Research Article

www.dergipark.org.tr/en/pub/mediterranean

MEDITERRANEAN AGRICULTURAL SCIENCES (2026) 39: 9
DOI: 10.29136/mediterranean.1871565

Insecticidal effect of *Satureja hortensis* essential oil on *Rhyzopertha dominica* (Fabricius, 1792) (Coleoptera: Bostrichidae)

Nasibe TEKINER AYDIN[1], Goksel TOZLU[2], Elif TOZLU[2], Fatih DADASOGLU[2]

[1]Artvin Coruh University, Yusufeli Vocational School, Department of Plant Protection, Artvin, Türkiye
[2]Ataturk University, Faculty of Agriculture, Departmen of Plant Protection, Erzurum, Türkiye

Corresponding author: N. Tekiner Aydin, e-mail: nasibetekiner@artvin.edu.tr
Author(s) e-mail: gtozlu@atauni.edu.tr, elifalpertozlu@atauni.edu.tr, fdadasoglu@atauni.edu.tr

ARTICLE INFO

Received: January 25, 2026
Received in revised form: March 27, 2026
Accepted: May 5, 2026

Keywords:

Biofumigation
Volatile compounds
Grain pest control
Rhyzopertha dominica

ABSTRACT

Although chemical pesticides have been effectively used to manage stored product pests, their overuse has led to environmental pollution, residue problems, threats to non-target organisms and human health, prompting researchers to develop environmentally friendly and effective agents. This study evaluated the insecticidal (fumigant) effectiveness of different dose applications of essential oil isolated from *Satureja hortensis* against adult *Rhyzopertha dominica* under laboratory conditions. The essential oil obtained by the hydrodistillation method at 5, 10, and 20 µL application doses were subjected to fumigant activity tests against adult *R. dominica* (Fabricius, 1792) (Coleoptera: Bostrichidae) and mortality rates were recorded at 6-hour intervals until 96 hours. The highest fumigant activity was recorded at 98% mortality rate after 96 hours, and the most effective dose was determined to be 20 µL. The study determined that *S. hortensis* essential oil has significant fumigant toxicity against adult *R. dominica*, and it was concluded that it could be used as a potential bioinsecticide for further studies.

1. Introduction

The world's population is projected to reach approximately 10 billion by 2050, and the resulting increase in food demand necessitates achieving the highest possible yields from existing agricultural land. In this context, minimizing losses at all stages of agricultural production from cultivation to harvest and from harvest to consumption is critically important for productivity, product quality, and food security. Losses in agricultural products during storage, primarily due to pests among biotic factors, represent one of the most significant problem areas. It has been reported that quantitative and qualitative losses caused by pests have reached serious levels worldwide, with 10-40% of total losses in stored agricultural products attributed to storage pests (Chen et al. 2018a; FAO 2019). It is currently stated that more than 600 species of storage pests, not only cause quality losses but also reduce the nutritional value of products, promote microbial contamination, and lead to the wastage of millions of tons of agricultural products every year (Rajendran and Sriranjini 2008). The majority of economically important storage pests belong to species within the orders Coleoptera and Lepidoptera (Morales-Quiros et al. 2019). Among these pests is *Rhyzopertha dominica* (Fabricius, 1792) (Coleoptera: Bostrychidae), commonly known as the lesser grain borer, a species of global economic importance that is frequently encountered both in the field at harvest and during storage (Demis and Yenewa 2022). This species has been reported to cause significant damage to wheat, barley, maize, rice, sorghum, and various other cereal crops (Chandel et al. 2019). It has also been reported that *R. dominica* can survive not only in legumes but also in stored medicinal products, leather filling materials, mud plaster, wood, paper, hardcover books, and cork-based packaging materials. (Edde 2012; Quellhorst et al. 2021). Both the adult and larval stages of the pest penetrate the grain kernels and consume the endosperm, directly causing crop losses and compromising the physical structure of the grains, thereby negatively affecting their quality and economic value. Furthermore, the galleries created during feeding provide a conducive environment for the development of microorganisms, facilitating secondary damage such as toxin production (Edde 2012). *R. dominica* is considered a primary pest due to its ability to infest intact cereal grains.

Although chemical methods have been employed for many years to control *R. dominica* and other storage pests, a major limitation is that the pesticides available for this purpose are largely restricted to a small number of active ingredients, such as pyrethrins, methyl bromide, and phosphine. (Hagstrum and Athanassiou 2019; Hamel et al. 2020). In addition, the adverse effects of chemical control on the environment and human health, the risk of residues in stored products, and the widespread development of resistance in pest populations have raised concerns regarding the sustainability of these methods (Wakil et al. 2021; Leskovac and Petrović 2023). For these reasons, research into developing environmentally friendly, sustainable, and effective alternative pest control methods has accelerated in recent years. In this context, plant-derived and environmentally friendly compounds have begun to emerge as prominent alternatives against storage pests in recent years. Essential oils are obtained from plant species belonging mainly to the Asteraceae, Cupressaceae, Lamiaceae, Lauraceae, Rutaceae, Myrtaceae, Piperaceae, and Poaceae families (Campolo et al. 2018). Plants that produce essential oils are distributed across

© Akdeniz University Faculty of Agriculture

extensive geographical areas worldwide; Türkiye, in particular, occupies a remarkable position in terms of these resources due to its rich floristic diversity and potential in aromatic plants (Güner et al. 2000). In recent years, plant essential oils have attracted attention due to the insecticidal, repellent, fumigant, or feeding-inhibiting properties of the active compounds they contain. These compounds offer significant advantages over synthetic pesticides, as they do not create residue problems and exert more limited negative effects on non-target organisms. In addition, essential oils play a key role in the defense mechanisms that plants develop against both biotic and abiotic stress factors (Zuzarte and Salgueiro 2015). Given these properties, plant-derived essential oils are regarded as a promising alternative pest control method within the framework of environmentally friendly and sustainable approaches (Campolo et al. 2018; Chandel et al. 2019; Ebadollahi et al. 2021; Ebadollahi et al. 2022; Gupta et al. 2023). The use of essential oils for controlling storage pests has attracted increasing attention in recent years due to their perceived low risk to human health and the environment. Accordingly, numerous studies have been conducted worldwide, as well as in Türkiye, on plant-derived essential oils with insecticidal properties and their active compounds (Alkan et al. 2018; Quan et al. 2018; Chen et al. 2018b; Karabörklü et al. 2019; Alkan 2020; Wang et al. 2021; Parichanon et al. 2025). The genus *Satureja*, one of these plant resources, belongs to the Nepetoideae subfamily of the Lamiaceae family and comprises approximately 200 species of aromatic herbaceous and shrub-like plants. (Momtaz and Abdollahi 2010). Some species of this genus, traditionally known as oregano particularly summer oregano (*Satureja hortensis* L.) are widely cultivated in various countries and are notable for their biological activity owing to their rich essential oil composition (Magierowicz et al. 2019). Due to these characteristics, *Satureja* species are regarded as important plant resources and environmentally friendly alternative control agents against storage pests. The efficacy of essential oils derived from species of the genus *Satureja* has been investigated by numerous researchers against a wide range of insect groups, including those in the orders Coleoptera, Diptera, Hemiptera, Homoptera, Lepidoptera, Phthiraptera, and Thysanoptera, as well as other arthropods such as mites and ticks, and plant-pathogenic nematodes, demonstrating their effectiveness against these organisms. (Ebadollahi et al. 2021). This study aimed to evaluate the biological effects of *S. hortensis* (also known as savory, summer thyme, or lentil herb) essential oil against *R. dominica*, a major storage pest. Conducted under laboratory conditions, this research is expected to contribute to biologically based approaches for storage pest management by demonstrating the potential of plant-derived products as alternatives to chemical control.

2. Materials and Methods

2.1. Insect culture

The insect cultures used in the experiments were obtained from the stock culture of the Department of Plant Protection, Faculty of Agriculture, Atatürk University. Soft bread wheat (*Triticum aestivum* L.) was used as the food for the cultivation of *R. dominica.* Adult individuals aged 2-3 weeks were preferred in the studies, and the insects were adapted to laboratory conditions before the experiments. The cultures were maintained in 250 mL glass desiccators containing approximately 250 g of pesticide-free wheat grains, which served as both a food source and a rearing substrate. The cultivation process was carried out in a climate chamber maintained at a constant temperature of 26±1°C, 65±5% relative humidity, and a 14:10 hour light:dark photoperiod (Gvozdenac et al. 2018).

2.2. Plant materials and essential oil extraction

The essential oil used in this study was obtained from naturally occurring *S. hortensis* plants. The plant material was collected from Oltu-Narman, Yaylaçayır Village, Erzurum (40º42'40"-41º51'30") province, Türkiye, during the summer season (June 2023) and the samples, along with their scientific names, were documented in the herbarium of the Department of Plant Protection, Faculty of Agriculture, Atatürk University. A herbarium voucher number was not assigned for the collected specimens. The above-ground parts of these plants (stems, leaves, and flowers) were air-dried in the shade at room temperature and then ground into a homogeneous powder using an electric grinder. Essential oil extraction was carried out using a Clevenger-type hydrodistillation apparatus, with 100 g of plant material placed in a 2000 mL volumetric flask containing 1000 mL of distilled water. The distillation process was conducted for 3 hours, and the resulting essential oil was stored in amber-colored glass vials at +4°C in a refrigerator to minimize exposure to light and oxygen (Tozlu et al. 2011). The essential oil yield was not calculated, as the study focused on biological activity rather than quantitative extraction efficiency.

2.3. Insecticidal bioassay

The insecticidal efficacy of the essential oils was evaluated using the method described by McDonald et al. (1970). For this purpose, No. 1 Whatman filter paper was cut into 2×2 cm pieces and attached to the lids of 90 mm diameter Petri dishes. Different doses of essential oil (5, 10, and 20 µL; equivalent to 0.005, 0.010, and 0.020 mL) were applied to the filter papers using a micropipette. The experiments were conducted using a randomized complete block design with three replications; each Petri dish contained 10 adult insects and 10 wheat grains as a food source. Sterile water was used as the negative control, while a commercial plant protection product containing lambda-cyhalothrin (Tekvando 5 EC, Safa Agriculture) served as the positive control. Following the application, the Petri dishes were monitored at 6-hour intervals, and the number of dead insects was recorded over a 96-hour period.

2.4. Statistical analysis

The data obtained from the experiment were analyzed using the JMP 5.0.1 statistical software package. Differences between mean values were evaluated using Duncan's multiple range test at a 5% significance level. In the statistical model, essential oil dose and exposure time were considered as independent variables. In the commercial preparation containing lambda-cyhalothrin, which was used as a positive control, 100% mortality was observed in all individuals within a short period; therefore, due to the absence of variance, this group was not included in the statistical analyses.

3. Results and Discussion

Previous studies have shown that the chemical composition of *S. hortensis* essential oil is predominantly comprised of phenolic monoterpenes and their precursor hydrocarbons. Carvacrol and thymol are the primary constituents of the essential oil, followed by monoterpene hydrocarbons such as γ-terpinene and p-cymene (Mahboubi and Kazempour 2011; Miladi et al. 2013; Farzaneh et al. 2015). Previous studies have also reported

© Akdeniz University Faculty of Agriculture

that phenolic compounds, such as carvacrol and thymol, which are present in high concentrations in the essential oil, exhibit fumigant and toxic effects on storage pests (Tozlu et al. 2011; Ghorbanpour et al. 2016; Magierowicz et al. 2019; Ebadollahi 2020). These compounds are reported to affect the respiratory system and neural transmission mechanisms of insects, ultimately leading to mortality (Jankowska et al. 2018). In this context, the observed biological effects may be associated with essential oil constituents previously reported for the same plant species. Various researchers have reported that the differences in the main components and their ratios identified in the chemical profile of *S. hortensis* essential oil may be due to geographical location, cultivation conditions, drying and extraction methods, ontogenetic periods, and seasonal factors (Miladi et al. 2013; Ghorbanpour et al. 2016; Ebadollahi 2020). Indeed, Magierowicz et al. (2019) reported that *S. hortensis* essential oil contains 73.24% carvacrol, and that this compound exhibits high insecticidal activity against *Acrobasis advenella* larvae. Abbad et al. (2023) tested essential oils obtained from wild and cultivated forms of *S. calamintha* against *T. confusum*, *R. dominica*, and *S. oryzae*. They reported that the essential oil from the wild form exhibited higher efficacy, which was attributed to the concentration of its active compounds. Overall, studies indicate that essential oils and their active compounds can be effectively employed against stored-product pests. However, the potential for odor residues in stored products presents a limitation to their application (Pierattini et al. 2019). Accordingly, the insecticidal activity of *S. hortensis* essential oil on adult *R. dominica* individuals was evaluated in this study (Figure 1). Time-dependent mortality rates were determined in adult *R. dominica* exposed to essential oil at different doses (5, 10, and 20 µL) over a 96-hour period. The changes in mortality rates, dependent on both dose and exposure time, are presented in Figure 2. According to the findings, adult *R. dominica* individuals were highly susceptible to the fumigant toxicity of *S. hortensis* essential oil (Figure 2). Across all tested doses (5, 10, and 20 µL),

A B

Figure 1. Application of *Satureja hortensis* essential oil to adult *Rhyzopertha dominica* (A), adult *Rhyzopertha dominica* (B, Photo by John Obermeyer)

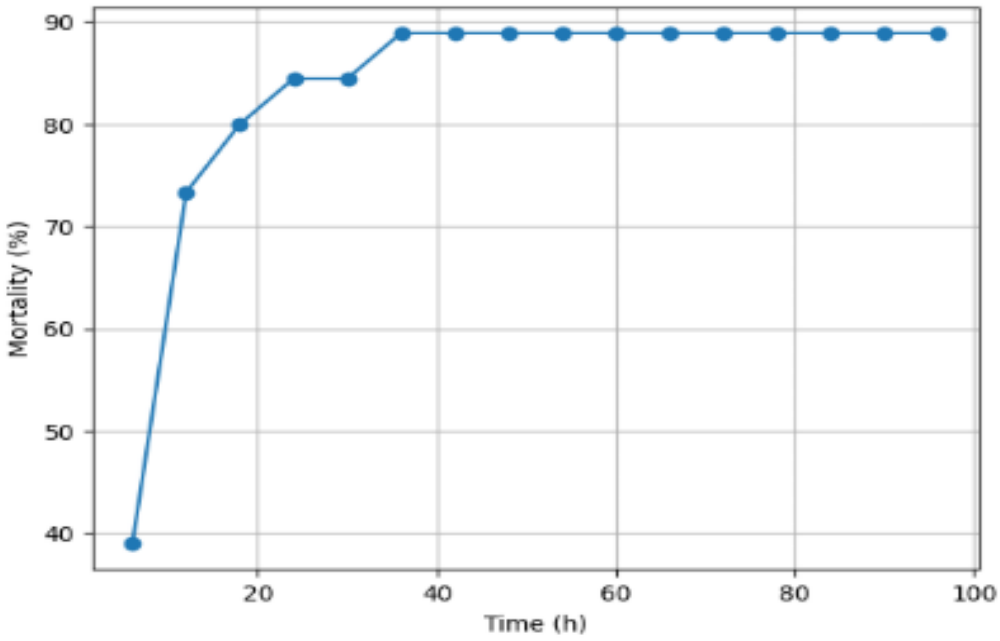

Figure 2. Time-dependent mortality of adult *Rhyzopertha dominica* exposed to *Satureja hortensis* essential oil over a 96-hour period.

© Akdeniz University Faculty of Agriculture

mortality reached 39.04% within the first 6 hours after application. The mortality rate increased with longer exposure, rising to 73.33% at 12 hours and peaking at 88.89% at 36 hours. Overall, mortality increased significantly with exposure time across all tested doses. No significant change in mortality was observed between 36 and 96 hours (Figure 2). The evaluation of mortality data recorded at 6-hour intervals after application revealed that increasing the exposure time to the essential oil significantly elevated the mortality rate. This indicates that the insecticidal effect of *S. hortensis* essential oil intensifies over time, with the fumigant mode of action being particularly pronounced during the initial stages. In this study, three different doses of *S. hortensis* essential oil were applied, and significant differences were observed among the doses. Statistical analysis revealed that, after 96 hours of exposure, a dose of 5 µL resulted in 55.71% mortality (C), while doses of 10 µL and 20 µL caused mortality rates of 88% (B) and 98% (A), respectively (FRatio: 23.855; Table 1). In the positive control group, complete mortality (100%) was observed during the initial post-intervention assessment periods. These results indicate that mortality increases proportionally with the dose of essential oil. This effect is likely related to both the duration of exposure and the capacity of the active compounds in the essential oil to affect the target organism (Table 1). Essential oils are increasingly recognized as natural alternative pest control agents to synthetic pesticides due to their relatively low risk to non-target organisms, environmentally protective properties, insect-repellent effects, and effectiveness against stored-product pests (Parichanon et al. 2025).

Table 1. Effect of different doses of *Satureja hortensis* essential oil against *Rhyzopertha dominica* after 96 hours of exposure

Doses (µL)	Mortality (%)	Group
20	98.00±0.81	A
10	88.00±2.44	B
5	55.71±1.92	C
**Positive control*	100	-
**Negative control*	0	-
CV	**14.70**	
LSD	**6.21**	

*Positive control showed 100% mortality and negative control showed 0% mortality; therefore, these groups were excluded from statistical analysis due to the absence of variance.

The results of the present study demonstrated that *S. hortensis* essential oil exhibited strong fumigant toxicity against *R. dominica*. Similar insecticidal effects of plant essential oils against stored-product pests have been reported in previous studies. For example, essential oils of *Curcuma longa* (Tripathi et al. 2002), *Ocimum basilicum* and *O. gratissimum* (Yeom et al. 2015), *Coriandrum sativum* (Kim and Lee 2014), and *Artemisia spicigera* (Kalinovic et al. 2008) have been shown to be effective. In addition, essential oils obtained from *Syzygium aromaticum* (Quan et al. 2018), *Laurus nobilis* (Kim and Lee 2014), *Salvia officinalis* (Alkan et al. 2018), and *Citrus aurantium* (Djebbi et al. 2023) have also demonstrated fumigant toxicity against *R. dominica*. In line with these findings, the high mortality observed in the present study supports the potential of *S. hortensis* essential oil as an effective natural control agent against stored-product pests. Tozlu et al. (2011) have reported that *S. hortensis* essential oil, at a dose of 20 µL, shows a high level of efficacy against *Bruchus dentipes*, especially after the first 6 hours, and can be considered as a potential plant insecticide. Ebadollahi (2020) showed that the essential oil of *S. hortensis* was more effective against *R. dominica* than *Tribolium castaneum*, while Alkan (2020) reported that the essential oil of *Achillea millefolium* had a higher efficacy against *R. dominica* compared to *Sitophilus granarius*. In this study, it was determined that the essential oil of 20 µL *S. hortensis* was approximately 98% effective against adult *R. dominica*. This suggests that *R. dominica* is a species sensitive to essential oils, and this sensitivity may stem from both the compounds in the essential oil and the physiological characteristics of the insect. In this study, the insecticidal effect of *S. hortensis* essential oil on adult *R. dominica*, a major storage pest, was evaluated from a biological perspective. Previous studies have reported that the essential oil of *S. hortensis* is rich in phenolic monoterpenes, particularly carvacrol and thymol, as determined by GC-MS analysis (Tozlu et al. 2011; Magierowicz et al. 2019; Koca and Yılmaz 2025). This chemical composition has been associated with strong fumigant toxicity. In line with these reports, the high insecticidal activity observed in the present study, particularly at the highest dose (20 µL), may be attributed to the presence of these bioactive compounds. Following application of the essential oil at different doses, mortality rates increased in a dose- and time-dependent manner, indicating that *R. dominica* is highly sensitive to the essential oil. These findings suggest that *S. hortensis* essential oil could serve as an effective, environmentally friendly, and biodegradable alternative control agent against stored-product pests. However, further studies under actual storage conditions, particularly on formulation development and persistence, are necessary to fully establish its practical application potential.

References

Abbad I, Soulaimani B, Abbad A (2023) Chemical composition, insecticidal and allelopathic properties of essential oils obtained from wild and cultivated Moroccan *Satureja calamintha* (L.). Journal of Natural Pesticide Research 3: 100021.

Alkan M, Şimşek Ş, Yılar M, Ertürk S (t18) Behavioural and insecticidal activity of *Salvia officinalis* L.(Lamiaceae) essential oil against *Tribolium confusum* Jacquelin du Val (Coleoptera: Tenebrionidae) and *Rhyzopertha dominica* Fabricius (Coleoptera: Bostrichidae). Plant Protection Bulletin 58(2): 71-78.

Alkan M (2020) Chemical composition of *Achillea millefolium* L.(Asteraceae) essential oil and insecticidal effect against *Sitophilus granarius* (Coleoptera: Curculionidae) and *Rhyzopertha dominica* (Coleoptera: Bostrichidae). Plant Protection Bulletin 60(1): 85-93.

Campolo O, Giunit G, Russo A, Palmeri V, Zapalla L (2018) Essential oils in stored product insect pests control. Journal of Food Quality 1: 6906105.

Chandel RK, Nebapure SM, Sharma M, Subramanian S, Srivastava C, Khurana SP (2019) Insecticidal and repellent activities of eucalyptus oil against lesser grain borer *Rhyzopertha dominica* (Fabricius). The Journal of Microbiology Biotechnology and Food Sciences 9(3): 525.

Chen X, Wu L, Shan L, Zang Q (2018a). Main factors affecting post-harvest grain loss during the sales process: a survey in nine provinces of china. Sustainability 10(3): 661.

Chen ZY, Guo SS, Cao JQ, Pang X, Geng ZF, Wang Y, Zhang Z, Du SS (2018b) Insecticidal and repellent activity of essential oil from *Amomum villosum* Lour and its main compounds against two stored-product insects. International Journal of Food Properties 21(1): 2265-2275.

Demis E, Yenewa W (2022) Review on major storage insect pests of cereals and pulses. Asian Journal of Advances in Research 12(1): 41-56.

Djebbi T, Soltani A, Chargui H, Yangui I, Teka N, Boushih E, Mediouni Ben Jemâa J (2023) Encapsulated bio-insecticide from *Citrus aurantium* (Rutaceae) essential oil and pectin and potential for the control of the lesser grain borer *Rhyzopertha dominica* (Bostrichidae). Waste and Biomass Valorization 14(9): 2997-3011.

© Akdeniz University Faculty of Agriculture

Ebadollahi A (2020) Estragole-rich essential oil of summer savory (*Satureja hortensis* L.) as an eco-friendly alternative to the synthetic insecticides in management of two stored-products insect pests. Acta Agriculturae Slovenica 115(2): 307-314.

Ebadollahi A, Jalali Sendi J, Ziaee M, Krutmuang P (2021) Acaricidal, insecticidal, and nematicidal efficiency of essential oils isolated from the *Satureja* genus. International Journal of Environmental Research and Public Health 18: 6050.

Ebadollahi A, Naseri B, Abedi Z, Setzer, WN (2022) Chemical profiles and insecticidal potential of essential oils isolated from four *Thymus* species against *Rhyzopertha dominica* (F.). Plants 11(12): 1567.

Edde PA (2012) A review of the biology and control of *Rhyzopertha dominica* (F.), the lesser grain borer. Journal of Stored Products Research 48: 1-18.

FAO (2019) Food and Agricultural Organization. www.faostat.org. Accessed 20 January, 2026.

Farzaneh M, Kiani H, Sharifi R, Reisi M, Hadian J (2015). Chemical composition and antifungal effects of three species of *Satureja* (*S. hortensis*, *S. spicigera*, and *S. khuzistanica*) essential oils on the main pathogens of strawberry fruit. Postharvest Biology and Technology 109: 145-151.

Ghorbanpour M, Hadian J, Hatami M, Salehi-Arjomand H, Aliahmadi A (2016) Comparison of chemical compounds and antioxidant and antibacterial properties of various *Satureja* species growing wild in Iran. Journal of Medicinal Plants 15: 58-72.

Gupta I, Singh R, Muthusamy S, Sharma M, Grewal K, Singh HP, Batish DR (2023) Plant essential oils as biopesticides: applications, mechanisms, innovations, and constraints. Plants 12(16): 2916.

Güner A, Özhatay N, Ekim T, Baer KHC (2000) Flora of Turkey, Volume 11, Edinburgh University Press Edinburgh.

Gvozdenac S, Šućur J, Manojlović A, Prvulović D, Malenčić Đ (2018). Influence of winter savory (*Satureja montana*) aqueous extract on mortality of lesser grain borer (*Rhyzopertha dominica*). Botanica Serbica 42(2): 277-281.

Hagstrum DW, Athanassiou CG (2019) Improving stored product insect pest management: from theory to practice. Insects 10: 332.

Hamel D, Rozman V, Liska A (2020) Storage of cereals in warehouses with or without pesticides. Insects 11(12): 846.

Jankowska M, Rogalska J, Wyszkowska J, Stankiewicz M (2018) Molecular targets for components of essential oils in the insect nervous system—a review. Molecules 23(1): 34.

Kalinovic I, Korunić Z, Rozman V, Liska A, Hamel D (2008) Effect of cineole fumigation of space differently occupied with stored pest infested wheat. Cereal Research Community 36: 963-966.

Karabörklü S, Azizoglu U, Yilmaz S, Ayvaz A, Akdeniz M (2019) The chemical composition of *Cyclotrichium origanifolium* essential oil and its insecticidal activity against four stored-product insect pests. Comptes Rendus de L'Academie Bulgare des Sciences 72(6): 841-850.

Kim SI, Lee DW (2014) Toxicity of basil and orange essential oils and their components against two coleopteran stored products insect pests. Journal of Asia-Pacific Entomology 17(1): 13-17.

Koca AS, Yılmaz A (2025) Effective control of *Sitophilus zeamais* (Motsch.)(Coleoptera: Curculionidae) using essential oil blends: an alternative to single-oil applications. Journal of Crop Health 77(2): 57.

Leskovac A, Petrović S (2023). Pesticide use and degradation strategies: food safety, challenges and perspectives. Foods 12(14): 2709.

Magierowicz K, Górska-Drabik E, Sempruch C (2019) The insecticidal activity of *Satureja hortensis* essential oil and its active ingredient-carvacrol against *Acrobasis advenella* (Zinck.) (Lepidoptera, Pyralidae). Pesticide Biochemistry and Physiology 153: 122-128.

Mahboubi M, Kazempour N (2011) Chemical composition and antimicrobial activity of *Satureja hortensis* and *Trachyspermum copticum* essential oil. Iranian Journal of Microbiology 3(4): 194-200.

McDonald LL, Guy RH, Speirs RD (1970) Preliminary evaluation of new candidate materials as toxicants, repellents and attractants against stored-product insects. Agricultural Research Service, US Department of Agriculture, Washington DC. Marketing Research Report No. 882.

Miladi H, Ben Slama R, Mili D, Zouari S, Bakhrouf A, Ammar E (2013) Chemical composition and cytotoxic and antioxidant activities of *Satureja montana* L. essential oil and its antibacterial potential against *Salmonella* spp. strains. Journal of Chemistry 275698: 9.

Momtaz S, Abdollahi M (2010) An update on pharmacology of *Satureja* species; from antioxidant, antimicrobial, antidiabetes and antihyperlipidemic to reproductive stimulation. International Journal of Pharmacology 6: 454-461.

Morales-Quiros A, Campabadal CA, Lazzari S, Lazzari FA, Maier DE, Phillips TW (2019) Chilled aeration to control pests and maintain grain quality during summer storage of wheat in the north central region of Kansas. Applied Engineering in Agriculture 35(4): 657-688.

Parichanon P, Ascrizzi R, Echeverría MC, Farina P, Pieracci Y, Flamini G, Conti B (2025) The aromatic plant essential oils and their hormetic effect on *Rhyzopertha dominica* (Coleoptera: Bostrichidae). Crop Protection 194: 107235.

Pierattini EC, Bedini S, Venturi F, Ascrizzi R, Flamini G, Bocchino R, Girardi J, Giannotti P, Ferroni G, Conti B (2019) Sensory quality of essential oils and their synergistic effect with diatomaceous earth, for the control of stored grain insects. Insects 10(4): 114.

Quan M, Liu QZ, Liu ZL (2018) Identification of insecticidal constituents from the essential oil from the aerial parts of *Stachys riederi* var *japonica*. Molecules 23(5): 1200.

Quellhorst H, Athanassiou CG, Zhu KY, Morrison WR (2021) The biology, ecology and management of the larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae). Journal of Stored Products Research 94: 101860.

Rajendran S, Sriranjini V (2008) Plant products as fumigants for stored-product insect control. Journal of Stored Products Research 44(2): 126-135.

Tozlu E, Cakir A, Kordali S, Tozlu G, Ozer H, Akcin TA (2011) Chemical compositions and insecticidal effects of essential oils isolated from *Achillea gypsicola*, *Satureja hortensis*, *Origanum acutidens* and *Hypericum scabrum* against broadbean weevil (*Bruchus dentipes*). Scientia Horticulturae 130: 9-17.

Tripathi AK, Prajapati V, Verma N, Bahl JR, Bansal RP, Khanuja SPS, Kumar S (2002) Bioactivities of the leaf essential oil of *Curcuma longa* (var. ch-66) on three species of stored-product beetles (Coleoptera). Journal of Economic Entomology 95(1): 183-189.

Wakil W, Kavallieratos NG, Usman M, Gulzar S, El-Shafie HAF (2021) Detection of phosphine resistance in field populations of four key stored-grain insect pests in Pakistan. Insects 12(4): 288.

Wang Z, Xie Y, Sabier M, Zhang T, Deng J, Song X, Liao LQ, Yang S, Cao Y, Liu X, Zhou G (2021) Trans-anethole is a potent toxic fumigant that partially inhibits rusty grain beetle (*Cryptolestes ferrugineus*) acetylcholinesterase activity. Industrial Crops and Products 161: 113207.

Yeom HJ, Jung CS, Kang J, Kim J, Lee JH, Kim DS, Kim HS, Park PS, Kang KS, Park IK (2015) Insecticidal and acetylcholine esterase inhibition activity of Asteraceae plant essential oils and their constituents against adults of the German cockroach (*Blattella germanica*). Journal of Agricultural and Food Chemistry 63(8): 2241-2248.

Zuzarte M, Salgueiro L (2015) Essential oils chemistry. In: Bioactive essential oils and cancer. Springer Cham, Switzerland, pp: 18-61.

© Akdeniz University Faculty of Agriculture