FUMIGANT AND REPELLENT EFFECTS OF SELECTED ESSENTIAL OILS AGAINST *SITOPHILUS GRANARIUS* (L.) (COLEOPTERA: CURCULIONIDAE)

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Abstract. The granary weevil (*Sitophilus granarius*) is a serious insect pest that causes economic losses to stored grains and their products. The effectiveness of essential oils (EOs) against the granary weevil has been studied; nevertheless, there is still a lack of data on the comparison of EOs fumigation and repellency effects. This study aimed to compare the fumigant toxicity and repellent effects of the 8 EOs, clove *(Syzygium aromaticum),* river red gum (*Eucalyptus camaldulensis*), garlic *(Allium sativum),* ginger *(Zingiber officinale*), lemon *(Citrus lemon*), mint *(Mentha longifolia*), almond *(Prunus dulcis*), and basil *(Ocimum basilicum*) against adults of the granary weevil. The fumigation bioassay showed that clove EO was the most toxic EO, with the lowest calculated LC_{50} value of 0.52% after 48 h of exposure. The 1, 2, 4, and 8% concentrations of *S. aromaticum* had a great fumigant effect against granary weevil compared with the other tested EOs. The 2, 4, and 8% concentrations of *clove* EO have a significant effect on the repellency percentage of granary weevil compared with river red gum, garlic, ginger, lemon, mint, almond, and basil after 20 min and 120 min of exposure test. Thus, using clove EO as a fumigant and repellent to treat cereal grains and their products infested by granary weevil may play a significant role in controlling this serious pest.
Keywords: *stored grains, clove, toxicity, efficiency, insecticides*

Introduction

Cereal crops are among the most significant globally and are essential for food security. Rice, corn, and wheat are the three main cereal crops, although other significant cereal grains include barley, oats, rye, sorghum, and millet. The grains are used in a variety of food products, including porridge, breakfast cereals, bread, and beverages with a cereal foundation. Moreover, over 75% of the calories and 67% of the protein consumed globally come from cereals, making them the most important food source worldwide. Cereals provide roughly 15-20 times more energy per gram than fruits and vegetables, with an energy content of 1000–4000 kJ/kg. Many vitamins, minerals, and phytochemicals are rich in cereals. They are also easily carried, packaged, and they are also easily transported and stored. Cereals can grow in poor soil and harsh environmental conditions, with yields remaining largely unaffected. Compared to most other crops, cereals produce the highest yield (Opiyo et al., 2022). Since crops are often planted

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seasonally while consumers need a year-round supply, they must be stored after harvest either for short- or long-term storage to meet demand in the food supply chain and preserve seeds for the next planting season. Due to pests, disease agents, birds, rats, and unfavorable environmental factors, there are significant losses in both quantity and quality during this time. Several studies have reported that the majority of losses occur during storage operations (Majumder et al., 2016).

Insect infestation during grain storage leads to significant loss of stored grain and their products which results in significant financial losses all over the world (Aloke et al., 2024). Many insect pests attack stored cereal grains and their products and cause low product quality with significant losses ranging from 20 to 90% (Demis and Yenewa, 2022). Approximately 1660 species of insect pests have been identified as affecting the quality of preserved goods (Semeão et al., 2013). The main pests of cereal grains in storage, such as wheat, rice, and maize, are grain weevils (Curculionidae). A considerable decrease in both quantity and quality results from insect infestation of grain that has been stored. The weevils of the genus *Sitophilus*, including the rice weevil (*Sitophilus oryzae* L.), granary weevil (*Sitophilus granarius* L.), and maize weevil (*Sitophilus zeamais* Motsch), infest grains in granaries more than other insect species (Germinara et al., 2008; Belda and Riudavets, 2010). Moreover, *Sitophilus granarius* (L.), is considered a serious insect pest that can damage stored grain and their products in the world, which leads to major economic losses (Keskin and Ozkaya, 2015; Plata-Rueda et al., 2018).

The primary method of controlling grain-eating insects in granaries is the direct use of contact insecticides, also referred to as grain protectants. Many synthetic organophosphorus pesticides are among these substances; they may have an adverse impact on the environment and human health due to their residue in grain (Malalgoda and Simsek, 2021). Conventional insecticides have been used to control insect pests of stored goods since 1960 (Stejskal et al., 2021). The utilization of those chemical insecticides is facing many challenges. After frequent use of the chemical insecticides, the insect pests become resistant to them. In addition, the harmful of their residual effects cause bad impacts on the environment and human and animal health which decrease the usage of those chemical compounds (Kaan et al., 2016). The resistance of various stored grain insect pests, including granary weevil, *S. granarius*, against many synthetic insecticides, like malathion, deltamethrin, fenitrothion, tetrachlorvinphos and phosphine, has been indicated (Tyler and Binns, 1982; Mutlu et al., 2019). Tunc and Sahinkaya (1998) and Keita et al. (2000) have shown that, as a result, there is a lot of interest in producing naturally safe compounds that are less harmful to the environment and mammalian health than conventional pesticides, as solutions to non-selective synthesis of pesticides for controlling insect pests. Thus, it is crucial to develop alternate or additional procedures (El-Naggar and Jehan, 2013). Many researchers have recently concentrated on various methods for controlling insect pests, such as using plant inducers to increase plants' systemic resistance to specific insect pests (Zayed et al., 2022) and using plant essential oils to suppress various insect pests (El-Nabawy et al., 2022). Moreover, Nasr et al. (2022) demonstrated that pests that affect stored grain can be efficiently controlled by gamma irradiation. As a result, new compounds are produced utilizing imitations of biological poisons that occur in nature and have a variety of biological effects. However, prior research showed that flowering plants and organic fertilizers increased the population of natural enemies, which in turn reduced the number of related insect pests (El-Nabawy et al., 2015, 2016a). Also, El-Nabawy et al. (2016b) showed the positive effect of flowering

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plants to enhance the numbers of spiders and insect natural enemies. Additionally, Shawer et al. (2021) and Taha et al. (2022) indicated that the emergence times and cold storage durations have an impact on *Trichogramma Evanecsens*' fitness. So, the need for the safety of food products and a clean environment has raised the demand for safe biocontrol agents (Kaan et al., 2016).

The majority of essential oils (EOs) are volatile extracts from medicinal and aromatic plants (Tamokou et al., 2017*)*. The Lamiaceae plant family, which has roughly 6900-7200 species from 236 genera and is found worldwide with a predominance in temperate and Mediterranean climates, is the most significant origin of essential oils (Tamokou et al., 2017*)*. Biologically active substances with antibacterial, insecticidal, nematicidal, herbicidal, fungicidal, anti-inflammatory, and antioxidant properties can be found in essential oils (Bassolé and Juliani, 2012; Turek and Stintzing, 2013; Valerio et al., 2021). The majority of substances in essential oils are volatile terpenes (Bassolé and Juliani, 2012), containing 20 to 60 different substances, and they are frequently distinguished by up to three major components that are present in relatively high concentrations, while other compounds are only present in trace amounts (Bassolé and Juliani, 2012; Turek and Stintzing, 2013; Valerio et al., 2021). EO components can be divided into four chemical classes and two major groups. Monoterpenes, which make up 80% of the EO's composition, and sesquiterpenes are terpene hydrocarbons (Turek and Stintzing, 2012; El Asbahani et al., 2015). Alcohols, phenols, aldehydes, and esters make up the majority of oxygenated substances. In EOs, terpenes are more prevalent, and aromatic and oxygenated chemicals are less prevalent (Turek and Stintzing, 2012; El Asbahani et al., 2015; Buckle, 2014). Moreover, several previous studies indicated the effectiveness of clove EO for its insecticidal and repellent effects against different insect pests including fire ants (Kafle and Shih, 2013), aphids (UshaRani, 2005; Kareem, 2012), weevils (Kerdchoechuen et al., 2010), moths (Mbonu, 2010; Ajanta et al., 2010), and psyllids (Tian et al., 2015).

In insects, the toxic effects of EOs can activate physiologically significant proteins and enzymes. High contact toxicity was caused by mint (*Mentha arvensis*) EO in *S. granarius* adults, and quantitative proteomics analysis showed that the exposed insects underwent significant physiological changes. The majority of differentially expressed proteins (DEPs) are upregulated and associated with the growth and operation of the neurological and muscular systems, cellular respiration, protein synthesis, and detoxification (Renoz et al., 2021). By inhibiting detoxification enzymes, EOs can increase the toxicity of insecticides to insect pests that are resistant to them. The deltamethrin-resistant and -susceptible bed bugs (*Cimex lectularius*) are subjected to topical bioassays with binary mixtures of deltamethrin and specific EOs or their primary constituents, which significantly increase their mortality by inhibiting the P450 activity in resistant bed bugs (Gaire et al., 2021). Plant-derived EOs are being studied for their wide-ranging pest control effects. As a result, they have promising applications as fumigants for stored-product insect pests (Sarac and Tunc, 1995; Ho et al., 1997; Tripathi et al., 1999; El-Wakeil, 2013; Campolo et al., 2018; Dimetry et al., 2019). Furthermore, Campolo et al. (2018) have shown the repellant effect of EOs against the insect pests of stored products. EOs of many plant species, belonging to different plant families, have been indicated as effective agents able to decrease insect species that attack stored cereal grains and products, especially granary weevils (Trivedi et al., 2018; Guettal et al., 2021). Also, plant EOs have lower toxicity residual to the environment and mammalian than conventional insecticides (Kafle and Shih, 2013). Moreover, there are some issues with the direct use of EOs as biopesticides, including phytotoxicity, which has long been thought to be a

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major barrier to their development into biopesticides, their potential impact on the organoleptic features of the resulting food, and the quantities required (Isman, 2019). As a result of their volatility and sensitivity to deterioration, EOs also lose effectiveness when administered directly in the field (Raveau et al., 2020). The practical applications of EOs in biocontrol must therefore be improved through additional research.

Some researchers have indicated that monoterpenoids are the major constituents of EOs and many insect pests have been influenced by some of the monoterpenoids (Dehsheikh et al., 2020). Jiang et al. (2016) have shown that the linalool constituent has high repellent and insecticidal impacts. Linalool constituent has been detected as an inhibitor of the enzyme of acetylcholinesterase (Ryan and Byrne, 1988). Also, the efficacy of EOs has been reported by Li et al. (2020), who indicated that the linalool constituent inhibits c-aminobutyric acid type A receptors and nicotinic acetylcholine receptors.

The detailed studies about the comparison between the fumigant toxicity and repellent effects of EOs on granary weevils are still poor. We may hypothesize that the usage of clove *(S. aromaticum*) EO as a repellent material or fumigant toxicant might be useful for the management of granary weevils and for protecting stored grains and their products. So, the main object of this experiment was to assume the fumigant toxicity and repellent effects of clove in comparison with seven common EOs against the granary weevil (*S. granarius*) to identify the suitable and best management applications.

Materials and methods

Experimental site

This experiment was conducted at the Department of the Economic Entomology, Faculty of Agriculture, Kafrelsheikh University, Kafrelsheikh, Egypt.

The eight essential oils

The used EOs, clove (*Syzygium aromaticum* L.), river red gum (*Eucalyptus camaldulensis* Dehnh), garlic (*Allium sativum* L.), ginger (*Zingiber officinale* Roscoe), lemon (*Citrus lemon* Burm), mint (*Mentha longifolia* L.), almond (*Prunus dulcis* Mill. D. A. Webb) and basil (*Ocimum basilicum* L.) were obtained from the Company of El-captain for EOs, Egypt.

Granary weevils (S. granarius)

The adults of *S. granarius* were obtained from the stores of cereal grains and transferred to the insect laboratory in the Economic Entomology Department, Faculty of Agriculture, Kafrelsheikh University, Kafrelsheikh, Egypt, for increasing and preparing them for the test. The adults of *S. granarius* were mass reared in plastic jars covered with a part of muslin cloth. For rearing the *S. granarius*, the plastic jars were left in the laboratory for 6 months for increasing their numbers. Then, to obtain nearly identical adults in size and age, 300 adults of *S. granarius* were inserted into a clean jar with 100 g of wheat flour and they were kept for 3 days for egg-laying and then they were transferred from those jars, the jars were kept under laboratory conditions 27 ± 2°C and 65 ± 5% R.H until the progeny become adults. The average of developmental stages of *S. granaries* during summer season is 32 to 34, including incubation period (3 to 4 days), larval period (23 to 24 days), and pupal period (5 to 6 days) (Fouad et al., 2024).

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Fumigation effects

A fumigation test was conducted for all tested EOs, *S. aromaticum, E. camaldulensis*, *A. sativum, Z. officinale*, *C. lemon, M. longifolia, P. dulcis*, and *O. basilicum.* Thirty adults of *S. granarius, were* inserted in 200 ml conical flasks without cereal grains and the flask volumes were measured by the volume of water it could enter. A 0.7 ml of each concentration 1, 2, 4, and 8% (v/v) was applied on the filter paper using a pipette and the solvent only was applied as a control treatment and the treated filter papers were placed below the closer and sealed with glass closer fitted to make great surface areas for EOs evaporation. Each concentration was repeated six times. After 48 h of exposure, the individuals of *S. granarius* were transferred into clean Petri dishes and the dead adult numbers were counted and recorded immediately, and the mortality rate was calculated using the Abbott's formula (1925). Also, the values of LC_{30}, LC_{50} and LC_{90} were determined according to Probit analysis (Finney, 1971).

Repellency effects

The eight EOs were evaluated for repellency impact against *S. granarius* in 10 cm glass Petri dishes. The tested percentages of the eight EOs were 1, 2, 4, and 8% (v/v), and were diluted in an acetone solvent to make the required percentages. Nine cm diameter Whatman filter papers were divided by drawing a line to two equal similar halves. By using a pipette a 0.3 ml of each oil dilution was treated to one part of the Whatman filter paper and the second part of the filter paper was applied with only acetone solvent. The filter papers were inserted in a Petri dish and they were exposed to natural conditions and kept open for 1 h till total solvent evaporation. Then, thirty adults of *S. granarius* were put in the central line of the filter paper. Each percentage of the tested EOs was repeated six times. The numbers of *S. granarius* were counted and recorded after 20 and 120 min on both untreated and treated parts. According to Nerio et al. (2009), the repellency proportions were counted as shown in the following equation:

$$PR = [(Nc - Nt)/(Nc + Nt)] \times 100$$

where: PR = the percentages of repellency after exposure time. Nc = the number of *S. granarius* on the untreated part after the exposure time. Nt = the number of *S. granarius* on the treated part after the exposure time.

Statistical analysis

The data were statistically analyzed by using SPSS software (2006). The data was tested by the Shapiro–Wilk normality test, which confirmed the normal distribution of the data. Thus, the statistical analysis was conducted on the original data. Each variable was subjected to analysis, and the treatments were compared using two-way ANOVA. Tukey's test was used to evaluate the differences between the treatment means.

Results

Fumigant toxicity (mortality bioassay)

The fumigant toxicity test against granary weevil after 48 h from the exposure indicated that the mortality percentage was significantly higher by using the clove EOs

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than by river red gum, garlic, ginger, lemon, mint, almond and basil EOs against granary weevil in all tested concentrations, 1, 2, 4, and 8%, $p < 0.01$ (*Fig. 1; Table 1*). Moreover, the fumigant toxicity test showed that the almond EO was significantly lower than the other tested essential oils after 48 h from the exposure in 4, and 8% concentrations.

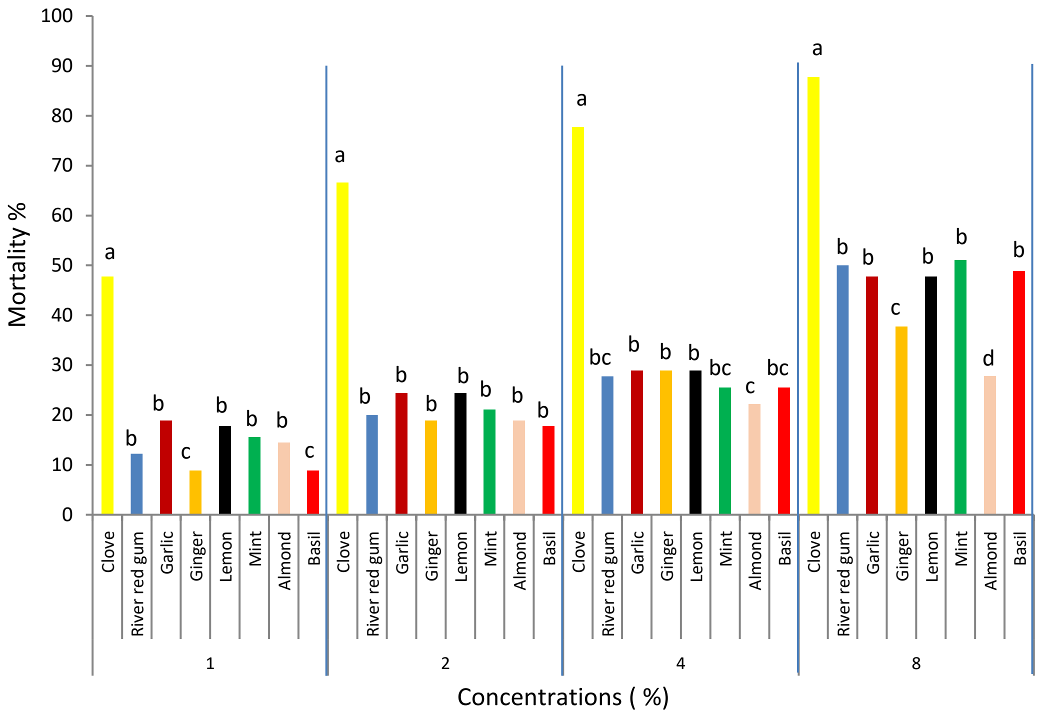

Figure 1. *The fumigant toxicity effect of 8 EOs on the adults of S. granarius after 48 h from the exposure time. Different letters above the bars in each concentration indicate a significant (p < 0.05) difference*

Table 1. *Analysis of variance of fumigant toxicity effect of eight EOs and its concentrations against* S. granarius *after 48 h from the exposure time*

Source of variance	Sum of squares	df	Mean square	F	P-value	F crit
Concentrations (%)	2353.562	3	784.520	1518.427	0.000**	2.661
Essential oils	3730.479	7	532.925	1031.469	0.000**	2.067
Interaction	256.270	21	12.203	23.619	0.000**	1.62
Within	82.9666	160	0.516			

**$p < 0.01$

Data in *Tables 2* and *3* show that the clove EO had a high fumigation toxicity effect against granary weevil after 24 h of exposure. The LC50 values of tested EOs indicated that the clove EO was the most effective one with an LC50 value of 0.52, followed by river red gum with an LC_{50} value of 6.20, garlic 9.43, ginger 13.22, lemon 15.39, mint 18.14, almond 24.28 and basil 24.19%. Moreover, the LC_{90} values of tested EOs indicated that the clove EO was the most effective one with an LC_{90} value of 4.00, followed by

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river red gum with an LC_{90} value of 11.45, garlic 15.60, ginger 19.93, lemon 20.46, mint 21.67, almond 33.87 and basil 27.32%. Additionally, the LC_{30} values of the tested EOs indicated that the clove EO was the most effective EO with an LC_{30} value of 0.22, followed by river red gum with an LC_{30} value of 4.82, garlic 7.68, ginger 11.17, lemon 13.70, mint 16.87, almond 21.35, and basil 23.01%.

Table 2. *The effect of 8 essential oils fumigation on the LC_{30}, LC_{50} and LC_{90} of* S. *granarius after 48 h from exposure*

Essential oil	LC_{30} (%)	Confidence limits 95%		LC_{50} (%)	Confidence limits 95%		LC_{90} (%)	Confidence limits 95%	
		Lower	Upper		Lower	Upper		Lower	Upper
Syzygium aromaticum	0.22	0.01	0.49	0.52	0.09	0.85	4.00	2.71	14.66
Eucalyptus camaldulensis	4.82	4.36	5.21	6.20	5.64	7.65	11.45	8.74	23.77
Allium sativum	7.68	6.86	8.17	9.43	8.71	12.29	15.60	12.09	43.06
Zingiber officinale	11.17	10.49	12.15	13.22	12.15	20.23	19.93	15.59	78.42
Citrus lemon	13.70	12.86	14.19	15.39	14.72	17.85	20.46	17.72	36.07
Mentha longifolia	16.87	16.38	17.25	18.14	17.65	19.27	21.67	20.05	26.69
Prunus dulcis	21.35	20.67	25.69	24.28	22.92	29.07	33.87	31.78	35.65
Ocimum basilicum	23.01	22.60	23.39	24.19	23.72	25.21	27.32	25.92	31.21

Table 3. *Analysis of variance of eight EOs and its Lethal doses, LC_{30}, LC_{50} and LC_{90} of* S. *granarius after 48 h from the exposure time*

Source of variance	Sum of squares	df	Mean square	F	P-value	F crit
Essential oils	1498.753429	7	214.1076327	96.3198053	0.000**	2.76419925
Lethal doses	211.6049083	2	105.8024542	47.5969570	0.000**	3.73889183
Error	31.12035833	14	2.222882738			
Total	1741.478696	23				

**p < 0.01

Repellency effect

As shown in *Figures 2* and *3*, and *Table 4,* the repellency test after 20 and 120 min of exposure indicated that the repellency percentage was significantly higher by using the clove EOs and river red gum than ginger, lemon, mint, almond and basil EOs against granary weevil in 1% concentration. Also, the clove EOs was the most repellent EOs against granary weevil in 2, 4, and 8% concentrations compared with river red gum than garlic, ginger, lemon, mint, almond and basil EOs. Moreover, the repellency test after 120 min of exposure showed that the repellency percentage was significantly lower by almond than clove, garlic, ginger, lemon, mint, almond, and basil EOs.

Discussion

Many studies have recently assessed the impact of the tested EOs on mortality or repellency against granary weevil. However, the comparison between the effects of an insecticide and an insect repellent does not yet have adequate precise results. Therefore,

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the purpose of this study was to determine how the tested EOs' effects on toxicity and repellency varied. We studied the insecticidal activities and repellency of eight essential oils, namely clove, river red gum, garlic, ginger, lemon, mint, almond, and basil EOs, on granary weevil. Results of this work indicated that the clove EO was the most toxic and repellent EO to the adults of granary weevil.

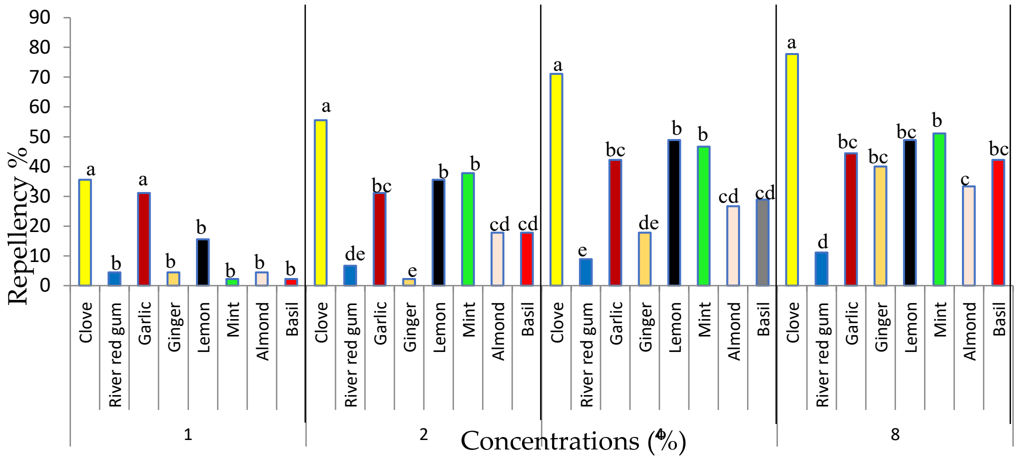

***Figure 2.** The repellency effect of 8 EOs on the adults of* S. *granarius after 20 min from exposure. Different letters above the bars in each concentration indicate a significant (p < 0.05) difference*

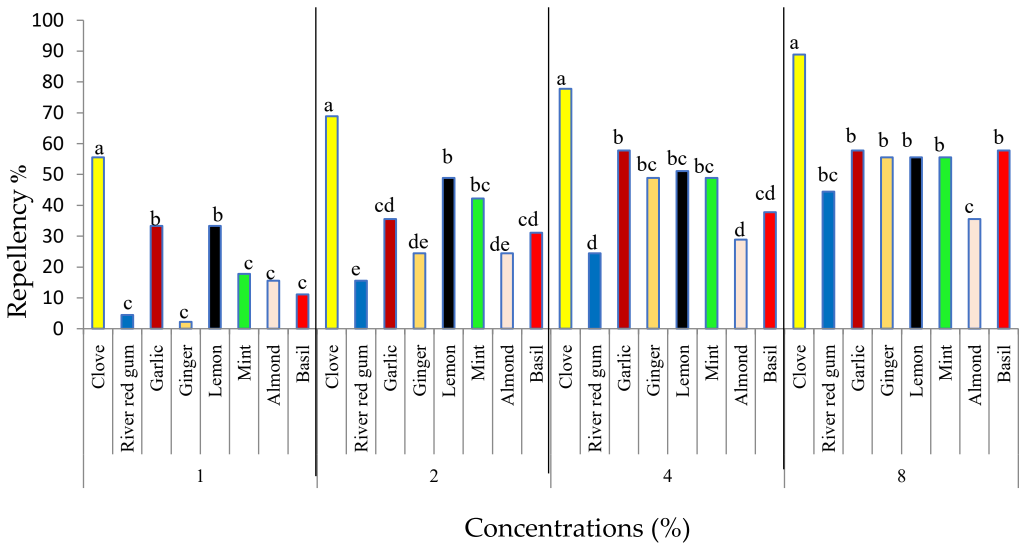

***Figure 3.** The repellency effect of 8 EOs on the adults of S. granarius after 120 min of exposure. Different letters above the bars in each concentration indicate a significant (p < 0.05) difference*

Generally, all the tested essential oils effectively repelled the granary weevils, however, the effectiveness differed across the oils. After 20 and 120 min of exposure, this study's repellent tests showed that clove EO had good potential as a material to repel granary weevil this may be caused by variations in the chemical composition. According

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to earlier studies, such as those by Abo-El-Saad (2011), who demonstrated that clove oil's significant insecticidal activity may be attributed to its primary constituents, eugenol and caryophyllene, the effectiveness of clove EO may be due to a number of factors that enhance the repellency, such as the odor, chemical characteristics, and main components. Eugenol is the primary ingredient of clove oil (48.92%) as determined by Abo-El-Saad (2011) and may be the reason for clove EO's significant repelling activity. Additionally, according to Boraei (2016), eugenol (37.43%) is the primary component of clove essential oil. This ingredient has been shown to be a potent insect pest repellant in numerous earlier investigations (Huang et al., 2002; Zapata and Smagghe, 2010). Also, several pest species, including fire ants (Kafle and Shih, 2013), aphids (UshaRani, 2005; Kareem, 2012), weevils (Kerdchoechuen et al., 2010), moths (Mbonu, 2010; Ajanta et al., 2010), and psyllids (Tian et al., 2015) have been studied extensively for their insecticidal and repellent properties in relation to clove essential oil (Chaieb et al., 2007; Kafle and Shih, 2013; Cortés-Rojas et al., 2014). Czarnobai De Jorge et al. (2022) indicated that clove essential oil in a synthetic form might work as a good repellant against the females of *Cacopsylla pyri* and *Cacopsylla pyricola*. However, Matsumoto et al. (1987) have demonstrated that the EOs of bitter almond, spearmint, and birchbark were utilized in a mixture that was marketed as a pesticide, insect repellent, and acaricide.

Table 4. *Analysis of variance of the repellency effect of 8 EOs concentrations after 20 and 120 min of exposure*

Time after exposure	Concentrations %	Sum of squares	df	Mean square	F	Sig.
20 min	1	87.29	5	12.47	21.37	**
	2	148.66	5	21.23	39.20	**
	4	185.95	5	26.56	30.36	**
	8	163.95	5	23.42	26.76	**
120 min	1	152.50	5	21.78	29.04	**
	2	134.62	5	19.23	41.96	**
	4	135.62	5	19.37	33.21	**
	8	110.62	5	15.80	18.96	**

**$p < 0.01$

The clove EO has a high toxicity index and a quick effect. This is likely a result of the oil's ability to penetrate an insect's cuticle and come into contact with the nerve endings in the pest's trachea, which results in neurotoxic activity and a quicker demise (Bessette et al., 2013). According to Ryan and Byrne (1988) hypothesis, the toxic impact may result from reversible competitive inhibition of acetyl cholinesterase caused by the occupation of the hydrophobic location of the active center of the enzyme. Additionally, Correa et al. (2015) and Khalid et. (2015) found that the clove and cinnamon EOs have the potential to suppress the numbers of *S. zeamais*, and they decreased their respiration and growth rates.

Plant EOs typically contain a large number of monoterpenoids, including d-limonene, -terpineol, pulegone, â-myrcene, and linalool, which have a deleterious impact on a variety of insect pests, including the housefly and the German cockroach (El-Wakeil, 2013, 1998; Dehsheikh et al., 2020). A substantial contributor to the repellent and insecticidal properties, linalool was thought to be an acetylcholinesterase inhibitor

(Dimetry et al., 2019; Jiang et al., 2016; Ryan and Byrne, 1988). According to Bhavaniramya et al. (2019), the use of clove EO has extended storage times without compromising food safety. Moreover, plant EOs are frequently used in food products for food preservation due to their aroma, flavor, and potent antibacterial activities. They have terpenes and aromatic volatile compounds, which are crucial for food safety. Because of their aroma, flavor, and potent antibacterial effects, plant EOs are frequently used in food products to preserve food. They contain volatile aromatic compounds and terpenes, which contribute significantly to food safety without compromising quality (El-Bakry et al., 2016). As a result, using EOs can extend the shelf life of food goods without compromising their quality. Finally, the essential oils utilized have varying degrees of toxicity to adult granary weevils, according to our findings. The various families of the studied plant species could be the cause of this variation in efficacy.

Conclusions

The clove essential oil was the most effective essential oil against *S. granarius*, according to a fumigation bioassay, with an estimated lethal concentration of 50 (LC_{50}) after 48 h of exposure. Compared to the other evaluated EOs, the 2, 4, and 8% concentrations of *S. aromaticum* demonstrated a significant fumigant impact against *S. granarius*. In comparison to *E. camaldulensis, A. sativum, Z. officinale, C. lemon, M. longifolia, P. dulcis,* and *O. basilicum*, the 2, 4, and 8% concentrations of *S. aromaticum* EO significantly affect the repellency percentage of *S. granarius* after 20 and 120 min of exposure. Thus, treating cereal grains and their products that are infested with *S. granarius* may benefit from the use of *S. aromaticum* EOs as a fumigant and repellant EOs. Thus, using the clove EO as a fumigant and repellent EO to protect the cereal grains from *S. granarius* could play an essential role in integrated pest management of that insect pest. However, in the future, further tests are needed to evaluate the negative impacts of the tested essential oils on the environment and human health. Also, to estimate their residues on treated stored cereals and their products to know the safety level.

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