithan and Khan Sahib, Budgam during June-September when the plants produce flowers and seeds, as during this period they are expected to have high concentration of secondary metabolites. All the samples of the plant material were shade dried in the laboratory under natural conditions at room temperature (23–24 ^{o}C) and proper ventilation for 5–7 days. For evaluation of its bioefficacy as insecticides against *T. castaneum* (H.), *C. cephalonica* (St.) and *C. chinensis* (L.) which cause severe damage to stored grains and other products.

The essential oil of *A. absinthium* (L.) was extracted by means of steam distillation using a clevenger's apparatus. 100 g of shade dried raw samples, cut into pieces was taken in a 2000 ml flask which was on one end connected to the condenser and on the other end to double necked flat bottomed 2000 ml flask containing 1600 ml of distilled water as solvent and was kept on a hot plate set at a temperature of 100^{o}C. The steam/vapours generated in the flask were allowed to pass through the plant material which softened the cells and allowed the essential oil to escape in vapour form along with the solvent vapours. The vapours passed through a condenser to form a liquid from which the essential oil was separated/decanted in oil separator connected to the distillation apparatus. The essential oil obtained was dried over anhydrous sodium sulphate (Na2SO4) and stored in airtight glass vials in the refrigerator at 4^{o}C till further use for insect bioassay studies.

2.2. Insect/culture rearing

The experimental procedures were carried out under laboratory conditions in the Division of Entomology and Research Centre for Residue & Quality Analysis, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar Srinagar during 2012 and 2013. Culture of these insects was established and maintained in sterilised plastic jars of 5 litre capacity placed in the incubator at 26 ± 1 ^{o}C and 60 ± 5 per cent relative humidity. The culture/rearing medium was crushed maize/wheat flour for *T. castaneum* (H.), unshelled moong for *C. chinensis* (L.) and rice for *C. cephalonica* (St.). The foods were kept in an oven for sterilization for 24 hours at 60^{o}C to disinfect them.

After emergence, adults were kept in the culture medium for a maximum of 7 days for mating and oviposition and then removed from the jars by using fine camel hair brush. After separating the adults, the grains along with eggs of the insects were kept again in the same jars. Jars were placed in the incubator at respective temperature and humidity for rearing of a homogenous population of each insect. Adult insects (1–7 day old) of all the three species were used for bioassay studies.

2.3. Toxicity bioassay

The bioactivity of the essential oil against stored pests viz., *T. castaneum* (H.), *C. cephalonica* (St.) and *C. chinensis* (L.) was carried out following bioassay procedure of Finny (1971). Evaluation of the contact toxicity of essential oil extracted from *A. absinthium* (L.) was carried out by two methods.

2.3.1. Topical application

Contact toxicity by topical treatment were carried out using the method described by McDonald et al. (1970). Five to seven day old adults of the insect species were first transferred separately into Petridishes lined with moist filter paper and chilled (at -4^{o}C) in the refrigerator for two minutes to reduce their mobility so as to enable the essential oil topical treatment to be carried out. Different doses (0.25, 0.50, 1.00, 1.50, 2.00 µl) were applied topically to the pronotum of the insects, using a micro-applicator. 25 insects of each species were treated with each dose. In control no essential oil was used. Each treatment was replicated four times. After treatment, the insects (both treated and untreated) were transferred to glass vials with culture media and kept in incubator at 26 ± 1^{o}C and 65 ± 5 per cent relative humidity. Mortalities were observed after 6, 24, 48 and 72 hours after treatment and the results obtained were subjected to probit analysis.

2.3.2. Induction method

Contact toxicity by induction method were carried out using the procedure described by (Shaaya et al., 1997; Asawalam et al., 2006). Different volumes (2.5, 5.0, 10.0, 15.0 and 20.0 µl) of oil were dissolved in 10 ml of hexane and applied to 20 g of food in 100 ml glass beakers and shaken thoroughly well to ensure even distribution of the oil over the grain surface. The treated grains were kept for 30 minutes to allow hexane to evaporate completely. Thirty (1–7 day old) adults of each insect species were separately transferred in the beakers containing treated grains which were then covered with muslin cloth and kept in incubator at 26 ± 1oC and 65 ± 5 per cent relative humidity. In control only hexane was used. Each treatment was replicated four time and observations on mortality were recorded after 24, 48, 72 and 96 hours after treatment. The efficacies were worked out through probit analysis.

Statistical analysis

The data were corrected using Abbott's formula (Abbot, 1925) for the mortalities in the controls, and the data were subjected to probit analysis using Biostat version 2009 to estimate LC_{50} values of the essential oil and the crude extracts against each stored product insect pest species.

Results and Discussion

Extraction of essential oil

During the present investigations shade dried leaves of *A. absinthium* (L.) using Clevenger type steam distillation process, yielded 1.2–1.6 ml/100g dry weight. Derwich *et al*. (2009) have reported an essential oil yield of 0.59, 0.57 and 0.31 ml/100 g of dry leaf respectively from the aerial parts of *A. herba-alba* (Asso.), *A. absinthium* (L.) and *A. pontica* (L.), respectively. Liu et al. (2010) have reported a yield of 0.87 and 0.75 ml/100g in case of *A. capillaries* (Thunb.) and *A. mongolica* (B.), respectively. However higher essential oil yield was reported by Gonzalez and Andres (2012) from several plants including *A. absinthium* (L.) to the extent of 2.5 ml/100g dry weight using super critical fluid extraction with carbon dioxide. Similar results were also obtained by Martin et al. (2011).

The essential oil yield besides other factors also depends upon the phenological stage of the plant and geographical location and the extraction procedure. The higher yield recorded during the present investigations could be due to any of the above factors.

Table 1
Chemical characterisation of essential oil derived from leaves of *A. absinthium* on GC/FID

S. No.	Name of the compound	RT (minutes)	Relative area (%)
1.	Camphor	12.61	12.428
2.	α-pinene	13.15	9.905
3.	β-pinene	13.42	0.545
4.	P-cymene	14.37	13.194
5.	α-thujone	16.37	1.629
6.	β-thujone	17.37	17.255
7.	α-terpineol	19.70	12.277
8.	Terpinen 4 ol	20.23	10.105
9.	Unknown	20.58	0.001
10.	Unknown	21.17	0.001
11.	Unknown	23.08	0.044
12.	Unknown	23.52	0.011
13.	Unknown	23.67	0.039
14.	Eugenol	25.17	12.202
15.	Unknown	25.25	0.011
16.	Farnesol	33.74	5.807
17.	Myrecene	34.33	4.546
Total		100.000	

Chromatogram showing various components in the essential oil of A. absinthium

Chemical characterization of essential oil derived from A. absinthium

GC analysis of the essential oil from *A. absinthium* (L.) yielded 17 known components (Table 5). Among these components, β-thujone (17.25%) was the most dominant followed by p-cymene (13.19%), camphor (12.42%), α-terpineol (12.27%), eugenol (12.20%), terpinen-4-ol (10.10%), α-pinene (9.90%), farnesol (5.80%), myrecene (4.54%) and α-thujone (1.62%). Farzaneh et al. (2006) reported several components in the essential oil extracted from *A. scoparia* Wald. *A. sieberi* (B.) and *A. Aucheri* (Bois.). However, two components viz., α-thujone (81.7%) and β-thujone (14.5%) were found to impart toxicity against insects. However, the lower content of α-thujone obtained in the present investigation draw its support from the findings of Rezaeinodehl and Khangholi (2008) who reported β-thujone to the extent of 18.7 per cent from *A. kulbadica* (Bois.). Similarly Derwich *et al*. (2009) reported α-thujone to the extent of 48.25 per cent in *A. herba-alba* (Asso.), 39.69 per cent in case of *A. absinthium* (L.) and 22.13 per cent in case of *A. pontica* (L.), while as β-thujone was found to the extent of 8.99, 7.25 and 2.56 per cent in the three species of *Artemisia* respectively. Militello et al. (2011) reported β-thujone to the extent of 45 per cent in *A. arobrescens* (L.). Naseri et al. (2011) have also reported β-thujone to the extent of 20.7 per

cent in *A. spicigera* (C. Koch.). The variations recorded in the findings of several workers depends upon the species and the time of extraction of the essential oil.

Table 2
Contact toxicity (topical application) of essential oil of *A. absinthium* against adults of *C. cephalonica, T. castaneum and C. chinensis.*

Dose of oil µl insect^{-1}	No. of insects used	Corrected mean mortality ± SE (hours after exposure)											
		C. cephalonica			*T. castaneum*				*C. chinensis*				
6		24	48	72	6	24	48	72	6	24	48	72	
2.0	25	6.25 ± 0.47 (25.00)	11.00 ± 0.70 (44.00)	14.75 ± 0.85 (59.00)	16.00 ± 0.91 (64.00)	5.50 ± 0.64 (22.00)	9.00 ± 1.29 (36.00)	11.25 ± 1.10 (45.00)	13.75 ± 1.37 (55.00)	5.75 ± 0.85 (23.00)	10.25 ± 10.87 (41.00)	11.25 ± 0.75 (45.00)	16.25 ± 1.25 (65.00)
1.50	25	5.75 ± 0.25 (23.00)	9.25 ± 0.85 (37.00)	11.00 ± 0.70 (44.00)	13.75 ± 0.75 (55.00)	4.00 ± 0.40 (16.00)	5.75 ± 0.85 (23.00)	8.50 ± 1.25 (34.00)	12.00 ± 0.91 (48.00)	5.75 ± 0.47 (23.00)	8.25 ± 0.85 (33.00)	10.25 ± 1.03 (41.00)	13.00 ± 1.29 (52.00)
1.00	25	4.00 ± 0.40 (16.00)	7.50 ± 0.28 (30.00)	10.75 ± 0.75 (43.00)	11.25 ± 0.94 (45.00)	2.50 ± 0.64 (10.00)	4.50 ± 0.64 (18.00)	6.00 ± 0.70 (24.00)	6.00 ± 0.91 (24.00)	3.75 ± 0.47 (15.00)	5.5 ± 0.64 (22.00)	7.50 ± 1.32 (30.00)	10.00 ± 0.91 (40.00)
0.50	25	3.00 ± 0.40 (12.00)	5.25 ± 0.47 (21.00)	8.75 ± 0.47 (35.00)	9.75 ± 0.47 (39.00)	2.25 ± 0.47 (9.00)	4.00 ± 0.70 (16.00)	4.50 ± 0.64 (18.00)	6.25 ± 0.75 (25.00)	3.00 ± 0.40 (12.00)	4.00 ± 0.70 (16.00)	5.50 ± 0.64 (22.00)	8.25 ± 0.62 (33.00)
0.25	25	2.00 ± 0.40 (8.00)	3.75 ± 0.47 (15.00)	4.75 ± 0.47 (19.00)	7.00 ± 0.40 (28.00)	1.50 ± 0.28 (6.00)	3.0 ± 0.40 (12.00)	4.00 ± 0.40 (16.00)	5.50 ± 0.64 (22.00)	1.75 ± 0.47 (7.00)	2.50 ± 0.28 (10.00)	3.50 ± 0.64 (14.00)	5.50 ± 0.95 (22.00)
0.00	25	0.00 ± 0.00 (0.00)	1.25 ± 0.25 (5.00)	1.25 ± 0.25 (5.00)	2.75 ± 0.25 (11.00)	0.00 ± 0.00 (0.00)	0.75 ± 0.47 (3.00)	1.00 ± 0.40 (4.00)	1.50 ± 0.28 (6.00)	0.00 ± 0.00 (0.00)	0.00 ± 0.00 (0.00)	1.50 ± 0.64 (6.00)	2.00 ± 0.40 (8.00)

Figures in parenthesis indicate corrected per cent mean mortality

Table 3
Comparative contact toxicity (topical application) of *A. absinthium* oil against different stored product pests

Insect species	Time (hr)	LD_{50} (µl/insect)	χ^2	p-value
Corcyra cephalonica	6	3.4867 (2.9083–4.0651)	0.05	0.99
	24	2.1021 (1.7040–2.5002)	0.20	0.99
	48	1.6608 (1.2648–2.0568)	0.56	0.96
	72	1.3399 (0.9344–1.7454)	0.24	0.99
Tribolium castaneum	6	3.7330 (3.1395–4.3264)	0.37	0.94
	24	2.9757 (2.4042–3.5472)	0.84	0.83
	48	2.2680 (1.7914–2.7446)	0.74	0.86
	72	1.7615 (1.3690–2.1539)	1.98	0.57
Callosobruchus chinensis	6	3.0416 (2.5664–3.5169)	0.43	0.93
	24	2.3684 (1.9463–2.7904)	0.29	0.96
	48	2.1185 (1.6678–2.5692)	0.87	0.99
	72	1.3989 (0.9690–1.8287)	0.35	0.94

Contact toxicity (topical application) of the essential oil of A. absinthium against storage insect pests

The present study revealed that the essential oil from *A. absinthium* (L.) exhibited contact toxicity against *C. cephalonica* (St.), *T. castaneum* (H.) and *C. chinensis* (L.) when applied topically to the pronotum of the insects (Table 2& 3). Considerable difference was noted in the toxicity with respect to three insects. *C. cephalonica* (St.) was more sensitive to the essential oil followed by *C. chinensis* (L.) and *T. castaneum* (H.) as is clear from LD_{50} values of 1.3399, 1.3989 and 1.7615 µl/insect respectively after 72 h of exposure. It was observed that toxicity was dose and time dependent. These results draw support from the findings of Aggarwal et al. (2001) who have reported that 0.1 ml/insect of 1,8- cineole, one of the components of the essential oil of *A. annua* (L.) caused 100 per cent mortality of *C. maculates* (F.), *R. dominica* (F.) and *S. oryzae* (L.) after 72 h of exposure. Similarly, Liu et al. (2010) reported lesser contact toxicity of 105.92 and 87.92 µg/adult against *S. zeamais* (Motsch.) by using essential oil from *A. capillaris* (T.) and *A. mongolica* (B.), respectively.

Table 4
Contact toxicity (Induction Method) of essential oil of *A. absinthium* against adults of *C. cephalonica, T. castaneum and C. chinensis*

Dose of oil µl insect^{-1}	No. of insects used	Corrected mean mortality ± SE (hours after exposure)											
		C. cephalonica			*T. castaneum*				*C. chinensis*				
24		**48**	**72**	**96**	**24**	**48**	**72**	**96**	**24**	**48**	**72**	**96**	
2.00	30	6.25 ± 0.62 (20.83)	10.75 ± 0.47 (35.83)	17.75 ± 0.85 (59.17)	26.00 ± 0.91 (86.67)	7.00 ± 0.40 (23.33)	12.00 ± 0.40 (40.00)	19.25 ± 0.478 (64.17)	26.75 ± 0.4 (89.17)	8.50 ± 0.28 (28.33)	14.25 ± 0.62 (47.50)	20.00 ± 0.40 (66.67)	28.00 ± 0.40 (93.33)
1.50	30	5.50 ± 0.64 (18.33)	9.25 ± 0.25 (30.83)	10.75 ± 0.47 (35.83)	14.75 ± 0.47 (49.17)	5.00 ± 0.40 (16.67)	10.00 ± 0.40 (33.33)	11.50 ± 0.28 (38.33)	16.25 ± 0.4 7 (54.17)	7.00 ± 0.40 (23.33)	11.00 ± 0.57 (36.67)	14.00 ± 0.40 (46.67)	18.25 ± 1.31 (60.83)
1.00	30	2.50 ± 0.28 (8.33)	7.00 ± 0.40 (23.33)	8.5 ± 0. 64 (28.33)	10.5 ± 0.64 (35.00)	4.25 ± 0.25 (14.67)	5.75 ± 0.25 (19.17)	7.25 ± 0.25 (24.17)	8.75 ± 0.47 (29.17)	5.75 ± 0.47 (19.17)	6.75 ± 0.62 (22.50)	9.00 ± 0.40 (30.00)	12.00 ± 0.40 (40.00)
0.50	30	1.75 ± 0.25 (5.83)	3.00 ± 0.40 (10.00)	5.00 ± 0.70 (16.67)	7.00 ± 0.40 (23.33)	2.25 ± 0.25 (7.50)	3.50 ± 0.28 (11.67)	5.25 ± 0.47 (17.50)	7.5 ± 0.64 (25.00)	3.75 ± 0.47 (12.50)	4.75 ± 0.47 (15.83)	7.25 ± 0.47 (24.17)	8.75 ± 0.47 (29.17)
0.25	30	1.50 ± 0.28 (5.00)	3.00 ± 0.40 (10.00)	4.25 ± 0.25 (14.17)	6.00 ± 0.57 (20.00)	1.50 ± 0.28 (5.00)	2.50 ± 0.28 (8.33)	3.25 ± 0.47 (10.83)	5.25 ± 0.47 (17.50)	1.50 ± 0.28 (5.00)	2.50 ± 0.64 (8.33)	4.00 ± 0.40 (13.33)	5.00 ± 0.40 (16.67)
0.00	30	0.00 ± 0.00 (0.00)	0.50 ± 0.28 (1.67)	1.00 ± 0.40 (3.33)	1.50 ± 0.28 (5.00)	0.00 ± 0.00 (0.00)	0.00 ± 0.00 (0.00)	1.25 ± 0.25 (4.17)	1.50 ± 0.28 (5.00)	0.00 ± 0.00 (0.00)	0.00 ± 0.00 (0.00)	1.00 ± 0.40 (3.33)	1.75 ± 0.25 (5.83)

Figures in parenthesis indicate corrected per cent mean mortality

Table 5
Comparative contact toxicity (induction method) of essential oil of *A. absinthium* against different stored product pests

Insect species	Time (hr)	LD_{50} (µl/insect)	χ^2	p-value
Corcyra cephalonica	**72**	18.9966 (15.7393–22.2580)	1.62	0.65
	96	15.1845 (12.8553–17.5262)	4.99	0.17
Tribolium castaneum	**72**	17.7603 (15.1885–20.3320)	3.76	0.28
	96	12.8208 (10.7241–14.9175)	5.36	0.14
Callosobruchus chinensis	**72**	15.4203 (12.6356–18.2051)	1.27	0.73
	96	11.1236 (8.9787–13.2685)	3.27	0.35

Contact toxicity (induction method) of the essential oil of A. absinthium against storage inset pests

The study revealed toxicity of the essential oil of *A. absinthium* (L.) against *C. cephalonica* (St.), *T. castaneum* (H.) and *C. chinensis* (L.) when induced in the artificial diet of the insects as depicted from (Table 4 & 5). It was observed that toxicity effects varied with oil concentration, period of exposure and insect species. The essential oil was more toxic to *C. chinensis* (L.) followed by *T. castaneum* (H.) and *C. cephalonica* (St.) as is evident from LC_{50} values of 11.1236, 12.8208 and 15.1845 µl respectively at 96 h of exposure. These observations are in agreement with the findings of Zamani *et al*. (2010) who reported that 11.13 per cent of the essential oil from *A. annua* (L.) induced 75 per cent mortality of Indian meal moth (*P. interpunctella*

Hub.) after 24 h of exposure. Similarly Upadhyay and Jaiswal (2007) reported that at 14.022 µl of the essential oil of *P. nigrum* (L.), 50 per cent mortality of *T. castaneum* (H.) was induced after 24 h of exposure. These results also draw support from the findings of Kouninki et al. (2007) who reported that essential oil of *X. aethiopia* (D.) at a concentration of 1 ml/100 g of grain caused 100 per cent mortality of *S. zeamais* (Motsch.) at 24 h of exposure. Similarly, Kotan et al. (2008) reported that essential oil of *S. hydrangea* (Dc.) at 100ml/kg of grain caused 68.3 and 75.01 per cent mortality of *S. granarius* (L.) and *T. confusum* (J. Du V.) respectively after 24 h of exposure. In the present investigations higher toxicity was observed when the essential oil was inducted in the food but it was surely less toxic when applied topically for obvious reasons of quick bioavailability.

Conclusion

From the present investigations, it is concluded that the essential oil of *A. absinthium* (L.) exhibited both fumigant and contact toxicity and has potential for use as alternative stored grain protectant in granaries and store house against *C. cephalonica* (St.), *T. castaneum* (H.) and *C. chinensis* (L.) and possibly against other insect pests of stored products. The crude extract of *A. absinthium* (L.)can also be employed as a grain protectant against stored product pests. Keeping in view the insecticidal properties of the essential oil of *A. absinthium* (L.) and its local availability in abundance, there is a good potential to exploit the essential oil of *A. absinthium* (L.) as a future fumigant.

Declarations

Conflict of interest

The author(s) show no conflict of interest

Author Contribution

P.B. contributed to conceptualization, methodology, formal analysis, data analysis, and writing of the original draft. M.A.R. was responsible for data curation and visualization. M.M. contributed to conceptualization and manuscript review and editing. S.A.G. contributed to data curation. M.A.P. provided supervision and reviewed and edited the manuscript. U.A. prepared the tables and reviewed and edited the manuscript. H.M. contributed to data analysis, prepared the graphs and tables, and reviewed and edited the manuscript. All authors have read and approved the final version of the manuscript.

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Figures

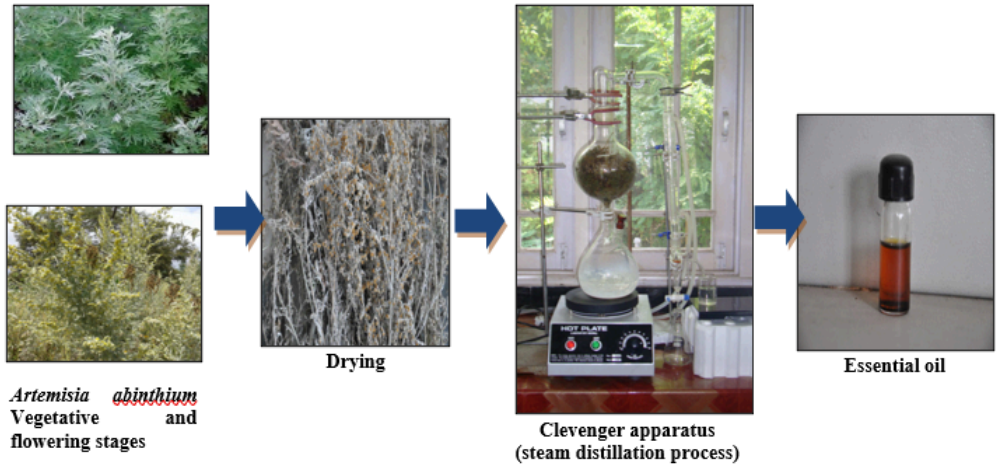


Figure 1

Clevenger apparatus used for steam distillation process of *Artemisia absinthium* under laboratory conditions

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