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Insecticidal effects of some plant extracts against Khapra beetle [*Trogoderma granarium* Everts (Coleoptera: Dermestidae)]

Bazı bitkisel ekstraktların Khapra böceği [*Trogoderma granarium* Everts (Coleoptera: Dermestidae)]'ne karşı insektisidal etkileri

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ABSTRACT

The study aims to determine the toxicity of extracts in three different solvents (methanol, hot water, and cold water) obtained from 10 different plants [*Rosmarinus officinalis* L. (Lamiaceae), *Nigella sativa* L. (Ranunculaceae), *Laurus nobilis* L. (Lauraceae), *Anethum graveolens* L. (Apiaceae), *Origanum onites* L. (Lamiaceae), *Lavandula angustifolia* Mill. (Lamiaceae), *Foeniculum vulgare* Mill. (Apiaceae), *Hypericum perforatum* L. (Clusiaceae), *Mentha piperita* L. (Lamiaceae), and *Nicotiana tabacum* L. (Solanaceae)] against the larvae of the third instar of *Trogoderma granarium* Everts (Coleoptera: Dermestidae) collected from different provinces of Türkiye. The results of the study varied depending on the plant species and the solvent used. Based on the observations, methanol was found to be the most effective solvent, followed by hot water and then cold water. On the 14th day of application, the highest mortality rate of 100% was observed when methanol was used as a solvent at a concentration of 20% (w/v) of the plant extracts. In contrast, this rate was 44% when cold water was used and 56% when hot water was used. According to the research results, extracts of *A. graveolens*, *N. tabacum*, and *N. sativa* showed a highly toxic effect on the pest, suggesting that these extracts are promising for the control of storage pests. However, more extensive studies are still needed to confirm the applicability and feasibility of these applications on an industrial scale.

INTRODUCTION

Ensuring adequate nutrition for every newborn is a critical challenge in the context of a growing world population, and Türkiye is a major player in the global production and export of stored products, especially cereals (Erdem 2020). Neglecting the crucial aspects of food storage can lead to diseases and pests in warehouses, resulting in significant losses in stored products. Storage pests are one of the main biotic factors that cause losses in the products produced by growers. The FAO reports that annual crop losses due to stored product pests during post-harvest are 10-30%

worldwide (Kiaya 2014). Pests in stored products can cause direct or indirect damage by feeding on the infested items. Their consumption leads to weight loss, adverse plant quality, changes in nutritional value, and a decline in seed quality and commercial value (Boyer et al. 2012, Rosentrater 2022).

The Khapra beetle [*Trogoderma granarium* Everts (Col.: Dermestidae)] poses a significant threat to stored wheat in Türkiye and is one of the 100 most invasive species worldwide (Athanassiou et al. 2019, Yadav et al. 2021). It is classified as a primary pest and is subject to post-harvest quarantine measures due to its ability to cause direct damage to cereals (Hagstrum et al. 2012). The population density of this species increases significantly in environmental conditions above 30 °C (Kavallieratos et al. 2017), which can lead to the plants infested by it becoming completely unusable. The Khapra beetle, which can cause losses of up to 30% in post-harvest crops (Honey et al. 2017), causes damage primarily through its larvae. These larvae feed on the embryo and endosperm of cereal grains, effectively turning the grains into husks (Ahmedani et al. 2007). The rashes caused by these larvae significantly affect product quality. In addition, the body parts of the larvae can cause severe allergic reactions and respiratory problems.

In studies conducted in Türkiye and other countries, attempts have been made to control this pest species using various control methods. However, these control methods have not achieved the desired goal of maintaining the pest and it has been reported that the pest has developed considerable resistance to phosphine, malathion, and some pyrethroids used for control (Ahmedani et al. 2007). Given the increasing damage attributed to conventional fumigants and preservative insecticides in recent years, many researchers have turned to exploring alternative strategies beyond chemical control measures (Regnault-Roger et al. 2005, Saıfı et al. 2023, Yiğit et al. 2023). Recent studies on the control of stored product pests have begun to emphasize the use of natural products of plant origin.

Plants have evolved various defense mechanisms to protect themselves from potential threats in their natural environment (War et al. 2012). These defense mechanisms range from physical barriers within the plant to chemicals synthesized by the plants themselves. Natural insecticidal compounds found in plants have been shown to have a lethal effect on insects (Boulogne et al. 2012, Mann and Kaufman 2012). Researchers have identified nearly 2000 different plants that have insecticidal properties (Grainge and Ahmed 1988, Prakash and Rao 2018).

Although the use of plant extracts for pest control in agriculture has been known for 3000 years, these studies have been intensified, especially in the last 30 years (Pavela 2016). In recent years, more and more studies have been carried out on insecticides from plants. Using various methods, researchers extract plant compounds from different parts of plants, including flowers, leaves, and seeds. These studies investigate the efficacy of these herbal extracts against agricultural pests and show successful results in various studies in controlling numerous pest species, including *Callosobruchus maculatus* F. (Coleoptera: Bruchidae) (Dessenbe et al. 2022, Karunaratne and Karunaratne 2012, Kasinathan et al. 2014), *Rhyzopertha dominica* (F.) (Coleoptera: Bostrychidae) (Guruprasad and Akmal 2014, Guruprasad and Pasha 2015), *Sitophilus oryzae* L. (Coleoptera: Curculionidae) (Hematpoor et al. 2022, Rajashekar et al. 2014), *Sitophilus granarius* L. (Coleoptera: Curculionidae) (Jawalkar and Zambare 2020, Kısa et al. 2018), and *T. granarium* (Derbalah 2012, Musa et al. 2009, Omar et al. 2012).

The studies have significantly increased our knowledge of the use of herbal extracts to control agricultural pests. However, conventional research methods rely heavily on organic solvents such as methanol, ethanol, acetone, and ethyl acetate to test these extracts. However, the widespread use of these solvents poses a health risk to researchers and contributes to environmental problems (Dirar et al. 2019). Therefore, the selection of a suitable extraction solvent is of utmost importance.

In the existing literature, there are remarkably few studies using hot and cold water as extraction solvents, so the comprehensive knowledge in this area remains incomplete and fragmented. To fill this critical gap, this research aims to evaluate toxic effects of extracts from 10 different plants [rosemary (*Rosmarinus officinalis*), black cumin (*Nigella sativa*), bay laurel (*Laurus nobilis*), dill (*Anethum graveolens*), Izmir thyme (*Origanum onites*), lavender (*Lavandula angustifolia*), Fennel (*Foeniculum vulgare*), St. John's wort (*Hypericum perforatum*), peppermint (*Mentha piperita*), tobacco (*Nicotiana tabacum*)] prepared in three different solvents (methanol, hot water, and cold water) against the larvae of the third instar of the Khapra beetle [Trogoderma granarium Everts (Col.:Dermestidae)].

MATERIALS AND METHODS

Cultivation of Trogoderma granarium used in bioassay

In this study, the 3rd larval stage of the Khapra beetle, *Trogoderma granarium* Everts (Col.: Dermestidae), one of the most common pests of stored grain in Türkiye, was used. The larvae used for the biological tests were obtained from the stock culture in the Entomology Laboratory of Kahramanmaraş Sütçü İmam University, Faculty of Agriculture, Department of Plant Protection.

Soft bread wheat served as food for the breeding of *T. granarium*. To prevent contamination by insects, the wheat was stored in a freezer at -20 °C for one week (Tefera et al. 2010). To extract the insect eggs, 100-200 adult insects were placed in jars containing 300-400 g of wheat and 5% dry yeast. These jars were then placed in an air-conditioned chamber for 3-4 days to allow the adult insects to lay their eggs. After this period, the jars containing the adult *T. granarium* were sieved using 500 µm and 212 µm sieves. The larger sieve collected the wheat, the smaller sieve retained the insects and eggs, while the flour was collected in a separate container.

The eggs and insects collected in the 212 µm sieve were subjected to a further sieving process in order to separate them. The isolated eggs were transferred to 650 ml glass bottles filled with prepared wheat. These glass containers were covered with breathable gauze to allow air circulation, and incubated in the dark at 30±1 °C and 65±5% humidity. Their development was monitored regularly. When a new generation of adults was observed, they were screened for contamination and relocated to uncontaminated wheat to ensure the continuity of the culture. This procedure was maintained carefully throughout the study.

Collection of plants and preparation of extracts

The plants whose efficacy was determined in the study, their families, the plant parts used, and the types of solvents used for extraction are listed in Table 1.

The seeds of fennel (*Foeniculum vulgare*), dill (*Anethum graveolens*), and black cumin (*Nigella sativa*) used in this study were obtained from a commercial market in June 2021. The flowers of St. John's wort (*Hypericum perforatum*) (during the flowering period of the plant) and the leaves of laurel (*Laurus nobilis*) were collected from Samsun, Atakum Çakırlar district between June-July 2020. The lavender flowers (*Lavandula angustifolia*) (during the flowering period) were collected in Çaltıbozkır district of Mersin Silifke district. The flowers and leaves of Izmir thyme (*Origanum onites*) were collected during the flowering period from Balandız village in Mersin Silifke district. The leaves of medicinal mint (*Mentha piperita*) were collected in Kahramanmaraş 12 Şubat Gayberli district. The leaves of rosemary (*Rosmarinus officinalis*) were collected from Yeni Mahalle district of Samsun Atakum. The leaves of tobacco (*Nicotiana tabacum*) were collected from the village of Sarıkaya in the Samsun Bafra Hacı Hafızlar district.

The relevant plant parts of the tested plants were collected from the indicated locations and brought to the laboratory, then placed on blotting paper in dark rooms without direct sunlight and high humidity, and dried at room temperature (23-24 °C) for about one week. The dried plant materials were mechanically crushed using a blender (Fakir Mr. Chef Quadro). The plant powders were then filled into glass jars, labeled, and stored in the dark until used in the study.

Methanol (Merck 99.5%), hot water (100 °C), and cold water (25 °C) were used as three different solvents in biological tests.

Obtaining methanol extraction

The method described in de Souza Tavares et al. (2009) was followed for the extraction of methanol extracts from the selected plants. Each plant material was weighed exactly 100 grams using a precision balance (OHAUS Pioneer,

Table 1. Information about the plants used in the study.

	Scientific name	Common name	Family	Part used	Solvent used
1.	*Foeniculum vulgare* Mill.	Fennel	Apiaceae	Seed	
2.	*Anethum graveolens* L.	Dill	Apiaceae	Seed	
3.	*Nigella sativa* L.	Black cumin	Ranunculaceae	Seed	
4.	*Hypericum perforatum* L.	St. John's Wort	Clusiaceae	Flower	Methanol
5.	*Lavandula angustifolia* Mill.	Lavender	Lamiaceae	Flower	Hot water
6.	*Origanum onites* L.	Izmir thyme	Lamiaceae	Flower+Leaf	Cold water
7.	*Mentha piperita* L.	Medicinal mint	Lamiaceae	Leaf	
8.	*Rosmarinus officinalis* L.	Rosemary	Lamiaceae	Leaf	
9.	*Laurus nobilis* L.	Laurel	Lauraceae	Leaf	
10.	*Nicotiana tabacum* L.	Tobacco	Solanaceae	Leaf	
11.	Azadirachtin	Nimbecidine		790 g/l Neem oil + 0.3 g/l	

Merck KGaA, Darmstadt, Germany). These weighed plant materials were then placed into 1000 ml autoclave bottles, to which 600 ml of methanol (Merck 99.5%) was added as an organic solvent.

The samples that were prepared were subjected to a 24-hour shake at room temperature at a speed of 120 rpm on an orbital shaker (Daihan SHO-2D, Hanoi, Vietnam). After the shake period, the suspensions of each plant were filtered separately using filter paper (Whatman Filter Paper No. 1) to remove the liquid part of the suspension and discard the pulpy residue. After filtration, the methanol in the resulting liquid was removed using a vacuum rotary evaporator (Heidolph Rotovap, Shanghai, China) at 170 rpm for 1 hour at 40±2 °C. The extracts obtained were placed in a water bath at 42 °C for 24 hours to ensure complete evaporation of the residual methanol, so that a pure extract was obtained after these procedures.

The plant extracts were stored in amber-colored vials sealed with plastic lids, where in the methanol was evaporated separately for each plant. These vials were stored in the refrigerator at a temperature of +4 °C until use. When needed, the solid extracts were dissolved with 10% acetone (Sigma-Aldrich) in water (v/v) to reach the target concentration (20% w/v) established for the study.

Obtaining cold and hot water extractions

To prepare cold water extracts, 20 g of each plant material was placed in an Erlenmeyer for 20% (w/v) solution and 80 ml of pure water at 25 oC. These solutions were then shaken in a shaker at 100 rpm for 24 hours at 4 °C. The resulting plant-water mixtures were successively sieved through cheesecloth and a 38-micron sieve (400 mesh), and collected in a beaker. These solutions were then transferred to tubes of 15 ml volume, centrifuged at 5000 rpm for 10 minutes and the supernatant of the solutions was passed through Whatman filter paper (No. 1). The extracts thus obtained were filled into white 500 ml plastic bottles and stored in a refrigerator at +4 °C until use (Dura and Kepenekçi 2022, Parwinder 1989).

For the hot water extracts, the plant-water mixtures were boiled at 100 ºC for 10 minutes in the indicated ratio of dry plant material and pure water. After boiling, these solutions were successively filtered through cheesecloth and Whatman filter paper (No. 1). The resulting hot water extracts were carefully poured into white 500 ml plastic bottles and stored in a refrigerator at +4 ºC until use.

Determination of insecticidal effects of plant extracts against Trogoderma granarium larvae

The insecticidal activity of the extracts of the plants used in the study, obtained at a concentration of 20% in 3 different solvents, was tested against 3rd instar *T. granarium* larvae (8-10 days old).

A soft wheat variety (*Triticum aestivum* L. Poaceae) with a moisture content of 11±1% was used for the biological tests. Before the experimental units were set up, the insect feed (common wheat variety) was sterilized by storing it in a freezer at -20 ºC for one week to prevent possible contamination by insects. All experiments were performed randomly, with 5 replicates and 10 larvae in each replicate. A control group was formed for each treatment. Two separate control groups were formed for the extract experiments. The preparation of Nimbecidin (790 g/l neem oil + 0.3 g/l Azadirachtin) was used as a positive control and pure water as a negative control.

To test the effect of the plant extracts on insect mortality, plastic containers of a volume of 100 ml were used. For both pests, 10 g of wheat was weighed into each container using a precision balance and made available for feeding. The solution at the target concentration was mixed with a vortex device (WiseMix VM-10, Wertheim, Germany) for 1 minute before use. 2 ml of the extract solution taken from the target concentration solution was sprayed evenly onto the feed in all jars except the control group. The solution was then stirred with a glass cylinder to ensure uniform mixing of the extracts with the wheat grains. For the control group, 2 ml of pure water was sprayed onto 10 g of feed in plastic jars. After 10 larvae were placed in each jar, the plastic jars were labeled and covered with a muslin cloth to prevent the larvae from escaping. The jars were placed in a climatic cabinet with a temperature of 30 ºC and a relative humidity of 70±5% (Panezai et al. 2019).

After the biological tests, the dead and live larvae were counted on the 14th day of treatment and the data recorded. During the counting, the insects in the plastic jars were touched individually with a fine-tipped brush and observed to see whether they were alive or not. Those that were motionless were considered dead, while those that barely moved were considered alive. The dead insects were kept for 24 hours after the count to see if there was any sign of movement. The same procedure was repeated for the control groups.

Evaluation and analysis of data

As a result of the biological tests on wheat, the mortality of the tested insect species was analyzed according to the Abbott formula (Abbott 1925), and the percentage mortality rates were determined. A one-way analysis of variance (one-way ANOVA) was applied to the data resulting from the variation of the biological tests. In addition, statistical differences between treatments were compared using Tukey's test at P≤0.05. All statistical analyses were performed using Minitab software.

RESULTS

The insecticidal activity of the extracts of the plants used in the study at 20% concentration in 3 different solvents was tested 14 days after application against 3rd instar *T. granarium* larvae, and the findings obtained are given in Table 2.

The analysis revealed significant effects of both different plant treatments and different solvents on the mortality rate of *T. granarium* in the 3rd larval instar (for plant: $F_{10,152}$=6.48, P=0.000; for solvent: $F_{2,152}$=87.61, P=0.000). There was also a statistically significant interaction between the plant and the solvent ($F_{20,132}$=13.03, P=0.000). When the mortality rates of the larvae treated with hot water extracts were compared with the control group, significant differences were found between the treatments ($F_{11,48}$=13.35; P=0.000). Similar significant differences were found when examining the mortality rates of the larvae treated with cold water ($F_{11,48}$=8.40; P=0.000) and methanol extracts ($F_{11,48}$=111.38; P=0.000) compared to the control group.

Examination of the overall mortality rates of the noxious larvae of the hot water extracts of various plants showed that the mortality rates of the plants *Azadirachta indica* A. Juss (Meliaceae), *F. vulgare*, *H. perforatum*, *L. nobilis*, *N. tabacum*, and *O. onites* were statistically in the same group as those of the others. In contrast, the mortality rates of the plants *L. angustifolia* and *N. sativa*, which were in different groups, were statistically significantly lower. The mortality rates of *A. graveolens*, *M. piperita*, and *R. officinalis* were also statistically in the same group, but their mortality rates were statistically significantly lower than those of all other plants. For the larvae of *T. granarium*, the mortality rates of the cold-water extracts of all plants were statistically in the same group. On the other hand, the mortality rates of the methanol extracts of *A. graveolens* and *N. tabacum* were statistically in the same group, which means that the mortality rates of the larvae were statistically significantly higher than the mortality rates of all other extracts (Table 2).

Table 2. Mean percentage mortality rates of 20% concentration of all plant extracts on Trogoderma granarium on the 14th day of the application

Plants	Extracts			F Value	P Value
	Hot Water	Cold Water	Methanol		
A. graveolens	28±5.83Cb*	32±3.74Ab	100±0.00Aa	$F_{2,12}$=102.33	P=0.000
F. vulgare	34±2.45BCb	32±4.90Ab	62±2.00BCDa	$F_{2,12}$=24.82	P=0.000
H. perforatum	34±2.45BCb	36±4.00Ab	52±2.00DEa	$F_{2,12}$=11.23	P=0.002
L. nobilis	30±3.16BCa	40±5.48Aa	44±4.00EFa	$F_{2,12}$=2.79	P=0.101
L. angustifolia	46±2.45ABb	40±4.47Ab	64±2.45BCa	$F_{2,12}$=14.62	P=0.001
M. piperita	26±2.45Cb	30±5.48Aab	44±2.45EFa	$F_{2,12}$=6.38	P=0.013
N. tabacum	30±4.47BCb	36±2.45Ab	92±3.74Aa	$F_{2,12}$=87.70	P=0.000
N. sativa	56±5.10Ab	44±2.45Ab	70±0.00Ba	$F_{2,12}$=15.88	P=0.000
O. onites	38±3.74BCb	26±5.10Ab	58±2.00CDa	$F_{2,12}$=17.82	P=0.000
R. officinalis	26±2.45Cb	26±2.45Ab	56±2.45CDa	$F_{2,12}$=50.00	P=0.000
Positive ControL *(A. indica)*	36±2.45BCa	36±2.45Aa	36±2.45Fa	$F_{2,12}$=0.00	P=1.000
Negative Control (Natural death)	2±2.45Da	0±0.00Ba	2±2.00Ga	$F_{2,12}$=0.50	P=0.619
F Value	$F_{11,48}$=13.35	$F_{11,48}$=8.40	$F_{11,48}$=111.38	For plant: $F_{10,152}$=6.48; P=0.000 For solvent: $F_{2,152}$=87.61; P=0.000 For Plant*Solvent: $F_{20,132}$=13.03; P=0.000	
P Value	P=0.000	P=0.000	P=0.000		

*Two-way analysis of variance (ANOVA) was applied to the data and the differences between the averages were determined by Tukey test at 5% significance level. Different capital letters in the same column and different lower case letters in the same row are statistically different from each other.

The mortality rates using hot water as a solvent administered on day 14 of the study were 28% for the extract of *A. graveolens*, 36% for the extract of *A. indica*, 34% for the extract of *F. vulgare*, 34% for the extract of *H. perforatum* extract, 30% for the *L. nobilis* extract, 46% for the *L. angustifolia* extract, 26% for the *M. piperita* extract, 30% for the *N. tabacum* extract, 56% for the *N. sativa* extract, 38% for the *O. onites* extract and 26% for the *R. officinalis* extract. The highest mortality rate (56%) for hot water extracts against *T. granarium* larvae was obtained for the *N. sativa* plant (Table 2).

Using cold water as a solvent administered on day 14 of the study, the mortality rates (%) for *A. graveolens*, *A. indica*, *F. vulgare*, *H. perforatum*, *L. nobilis*, *L. angustifolia*, *M. piperita*, *N. tabacum*, *N. sativa*, *O. onites* and *R. officinalis* were 32, 36, 32, 32, 36, 36, 40, 40, 40, 30, 36, 44, 26 and 26 plants, respectively. *N. sativa* caused the highest mortality rate (44%) among the cold-water extracts on *T. granarium* larvae (Table 2).

When methanol was used as a solvent on day 14 of the study, the percent mortality rates were 100, 36, 62, 52, 44, 64, 44, 92, 70, 58 and 56 for *A. graveolens*, *A. indica*, *F. vulgare*, *H. perforatum*, *L. nobilis*, *L. angustifolia*, *M. piperita*, *N. tabacum*, *N. sativa*, *O. onites* and *R. officinalis*, respectively. As a result of the treatments, it was found that the most effective plant extract against the larvae was the methanol extract of A. graveolens and a 20% dose of this extract completely killed the larvae of the pest (Table 2).

DISCUSSION

Research into the properties and effects of plant extracts holds the great promise of obtaining chemical raw materials from our natural resources in a more cost-effective and sustainable way, thereby achieving considerable economic benefits. Research into these properties must be prioritized as part of good agricultural practice, with the aim of developing, producing, advocating, and promoting the widespread use of natural plant extracts. These extracts can serve as viable alternatives to synthetic pesticides, promote healthier food production, and potentially improve international trade in agricultural products. Prioritizing the use of these extracts will not only contribute to a healthier food supply but also improve global agricultural trade.

In contrast to the active ingredients used in chemical control of stored product pests, biopesticides derived from medicinal plant products showed a lower resistance to stored product pests, did not produce toxic residues, persist within the plant, and exhibit lower toxicity to mammals and the environment. Many researchers had shown in studies on the control of stored product pests that these products were effective in different ways (Isman 2006, Koul 2008).

The results of all biological tests showed that the plant extracts prepared with different solvents exhibited varying degrees of insecticidal activity against the larvae of the 3rd instar of *T. granarium*. A closer look at the study results revealed that these statistical differences in lethal efficacy depended on several factors, such as the specific plant variety and the types of solvents used in the preparation of the extract. This observation is supported by numerous scientific studies that have also emphasized the influence of these variables on the insecticidal efficacy of plant extracts. Sarmamy et al. (2011) reported a mortality rate of 1.54% in *T. granarium* larvae 96 hours after application of a 6% concentration of *N. tabacum* water extract. Zia-ul-Haq et al. (2014) tested the lethal effect of 7 different plant leaf or seed extracts, including *A. indica*, on *T. granarium* and reported that the mortality rate was 24.69% at a concentration of 15%. In agreement with these studies, comparable results were observed in this study. Thus, the use of the cold-water extract of *N. tabacum* at a concentration of 5% resulted in a mortality rate of 2% in larvae four days after application. In contrast, the use of an *A. indica* extract at a concentration of 15% resulted in a 22% mortality rate in the larvae of *T. granarium* on the tenth day after application. Considering these collective results, it was evident that the mortality rate of *T. granarium* larvae was generally relatively low. Eliopoulos (2013) found that the larvae of *T. granarium* have the potential to live in unsuitable environments and can resist many typical insecticides. In addition, Vadivambal et al. (2007) found that the dense hairiness of the larval body forms a protective barrier that prevents direct contact between insecticides and the cuticular layer. These results confirmed the low mortality rate observed in the larvae of *T. granarium* in this study. Their inherent adaptability and physical defenses contributed to their resistance to insecticidal activities, which was consistent with the observed results.

Methanol and distilled water are both polar solvents, but their polarity values are different (Awadh et al. 2008). If the polarity values of solvents are different, the variety and amounts of substances dissolved in the solvents may also vary (Çolak et al. 2020, Navarro del Hierro et al. 2021). Researchers have found that certain secondary metabolites in certain plant organs are extracted with various solvents and that the number of secondary compounds with insecticidal activity decreases when different solvents are used (Çolak et al. 2020, Karakoç and Gökçe 2012, Nawaz et al. 2020). Changes in the polarity of solvents mean that extracts obtained from the same plants with different solvents have very different insecticidal activities. These different insecticidal activities are attributed to the effective ability of the extracts to form hydrogen bonds and eliminate free radicals. In a study conducted by Dessenbe et al. (2022), it was found that increasing the polarity of the solvents leads to an increase in the number of compounds in the plant. Extracts obtained from the same plant with different solvents had different components, and these extracts showed significant insecticidal activity against *C. maculatus* and *Sitophilus zeamais* (Motsch.) (Coleoptera: Curculionidae). Karakas (2016) reported that leaf extracts of *Anethum graveolens* and *Ocimum basilicum* L. (Lamiaceae) showed a different mortality rate of *S. granarius* beetles depending on the polarity of the solvent. Hiruy and Getu (2018) observed differences in the mortality of *S. zeamais* by the application of solvent extracts from the leaves of *Calpurnia aurea* (Ait.) Benth (Fabaceae) and *Milletia ferruginea* (Hochst) Baker (Fabaceae), depending on the polarity of the solvent. Similarly, Uddin II (2020) found that the mortality of *C. maculatus* when using plant extracts obtained with different polarities from *Trichilia heudelotii* Planch (Meliaceae) varied depending on the polarity of the solvent. As we have seen, the insecticidal activity of plant extracts varies in studies conducted with different methods and solvents with different polarities. There are many supporting studies in the literature on stored pests in this context (Aba-Toumnou et al. 2016, Awadh et al. 2008, Gebreslassie and Eyasu 2019, Karakas 2016, Khan et al. 2016, Li et al. 2013, Navarro del Hierro et al. 2021, Rafińska et al. 2019, Suleiman et al. 2018, Uddin II 2020, Wakeel et al. 2019, Zhang et al. 2017, Zhang et al. 2019). In this study, it is hypothesized that the reason for the stronger insecticidal activity of methanol extracts compared to water extracts is related to all this information.

The efficacy of plant extracts as insecticides depends not only on factors such as plant species, age, insect type, and geographical location, but also on the solvents used in the extraction process (Shaalan et al. 2005). Most researchers have generally favored solvents such as methanol, ethanol, acetone, and ethyl acetate in their studies on herbal extracts (Truong et al. 2019). The excessive use of these organic solvents poses health and safety risks to researchers and is not suitable for the environment. Therefore, the selection of the appropriate extraction solvent is very important (Dirar et al. 2019). There were limited studies in the literature in which hot and cold water were chosen as extraction solvents. The use of water as solvent was considered the preferred method in the extraction of extracts for human control of stored products. Since it was of great importance to include extracts from cold and hot water commonly used by humans in scientific research using different solvents, this study was considered to be important.

In this study, the effect of extracts of 10 different plants (*R. officinalis*, *N. sativa*, *L. nobilis*, *A. graveolens*, *O. onites*, *L. angustifolia*, *F. vulgare*, *H. perforatum*, *M. piperita*, and *N. tabacum*) prepared with three different solvents (methanol, hot water, and cold water) on the third instar larvae of *T. granarium* was investigated. The following conclusions were drawn from the results.

The extracts obtained from *A. graveolens*, *N. tabacum*, and *N. sativa* showed remarkably high insecticidal activity against the larvae of *T. granarium*. These particular extracts are promising for effective control of this pest.

The *N. sativa* plant extracts, especially the 20% concentration in the variants with hot water and methanol, showed a mortality rate of more than 50%. In contrast, none of the other plant extracts, whether in hot or cold water, achieved a mortality rate of 50% or more.

The methanol extracts of *N. tabacum*, *A. graveolens*, and *N. sativa* showed mortality rates of 92%, 100%, and 70%, respectively. In contrast, the methanol extracts of the other plants consistently did not exceed a mortality rate of 70%.

The overarching observations indicate that methanol was found to be the most effective solvent for extracting the insecticidal properties of these plants, followed by hot water and cold water in descending order of effectiveness. However, more comprehensive studies should be conducted to determine the applicability of such applications in practice and to establish their applicability on an industrial scale.

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Author's Contributions

Authors declare the contribution of the authors is equal.

Statement of Conflict of Interest

The authors have declared no conflict of interest.

ÖZET

Çalışmanın amacı; Türkiye'nin değişik illerinden toplanan 10 farklı bitkinin [*Rosmarinus officinalis* L. (Lamiaceae), *Nigella sativa* L. (Ranunculaceae), *Laurus nobilis* L. (Lauraceae), *Anethum graveolens* L. (Apiaceae),

Origanum onites L. (Lamiaceae), *Lavandula angustifolia* Mill. (Lamiaceae), *Foeniculum vulgare* Mill. (Apiaceae), *Hypericum perforatum* L. (Clusiaceae), *Mentha piperita* L. (Lamiaceae) ve *Nicotiana tabacum* L. (Solanaceae)] 3'er farklı çözücüde (metanol, sıcak su ve soğuk su) oluşturulan ekstraktlarının Trogoderma granarium Everts (Coleoptera: Dermestidae)'un 3. dönem larvalarına karşı toksisitesini belirlemektir. Çalışma sonuçları; bitki türüne ve kullanılan çözücüye göre değişiklik göstermiştir. Yapılan gözlemler sonucunda genellikle en etkili çözücü, metanol olarak belirlenmiş ve bunu sırasıyla sıcak su ve soğuk su çözücüleri takip etmiştir. Uygulamanın 14. gününde bitki ekstraktlarının %20 (w/v) konsantrasyonunda çözücü olarak metanol kullanıldığında en yüksek ölüm oranı %100 olarak belirlenirken; bu oran soğuk su kullanıldığında %44 ve sıcak su kullanıldığında ise %56 olarak tespit edilmiştir. Ayrıca; araştırma sonuçlarına göre, *A. graveolens*, *N. tabacum* ve *N. sativa* bitkilerine ait ekstraktların zararlı üzerinde yüksek toksik etki gösterdikleri belirlenerek bu ekstraktların depolanmış ürün zararlıların mücadelesinde oldukça umut verici olduğu düşünülmektedir. Ancak, bu uygulamaların pratikte kullanılabilirliğini kesinleştirmek ve endüstriyel ölçekte uygulanabilirliğini belirlemek için daha kapsamlı çalışmalara ihtiyaç duyulmaktadır.

Anahtar kelimeler: depolanmış ürün zararlısı, bitki ekstraktı, sıcak su, soğuk su, metanol

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