

Effects of some essential oils to the bean weevil *Acanthoscelides obtectus* Say (Coleoptera: Chrysomelidae)*Bazı uçucu yağların fasulye tohum böceği Acanthoscelides obtectus Say (Coleoptera: Chrysomelidae) üzerindeki etkileri*Betül KAYAHAN^{1*} , Ali KAYAHAN² ¹Isparta University of Applied Sciences, Agriculture Faculty, Department of Plant Protection, Isparta, Türkiye²Yozgat Bozok University, Faculty of Agriculture, Department of Plant Protection, Yozgat, Türkiye**Citation Information /Atıf bilgisi:**

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Abstract

A significant pest of beans, *Acanthoscelides obtectus* Say (Coleoptera: Chrysomelidae), is widely distributed and causes considerable economic losses in dry beans (*Phaseolus vulgaris* L.) worldwide. In this study, the repellent and toxic effects of the essential oils of clove (*Eugenia caryophyllata*), ginger (*Zingiber officinalis*), and anise (*Illicium verum*) were evaluated against the bean weevil *A. obtectus*, a major pest of stored dry beans. All experiments and insect colony maintenance were conducted in climate chambers at 25±1°C and 60±5% relative humidity. The repellent effects of the essential oils were tested at a dose of 25,000 ppm L⁻¹, and repellent indices were calculated. The repellent indices were 71.96, 52.83, and 25.76 for clove, ginger, and anise oils, respectively. In addition to repellency, the oils also exhibited toxic effects on the pest. Mortality rates of *A. obtectus* increased with increasing doses of the essential oils. Lethal concentrations (LC₃₀, LC₄₀, LC₅₀, and LC₉₀) were determined based on mortality data. Among the tested oils, *E. caryophyllata* showed the highest toxicity, with lower lethal concentration values than the other two oils. Overall, the results indicate that these essential oils have potential for the management of *A. obtectus*. However, further studies under different conditions and application strategies are needed to enhance their practical use in pest control.

Keywords: Fumigant, repellent, essential oil, clove, ginger, anise

Öz

Fasulyenin önemli zararlılarından biri olan *Acanthoscelides obtectus* Say (Coleoptera: Chrysomelidae), dünya genelinde yaygın olarak bulunan ve kuru fasulyede (*Phaseolus vulgaris* L.) önemli ekonomik kayıplara neden olan bir türdür. Bu çalışmada karanfil (*Eugenia caryophyllata*), zencefil (*Zingiber officinalis*) ve anason (*Illicium verum*) uçucu yağlarının kuru fasulyede önemli zararlılardan biri olan fasulye tohum böceği *A. obtectus* üzerindeki repellent ve toksik etkileri araştırılmıştır. Tüm deneyler ve böcek kolonisi üretimi 25±1°C sıcaklık ve %60±5 bağıl nem koşullarına ayarlanmış iklim odalarında yürütülmüştür. Uçucu yağların repellent etkileri 25,000 ppm L⁻¹ dozunda test edilmiş ve repellent indeksleri hesaplanmıştır. Buna göre repellent indeksleri sırasıyla karanfil, zencefil ve anason yağları için 71,96, 52,83 ve 25,76 olarak belirlenmiştir. Repellent etkinin yanı sıra uçucu yağların zararlı üzerinde öldürücü etkileri de tespit edilmiştir. Uçucu yağ dozları arttıkça *A. obtectus*'ün ölüm oranının da arttığı gözlemlenmiştir. Elde edilen ölüm oranlarına göre uçucu yağların öldürücü dozları (LC₃₀, LC₄₀, LC₅₀ ve LC₉₀) hesaplanmıştır. Test edilen yağlar arasında karanfil en yüksek toksisiteyi göstermiş ve diğer iki uçucu yağa kıyasla daha düşük öldürücü doz değerlerine sahip olmuştur. Elde edilen sonuçlar, çalışmada kullanılan uçucu yağların *A. obtectus*'ün kontrolünde potansiyel taşıdığını göstermektedir. Ancak bu yağların pratik kullanımını artırmak için farklı uygulama yöntemleri ve koşullar altında daha fazla çalışmaya ihtiyaç bulunmaktadır.

Anahtar Kelimeler: Fumigant, repellent, uçucu yağ, karanfil, zencefil, anason



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Introduction

Agricultural production, which holds an important place in both human and animal nutrition, plays a significant role in increasing the income levels of countries economically (Tunçer and Günay, 2017). Looking at the global human population, it is evident that the population continues to grow (Kışlalioğlu and Berkes, 1991), and with this growth, ensuring food supply, its continuity, and increasing production have become critical (Donahaye and Messer, 1992). Since the Industrial Revolution, supporting the growing and aging population and ensuring regional and global sustainability is heavily dependent on agricultural production. Some studies have indicated a decline in cereal and grain production and yields in recent years (Schmidhuber and Tubiello, 2007; Grassini et al., 2013; Asseng et al., 2015). Additionally, the COVID-19 pandemic that started in early 2020 led to mobility restrictions, raising concerns about the negative impact on food security, particularly in developing countries (Erokhin and Gao, 2020; Hickey and Unwin, 2020; Rizou et al., 2020; Lamichhane and Reay-Jones, 2021). In a recent study evaluating food security, it was reported that more than 45% of the population in Africa and the Middle East would face hunger by 2050 (Fujimori et al., 2019).

The outbreaks of pests and diseases in agricultural production, climate change, land intensification, global trade, and increasing water demand and scarcity are factors that will continue to maintain the importance of food security (Rosegrant and Cline, 2003; Savary et al., 2006; Schmidhuber and Tubiello, 2007; Adhikari et al., 2015; Ye et al., 2021). Legumes, after cereals, form the second most important group in terms of production. The highest share in these productions belongs to oilseeds such as soybeans and peanuts. Looking at the global production of legumes, it is known that peas (Dry: 14.2 million tons, Green: 21 million tons) have the second-highest production, followed by chickpeas (Dry: 18.1 million tons) and lentils (Dry: 6.7 million tons) (FAOSTAT, 2022). In Turkey, the legume production is approximately 1.31 million tons (TÜİK, 2023). Without a rapid increase in yields, it is expected that by 2050, the production gap in legumes will reach 10 million tons (Joshi and Rao,

2017). As a result of this negative outlook, there is a growing awareness of the need to increase legume production to help ensure global food security (FAO, 2010; Godfray et al., 2010). With increased production, there has also been an increase in the number and populations of diseases and pests in crop plants. In the control of these pests and diseases, chemical control is often preferred due to its rapid effects. However, pests, in particular, are developing resistance to these chemicals. Because of these issues, both producers and researchers are turning to alternative methods (Lacey et al., 2001).

The protection of agricultural products, particularly methods to improve the quality of these products, also requires the development of different methods. Proper storage of cereals helps to monitor the quality of seeds and grains (Magalhães et al., 2014). During the storage phase, cereals are highly susceptible to insects and diseases (especially fungi), and contamination can lead to significant losses (Ahmad et al., 2021). In addition to providing proper storage conditions, the use of pesticides to control these pests is widely preferred for quick solutions. However, excessive use of pesticides brings about various negative consequences (Fields and White, 2002).

A significant pest of beans, *Acanthoscelides obtectus* Say (Coleoptera: Chrysomelidae), is a species widely distributed across the globe and causes economic damage to dry beans (*Phaseolus vulgaris* L.) (Alvarez et al., 2005; Fogang et al., 2012; Soares et al., 2015; Njoroge et al., 2017). Considering global climate changes, it is expected that some pest species, including *A. obtectus*, will particularly concentrate in Europe and its surrounding regions (Adler et al., 2022). Studies on bean production areas have reported that losses due to *A. obtectus* can reach up to 90% (Berim, 2007). This pest causes damage not only by feeding on the bean seed coat but also by opening holes through which different microorganisms and insects can enter, causing further harm (Jimenez et al., 2007). It is known that this pest causes significant damage both directly and indirectly to fields and storage areas (Schmale et al., 2002; Rees, 2004; Hagstrum and Subramanyam, 2006), and it is critical to keep its population below the economic damage threshold (4% damaged beans) (Baier and Webster, 1992;

Hagstrum and Flinn, 2014). Chemical, biological, mechanical, and cultural methods have been used to control this pest, with successful results reported (Abate and Ampofo, 1996; Boyer et al., 2012; Mutungi et al., 2015; Velten et al., 2008; Yankova and Sofkova, 2013; Rodríguez-González et al., 2019). However, these methods still rely on insecticides despite the resistance developed by stored-product pests (Boyer et al., 2012; Collins and Schlupalius, 2018) and the residue problem (Daglish et al., 2018). Some insecticide formulations that are effective against this pest also reduce the effectiveness of stored-product pest control (Toews and Subramanyam, 2003; Hagstrum and Subramanyam, 2006; Athanassiou and Arthur, 2018; Daglish et al., 2018).

To overcome these negative impacts, reduce pesticide usage, and protect products, the use of essential oils (EOs) has emerged as an alternative control method. These secondary metabolites are produced by plants as a result of various physiological activities and are classified based on their biochemical activities (Lü, 2017). It is possible to obtain essential oils from plants with different secondary metabolites through various methods. In their study, Doğan et al. (2025) extracted essential oil from Bay Laurel (*Laurus nobilis*) using a microwave-assisted distillation system. Additionally, Ağamirzaoğlu et al. (2024) investigated the secondary metabolites of different oregano (*Origanum* sp.) species, and based on the results obtained, it was reported that some metabolites were present at high levels. These metabolites have significant potential in agricultural production and are highly effective against pests. They exert their effects through contact and fumigation

methods, and particularly show repellent effects, high mortality rates, and reduced egg production and larval development against pests in cereals (Ayvaz et al., 2010). Recent studies have reported that different essential oils have been studied for their effects on *A. obtectus* and other stored-product pests, and positive results have been obtained in reducing pest populations (Sağlam Altınköy and Bilginoğlu, 2022; Selimoğlu et al., 2015; Bayındır Erol and Birgücü, 2020; Çetin et al., 2014; Çetin et al., 2009; Bozhüyük et al., 2019; Çiftci et al., 2021; Rodríguez-González et al., 2019; Moura et al., 2021; Ayvaz et al., 2010; Wang et al., 2019; Plata-Rueda et al., 2021; Lazarević et al., 2020). However, one study indicated that the use of these essential oils is limited due to light sensitivity and rapid oxidation. Therefore, it is recommended that their use be cautious and under suitable conditions (Rajkumar et al., 2020).

For this reason, determining the potential and application possibilities of essential oils derived from plants is of great importance. In this study, the effects of essential oils from *Eugenia caryophyllata*, *Zingiber officinalis*, and *Ilicium verum* on the bean weevil *Acanthoscelides obtectus*, which causes economic loss in dry beans, were investigated.

Material and Method

The plant essential oils used in this study, namely *Eugenia caryophyllata*, *Zingiber officinalis*, and *Ilicium verum*, were purchased commercially from Botalife (Botalife Natural Products, Türkiye). The oils were supplied as commercially available pure essential oils and were used without further purification (Table 1).

Table 1. Informations of essential oils

Essential oils	Family
Clove, <i>Eugenia caryophyllata</i>	Myrtaceae
Ginger, <i>Zingiber officinalis</i>	Zingiberaceae
Anise, <i>Ilicium verum</i>	Schisandraceae

Essential oils were supplied by Botalife®

Acanthoscelides obtectus culture

The individuals used in the experiments were selected from individuals that had not been

exposed to any insecticide for two years. The mixed-sex (male-female) individuals collected from this production were placed in plastic containers (20x20x20 cm) containing bean seeds

where they could feed, and mating and egg-laying were ensured. Afterward, larvae hatching from the eggs were allowed to mature into adults, and care was taken to use individuals of the same age (the first individuals to emerge from the pupae) in the experiments. The laboratory production of this pest was carried out in climate chambers at a temperature of $25\pm1^{\circ}\text{C}$ and relative humidity of $60\pm5\%$ (Savković et al., 2019; Vuts et al., 2024).

Establishment of trials

Fumigant effect trials

In this phase of the experiments, the fumigant effects of different doses of the oils (12500, 10000, 7500, 5000, 2500, 1250, 675 ppm L^{-1}), as given in Table 1, were determined on *A. obtectus*. The prepared doses of the volatile oils were absorbed into filter papers with dimensions of $1\times1\text{ cm}^2$ and fixed in places in the experimental containers ($5\times5\times5\text{ cm}$) where they would not come into contact with the insects. Ten individuals of the same age from the laboratory-reared pest population were transferred to the containers where the experiments were to be conducted. Then, to avoid experimental error due to feeding deficiency, bean seeds were placed in the containers. Live and dead individuals were recorded at 24, 48, 72 hours. The experiments were actualized out with 10 repetitions for each oil and dose, with 10 individuals in each repetition. The fumigant effect trials were conducted in climate chambers at a temperature of $25\pm1^{\circ}\text{C}$ and relative humidity of $60\pm5\%$.

Repellent effect trials

In this phase of the experiments, the repellent effects of the volatile oils (25000 ppm L^{-1}) on *Acanthoscelides obtectus* were investigated, 2% Tween20 solution was used as the solvent in preparing the doses, and two different olfactometers (Y-type and four-arm) were used to investigate the insect's orientation. The oils were applied separately to filter papers ($1\times1\text{ cm}^2$ in size) by soaking them with the prepared doses. In the first stage of these experiments, the Y-type olfactometer was used. For this purpose, one arm

of the olfactometer was treated with the filter paper soaked in the dose, while the other arm contained only the control treatment—filter paper soaked with 2% Tween20. Then, 20 individuals of *A. obtectus* were placed in the entry opening, and after 24 hours, the orientation of the individuals was recorded. In the second stage, a four-arm olfactometer was used. In this case, three arms of the olfactometer were treated with filter papers soaked in different essential oils, and the fourth arm contained the control treatment with filter paper soaked only in 2% Tween20. Again, 20 individuals of *A. obtectus* were placed in the entry opening, and after 24 hours, the orientation of the individuals was recorded. All olfactometer trials were conducted with 10 repetitions. The repellent effect trials were carried out in climate chambers at a temperature of $25\pm1^{\circ}\text{C}$ and relative humidity of $60\pm5\%$. In this phase of the experiments, the approach or avoidance of *A. obtectus* individuals towards or away from the volatile oils was analyzed according to Bayındır Erol and Bürgücü (2020).

Statistical analyses

The repellent effects of the volatile oils were determined using the equation by Pascual-Villalobos and Robledo (1998). According to this equation:

$$\text{RI} = [(C-T)/(C+T)]\times100$$

RI: Repellent Index; C: Numbers of Individuals on Control Application; T: Numbers of Individuals on Essential Oils Application

In the statistical analyses of the orientation data obtained from the Y-type olfactometer in the first stage of the olfactometer trials, a two-tailed t-test (Paired-Samples t-test) was applied. For the data obtained from the four-arm olfactometer in the second stage of the trials, one-way analysis of variance (One-Way ANOVA) was used. To determine the statistical significance of the results from the second stage of the olfactometer trials, Tukey's multiple comparison test (Tukey, 1949) was employed. In the statistical analysis of the fumigant effects of the volatile oils on *Acanthoscelides*

obtectus, mortality rates recorded at 24, 48, and 72 hours were used for evaluation. The mortality rates were determined according to Abbott (1925), as follows:

$$\text{Percentage effect} = \left(\frac{\text{Number of live individuals in control} - \text{Number of live individuals in application}}{\text{Number of live individuals in control}} \right) \times 100$$

In the fumigant effect trials, one-way analysis of variance (One-Way ANOVA) was applied to the results, and Tukey's multiple comparison test (Tukey, 1949) was used to emphasize the statistical significance and determine the differences between groups. Additionally, the different lethal doses (LC_{30} , LC_{40} , LC_{50} , LC_{90}) of the oils applied in the trials on *Acanthoscelides obtectus* were determined using PROBIT analysis. The statistical analyses were performed using Minitab (Ver. 17) software.

Results and Discussion

The results of the study showed that as the doses of different essential oils (*Eugenia caryophyllata*, *Zingiber officinalis*, *Ilicium verum*) increased, the mortality rate of *Acanthoscelides obtectus* also increased. Looking at the number of live and dead individuals at different time points, the mortality caused by the doses varied depending on the duration. The highest dose applied, 12500 ppm L^{-1} , resulted in mortality rates of 90.72%, 86.60%, and 81.44% for the oils after 24 hours, respectively. It was determined that *Eugenia caryophyllata* was the most effective essential oil in terms of both duration and dose (Figure 1).

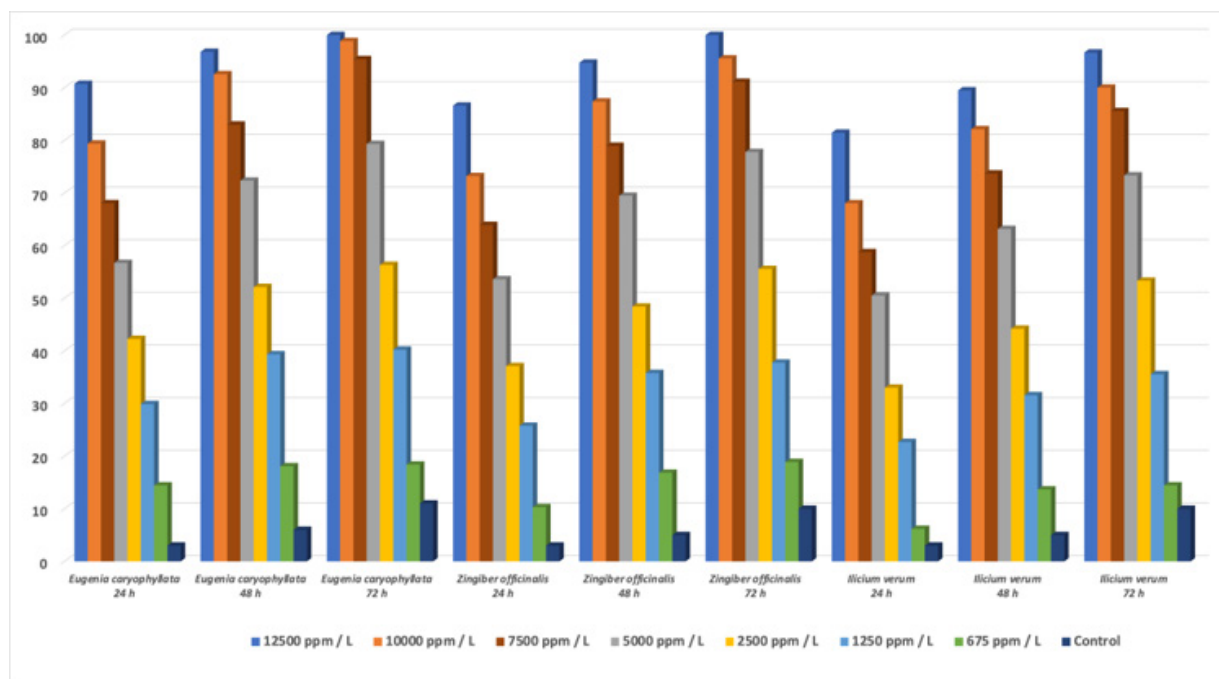


Figure 1. Abbott-corrected mortality (%) of adult *Acanthoscelides obtectus* exposed to different concentrations of *Eugenia caryophyllata*, *Zingiber officinalis*, and *Ilicium verum* essential oils after 24, 48, and 72 h of fumigant exposure. Mortality percentages were calculated according to Abbott (1925)

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In the statistical evaluation conducted on live and dead individuals in the study, significant differences were observed both between the doses of the essential oils and among the different essential oils at the same dose. Specifically, it was determined that there was a statistically significant difference in all doses of *Eugenia caryophyllata*. Another essential oil used in the study, *Zingiber officinalis*, showed similar effects between the 10000 and 7500 ppm L-1 doses; however, these doses were significantly different from the other doses. For *Illicium verum*, the 2500 and 1250 ppm L-1 doses were similar to each other, while they were significantly different from the other doses. Additionally, the 675 ppm L-1 doses of *Z. officinalis* and *I. verum* were found to be similar to the control

application ($DF_{Eugenia\ caryophyllata} = 7$; $F_{Eugenia\ caryophyllata} = 248.18$; $P_{Eugenia\ caryophyllata} = 0.001$; $DF_{Zingiber\ officinalis} = 7$; $F_{Zingiber\ officinalis} = 198.56$; $P_{Zingiber\ officinalis} = 0.001$; $DF_{Illicium\ verum} = 7$; $F_{Illicium\ verum} = 146.23$; $P_{Illicium\ verum} = 0.001$) (Table 2). Furthermore, statistical analyses were also performed on different oils at the same dose. It was observed that *E. caryophyllata* was more effective in inducing mortality, particularly at higher doses, compared to the other oils, and this difference was statistically significant ($DF_{12500\ ppm/L} = 2$; $F_{12500\ ppm/L} = 5.18$; $P_{12500\ ppm/L} = 0.012$; $DF_{10000\ ppm/L} = 2$; $F_{10000\ ppm/L} = 8.81$; $P_{10000\ ppm/L} = 0.001$; $DF_{7500\ ppm/L} = 2$; $F_{7500\ ppm/L} = 4.10$; $P_{7500\ ppm/L} = 0.028$; $DF_{5000\ ppm/L} = 2$; $F_{5000\ ppm/L} = 1.37$; $P_{5000\ ppm/L} = 0.271$; $DF_{2500\ ppm/L} = 2$; $F_{2500\ ppm/L} = 5.60$; $P_{2500\ ppm/L} = 0.009$; $DF_{1250\ ppm/L} = 2$; $F_{1250\ ppm/L} = 1.69$; $P_{1250\ ppm/L} = 0.203$; $DF_{675\ ppm/L} = 2$; $F_{675\ ppm/L} = 3.30$; $P_{675\ ppm/L} = 0.049$) (Table 3).

Table 2. Mean number of dead adult *Acanthoscelides obtectus* (out of 10 insects per replicate) after 24 h of fumigant exposure to different essential oils

Doses (ppm / L)	N	<i>Eugenia caryophyllata</i>	N	<i>Zingiber officinalis</i>	N	<i>Illicium verum</i>
12500	100	9.10±0.180 ^{a*}	100	8.70±0.153 ^{a*}	100	8.20±0.249 ^{a*}
10000	100	8.00±0.211 ^b	100	7.40±0.163 ^b	100	6.90±0.180 ^b
7500	100	6.90±0.180 ^c	100	6.50±0.224 ^b	100	6.00±0.258 ^{bc}
5000	100	5.80±0.249 ^d	100	5.50±0.224 ^c	100	5.20±0.291 ^c
2500	100	4.40±0.163 ^e	100	3.90±0.233 ^d	100	3.50±0.167 ^d
1250	100	3.20±0.200 ^f	100	2.80±0.291 ^e	100	2.50±0.307 ^d
675	100	1.70±0.213 ^g	100	1.30±0.213 ^g	100	0.90±0.233 ^e
Control	100	0.30±0.153 ^h	100	0.30±0.153 ^g	100	0.30±0.153 ^e

*In the study, different letters within the same column indicate a statistically significant difference (This comparison was made between different doses of the same essential oil) Means within the same column followed by different lowercase letters are significantly different according to Tukey's Honestly Significant Difference (HSD) multiple comparison test following one-way ANOVA ($p < 0.05$). Comparisons were performed among different doses within each essential oil.

Table 3. Comparison of the mean number of dead adult *Acanthoscelides obtectus* (out of 10 insects per replicate) among essential oils after 24 h of fumigant exposure

Doses (ppm / L)	N	<i>Eugenia caryophyllata</i>	N	<i>Zingiber officinalis</i>	N	<i>Illicium verum</i>
12500	100	9.10±0.180 ^{a*}	100	8.70±0.153 ^{ab}	100	8.20±0.249 ^b
10000	100	8.00±0.211 ^{a*}	100	7.40±0.163 ^{ab}	100	6.90±0.180 ^b
7500	100	6.90±0.180 ^{a*}	100	6.50±0.224 ^{ab}	100	6.00±0.258 ^b
5000	100	5.80±0.249 ^a	100	5.50±0.224 ^a	100	5.20±0.291 ^a
2500	100	4.40±0.163 ^{a*}	100	3.90±0.233 ^{ab}	100	3.50±0.167 ^b

Table 3. Continued

1250	100	3.20±0.200 ^a	100	2.80±0.291 ^a	100	2.50±0.307 ^a
675	100	1.70±0.213 ^{a*}	100	1.30±0.213 ^{ab}	100	0.9±0.233 ^b

*Different letters in the same row indicate a statistically significant difference (This comparison was made between different essential oils at the same dose) Means within the same column followed by different lowercase letters are significantly different according to Tukey's Honestly Significant Difference (HSD) multiple comparison test following one-way ANOVA ($p < 0.05$). Comparisons were performed among different doses within each essential oil.

Based on the mortality rates obtained at the end of the study, the different lethal concentrations of the applied essential oils were determined through Probit analysis. When evaluating the potential effectiveness of these

oils on the pest, it was observed that *Eugenia caryophyllata*, which caused the highest mortality, had calculated lethal concentrations lower than those of the other two essential oils. The results of the Probit analysis for these essential oils are

Table 4. Toxicity of different essential oils on *Acanthoscelides obtectus* after 24 h

Essential oils	N	LC30 (ppm L-1) (95% CI)a	LC40 (ppm L-1) (95% CI)a	LC50 (ppm L-1) (95% CI)a	LC90 (ppm L-1) (95% CI)a	Slope ±SEb	X2 (df)c
<i>Eugenia caryophyllata</i>	700	1536.30 (964.62- 2446.81)	2285.59 (1453.08- 3640.16)	3313.21 (2080.30- 5276.82)	21673.80 (13608.56- 34518.99)	1.586±0.103	0.970 (5)
<i>Zingiber officinalis</i>	700	1896.49 (1194.94- 3009.90)	2812.69 (1772.23- 4463.99)	4065.49 (2561.60- 6452.30)	26207.37 (16512.83- 41593.49)	1.595±0.102	0.957 (5)
<i>Illicium verum</i>	700	2347.84 (1492.92- 3692.33)	3451.14 (2194.48- 5427.44)	4946.86 (3145.56- 7779.68)	30570.75 (19439.01- 48077.09)	1.638±0.100	0.972 (5)

a 95% confidence intervals; b Standart error; c Chi-square value (x2) (Pearson) and degrees of freedom (df)

In this study, the repellent and attractant effects of the applied essential oils on the pest were also determined. According to the results, during the first phase of the olfactometer trials, a higher attraction to the control treatment was observed in all three essential oil applications. The

results of the t-test indicated that this orientation was statistically significant (Figure 2). In this phase, the repellent effects of the essential oils were determined using the equation by Pascual-Villalobos and Robledo (1998). The obtained results are presented in Table 5.

Table 5. Repellent indices of different essential oils calculated on adult *Acanthoscelides obtectus*

Essential oils	Repellent Index (RI)
Clove (<i>Eugenia caryophyllata</i>)	71.9626168
Ginger (<i>Zingiber officinalis</i>)	52.8301887
Anise (<i>Illicium verum</i>)	25.7575758

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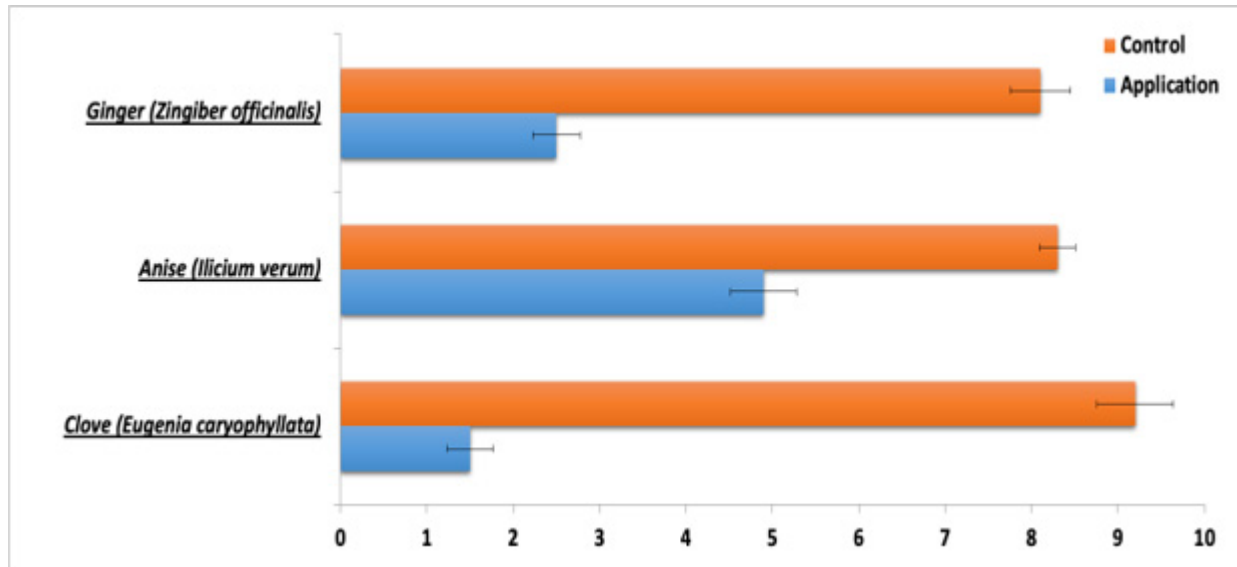


Figure 2. The repellent effects of different essential oils on adult *Acanthoscelides obtectus* (using a Y-type olfactometer) (Paired-samples tests $p < 0.05$, $DF = 16$, $t_{\text{clove}} = -14.88$, $t_{\text{ginger}} = -12.74$, $t_{\text{anise}} = -7.82$)

In the second phase of the olfactometer trials, the statistical analysis of the data obtained from the four-arm olfactometer was conducted using one-way ANOVA and Tukey's test. The results showed that the highest orientation was observed

towards the control group, although there was also some attraction to the other essential oils. Statistical differences between these groups were found ($p < 0.05$) (Figure 3).

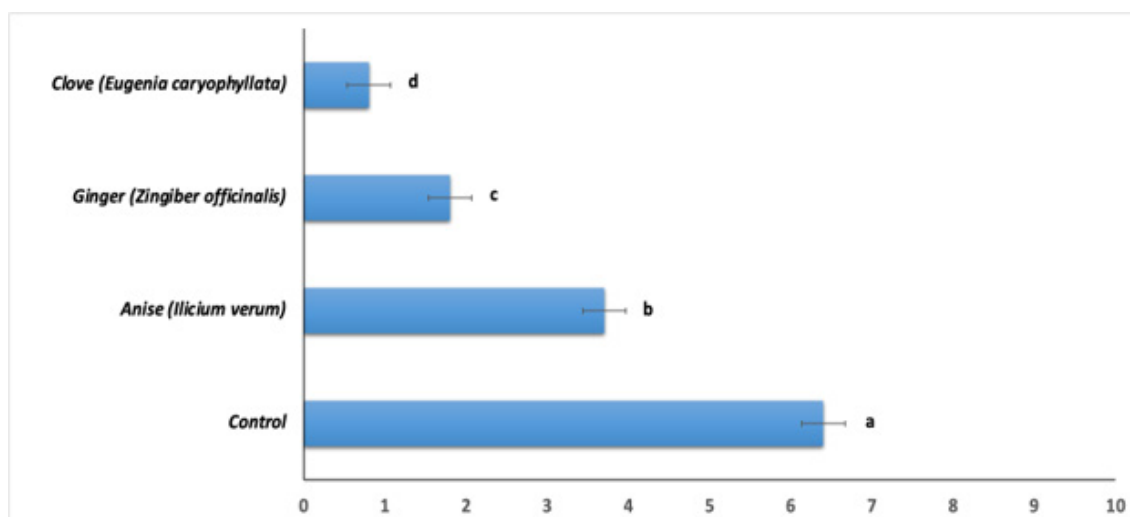


Figure 3. Repellent effects of different essential oils on adult *Acanthoscelides obtectus* (Four-arm olfactometer with one entrance and four exits was used) Different letters in the same row indicate a statistically significant difference (This comparison was made between different essential oils at the same dose) Means within the same column followed by different lowercase letters are significantly different according to Tukey's Honestly Significant Difference (HSD) multiple comparison test following one-way ANOVA ($p < 0.05$). Comparisons were performed among different doses within each essential oil

The results of the present study demonstrated that the essential oils tested exhibited both lethal and repellent effects against *Acanthoscelides obtectus*. These findings are consistent with previous studies reporting insecticidal activity of essential oils against this pest. Papachristos and Stamopoulos (2002) showed that rosemary, lavender, and mint essential oils caused significant mortality, although their effects differed between male and female adults. Likewise, Bittner et al. (2008), Ayvaz et al. (2010), Cetin et al. (2014), Atanasova and Ganchev (2018), Rodríguez-González et al. (2019), Bozhüyük et al. (2019), Bayındır Erol and Birgücü (2020), Lazarević et al. (2020), and Sağlam Altınköy and Bilginoğlu (2022) reported high insecticidal activity of various plant essential oils against *A. obtectus*, confirming the susceptibility of this species to plant-derived volatile compounds.

Although the insecticidal potential of essential oils has been widely documented, considerable differences in toxicity are evident among plant species. In the present study, *Eugenia caryophyllata* exhibited consistently lower LC values than *Zingiber officinalis* and *Illicium verum*, indicating greater toxicity. Similar variations have been reported by Selimoğlu et al. (2015), Ndomo et al. (2008), Karabörklü et al. (2010), Papachristos et al. (2004), and Sağlam Altınköy and Bilginoğlu (2022), who found substantial differences in LC₅₀ values among different essential oils tested against *A. obtectus*. These variations are most likely associated with differences in the qualitative and quantitative composition of essential oils, particularly the abundance of bioactive constituents, which determine their mode of action and toxicity.

The higher efficacy of *E. caryophyllata* observed in this study may therefore be attributed to its richer composition of highly active insecticidal compounds, whereas the comparatively higher LC values of *Z. officinalis* and *I. verum* suggest lower biological potency under the tested conditions. In addition to

chemical composition, differences in toxicity among essential oils may also result from variations in concentration, exposure period, volatility, penetration ability, and interactions between individual constituents, which together influence their overall biological activity.

Repellent activity was also observed for the tested essential oils and agrees with previous reports demonstrating behavioral effects of plant volatiles on *A. obtectus*. Repellent effects have previously been reported for *Eugenia caryophyllata* as well as for essential oils of *Origanum onites*, *Satureja thymbra*, *Myrtus communis* (Ayvaz et al., 2010), *Azadirachta indica*, *Cinnamomum zeylanicum*, *Citrus sinensis*, *Eucalyptus* spp., and *Piper nigrum* (Oliveira et al., 2018), *Citrus reticulata*, *C. limonum*, *Mentha piperita*, and *Lavandula angustifolia* (Khelfane-Goucem et al., 2016), as well as *Juniperus communis*, *Melaleuca alternifolia*, *Thymus vulgaris*, *Lavandula hybrida*, *Eucalyptus globulus*, and *Allium sativum* (Bayındır Erol and Birgücü, 2020). Similarly, Sağlam Altınköy and Bilginoğlu (2022) reported a 57.5% repellent effect for *Origanum onites* essential oil. These findings indicate that, besides causing mortality, essential oils can interfere with host-finding and oviposition behavior, thereby enhancing their usefulness in pest management.

Despite their promising biological activity, the practical application of essential oils remains limited by challenges related to formulation, stability, registration procedures, and commercialization. Pavela and Benelli (2016) emphasized that simplified regulatory procedures and improved application technologies are required to facilitate the commercial development of botanical insecticides. Similarly, Isman and Tak (2017) noted that, although numerous essential oils possess strong insecticidal activity, relatively few have reached commercial use because of these practical constraints.

Overall, the present findings demonstrate that the tested essential oils, particularly *Eugenia*

caryophyllata, possess considerable potential for the management of *A. obtectus*. Their combined lethal and repellent activities, together with their plant origin, support their potential incorporation into integrated pest management programs as environmentally friendly alternatives to conventional synthetic insecticides.

Conclusion

When the data obtained are evaluated, it can be seen that the three essential oils used in this study show promising results in terms of their potential against the pest. Among these, *Eugenia caryophyllata* appears to be more effective than the others, making it a step ahead in the control of *A. obtectus*. Overall, the results suggest that essential oils obtained from plants have high potential in terms of their effects on pests, but there are also aspects, especially regarding application methods, that need to be developed. This can be achieved through scientific studies such as the one presented here. Therefore, it is beneficial to conduct similar studies under different conditions and on various pests and beneficial insects.

Conflict of Interest

The authors stated that they did not have any real, potential or perceived conflict of interest.

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