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Insecticidal activities of some plant essential oils on *Rhyzopertha dominica* (F.) and *Sitophilus granarius* L. (Coleoptera: Bostrichidae and Curculionidae) adults

Bazı bitki uçucu yağlarının Rhyzopertha dominica (F.) ve Sitophilus granarius L. (Coleoptera: Bostrichidae ve Curculionidae) erginleri üzerindeki insektisidal aktiviteleri

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Abstract

In this study, the insecticidal activities of the essential oils extracted from *Cuminum cyminum* L., *Mentha longifolia* L. and *Allivum sativum* L. by hydrodistillation method using the Clevenger apparatus were investigated against *Rhyzopertha dominica* (F.) (Coleoptera: Bostrychidae) and *Sitophilus granarius* L. (Coleoptera: Curculionidae) adults. The tests were carried out under 25±1°C temperature, 65±5 proportional humidity and 16:8 (light:dark) conditions and doses of 5, 10, 15, 20 µL/petri. The results of the tested essential oils showed that they had insecticidal effect at different rates (between 1.25% and 100%) 96 hours after exposure. Among the essential oils tested, it was determined that the oil of *A. sativum* showed the highest effect against *R. dominica* and *S. granarius* adults, while the essential oils of *C. cyminum* and *M. longifolia* showed the lowest effect against each two pests. Additionally, LC_{50} and LC_{90} values of these oils against *R. dominica* and *S. granarius* adults were seperately recorded. According to LC_{50} and LC_{90} values, it was reported that *M. longifolia* and *C. cyminum* essential oils were more effective against adults of *R. dominica* (0.698 µL/insect, LC_{50} and 4.694, LC_{90}) and *S. granarius* (0.131 µL/ insect, LC_{50} and 2.452 LC_{90}), respectively. These datas showed that the mortalities increased depending on the increase in the doses of the tested three plant essential oils. Most importantly, considering all these results, it is seen that these essential oils can be used as a natural and environmentally friendly biopreparate against harmful *R. dominica* and *S. granarius* adults in stored grain crops.

Özet

Bu çalışmada, Clevenger düzeneği kullanılarak, hidrodistilasyon yöntemiyle elde edilen *Cuminum cyminum* L., *Mentha longifolia* L. ve *Allivum sativum* L. uçucu yağlarının ekin kambur biti, *Rhyzopertha dominica* (F.) ve buğday biti, *Sitophilus granarius* L. (*Coleoptera*: *Bostrichidae* ve *Curculionidae*) erginlerine karşı insektisidal aktiviteleri araştırılmıştır. Testler 25±1°C sıcaklık, 65±5 orantılı nem ve 16:8 (aydınlık:karanlık) şartlarda ve 5, 10, 15, 20 µL/petri dozlarında yapılmıştır. Sonuçlar, bu uçucu yağların uygulamadan 96 saat sonra farklı oranlarda (%1.25 ile %100 arasında) insektisidal etkiye sahip olduklarını göstermiştir. Test edilen uçucu yağlardan *A. sativum*'un yağının *R. dominica* ve *S. granarius* erginlerine karşı en yüksek oranlarda etki gösterdiği, bununla birlikte *C. cyminum* ve *M. longifolia* uçucu yağlarının ise bu iki zararlıya karşı en düşük etki gösterdiği saptanmıştır. Ayrıca, bu uçucu yağların, *R. dominica* ve *S. granarius* erginlerine karşı LC_{50} ve LC_{90} değerleri de kaydedilmiştir. LC_{50} ve LC_{90} değerlerine göre, *R. dominica* (0.698 µL/böcek, LC_{50} ve 4.694, LC_{90}) ve *S. granarius* (0.131 µL/böcek, LC_{50} ve 2.452 LC_{90}) erginlerine karşı, *M. longifolia* ve *C. cyminum* uçucu yağlarının daha etkili oldukları kaydedilmiştir. Bu sonuçlar, test edilen üç bitki uçucu yağlarının dozların artışına bağlı olarak ölümlerin de arttığını göstermiştir. Daha da önemlisi, bütün bu sonuçlar dikkate alındığında bu uçucu yağların depolanmış tahıl ürünlerinde zararlı *R. dominica* ve *S. granarius* erginlerine karşı doğal ve çevre dostu biyopraperat olarak kullanılabileceği görülmektedir.

INTRODUCTION

The world is facing a growing population and its increasing food requirements. Cereals, especially wheat is a vital source of food for this growing population. Wheat is the first cultivated crop among cereals, has the highest cultivation area, production and consumption in the world, and has a high adaptability (Doğan et al. 2014, 2015). However, there are many insect pests causing to

decrease the quality and edible quality of wheat especially during storage. *Sitophilus granarius* (L.) (Coleoptera: Curculionidae), the wheat weevil also known such as the grain weevil or granary weevil names, and *Rhyzopertha dominica* (F.) (Coleoptera: Bostrychidae), the lesser grain borer are among the most important pest insect species, which caused economical damages on the storaged wheats and the foods obtained from them. *S. granarius* is known as one of the oldest pests of stored wheat. Both its adults and larvae feed with grains in the storage houses after harvest. *R. dominica* is one of the most important insect pests infesting whole sound grain of different cereals and legumes in the world. Both adults and larvae of this insect pest are able to attack whole undamaged grains (Hagstrum and Flinn 1994). *R. dominica* larvae are immobile and feed on the surrounding food scraps, flour, undercooked produce, walnut, hazelnut, dried figs and leguminous products. Due to extremely population, both its adults and larvae can lead to very important economic damages.

In the past, in order to control these pests, many synthetic pesticides such as methyl bromide, phosphine (Attia and Greening 1981), lindane, malathion and cyfluthrin (Bengston et al. 1975, Lorini and Galley 1999) were used. However, syntetic pesticides caused different negative effects for humans and other warm blooded organisms, and also the problem of emerging resistance (Dansi et al. 1984). For all these reasons, the natural compounds of plant origin (essential oils, extracts, etc.) have recently come to the forefront with work accelerating work being carried out in this field. Essential oils are natural compounds obtained from parts of plants such as flowers, leaves, seeds, roots etc.. They occur naturally and are colorless or light yellow in color, volatile, fragrant, and can easily crystallize in liquid form at room temperature. In the recent years, many studies on the harmful insects using essential oils, extracts and compounds from different plants have shown that these natural compounds have insecticidal, ovicidal, repellent, attractant and feeding characteristics (Aksoy 1982, Shaaya et al. 1993, Kordalı et al. 2006, 2017, Ünal and Akkuzu 2009, Usanmaz Bozhüyük et al. 2020, Küçükaydın et al. 2020). Also, a great number of scientific studies carried out on the insecticidal activities of essential oils against *R. dominica* and *S. granarius* and the vast majority of them have been accomplished (Prates et al. 1998, Aslan et al. 2004, Yıldırım et al. 2005, Karakoç et al. 2006, Kordalı et al. 2006, Yang et al. 2010, Yıldırım et al. 2011, Küçükaydın et al. 2020). Compounds of plant origin (especially volatile oils), when used against agricultural pests, have minimal adverse effect on the ecosystem, help to reduce insect resistance and pose little known significant threat to human and environmental health. Considering these, the use of essential oils in the controlling of the insect pests is at the topic of this study, safe alternative to conventional and classical pesticides.

Turkey experiences changeable climate in terms of its both geographical position and topographical structure, giving rise to a vast array of plant species unique to the region. This feature also allows the growth of different numbers of endemic species. Many of these plant species are used as a medicine. They tend to be known locally by different names among the people and have been used for a variety of purposes (anti-inflammatory, anti-helminthic, anti-inflammatory, wound closure, digestion, antiseptic, diuretics, pain relief, etc.) (Baytop 1984, Güncan and Durmuşoğlu 2004). The plants of relevance in this study will be the species of Cumin (*Cuminum cyminum* L. (Apiaceae)), Wild Mint (*Mentha longifolia* L. (Lamiaceae)) and Garlic (*Allium sativum* L. (Liliaceae)).

Cumin is mostly grown as a medicinal and aromatic plant, but it is used as a cultivated spice plant in Turkey (Arslan and Ekim 1987). Cumin is known among the local people in the different regions of Anatolia with names like "Acem (Persian) Cumin", "Frank Cumin" and "Kefe Cumin". The most important cumin species in Turkey in terms of agriculture and economics is Acem (Persian) Cumin (*C. cyminum*). Cumin seeds contain 2-4% volatile oil and may be used as an insecticide against some insect species (Kan 2000). The spear-mint or wild mint (*M. longifolia*) is another common species in Turkey (especially North East Anatolia). Mint has been cultivated to be beneficial in combatting bronchitis, ulcerative colitis anorexia, liver disorders, and as an antiemetic (Güllüce et al. 2007). This plant also has the insecticidal effect against many harmful insects. The *Allium* is an important genus in the family Liliaceae. This genus has 168 species were recorded as endemic in Turkey (Eker and Koyuncu 2011). Garlic (*A. sativum*) belonging to genus *Allium* is one of the earliest plants in the family Liliaceae cultivated by humans with history going back to since antiquity. The garlic bulb is white or pinkish in color with a small number of pods (“teeth”). Its aroma is strong, with a burning quality (Baytop 1999). Research in recent years it has been reported that garlic is an important medicinal plant for treating cardiovascular diseases, regulating blood pressure, reducing blood sugar and cholesterol, having bacterial, viral, fungal and parasitic infections,

strengthening the immune system. It is also thought, to have anti-tumor and anti-oxidant properties (Block 1992).

The main objective of the present study was to investigate insecticidal activities of the essential oils obtained from three plant species, *C. cyminum*, *M. longifolia* and *A. sativum,* collected from different localities of Turkey against two destructive storage pests*, R. dominica* and *S. granarius* adults under laboratory conditions.

MATERIAL AND METHODS

Biological Materials

The adults (3-4 days) of *R. dominica* and *S. granarius* used in the study were collected from wheat mills and wheat storage houses located in Fethiye, Muğla province. Wheat flour, flour, bran, wheat crumb mixture was placed in different glass jars (1 kg). After then, tested adults insects in this study placed in these jars separately and incubated in the laboratory. The insects were reared under laboratory conditions (25±1 °C temperature and 65±5% relative humidity). The adult insects were removed with an aspirator and placed in petri dishes for application, separately for each insect species. After, the fumigant test was applied to the adult insects separately.

Plant Material

The plant species used in the study (*C. cyminum*, *M. longifolia* and *A. sativum*) were collected from Oltu, Pasinler and Tortum districts of Erzurum at their flowering stage in 2016-2017 (between June and September). The collected plant material was kept under shade and turned daily in a spacious place, dried and pulverized with a mill and then kept in a cool warehouse environment. Herbarium of the plant specimens used in this study are preserved in the herbarium of Atatürk University, Faculty of Agriculture, Department of Plant Protection, Erzurum, Turkey.

Obtaining Essential Oils and GC-GC/MS Analyzes

The seeds of *C. cyminum*, the dried flowers and leaves of *M. longifolia*, and the bulbs of *A. sativum* were ground and powdered. The powdered plant material was placed in a 5-liter glass balloon Clevenger Apparatus. Water was added in an enough amount and boiled for 4-6 hours. Then, the volatile oils were extracted with anhydrous sodium sulphate and ethanol. Ethanol was removed-off by rotary evaporator and volatile oils were stored in the refrigerator at +4 °C for use in the experiment. Hydrodistillation of *C. cyminum*, *M. longifolia* and *A. sativum* yielded 3.7%, 4% and 0.4% (w/w) of the essential oils, respestively. The yields were based on dry materials of plant samples. The tested essential oils GC-GC/MS analyzes were taken from previous studies (Hasimi et al. 2014, Okut et al. 2017, Demirci Kayıran et al. 2019)

Testing Insecticidal Effects of Essential Oils

The fumigant effects of the essential oils of *C. cyminum*, *M. longifolia* and *A. sativum* on the adults of *R. dominica* and *S. granarius* were tested in the laboratory conditions. Four doses of the tested plant essential oils (5, 10, 15, 20 µL/petri doses) were used in this treatment. Then, 1.5 x 1.5 cm measuring Whatman no.1 paper was placed on the inside of the cover of each glass petri dish (9 cm width x 1.5 cm depth made up according to 120 mL volume). Each petri dish was filled with 25 adult insect units (*R. dominica*) using an insect aspirator, and doses were injected onto Whatman paper on the petri dish. To feed these mature insects, enough amounts of flour, bran and crushing mixture are placed in the petri dishes and then surrounded with parafilm. This process was repeated for the adults of grain weevil (*S. granarius*) and the wheat and crumbs were placed in the petri dishes as feed. Malathion 65 EM® (650 g/L Malathion), a commercial chemical, was used with pure sterile purified water as a positive control. Experiments were carried out at 25±1 °C temperature, 65±5% humidity and in 16:8 (light-dark) laboratory conditions at the doses of 5, 10, 15, 20 µL/petri dishes. Each experiment was repeated three times for each insect species and doses. These processes were carried out separately for all doses of essential oils. Dead insects were counted at the 12^{th}, 24^{th}, 48^{th}, 72^{nd} and 96^{th} hours of the application, respectively.

Analysis and Evaluation of Data

Rhyzopertha dominica and *S. granarius* adults were exposed to essential oils obtained from plant species of *C. cyminum*, *M. longifolia* and *A. sativum*. Their death percentages were determined and percentage death figures were formed at the end of 12^{th}, 24^{th}, 48^{th}, 72^{nd} and 96^{th} hours. Two-way analysis of variance (ANOVA) was performed using SPSS (Statistical Package for Social Securities 17.0) software package to test whether there was a statistically significant difference between the obtained results. The differences between the averages by Duncan test. LC_{50} and LC_{90} values were calculated using the Finney (Finney 1971) method and the EPA Probit

Analysis Program was used to determine the LC_{50} and LC_{90} values for 95% confidence limits for each application.

RESULTS AND DISCUSSION

Chemical Compositions of the Essential Oils

The main components of the *C. cyminum*, *M. longifolia* and *A. sativum* essential oils were dedicated in Table 1. As the Table 1, the major compositions of the *C. cyminum* oil were β-pinene (15.77 %), α-Terpinene (15.52 %), 1-Phenyl-1-butanol (15.13 %) and Cumic aldehyde (12.74 %) (Hasimi et al. 2014); those of *M. longifolia* were Menthone (19.31 %), Pulegone (12.42 %), Piperitone (11.05 %) and Dihydrocarvon (8.32 %) (Okut et al. 2017); those of *A. sativum* were Allyl disulfide (66.97 %), Allyl sulfide (8.09 %), Allyl methyl disulfide (6.96 %) and Allyl trisulfide (5.45 %) (Demirci Kayiran et al. 2019).

Insecticidal Effects of the Essential Oils

In this study, insecticidal effects of the essential oils obtained from *C. cyminum*, *M. longifolia* and *A. sativum* plants were investigated against the adults (3-4 days) of *R. dominica* and *S. granaries*. As this test used applications of the essential oils at 5, 10, 15 and 20 µL/petri doses (Tables 2 and 3), when compared to controls, deaths occurring at different rates (ranging from 1.25% to 100%) on both harmful insect adults were observed. The highest mortality rate (100%) for *R. dominica* adults was recorded at 15 and 20 µL/petri doses of *A. sativum* essential oil and 10, 15 and 20 µL/petri doses for *S. granarius* adults at 12 hours after the application. The lowest mortality rate was recorded as 1.25% and 12.5% in 5 µL/petri dose of *M. longifolia* essential oil for *R. dominica* and *S. granarius* adults, respectively. In the cases of both pest adults, deaths were observed at doses ranging from 1.25% to 100% (except for 5 and 10 µL/petri doses of *C. cyminum* essential oil at the 12th hour of the application (Tables 2 and 3).

On the 24th hour of the application, it was determined that 100% mortality resulted in both pest adults for all doses of A. *sativum* essential oil (5, 10, 15 and 20 µL/petri). However, no death was observed in 5 µL/petri doses of *C. cyminum* essential oil for *R. dominica* adults. The least mortality rates were recorded in 5 µL/petri dose of *M. longifolia* essential oil for *R. dominica* adults (1.25%) and *S. granarius* (21.2%) (Tables 2 and 3). Similarly, at 48, 72, and 96 hours of application, all the doses of *A. sativum* plant essential oil (5, 10, 15 and 20 µL/petri) resulted in a 100% mortality for *R. dominica* and *S. granarius* adults. Moreover, the mortality rates of 5, 10, 15 and 20 µL/petri doses of *C. cyminum* essential oil at 48th hours of application were 0%, 5%, 7.50%, 23.70% for *R. dominica* adults while *M. longifolia* essential oil was recorded as 2.50%, 51.20%, 46.2% and 50%, respectively. However, at the end of 48 hours, the mortality rates of 5, 10, 15 and 20 µL/petri doses of *C. cyminum* and *M. longifolia* essential oils were 40%, 56.20%, 63.70%, 72.50%; and 40%, 48.70%, 52.50%, 77.50% for *S. granarius* adults, respectively (Tables 2 and 3). While at the end of 48 hours, the lowest mortality rate was observed as 6.25% at 10 µL/petri dose of *C. cyminum* essential oil for *R. dominica* adults, at the end of 72 hours of application, the highest mortality rate was recorded as 26.20% at 20 µL/petri dose for *R. dominica* adults. These mortality rates were found to be 58.70% (5 µL/petri) and 90% (20 µL/petri) for *S. granarius* adults, respectively. Similarly, while the lowest and highest mortality rates of *M. longifolia* oil for *R. dominica* adults were observed as 3.75% (5 µL/petri) and 61.20% (20 µL/petri), these

Table 1. Major constituents of the essential oils of the tested plants

Essential oils	Major components	Relative percent (%)	Literature
Cuminum cyminum	β-pinene	15.77	Haşimi et al. (2014)
	α-Terpinene	15.52	
	1-Phenyl-1-butanol	15.13	
	Cumic aldehyde	12.74	
Mentha longifolia	Menthone	19.31	Okut et al. (2017)
	Pulegone	12.42	
	Piperitone	11.05	
	Dihydrocarvon	8.32	
Allium sativum	Allyl disulfide	66.97	Demirci Kayiran et al. (2019)
	Allyl sulfide	8.09	
	Allyl methyl disulfide	6.96	
	Allyl trisulfide	5.45	

Table 2. Mortality rates after 12, 24, 48, 72 and 96 hours against *R. dominica* adults at doses of 5, 10, 15 and 20 µL/petri of three plant essential oils

Rhyzopertha dominica (F.)

Essential Oils	Dose (µL /L)	Death rate (%)				
		Aplication time (h)				
		12 h	24 h	48 h	72 h	96 h
Cuminum cyminum	5	0.0±0.0 a	0.0±0.0 a	0.0±0.0 a	0.0±0.0 a	0.0±0.0 a
	10	0.0±0.0 a	2.50±1.66 ab	5.00±0.00 a	6.25±1.44 ab	6.25±1.44 ab
	15	2.50±1.66 a	6.25±1.44 bc	7.50±1.66 a	8.75±1.44 b	11.2±3.63 b
	20	16.2±4.33 d	21.2±3.63 d	23.7±3.63 c	26.2±1.44 b	31.2±1.44 c
Mentha longifolia	5	1.25±0.83 a	1.25±0.83 ab	2.50±1.66 ab	3.75±2.66 a	5.00±4.08 ab
	10	5.00±4.08 ab	8.75±3.63 c	51.2±4.93 d	53.7±8.69 c	67.5±7.63 d
	15	10.0±4.08 bc	26.2±7.59 de	46.2±9.53 d	61.2±7.69 d	71.2±8.62 d
	20	12.5±5.0 cd	27.5±5.00 e	50.0±7.07 d	61.2±4.33 d	78.7±2.76 e
Allium sativum	5	96.2±2.76 e	100±0.0 f	100±0.0 e	100±0.0 e	100±0.0 f
	10	97.5±1.66 e	100±0.0 f	100±0.0 e	100±0.0 e	100±0.0 f
	15	100±0.0 e	100±0.0 f	100±0.0 e	100±0.0 e	100±0.0 f
	20	100±0.0 e	100±0.0 f	100±0.0 e	100±0.0 e	100±0.0 f
P. Control (Malathion 65 EM)	5	100±0.0 e	100±0.0 f	100±0.0 e	100±0.0 e	100±0.0 f
	10	100±0.0 e	100±0.0 f	100±0.0 e	100±0.0 e	100±0.0 f
	15	100±0.0 e	100±0.0 f	100±0.0 e	100±0.0 e	100±0.0 f
	20	100±0.0 e	100±0.0 f	100±0.0 e	100±0.0 e	100±0.0 f
N. Control (Sterile water)	-	0.0±0.0 a	0.0±0.0 a	0.0±0.0 a	0.0±0.0 a	0.0±0.0 a

Table 3. Mortality rates after 12, 24, 48, 72 and 96 hours against *S. granarius* adults at doses of 5, 10, 15 and 20 µL/petri of three plant essential oils

Sitophilus granarius L.

Essential Oils	Dose (µL /L)	Death rate (%)				
		Aplication time (h)				
		12 h	24 h	48 h	72 h	96 h
Cuminum cyminum	5	16.2±4.33 bc	23.7±6.40 b	40.0±9.71 b	58.7±5.95 bc	70.0±2.35 bc
	10	20.0±2.35 c	41.2±2.76 d	56.2±3.63 c	71.2±2.76 cde	76.2±1.44 cd
	15	21.2±1.44	47.5±1.66 e	63.7±3.63 d	78.7±4.93 def	95.0±2.35 ef
	20	27.5±2.88 d	47.5±1.66 e	72.5±5.00 e	90.0±5.27 ef	98.7±1.44 f
Mentha longifolia	5	12.5±1.66 b	21.2±2.76 b	40.0±2.35 b	51.2±7.94 b	63.7±11.1 b
	10	21.5±1.44 c	30.0±2.35 c	48.7±4.93 c	67.5±1.66 bcd	82.5±3.72 d
	15	28.7±2.76 d	40.0±3.33 d	52.5±1.66 c	68.7±3.63 bcd	90.0±2.35 e
	20	41.2±1.44 e	51.2±1.44 e	77.5±1.66 e	91.2±1.44 f	100±0.0 f
Allium sativum	5	78.7±7.59 f	100±0.0 f	100±0.0 f	100±0.0 f	100±0.0 f
	10	100±0.0 h	100±0.0 f	100±0.0 f	100±0.0 f	100±0.0 f
	15	100±0.0 h	100±0.0 f	100±0.0 f	100±0.0 f	100±0.0 f
	20	100±0.0 h	100±0.0 f	100±0.0 f	100±0.0 f	100±0.0 f
P. Control (Malathion 65 EM)	5	90.0±2.35 g	100±0.0 f	100±0.0 f	100±0.0 f	100±0.0 f
	10	93.7±1.44 gh	100±0.0 f	100±0.0 f	100±0.0 f	100±0.0 f
	15	98.7±1.44 h	100±0.0 f	100±0.0 f	100±0.0 f	100±0.0 f
	20	100±0.0 h	100±0.0 f	100±0.0 f	100±0.0 f	100±0.0 f
N. Control (Sterile water)	-	1.25±1.29 a	1.25±1.29 a	1.25±1.29 a	1.87±1.44 a	1.87±1.44 a

mortality rates were 51.20% (5 µL/petri) and 91.20% (20 µL/petri) for *S. granaries* adults (Tables 2 and 3). At the end of 96 hours, the mortality rates of 5, 10, 15 and 20 µL/petri doses of *C. cyminum* essential oil were 0.00%, 6.25%, 11.20%, and 31.20% for *R. dominica* adults. These mortality rates were recorded as 5.00%, 67.50%, 71.20% and 78.70% for *M. longifolia* oil, respectively. The essential oils of *C. cyminum* and *M. longifolia* caused to different mortality rates, 70.00%, 76.20%, 95.00%, 98.70%; 63.70%, 82.50%, 90% and 100%, against *S.*

granarius adults, respectively. It can be deduced that *C. cyminum* and *M. longifolia* essential oils are more effective on *S. granarius* adults while less toxic on *R. dominica* adults (Tables 2 and 3). Generally, when all these data are considered, in the application doses (5, 10, 15 and 20 µL/petri) and at application times (12, 24, 48, 72 and 96 hours) of *A. sativum* essential oil were found to cause significant mortality at rates ranging from 78.8% to 100% on *R. dominica* and *S. granarius* adults. In addition, it has been noted that *C. cyminum* and *M. longifolia* essential oils have lower insecticidal activity on *R. dominica*, but they have higher insecticidal activities on *S. granarius* adults. However, 100% mortality rates were established in all positive controls (except for 5, 10 and 15 µL/petri after 12 hour for *S. granarius* adults) (Tables 2 and 3).

Many studies were carried out to determine the insecticidal effects on *R. dominica* and *S. granarius* adults of essential oils obtained from different plants by different researchers in the past. Prates et al. (1998) using *Eucalyptus* spp. and *Citrus* spp. emphasized that the essential oil (Cineole) had significant insecticidal activity (up to 95%) on *R. dominica* adults. Karakoc et al. (2006) reported mortality rates in the 24th hour of application at 10, 20 and 30 °C of *C. cyminum* oil as 63.89%, 89.06% and 76.82% on *S. granarius* adults, respectively. In addition, the same researchers noted that *Mentha spicata* plant essential oil caused between 90.39% and 100% mortalities on *S. granarius* adults at 20 and 30 °C temperatures. In another study, the insecticidal effects in 1, 5, 10, and 20 µL/petri doses of essential oils obtained from 11 different plants were tested against *S. granarius* adults and the mortality rates were recorded between 0.67% and 100% in the 96th hour after application (Yıldırım et al. 2011). Tandorost and Karimpour (2012) determined that the essential oil from orange peel showed insecticidal activity on *Rhyzopertha dominica* adults. Yang et al. (2010) stated that seven days after the application of *A. sativum* plant volatile oil caused between 1.3% and 100% insecticidal effect against *Sitophilus oryzae* adults. In his work, Chaubey (2013), *A. sativum* emphasized that the plant's essential oil has a toxic effect on *Tribolium castaneum*, a storage pest. In this study, essential oils obtained from *C. cyminum*, *M. longifolia* and *A. sativum* plants were given at 5, 10, 15 and 20 µL/petri doses and at application times of 12, 24, 48, 72 and 96 hours. It has been determined that between 12.5% and 100% of the mortality occurred on *S. granarius* adults. These mortality rates were recorded between 1.25 and 100% for *R. dominica* adults (Tables 2 and 3). According to these results, researches made in previous years show that they are in line of present work. Considering the insecticidal effects of the three plant essential oils used in the study against *R. dominica* and *S. granarius*, it was concluded that the chemicals used to combat against both pests could be used as an alternative.

On the other hand, LC_{50} and LC_{90} values after 96 hours of the essential oils of *C. cyminum*, *M. longifolia* and *A. sativum* against *R. dominica* and *S. granarius* were calculated (Tables 4 and 5). According to LC_{50} and LC_{90} values, *A. sativum* essential oil was the most effective on *R. dominica* (0.347 and 0.640 µL/insect); and the essential oils of *C. cyminum* and *A. sativum* (LC_{50}, 0.131 and LC_{90}, 0.640 µL/insect) were for *S. granarius*, respectively. When the LC_{50} and LC_{90} values of these essential oils were compared for their effect on *R. dominica* and *S. granarius* adults, the lowest effective esential oil was found to be from *C. cyminum* based on LD_{50} (2.081 µL/insect) and LD_{90} (11.913 µL/insect) for *R. dominica* adults. These rates were recorded as 0.347 µL/insect (LD_{50}) for *A. sativum* essential oil and 2.467 µL/insect (LD_{90}) for *M. longifolia* essential oil against *S. granarius* adults (Tables 4 and 5). These results explained that the insecticidal activities of the tested essential oils increased with increasing doses and exposure times. All of the essential oils caused significant mortalities. Considering all these results, the studied essential oils can be used as potential natural and environmentally friendly agents against *R. dominica* and *S. granarius* beetle adults in stored wheat grains.

CONCLUSION

In the present study, we investigated to insecticidal activities of *C. cyminum*, *M. longifolia* and *A. sativum* oils against *R. dominica* and *S. granarius* adults. The results suggest that the tested three plant essential oils have the potential for use in the control of *R. dominica* and *S. granarius* adults. Among them, *A. sativum* oil was found to be more toxic (100%) against both pest adults after 96 of application. When the mortality rates according to the application doses are compared, it is observed that the application of four doses of *A. sativum* oil significantly inhibited the growth of adults of *R. dominica* and *S. granarius* (78.70% to 100%) as observed by the mortality rates, while *C. cyminum* and *M. longifolia* plant essential oils were observed to be relatively less effective against both pests. In the light of the present results, it can be suggested that the tested three plant essential oils can be used as new insecticidal determinants against the mentioned above two pest adults. However, more

Table 4. LC_{50} and LC_{90} toxicity values of three plant essential oils against *R. dominica* adults

	Rhyzopertha dominica (F.)				
	LC_{50} (Limits)	LC_{90} (Limits)	X^2	Slope ± SE (Limit)	Probability
Cuminum cyminum	2.081 (4.574-8.435)	11.913 (8.000-30.108)	4.894	3.862±0.802 (2.290-5.434)	0.002
Mentha longifolia	0.698 (1.621-2.229)	4.694 (3.641-7.796)	38.795	3.536±0.385 (2.2780-4.291)	0.137
Allium sativum	0.347	0.640	2.840	4.810 ± 8.409 (11.672-21.291)	0.987

Table 5. LC_{50} and LC_{90} toxicity values of three plant essential oils against *S. granarius* adults

	Sitophilus granarius L.				
	LC_{50} (Limits)	LC_{90} (Limits)	X^2	Slope ± SE (Limit)	Probability
Cuminum cyminum	0.131 (0.387-0.912)	2.452 (2.034-3.248)	12.326	2.300 ± 0.414 (1.489-3.112)	0.650
Mentha longifolia	0.173 (0.502-0.985)	2.467 (2.077-3.171)	17.994	2.537 ± 0.413 (1.727-3.347)	0.613
Allium sativum	0.347	0.640	2.840	4.810 ± 8.409 (11.672-21.291)	0.987

advanced studies need to be conducted to evaluate the mode of action and cost-efficacy of these essential oils on wide range of pests in storage houses of agricultural products. Also, it is hoped that this work will be a source for further studies.

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