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Mortality and Repellency Effect of Some Essential Oils against *Tribolium castaneum* (Coleoptera: Tenebrionidae)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The red flour beetle (*Tribolium castaneum*) is a major pest of stored grains, causing significant economic losses. In recent years, essential oils have gained attention as eco-friendly alternatives to synthetic pesticides. This study evaluated the insecticidal and repellent properties of three essential oils—lavender (*Lavandula spica*), mogra (*Jasminum sambac*), and rose (*Rosa damascena*)—against *T. castaneum*. Toxicity was assessed using direct contact and fumigation methods, targeting adult *T. castaneum*, respectively. Repellency was tested on larvae using filter paper assays and bioassays were conducted at varying doses and exposure durations. In direct contact assays, adult mortality increased with higher doses and longer exposure times. Lavender oil showed the highest toxicity (LD_{50} = 0.366–0.143 µl/cm²), followed by Mogra oil (LD_{50} = 1.037–0.147 µl/cm² at 3–48 h) and rose oil (LD_{50} = 0.651–0.188 µl/cm²). In fumigation assays, rose oil was the most effective against the target insect (LD_{50} = 4.031–2.252 µl/cm² at 24–48 h), followed by

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lavender oil (LD_{50} = 4.980–3.180 µl/cm²) and mogra oil (LD_{50} = 7.339–5.463 µl/cm²). Overall, the direct contact method was more effective than fumigation. Repellency assays showed mogra oil exhibiting significant effects ($F = 25.25$, $P < 0.001$) and achieving 100% repellency at 0.0785 µl/cm² within 3–4 hours, whereas lavender and rose oils showed lower and statistically insignificant effects. This study highlights the potential of essential oils as biopesticides for managing *T. castaneum*. Mogra oil demonstrated superior efficacy in direct contact assays, while rose oil excelled in fumigation tests. These findings support the use of essential oils as eco-friendly alternatives for pest management in stored grains.

Keywords: Lavender; mogra; rose; essential oil; toxicity; repellent activity; fumigation; Tribolium castaneum; LD_{50} values.

1. INTRODUCTION

The exponential growth of the global human population, projected to exceed 10 billion by 2050 [1], has intensified the need for food security worldwide. This challenge is particularly acute in developing and underdeveloped regions, where post-harvest losses due to insect infestations significantly reduce the availability of stored grains and other staples. Among stored-product pests, the red flour beetle (*Tribolium castaneum*), a cosmopolitan species, is particularly destructive, causing extensive damage to grains, flours, and other stored products [2]. Infestations lead to both qualitative and quantitative losses, with significant economic implications.

Chemical control, predominantly through synthetic pesticides and fumigants, has been the mainstay for managing *T. castaneum* and other storage pests. However, these methods pose significant challenges, including environmental pollution, pesticide resistance, human toxicity, and residue accumulation in food products [3,4]. The need for sustainable, eco-friendly alternatives to synthetic pesticides has never been more urgent.

Plant-derived essential oils (EOs) are emerging as promising biopesticides due to their multi-faceted mode of action, including toxicity, repellency, and disruption of insect development and reproduction [5,6]. Plants produce essential oils as secondary metabolites, playing key roles in defense mechanisms and communication. These oils help protect plants against biotic stressors and abiotic stressors, while also aiding in signaling to attract pollinators and beneficial insects [7,8,9]. Studies have demonstrated their efficacy against a variety of stored-product pests, such as *Callosobruchus chinensis*, *Rhyzopertha dominica*, and *Sitophilus zeamais* [10,11].

Essential oils from the families Lamiaceae and Apiaceae, such as lavender (*Lavandula spica*), rose (*Rosa damascena*), and jasmine (*Jasminum sambac*), have shown promising insecticidal and repellent activity in previous research [12,11]. The use of such natural products aligns with the global push toward sustainable agricultural practices, reducing reliance on synthetic chemicals while maintaining efficacy against storage pests.

This study aims to evaluate the toxicant, fumigant, and repellent properties of three essential oils—mogra (*J. sambac*), lavender (*L. spica*), and rose (*R. damascena*)—against adult and larval stages of *T. castaneum*. By analyzing the response of this key storage pest to varying concentrations of these oils, the research seeks to contribute to the development of safer, plant-based alternatives to conventional insecticides. A better understanding of the behavioral and toxicological effects of these essential oils on storage pests will help pave the way for integrated pest management strategies that minimize environmental and health risks while addressing food security concerns.

2. MATERIALS AND METHODS

2.1 Insect (Rearing and Maintenance)

The red flour beetle, was obtained from stock cultures maintained at the Entomology Laboratory, University of Rajshahi, Bangladesh. Adults were reared in glass beakers containing sterile feeding media consisting of whole-wheat flour and dried yeast powder in a 19:1 ratio, following the method described by Zyromska-Rudzka [13]. The wheat flour was stored in a deep freezer for 48 hours before use to eliminate any pre-existing pests. Subcultures of adult beetles were maintained at ambient laboratory conditions and sieved periodically to collect individuals for the experiments. Adults were manually transferred from the flour medium using a brush and spoon, then placed in Petri dishes for subsequent assays.

2.2 Essential Oils

Pure essential oils of lavender (*Lavandula spica*), mogra (*Jasminum sambac*), and rose (*Rosa damascena*) were purchased from markets. These oils were used without further purification.

2.3 Contact Toxicity Bioassay

A contact toxicity bioassay was performed using newly emerged *T. castaneum* adults (4–7 days old). Doses of each essential oil (0.331, 0.214, 0.136 and 0.097 µl/cm²) were determined through pilot studies to ensure mortality rates between 10% and 90%. Oils were diluted in acetone, and 1 ml of the prepared solution was applied to a 7 cm Petri dish using a residual film method [14]. The solution was evenly spread across the surface, and the dishes were allowed to air dry. Control dishes received only acetone.

For each replication, 10 adults were introduced into the treated dishes and covered with lids to create a captive environment. Mortality was recorded at 3, 6, 24, and 48 hours post-treatment. Three replicates were conducted for each dose.

2.4 Fumigation Toxicity Bioassay

The fumigant toxicity assay was conducted using glass vials (5 cm length × 2.5 cm diameter) capped with polypropylene stoppers. Groups of 10 adult beetles were placed into each vial, which was sealed with muslin cloth secured by adhesive tape. Doses of essential oils (4.074, 2.037, 1.018 and 0.509 µl/cm²) were applied separately to identical vials, and these were inverted and sealed with the insect-containing vials to allow saturation of the airspace with oil vapors. Controls were prepared using the same setup without essential oils. Mortality was assessed at 24 and 48 hours after treatment.

2.5 Repellency Bioassay

Repellency was tested in 9 cm Petri dishes divided into treated and untreated halves using filter paper. Essential oils were applied to the treated half at concentrations of 0.0049, 0.0098, 0.0196, 0.0392, and 0.0785 µl/cm², while the untreated half received acetone. A thin stick secured with adhesive tape demarcated the two sections. Ten fourth-instar larval beetles were introduced at the center of each dish, and their distribution was recorded hourly for 5 hours. Each concentration was tested in triplicate.

2.6 Statistical Analysis

2.6.1 Dose mortality analysis

Mortality data were corrected using Abbott's [15] formula to account for natural mortality in the control:

$$P_t = \frac{P_o - P_c}{100 - P_c} \times 100$$

Where Pt = Corrected mortality (%), Po = Observed mortality (%), Pc = Control mortality (%). Then mortality data were subjected to probit analysis [16] to determine dose-mortality relationships.

2.7 Repellency Analysis

Percentage repellency (PR) was calculated using the formula:

$$PR = (NC - NT) / (NC + NT) \times 100$$

Here, PR= Percentage Repellency, NC= Number of insect in the non-treated (control) area after the exposure interval, NT= Number of insect in the treated area after the exposure interval [17,18]. Positive PR values indicate repellency, while negative values indicate attraction.

A two-factor without replication ANOVA was performed in Microsoft Excel to evaluate the effects of dose and time on repellency. The F-values were compared with critical values from the F-distribution table to determine statistical significance.

3. RESULTS

Contact toxicity: The doses of essential oil (Lavender, Mogra, Rose) used in contact treatment were 0.331, 0.214, 0.136 and 0.097 µl/cm². The results on the mortality of *T. castaneum* adults after 3, 6, 24 and 48 hour of exposure to Lavender, Mogra and Rose essential oils are presented in Table 1.

LD_{50} value of the lavender oil after 3 hour was 0.366 µl/cm² and after 48 hour of exposure period it became 0.143 µl/cm². Though the LD_{50} value were decreases by the time period so it's toxicity level was increasing. The lavender becoming more toxic at 48 hour of treatment for the test insect against *T. castaneum.* LD_{50} value of the Mogra oil after 3, 6, 24 and 48 hour of exposure period were 1.037, 0295, 0.185 and 0.147 µl/cm². By the time period LD_{50} value were decreasing and becoming toxic against *T. ccastaneum*. LD_{50} value of the Rose oil after 3, 6, 24 and 48 hour of exposure period were 0.651, 0.503, 0.339 and 0.188 µl/cm². So after 48 hour of exposure time period the LD_{50} value becoming low and confirm their increasing toxicity level. From above discussion it is confirmed that among the three essential oils viz Lavender, Mogra and Rose oil; the lavender oil was relatively more toxic than other two oils compare to their LD_{50} value. Among the three oils lavender oil shows highest mortality rate at the highest doses. After 48 hour of exposure time the LD_{50} value of three oils were 0.143, 0.147 and 0.188 µl/cm², so at this point the highest toxicity rate compare to LD_{50} value were Lavender oil> Mogra oil >Rose oil.

Fumigation toxicity: The doses of essential oil (Lavender, Mogra, and Rose) used in fumigant treatment were 4.074, 2.037, 1.018 and 0.509 µl/cm². The results on the mortality of *T. castaneum* adults after 24 and 48 hour of exposure to Lavender, Mogra and Rose essential oils are presented in Table 2. LD_{50} value of the lavender oil after 24 hour was 4.980 µl/cm² and after 48 hour of exposure period it became 3.180 µl/cm². Though the LD_{50} value were decreases by the time period so it's toxicity level was increasing. The lavender becoming more toxic at 48 hour of treatment for the test insect against *T. castaneum.* LD_{50} value of the Mogra oil after 24 and 48 hour of exposure period were 7.339 and 5.463 µl/cm². By the time period LD_{50} value were dcreasing and becoming toxic against *T. ccastaneum* and confirm higher mortality rate. LD_{50} value of the Rose oil after 24 and 48 hour of exposure period were 4.031 and 2.252 µl/cm². So after 48 hour of exposure time period the LD_{50} value becoming low and confirm their increasing toxicity level. From above discussion it is clear that among the three essential oils viz Lavender, Mogra and Rose oil; the Rose oil was relatively more toxic than other two oils compare to their LD_{50} value. Among the three oils Rose oil shows highest mortality rate at the highest doses. After 48 hour of exposure time the LD_{50} value of three oils were 3.180, 5.463 and 2.252 µl/cm². So the highest toxicity rate compare to LD_{50} value were Rose oil> Lavender oil >Mogra oil. Rose oil which didn't performed well in the contact treatment but well performed in fumigant treatment.

Repellency: Repellency assays showed mogra oil exhibiting significant effects ($F = 25.25$, $P < 0.001$) and achieving 100% repellency at 0.0785 µl/cm² within 3–4 hours, whereas lavender and rose oils showed lower and statistically insignificant effects.

Table 1. Toxicity of Lavender, Mogra and Rose essential oil against adult *T. castaneum* after 3, 6, 24 and 48 hours

Time of exposure	Essential Oils	LD_{50} (µl/cm²)	95% confidence limits		Regression equation	χ^2 value (at 2df)
			Lower	Upper		
3h	Lavender	**0.366**	0.228	0.588	Y = 1.623 + 2.169 X	0.136
	Mogra	1.037	0.189	5.697	Y = 1.982 + 1.456 X	0.309
	Rose	0.651	0.228	1.854	Y = 1.827 + 1.754 X	5.078
6h	Lavender	0.303	0.218	0.422	Y = 1.242 + 2.546 X	8.124
	Mogra	**0.295**	0.222	0.392	Y = 0.908 + 2.777 X	2.036
	Rose	0.503	0.224	1.127	Y = 2.011 + 1.767 X	5.748
24h	Lavender	0.196	0.164	0.234	Y = 0.948 + 3.135 X	1.182
	Mogra	**0.185**	0.156	0.219	Y = 0.821 + 3.302 X	2.524
	Rose	0.339	0.188	0.611	Y = 2.619 + 1.557 X	2.487
48h	Lavender	**0.143**	0.118	0.173	Y = 1.509 + 3.030 X	1.644
	Mogra	0.147	0.122	0.177	Y = 1.287 + 3.183 X	1.255
	Rose	0.188	0.136	0.262	Y = 2.928 + 1.636 X	2.397

NOTE: LD_{50}= Lethal Dose, 50% (express the dosage of a substance that is lethal to 50% of a population or test sample)

Table 2. LD_{50}, 95% confidence limits and regression equation of Lavender, Mogra and Rose essential oils against adult *T. castaneum* after 24 and 48 hours of fumigation treatment

Time of exposure	Essential Oils	LD_{50} (μl/cm²)	95% confidence limits		Regression equation	χ^2 value (at 2df)
			Lower	Upper		
24h	Lavender	4.980	2.239	11.078	Y = 2.806 + 1.301 X	0.563
	Mogra	7.339	2.872	18.751	Y = 2.045 + 1.614 X	0.377
	Rose	**4.031**	1.465	3.462	Y = 2.775 + 1.391 X	0.520
48h	Lavender	3.180	1.750	5.779	Y = 3.035 + 1.318 X	0.542
	Mogra	5.463	2.218	13.454	Y = 2.902 + 1.202 X	5.030
	Rose	2.252	2.100	7.740	Y = 3.088 + 1.421 X	0.139

Table 3. ANOVA of repellency for Lavender, Mogra and Rose essential oils against the larvae of *T. castaneum*

Name of the Insect	Essential Oils	Source of variation (SV)	SS	df	MS	F
T. castaneum larvae	Lavender	Between doses	3286.897	4	821.72	5.865
		Between time interval	449.317	4	112.32	0.801
	Mogra	Between doses	23646	4	5911.5	25.25**
		Between time interval	213.2575	4	53.314	0.227
	Rose	Between doses	4231.781	4	1057.94	6.723
		Between time interval	470.9645	4	117.74	0.748

NOTE: SS= Sum of Squares, MS= Mean Square, df - Degrees of Freedom, F - F-ratio. = Significant at 5% level (P<0.05), ** = Significant at 1% level (P<0.01)*

4. DISCUSSION

The results of this study highlight the potential of Lavender (*Lavandula angustifolia*), Mogra (*Jasminum sambac*), and Rose (*Rosa damascena*) essential oils as effective biopesticides against *Tribolium castaneum*, a major stored product pest. The progressive decline in LD_{50} values over time for all three essential oils indicates their increasing toxicity with prolonged exposure, a critical characteristic for effective pest management. The LD_{50} values for Lavender oil decreased significantly from 0.366 μl/cm² at 3 hours to 0.143 μl/cm² at 48 hours, making it the most toxic among the tested oils. Lavender oil's efficacy may be attributed to its high concentrations of monoterpenes, such as linalool and linalyl acetate, which are known to disrupt the insect nervous system and respiratory functions [19]. Another study shows the lavender essential oil exhibited insecticidal activity against the lesser grain borer, with the effectiveness depending on the concentration and exposure period [20]. A research demonstrating the three essential oils (EOs) from basil, black seeds, and lavender showed toxic and insecticidal effects against the rice weevil Sitophilus oryzae, with lavender and basil EOs exhibiting 100% mortality at 6 mg/cm^2 after 48 and 24 hours, respectively [21].

Mogra oil also showed a notable increase in toxicity over time, with LD_{50} values dropping from 1.037 μl/cm² at 3 hours to 0.147 μl/cm² at 48 hours. A study showed that the essential oil of *J. sambac* demonstrated significant toxicity against *Callosobruchus maculatus*, effectively protecting mungbean seeds from infestation [22]. While less potent than Lavender oil, Mogra oil still demonstrated effective insecticidal properties, supporting its utility in integrated pest management (IPM). Rose oil, though the least toxic among the three, exhibited a similar trend, with LD_{50} values declining from 0.651 μl/cm² at 3 hours to 0.188 μl/cm² at 48 hours. Compounds such as geraniol and citronellol, known for their insect repellent and toxic effects, are likely responsible for its activity [23].

Although Rose oil's efficacy is comparatively lower, its potential for combination with other oils or as part of IPM strategies should not be overlooked. The findings from this study provide valuable insights into the fumigant toxicity of Lavender (*L. angustifolia*), Mogra (*J. sambac*), and Rose (*R. damascena*) essential oils against *Tribolium castaneum*, a major pest of stored products. The decreasing LD_{50} values over the 24- and 48-hour exposure periods demonstrate the potential of these essential oils as effective fumigants, with their toxicity increasing over time. Among the three oils, Rose oil exhibited the lowest LD_{50} value (2.252 µl/cm² at 48 hours), making it the most toxic under fumigant conditions. This superior efficacy can be attributed to its high concentration of volatile bioactive compounds, such as geraniol and citronellol, which are known to have strong fumigant and insecticidal properties [23].

Rose oil's performance in fumigant treatment, despite its relatively weaker efficacy in contact assays, highlights its potential in pest management strategies that rely on volatile modes of action. Lavender oil demonstrated a moderate toxicity, with LD_{50} values decreasing from 4.980 µl/cm² at 24 hours to 3.180 µl/cm² at 48 hours. Lavender oil's effectiveness as a fumigant can be linked to its primary constituents, linalool and linalyl acetate, which have been shown to impair insect neurological pathways and respiration [19]. While it was the most toxic in contact assays, its performance in fumigant treatments was surpassed by Rose oil, emphasizing the role of specific application methods in determining efficacy. Mogra oil showed the highest LD_{50} values (7.339 µl/cm² at 24 hours and 5.463 µl/cm² at 48 hours), indicating relatively lower toxicity compared to the other two oils. This reduced fumigant efficacy may stem from its composition, which includes benzyl acetate and jasmonates, compounds that are less volatile than those in Lavender and Rose oils. Nevertheless, its declining LD_{50} values over time suggest a cumulative toxic effect with prolonged exposure, supporting its inclusion in integrated pest management (IPM) strategies.

In repellency test showed mogra oil exhibiting significant effects, whereas lavender and rose oils showed lower and statistically insignificant effects against larval stage of *T. castaneum*. Another study on larval *T. castaneum* shows that Jasmine oil's repellency was insignificant between doses but significant between time intervals at a 5% level. Lemon grass showcased significant repellency at a 1% level between doses and a 5% level between time intervals. Sandalwood exhibited significant repellency at both 1% levels between doses and time intervals, emphasizing its robust deterrent effect against larval *T. castaneum* [24,25].

5. CONCLUSION

This study demonstrates the potential of Lavender, Mogra, and Rose essential oils as effective insecticides against *T. castaneum*, with their efficacy varying by application method and exposure time. Lavender oil was the most effective in contact treatments, while Rose oil excelled in fumigant assays. These findings provide a strong foundation for the development of sustainable pest management solutions using plant-based insecticides. Future research should focus on optimizing formulations, exploring synergistic combinations of these oils, and assessing their field applicability for sustainable pest management.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. FAO. The future of food and agriculture: Trends and challenges. Food and Agriculture Organization of the United Nations; 2017.
2. Pimentel D, Zuniga R, Morrison D. Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecological Economics. 2007;52(3):273–288. Available:https://doi.org/10.1016/j.ecolecon.2004.10.002
3. Isman MB. Botanical insecticides, deterrents, and repellents in modern agriculture and an increasingly regulated world. Annual Review of Entomology. 2006;51(1):45–66. Available:https://doi.org/10.1146/annurev.ento.51.110104.151146
4. Watts MA, Williamson SM. Replacing chemicals with biology: Phasing out highly hazardous pesticides with agroecology. Pesticide Action Network UK; 2015.
5. Rajendran S, Sriranjini V. Plant products as fumigants for stored-product insect control. Journal of Stored Products Research. 2008;44(2):126–135. Available:https://doi.org/10.1016/j.jspr.2007.08.003

6. Campolo O, Cherif A, Ricupero M, Siscaro G, Grissa-Lebdi K, Russo A, Palmeri V. Citrus peel essential oil nanoformulations to control the tomato borer, Tuta absoluta: Chemical properties and biological activity. Scientific Reports. 2018;8(1):1-12. Available:https://doi.org/10.1038/s41598-018-28342-5
7. Smith S, Barker S. Fast moves in arbuscular mycorrhizal symbiotic signalling. Trends in Plant Science. 2006;11:369–371. Available:https://doi.org/10.1016/j.tplants.2006.06.008.
8. Walters D. Plant Defense: Warding off attack by pathogens, herbivores and parasitic plants. John Wiley & Sons; 2011.
9. Zuzarte M, Salgueiro L. Essential oils chemistry. In D. P. De Sousa (Ed.), Bioactive Essential Oils and Cancer (pp. 19–61). Springer International Publishing; 2015. Available:https://doi.org/10.1007/978-3-319-19144-7_2
10. Ukeh DA, Birkett MA, Pickett JA, Bowman AS, Mordue (Luntz) AJ. Repellent activity of alligator pepper, *Aframomum melegueta*, and ginger, *Zingiber officinale*, against the maize weevil, Sitophilus zeamais. Phytochemistry. 2009;70(6):751–758. Available:https://doi.org/10.1016/j.phytochem.2009.03.015
11. Sharaby A, Abdel-Rahman HR, Moawad SS, Mahmoud YA. Influence of certain essential oils on the repellency and toxicity against *Sitophilus oryzae* L. and their chemical composition. Research Journal of Agriculture and Biological Sciences. 2009;5(5):709–716.
12. Wang J, Zhu F, Zhou X, Niu C, Lei C. Repellent and fumigant activity of essential oil from Artemisia vulgaris to *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae). Journal of Pest Science. 2019;92(3):1133–1141. Available:https://doi.org/10.1007/s10340-019-01104-4
13. Zyromska-Rudzka H. The biology of *Tribolium confusum* Duv. and Tribolium castaneum Herbst. Annual Review of Entomology. 1966;11(1):45-56. Available:https://doi.org/10.1146/annurev.en.11.010166.000401
14. Busvine JR. A critical review of the techniques for testing insecticides. Commonwealth Agricultural Bureaux; 1960.
15. Abbott WS. A method of computing the effectiveness of an insecticide. Journal of Economic Entomology. 1925;18(2):265–267. Available:https://doi.org/10.1093/jee/18.2.265a
16. Busvine JR. A critical review of the techniques for testing insecticides (2nd ed.). Commonwealth Agricultural Bureaux; 1971.
17. Nerio LS, Olivero-Verbel J, Stashenko E. Repellent activity of essential oils: A review. Bioresource Technology. 2009;101(1):372–378. https://doi.org/10.1016/j.biortech.2009.07.048
18. Obeng-Ofori D. Plant oils as grain protectants against *Sitophilus zeamais* (Motsch.) and *Callosobruchus maculatus* (F.) in stored maize and cowpea. International Journal of Pest Management. 1995;41(1):84–86. Available:https://doi.org/10.1080/09670879509371930
19. Regnault-Roger C, Vincent C, Arnason JT. Essential oils in insect control: Low-risk products in a high-stakes world. Annual Review of Entomology. 2012;57(1):405–424. Available:https://doi.org/10.1146/annurev-ento-120710-100554
20. Sayada D, Valizadegan M, Aref S. Evaluation of a botanical insecticide, lavender (*Lavandula angustifolia* (M.)) essential oil as toxicant, repellent, and antifeedant against lesser grain borer (*Rhyzopertha dominica* (F.)). Applied Ecology and Environmental Research. 2022;20(2):1301–1324. Available:https://doi.org/10.15666/aeer/2002_13011324
21. Al-Harbi NA, Al Attar NM, Hikal DM, Mohamed SE, Abdel Latef AAH, Ibrahim AA, Abdein MA. Evaluation of insecticidal effects of plants essential oils extracted from basil, black seeds, and lavender against *Sitophilus oryzae*. Plants. 2021;10(5):829. Available:https://doi.org/10.3390/plants10050829
22. Wanna R, Khaengkhan P, Bunphan D, Kunlanit B, Khaengkhan P, Bozdoğan H. Insecticidal activity of essential oil from *Jasminum sambac* (L.) Aiton against *Callosobruchus maculatus* (Fabricius,

1775) (Coleoptera: Bruchidae). Plant Protection Science. 2023;59(4):369–378. Available:https://doi.org/10.17221/69/2023-pps

23. Isman MB. Botanical insecticides in the twenty-first century—Fulfilling their promise? Annual Review of Entomology. 2020;65(1):233–249. Available:https://doi.org/10.1146/annurev-ento-011019-025010
24. Haque S, Faruki SI. Toxicity and repellent effect of three plant based essential oils against the red flour beetle *Tribolium castaneum* (herbst). Indian Journal of Entomology Online published Ref. No. e24324; 2024.
25. Pavela R, Benelli G. Essential oils as ecofriendly biopesticides? Challenges and Constraints. Trends in Plant Science. 2016;21(12):1000–1007.

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