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Abstract

Rice is one of the major cereal crops and staple food for large part of the world, especially Egypt. Unfortunately, huge quantities of it are lost because of being infected with insect pests during storage. The rice weevil, *Sitophilus oryzae* (Coleoptera: Curculionidae), is one of those pests. Such insect pests are controlled by using highly toxic chemicals that threaten human health and negatively affect the environment. The trend has been to search for eco-friendly insecticides instead of these dangerous chemicals. Plant oils have emerged as promising alternatives for managing storage pests for their eco-friendly properties, rapid biodegradability, and lower toxicity to humans and the environment. So, the present research bio-assayed the repellent effect of five essential oils; basil, clove, lavender, peppermint, and thyme, using three laboratory bioassays: food preference tests (including multiple- and two-choice bioassays) and an area-preference test. Results indicated that lavender oil exhibited the strongest repellent effect across all bioassays, followed by thyme oil, which also showed a marked repellency in the two-choice tests. In contrast, basil oil displayed mixed results, showing a repellent effect in the multiple-choice test while acting as an attractant in the two-choice bioassay. Peppermint and clove oils yielded moderate to insignificant effects depending on the test-type applied. Results support the potential of essential oils as natural and environmentally friendly alternatives to chemical insecticides, contributing to the protection of stored grains without harming human health or the environment.

المستخلص العربي

يعتبر الأرز أحد أهم محاصيل الحبوب والغذاء الأساسي لجزء كبير من العالم، وخاصة مصر. وللأسف، يتم فقد كميات هائلة منه بسبب إصابته بالآفات الحشرية أثناء التخزين. ومن أهم هذه الآفات سوسة الأرز، *Sitophilus oryzae* (رتبة غمدية الأجنحة: فصيلة السوس). تتم مكافحة هذه الآفات الحشرية باستخدام مواد كيميائية شديدة السمية تهدد صحة الإنسان وتؤثر سلبًا على البيئة. ولذلك كان الاتجاه هو البحث عن مبيدات حشرية صديقة للبيئة بدلاً من هذه المواد الكيميائية الخطرة. ظهرت الزيوت النباتية كبدائل واعدة لإدارة آفات المخازن لخصائصها الصديقة للبيئة وقابليتها للتحلل البيولوجي السريع وسميتها المنخفضة للإنسان والبيئة. لذلك، قام البحث الحالي بتحليل التأثير الطارد لخمسة زيوت أساسية؛ الريحان والقرنفل واللافندر والنعناع والزعتر، باستخدام ثلاث اختبارات حيوية مختبرية: اختبارات تفضيل الطعام (بما في ذلك الاختبارات الحيوية متعددة الخيارات والاختيارات الثنائية) واختبار تفضيل المنطقة. أشارت النتائج إلى أن زيت اللافندر أظهر أقوى تأثير طارد في جميع الاختبارات الحيوية، يليه زيت الزعتر، الذي أظهر أيضًا تأثيرًا طاردًا ملحوظًا في اختبارات الاختيار من متعدد. في المقابل، أظهر زيت الريحان نتائج متباينة، حيث أظهر تأثيرًا طاردًا في اختبار الاختيار من متعدد، بينما عمل كعامل جذب في الاختبار الحيوي ذي الاختيار من متعدد. أما زيتا النعناع والقرنفل، فقد أظهرا تأثيرات تتراوح بين المتوسطة والضعيفة، وذلك حسب نوع الاختبار المستخدم. وتدعم هذه النتائج إمكانات الزيوت العطرية كبدائل طبيعية وصديقة للبيئة للمبيدات الحشرية الكيميائية، مما يُسهم في حماية الحبوب المخزنة دون الإضرار بصحة الإنسان أو البيئة.

Key Words: Rice weevil, *Sitophilus oryzae*, plant oils, Botanical insecticides, repellency.

1. Introduction:

Insect pests represent a major problem in fields and warehouses. They destroy more than 35 percent of crops globally. We lose a lot of cereal grains via insect infestation during storage, particularly in the developing countries such as Egypt. **Rice**, being one of the staple foods mostly consumed in our daily life all over the world, has been infested by many important insect pests such as *Sitotroga cerealella*, *Sitophilus oryzae*, *Sitophilus granarius*. (Ileke and Ogungbite, 2014, 57).

The rice weevil, *Sitophilus oryzae* (Coleoptera: Curculionidae)**,** is one of the most economically significant pests affecting stored rice and other cereal grains, particularly in tropical and subtropical regions worldwide. It is responsible for extensive quantitative and qualitative losses in stored food grains, leading to significant economic implications for food security and trade (Singh et al., 2017, 502; Agrahari and Mishra, 2024, 98).

S. oryzae adults is small but its body is very strong. Typically measure between 2 to 3 mm in length and are characterized by an elongated snout (rostrum) and a cylindrical, reddish-brown to black body with faint light spots on the elytra (hardened forewings). They have well-developed chewing mouthparts at the tip of the snout, allowing them to bore into grains (Saad et al., 2018, 175).

The rice weevil is a holometabolous insect; its life cycle consists of four stages: egg, larva, pupa, and adult. The adult female *S. oryzae* lays eggs inside grain kernels, where the eggs hatch in about 3 days, and feed internally, hollowing out the grains. The larvae are legless, creamy white with a brown head capsule, and remain hidden inside the grain until pupation. The entire life cycle takes about 26 to 32 days under optimal conditions, leading to multiple generations per year in warm environments (Arabi, 2008, 3; Thulasy et al., 2025, 1).

S. oryzae primarily infests whole grains such as rice, wheat, maize and barley, where it actively breeds and completes its life cycle stages. Recent studies indicate that its host range has expanded to include split legumes, further increasing its threat to stored food supplies (Deepthi and Manjunatha, 2015, 182).

Both the adult and larval stages of *S. oryzae* are internal feeders, causing substantial reductions in grain weight due to internal consumption, nutritional value as larvae consume endosperm, market quality, making the grains unfit for human consumption and germination ability of stored seeds, reducing viability for future planting. Additionally, their activity facilitates secondary infestations by other stored grain insects, fungi and other microbial contaminants, exacerbating post-harvest losses. Infestation by *S. oryzae* not only results in direct consumption of the grains but also increases moisture levels within storage units, creating favourable conditions for fungal growth, particularly *Aspergillus* and *Penicillium* species, which produce mycotoxins harmful to human and animal health (Singh et al., 2017, 503; Saad et al., 2018, 176; Tayeb et al., 2018, 510; Tangadi et al., 2021, 22; Mahfuz et al., 2023, 36; Thulasy et al., 2025, 3).

The control of *S. oryzae* has traditionally relied on synthetic insecticides, such as methyl bromide and phosphine and fumigation which, despite their effectiveness, pose several challenges. Excessive and indiscriminate use of these chemicals has led to the development of insect resistance; reducing the effectiveness of chemical treatments over time. The presence of chemical residues in food products posing health hazards to consumers, environmental contamination and affecting beneficial organisms, soil health, and water sources. In addition, excessive use of chemical pesticides may lead to some diseases including neurotoxicity, endocrine disruption, and potential carcinogenic effects in humans (Akter and Akter, 2016, 52; Singh et al., 2017, 504; Saad et al., 2018, 178; Tayeb et al., 2018, 512; Agrahari and Mishra, 2024, 99; Thulasy et al., 2025, 2).

Thus, there is a growing demand for sustainable alternatives that ensure effective pest control without harming human health or the environment. The best of those alternatives are green pesticides, which originated from plants.

Plant-derived substances, including oils, have emerged as promising alternatives for managing storage pests. Botanical insecticides, also called green insecticides, are known for their eco-friendly properties, rapid biodegradability, and lower toxicity to humans and the environment **(**Ileke and Ogungbite, 2014,57; Singh et al., 2017, 505; Thulasy et al., 2025, 4).

Botanical insecticides offer multiple modes of action, including:

-Repellency: Certain plant compounds emit volatile organic chemicals that repel insects away from the grains (Maia and Moore, 2011, 10; Agrahari and Mishra, 2024, 100; Mahfuz et al., 2023, 37).

-Feeding Deterrence: Bioactive compounds such as alkaloids, flavonoids, and phenolics interfere with insect feeding behavior (Arabi, 2008, 6; Thulasy et al., 2025, 4).

-Oviposition Deterrence: Certain essential oils prevent females from laying eggs on treated grains, thus reducing population buildup over time (Tayeb et al., 2018, 514; Tangadi et al., 2021, 24).

-Toxicity: Some plant extracts exhibit neurotoxic effects on insects by disrupting neurotransmitter functions, leading to paralysis or mortality (Abd El-Salam, 2010, 5; Akter and Akter, 2016, 55; Seada et al., 2016, 4; Saad et al., 2018, 180; Tayeb et al., 2018, 513; Agrahari and Mishra, 2024, 100; Thulasy et al., 2025, 4).

In recent years, many researchers have studied the different possible effects of **plant oils** on stored grain insects. Among those studies, Popović et al. (2006, 38) and Seada et al. (2016, 4), who investigated the toxicity and repellency effects of basil oil against *Sitophilus oryzae*. Their results showed that the basil oil caused significant mortality and repellency effects, which were concentration- and time-dependent, in both two- and multiple-choice bioassays. Besides, Al-Harbi et al. (2021, 13-14) found that the basil oil recorded the highest repellence activity against *S. oryzae* with a value of 82.3% after 5-hours of exposure. As well, Abd El-Salam (2010, 3) concluded that the thyme oil can deter insects, and that deterrent effect is highly valuable for managing insect infestations in stored grains. Saad et al. (2018, 181) found that essential oils such as clove, neem, and eucalyptus have shown promising insecticidal properties due to their high content of bioactive compounds like eugenol, azadirachtin, and cineole, which interfere with insect physiology. Additionally, powders derived from pepper, garlic, and ginger have demonstrated inhibitory effects on *S. oryzae* development, making them valuable components of integrated pest management (IPM) strategies (Singh et al., 2017, 506; Thulasy et al., 2025, 6). Mahfuz et al. (2023, 37) stated that lavender oil showed very high repellent effect against *S. oryzae*. Also, Al-Harbi et al. (2021, 13) found that lavender oil achieved 100% mortality after 24 and 48 hours of exposure against S. oryzae adults. Besides, the oil was recorded high repellence activity against *S. oryzae* (Al-Harbi et al., 2021, 15).

Based on the aforementioned harmful effects of *S. oryzae* on stored grains, as well as the potential effectiveness of plant oils, as shown in previous researches, so, the present research aims to survey the repellent activity of essential oils derived from five plant species: *Ocimum basilicum* (basil), *Syzygium aromaticum* (clove), *Lavandula angustifolia* (lavender), *Mentha piperita* (peppermint), and *Thymus vulgaris* (thyme) against adult *S. oryzae* in stored paddy.

2. Materials and Methods

2.1 Insect Rearing

The adult rice weevils, *S. oryzae* (Fig. 1), used in the present experiment were collected from infested rice samples, identified, isolated, and then reared on rice under laboratory conditions as stock culture from October 2024 to March 2025 in the Zoology Laboratory, Department of Biological and Geological Sciences, Faculty of Education, Ain Shams University, Egypt.

The tested insects were of mixed sexes, and the rice was stored for a specific period at an appropriate temperature to ensure stable conditions before starting the experiments.

Figure (1): The rice weevil adult.
(https://www.naturespot.org/species/sitophilus-oryzae#gallery-1)

2.2 Tested Plant Oils

Table 1 represents a list of the botanical oils selected for this study. The selected plant oils used in the study include clove, basil, lavender, peppermint, and thyme. The oils were purchased from local markets specializing in natural herbs.
The selection of these oils was based on their toxicity against stored-product insects, in addition to their common use as food flavourings, spices, traditional remedies, and components in pharmaceutical formulations, as found in the previous literature.

Table 1: General information of the tested plant oils

English name	Scientific name	Family name	Arabic name
Clove	*Syzygium aromaticum*	Myrtaceae	قرنفل
Basil	*Ocimum basilicum*	Lamiaceae	ريحان
Lavender	*Lavandula angustifolia*		لافندر
Peppermint	*Mentha piperita*		نعناع بلدي
Thyme	*Thymus vulgaris*		زعتر

2.3 Repellency Bioassays

To determine the potential repellent effect of the tested plant oils against *S. oryzae* adults, three different experimental techniques were applied:

2.3.1 Food-Preference Tests

(a) Multiple-Choice Bioassay

Multiple-choice bioassay was done according to the methodology designed by Abdel-Rahman et al. (2011, 37) and adopted by Ismail (2018, 1339). In the present investigation, a similar strategy was adopted to study the repellent effect in the presence of rice treated with tested oils.

To conduct a multiple-choice bioassay, a set of small triangular mesh bags was arranged in a circular pattern within a rimmed tray. Six bags were randomly selected, each containing approximately 20 grams of rice treated as follows: five bags contained rice treated with one of the selected plant oils mixed with acetone as a solvent. One bag was treated with acetone alone, serving as a control. In the acetone-treated rice, the solvent was allowed to evaporate completely for half an hour before the test.

Figure (2): Food-preference test (Multiple-choice bioassay).

A total of 30 adult rice weevils were placed at the centre of the circular tray, initially confined within a perforated cover for 15 minutes to allow for acclimatization before the experiment began. Then the cover was carefully removed, allowing the weevils to explore treated rice freely. Once insect activity had completely ceased, the panel was securely covered with adhesive tape to ensure a tight seal.
After 24-hours treatment, the contents of each bag were gently emptied, and the weevils inside were collected and counted accurately. Weevils that remained outside the bags were not included in the final count. To validate the results, the experiment was repeated three times.

(b) Two-choice Bioassay

A procedure similar to the multiple-choice bioassay was used (Abdel-Rahman et al., 2011, 38 and Ismail, 2018, 1339). However, in this setup, the mesh bags were designed in a semi-circular shape to allow for a more precise comparison of the results, the choice between each tested oil versus its control (Fig. 3).

Petri dishes (14-cm in diameter) were used, with a mesh fabric arranged inside them in an opposing manner. The dishes were then securely sealed with a tight-fitting lid. Each Petri dish was prepared to include two different treatment conditions for comparison. One compartment contained approximately 20 grams of rice treated with one of the tested plant oils, while the other compartment held untreated rice as a control group.

Figure (3): Food-preference test (Two-choice bioassay).

Ten weevils were placed at the centre of each Petri dish, equidistant from both compartments. The dishes were left in complete darkness for 24 hours, allowing the insects to choose between the treated and untreated rice. After the designated period, the distribution of insects within each section of the dish was recorded. The mesh bags of treated rice were carefully collected, and the number of weevils in each half was counted to determine their preference. Any weevil that did not settle in either designated section was excluded from the final analysis. To ensure result accuracy, the experiment was repeated three times.

2.3.2. Area-Preference Test

To evaluate the repellent properties of each tested oils in the absence of rice, an area preference test was conducted based on the methodologies described by Abdel-Rahman et al. (2011, 38), with slight modification (Fig 4).

Test materials were prepared using Whatman filter paper No. 1 (9 cm in diameter), which was divided into two equal halves. The test oil was dissolved in acetone, and 0.3 ml of the solution was applied to one half of the filter paper. The treated papers were left to dry completely to ensure full evaporation of the solvent.

During the test setup, the treated half of the filter paper was attached to the untreated half (which had been exposed to the solvent only) using adhesive tape; to prevent any possible transfer of oils between the opposite halves of treated filter paper in each Petri dish., with a sufficient gap to maintain accurate measurements.

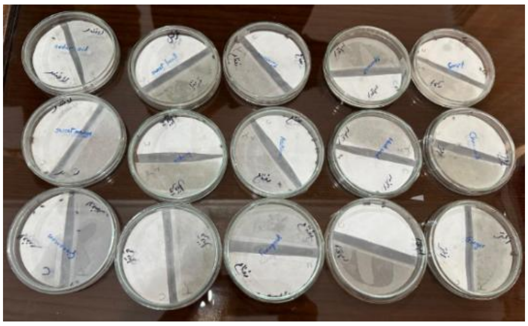

Figure (4): Area-preference test.

Ten weevils were placed in the centre of each Petri dish on the middle tape, randomly oriented to minimize potential external influences on the insects. Three replications were used for each tested oil. Counts of the weevils present in each half were made after 1- , 2- , 3- , 4- , 5- and 24- hours after treatments.

The resulting data was statistically calculated by the formula of Talukder and Howse (1993, 2465) and the average repellency values were classified to repellency classes based on the scale designed by Juliana and Su (1983, 155), as described in the following Data analysis section**.**

2.4 Data Analysis

- The results were calculated as mean ± standard deviation (SD) using Excel Program (Office 365).
- The percentage of change (Change%) was calculated using the following formula:

Change % = [Treated value - control value) / control value] × 100

-To determine the statistical differences between means, a paired sample *t*-Test was used to compare values between the treated and control groups by using “T test calculator online program”**.** The statistical significance levels were classified as follows:

“Highly significant” when ($P<0.01$), “Significant” when ($P<0.05$) and “Not significant” if ($P>0.05$).

-Calculation of Percentage of repulsion (PR%) in Area-preference tests was made using the formula of Talukder and Howse (1993, 2465), as follows:

(PR %) = [(N-C)/C]*100

Where: N= number of weevils present in the control half; C= total number of tested weevils in the Petri dish.

Positive PR% (+) expressed repellency and negative ones (-) expressed attractancy.

Average repellency values were classified as repellency classes based on the scale designed by Juliana and Su (1983, 155): Repellency classes:

(Repellency rate = Class): (<0.1=0), (0.1-20=I), (20.1-40=II), (40.1-60=III), (60.1-80=IV) and (80.1-100=V).

3. Results

In the present study, Repellency tests were conducted to evaluate the effectiveness of five essential oils: Basil, Clove, Lavender, Peppermint, and Thyme, in repelling *Sitophilus oryzae*. The study was performed under laboratory conditions using three different bioassays: Food-preference tests (multiple-choice and two-choice) and Area-preference tests. Results of the repellency tests are tabulated in Tables 2-4.

3.1 Food- preference tests

3.1.1 Multiple-choice bioassay

Table 2 represents the data of Multiple-choice bioassay of the tested oils against *S. oryzae*. As compared with the control, lavender oil demonstrated the strongest repellent effect with a highly significant change of -46.7% ($p<0.01$). In the second rank, thyme oil reveals also a highly significant change of -27 ($p<0.01$) as compared with controls. Basil oil showed a significant change of – 33.5% ($p<0.05$).

On the other hand, Peppermint and clove oils showed an insignificant change of -20.4% and 6.6% ($p>0.05$).

3.1.2 Two-choice bioassay

Table 3 represents the data of Two-choice bioassay of the tested oils against *S. oryzae*. As compared with the control, the ranking of the tested oils in terms of repellent effectiveness differed slightly. Thyme, lavender, clove and peppermint oils showed a highly significant repellent effect (-84.7, -57.1, -42 and -23.6%, respectively, $p<0.01$).

In contrast, basil oil showed a significant attractant effect (50%, $p<0.05$) which differ from the results obtained with multiple-choice bioassays.

3.2 Area-preference tests

Table 4 represents the data of Area-preference tests of the tested oils against *S. oryzae*. Lavender oil once again exhibited the highest repellency (-46.1%), classifying it as a Class III repellent, the highest repellency category in the present study. While peppermint and thyme oils demonstrated moderate repellent effects (-22.8%) and were classified as Class II repellents. Basil and Clove oils showed weaker repellency, with rates of -13.9% and -8.9%, respectively, placing them in Class I, the lowest repellency category.

Based on the present findings, lavender and thyme oils exhibited the highest repellency effect against *S. oryzae* across all experiments. Peppermint oil also demonstrated moderate repellent effects. In contrast, Basil oil exhibited weak repellent effects.

Table 2: Repellency effect of the tested oils on food preference of *S. oryzae* as evaluated by the **Multiple-choice bioassay**, at laboratory conditions.

Treatment[(1)]	Beetles found in sections%			% Change	*t*-Test	
	Min.	Max.	Mean ± SD		*p*-value	Significant level[(2)]
Control	10	26.7	16.7 ± 6.7			
Basil	0	26.7	11.1 ± 10.4	-33.5	0.0161	*
Clove	10	23.3	17.8 ± 5.2	6.6	0.4803	ns
Lavender	6.7	10	8.9 ± 1.5	-46.7	0.0001	**
Peppermint	3.3	20	13.3 ± 6.7	-20.4	0.0542	ns
Thyme	10	13.3	12.2 ± 1.5	-27	0.0007	**

(1)Three replicates for each treatment, 30 beetles per replicate.

(2)Significant level: ns, insignificant ($p>0.05$); *, significant ($p<0.05$); **, highly significant ($p<0.01$)

Table 3: Repellency effect of the tested oils on food preference of *S. oryzae* as evaluated by the **Two-choice bioassay**, at laboratory conditions.

Treatment[(1)]	% Beetles (Mean±SD)		% Change	*t*-Test	
	Control	Treated		*p*-value	Significant level[(2)]
Basil	40 ± 20	60 ± 20	50	0.0382	*
Clove	63.3 ± 8.9	36.7 ± 8.9	- 42	0.0001	**
Lavender	70 ± 6.7	30 ± 6.7	- 57.1	0.0001	**
Peppermint	56.7 ± 8.9	43.3 ± 8.9	- 23.6	0.0034	**
Thyme	86.7 ± 11.1	13.3 ± 11.1	- 84.7	0.0001	**

(1)Three replicates for each treatment, 10 beetles per replicate.

(2)Significant level: ns, insignificant ($p>0.05$); *, significant ($p<0.05$); **, highly significant ($p<0.01$)

Table 4: Repellency effect of the tested oils on Area-preference of S. oryzae as evaluated by using **Area-preference test** after 6-time intervals, at laboratory conditions.

Treatment[(1)]	Average repellency (hours after treatment)[(1)]						Overall average%	Repellency class [(2)]
	1h	2h	3h	4h	5h	24h		
Basil	-13.3	-16.7	-6.7	-23.3	-16.7	-6.7	-13.9	I
Clove	-20	-10	-10	0	-6.7	-6.7	-8.9	I
Lavender	-26.7	-53.3	-46.7	-50	-46.7	-53.3	-46.1	III
Peppermint	-26.7	-13.3	-26.7	-13.3	-20.0	-36.7	-22.8	II
Thyme	-33.3	-26.7	-30	-13.3	-30.0	-3.3	-22.8	II

(1) Average of three replicates, 10 beetles per replicate.

(2)Repellency class: repellency value<0.1=class 0, 0.1-20=I, 20.1-40=II, 40.1-60= III, 60.1-80= IV, 80.1-100= V.

4. Discussion

The increasing concern to avoid the negative impacts of chemical insecticides has accelerated the search for alternative eco-friendly pest management strategies. Among those, essential oils (EOs) extracted from aromatic plants which have demonstrated promising insecticidal and repellent activities against stored product pests such as *Sitophilus oryzae* (Al-Harbi et al., 2021, 2).

The current study emphasizes the potential use of essential oils as eco-friendly repellents for managing *Sitophilus oryzae* infestations in stored rice. Through a series of laboratory experiments, food-preference tests (including multiple-choice and two-choice bioassays) and area-preference tests, the repellent activity of five essential oils (basil, clove, lavender, peppermint, and thyme) were thoroughly assessed.

In the present investigation, the multiple-choice bioassay showed that lavender and thyme oils is the strongest repellent oils comparing with the control. While basil oil showed a significant repellency effect. On the other hand, Peppermint and clove oils showed an insignificant effect as compared with the control. Concerning the two-choice bioassay, Thyme, lavender, clove and peppermint oils showed a highly significant repellent effect comparing with the control. In contrast, basil oil showed a significant attractant effect, which differ from the results obtained with multiple-choice bioassays. Area-preference tests revealed that lavender oil once again exhibited the highest repellency (Class III). While peppermint and thyme oils demonstrated moderate repellent effects (Class II). Basil and Clove oils showed weaker repellency, (Class I). Based on the present findings, lavender and thyme oils exhibited the highest repellency effect against *S. oryzae* across all experiments. Peppermint and clove oils also demonstrated moderate repellent effects. In contrast, Basil oil exhibited weak repellent effects.

The study results concluded that the **lavender oil** is a promising candidate for developing eco-friendly pest management strategies against stored-product insects as it showed a strong repellency effect through different research bioassays against the rice weevil.

The promising results of lavender oil in different repellency tests were in accordance with the findings of Mahfuz et al. (2023, 37). They stated that lavender oil showed very high repellent effect against *S. oryzae*. Their results showed that the highest repulsion effect of lavender oil was observed after 5 hours of exposure (Class IV) after the area-preference tests. Also, Al-Harbi et al. (2021, 13) found that lavender oil achieved 100% mortality after 24 and 48 hours of exposure against S. oryzae adults. Besides, the oil was recorded high repellence activity against *S. oryzae* with a value of 77.5% after 5 h of exposure (Al-Harbi et al., 2021, 15). As well, Alkan et al. (2021, 405) stated that lavender oil has shown a remarkable potential eco-friendly insecticidal agent against *Sitophilus granarius*, a close relative of *S. oryzae.* The authors tested essential oils which were extracted from three commercial lavender cultivars. The oils exhibited varying levels of fumigant, contact, and repellent activity under laboratory conditions. In addition, Germinara et al. (2017, 135) found that lavender oil showed a significant repellent activity against *S. granaries* on wheat. In filter paper-disc bioassays, oil repellency reached Class V (>80%) and in arena-choice assays, the oil disrupted insect orientation even when wheat grain odours were present.

Chemical analysis of lavender oil made by Al-Harbi et al. (2021, 9-10) provided further insight into the bioactive components of the oil, such as eucalyptol, lavandulyl acetate, and eugenol. These constituents are known for their neurotoxic, fumigant, and repellent properties, which likely contribute to the observed toxicity and repellent activities. In the present study, similar trends were observed, and the presence of these compounds in lavender oil is consistent with its obvious repellent effect.

Additionally, the present study findings demonstrate that **thyme oil** exhibits significant repellent properties against the rice weevil. In multiple-choice bioassays, it showed a 27% reduction in insect preference comparing with the control. While the two-choice bioassay revealed the highly significant repellent effect with more striking decline of about 84.7% in the weevils' preference, and it was ranked Class-II in the repellent categories.

Saad et al. (2017, 926) evaluated a variety of botanical oils (including thyme) as ecofriendly alternatives for controlling rice weevils using fumigation techniques. Their study found that thyme oil exhibited only a delayed toxic effect, with significant mortality only appearing after 72 hours of exposure, making it the least effective among the oils they tested. This suggests that while thyme oil may not serve optimally as a fast-acting toxicant, its repellent properties play a crucial role in deterring infestations, thereby limiting potential damage before the pests have a chance to multiply on stored grains. Similarly, Abd El-Salam (2010, 3) concluded that the thyme oil may not have a rapid toxic effect but can deter insects and that deterrent effect is highly valuable for managing insect infestations in stored grains.

The repellent effect of the thyme oil apparent in the present study can likely be attributed to major constituents such as thymol and carvacrol, which appear to stimulate the chemosensory pathways of the insects and trigger avoidance responses (Hossain et al., 2019, 1441)

In the present investigation, **basil oil** showed significant repellent effect in the multiple-choice test, ranked Class-I repellency in area-preference bioassay. On the other hand, it showed a significant attractive effect in the two-choice bioassay. These results highlight that basil oil can be effective, but its efficacy is highly concentration-dependent and may vary with application method (Maia and Moore, 2011, 9-10). The present findings are somewhat in accordance with the studies of Popović et al. (2006, 38) and Seada et al. (2016, 4), who investigated the toxicity and repellency effects of basil oil against *Sitophilus oryzae*. Their results showed that the basil oil caused significant mortality and repellency effects, which were concentration- and time-dependent, in both two- and multiple-choice bioassays. Besides, Al-Harbi et al. (2021, 13-14) found that the basil oil recorded the highest repellence activity against *S. oryzae* with a value of 82.3% after 5-hours of exposure.

These findings agree with those of Popović et al. (2006, 38), who reported that basil essential oil exhibited notable mortality (30.7% after 48 h), repellency (72.5% after 48 h), and significant inhibition of F1 progeny (only 14.5 offspring compared to 208.6 in the control).

Basil oil is well-known by its antibacterial and antifungal activities, besides have deterring effect on some insects due to the presence of thujone, camphor, linalool,1,8-cineole, methylchaviol which have been reported to exert neurotoxic effects on insects by inhibiting acetylcholinesterase activity. Such compounds may act through contact toxicity, repellency, and disruption of reproductive processes (Seada et al, 2016, 9; Popović et al., 2006, 39).

Results of above-mentioned research concerning basil oil are different from the present results which may stem from variations in concentration, purity, or experimental conditions.

In the present investigation, **peppermint oil** showed an insignificant effect in multiple-choice food-preference test ($p>0.05$), ranked Class-I repellency, whereas it showed highly significant repellent effect in two-choice food preference tests.

The present results are somewhat different from the findings of Aarthi et al. (2022, 362) who bio-assayed the repellency effects of two different species of mint oils against *S. oryzae*. They found that spearmint oil showed the highest repellent activity (Class IV repellency), followed by peppermint oils, which also displayed class III and IV repellency at higher doses.

The chemical composition of the oils plays a pivotal role in their bioactivity. GC-MS analysis revealed that Spearmint oil rich in carvone and limonene, whereas peppermint oil contains higher concentrations of menthol and menthone (Remesh et al., 2023, 5). These constituents are well-documented for the difference between the repellency effects of the different plant species.

Therefore, the fluctuations in the repellent effects of peppermint oil in the present study can be attributed to the type of repellency tests, where insects interact differently with different methods of repellent bioassays, and the kind of the tested oil (Maia and Moore, 2011, 9-10).

Finally, **clove oil** exhibited varying repellent effects against *Sitophilus oryzae* across different types of bioassays. In the two-choice bioassay, clove oil showed a significant repellent effect of -42% ($p<0.01$), indicating strong efficacy in repelling the insect. However, its effect was considerably weaker in the multiple-choice bioassay and the area-preference test, with repellency rates of 6.6% and -8.9%, respectively. This variation suggests that the repellent efficacy of clove oil may be influenced by the type of bioassay and surrounding environmental conditions.

These results are consistent with findings by Maia and Moore (2011, 9-10) and Gitahi et al. (2021, 9) who reported that the effectiveness of clove oil against *S. oryzae* varies depending on the experimental setup, showing stronger effects in direct-choice tests compared to multiple-choice assays. Therefore, the repellent mechanism of clove components can be attributed to this process, where insects interact differently with the methods of repellent tests, as shown before with peppermint oil.

Besides, the current results are in harmony with results of Viteri Jumbo et al. (2014, 32) who determined evaluated the insecticidal and repellent activities of clove oil against the bean weevil, *Acanthoscelides obtectusin*. Their results indicate clove oil showed toxicity effects, but it appears a weak repellent for the grain weevils. They concluded that the repellent effect of clove leaf oil was a comparatively lower effect than the stem oil; the leaf oil exerted nearly half of the effect of stem oil. This variable efficacy of clove oil in the present results could be linked to its volatile composition, which may degrade rapidly in certain conditions, as noted by Maia and Moore (2011,10).

The repellent mechanism of plant oil can be attributed to the chemical signals that are perceived and processed in the olfactory centers of the central nervous system in response to odor molecules emitted in the insect’s environment. This process affects ion transport and in turn the release of acetylcholine esterase which hydrolyses acetylcholine responsible for signal (López and Pascual-Villalobos, 2010, 284; Agrahari and Mishra, 2024, 102). For a phytochemical component to act as a repellent, it must be volatile enough for its molecules to meet the insect's olfactory sensory organs and generate an odor perception. This ultimately leads to behavioral changes triggered by olfactory stimulation, which is essential for understanding the mechanisms of insect attraction and repellency (Gitahi et al., 2021, 9). As revealed in the present results, the plant oils tested showed different repellent effects against rice weevils.

5. Conclusion:

Based on the present findings, lavender and thyme oils exhibited the highest repellency effect against *S. oryzae* across all experiments, making them the most promising candidate for use as a natural insect repellent. Peppermint oil also demonstrated moderate repellent effects, making them potential alternatives. In contrast, Basil oil exhibited weak repellent effects, indicating its limited use in managing *S. oryzae*. In general, the present results support the potential of essential oils as natural and environmentally friendly alternatives to chemical insecticides, contributing to the protection of stored grains without harming human health or the environment.

Further research is needed to isolate the bioactive compounds, evaluate their activity, and assess the potential use of such plant oils widely in grain stores. The present work net results are consistent with Egypt's 2030 plan for sustainable development and going green.

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