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Theme

**Analyzing the toxicological effects of medicinal plant
essential oil on adult German cockroaches**

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With an abundance of Allah's help and grace, our steps progressed until we reached the end. To Him belong all praise, thanks, and gracious commendation."

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Dedication

بسم الله الرحمن الرحيم

(و اخر دعواهم ان الحمد لله رب العالمين)

الحمد لله

الحمد لله الذي هيا البدا و يسر اليسر وطيب المنتهى . الحمد لله الذي اغدقني سرورا وجعل طريقي يسير . الحمد لله على التمام و حسن الختام.

اليّ انا.. اما بعد

كونيّ الريح فلو لا الرياح لبارت الاحلام

اهدي تخرجي الى ابي الذي كلله الله بالهيبة و الوقار الى من احمل اسمه بكل فخر و اعتزاز بطلي وقرّة عيني و سندي بعد الله من دعمني بلا حدود واعطاني بلا مقابل .. شكرا لك بحجم السماء . الى من حملتني وهنا على وهن و غرست في قلبي القيم و منحتني الحب من العدم كل كلمات الشكر لا توفيكي حقكي يا امي.

الى اخوتي

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كنتم لي شدا و عضدا و سندا شكرا لكم بكم اشتد قلبي و قويت خطواتي

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الى كل من علمني حرفا.. الى كل اساتذتي الذين مروا في طريقي و تركوا

في قلبي اثرا على يمحي

. و بصمة لا تنسى.. شكرا لكم

الى صديقاتي اميمة، سماح، نبيلة، ريهام، شيماء، سارة، خديجة ، خولة، بسملة، نور، فاطمة الزهراء

الى كل زميلاتي و قريباتي

اللهم انفعني بما علمتني و زدني علما

زعيمة ♥

Dedication

إلى روح والدي الغالي،
الذي رحل عن الدنيا، لكنه لم يغيب عن قلبي.
أسأل الله أن يتغمده برحمته ويجعل مثواه الجنة.
﴿رَبِّ ارْحَمْهُمَا كَمَا رَبَّيَانِي صَغِيرًا﴾

[الإسراء: 24]

إلى أمي الحبيبة،
نبع الحنان، ودفء الأيام، وسري الباقي في الحياة.
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[الأحقاف: 15]

إلى ابنتي الغاليتين،
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[الكهف: 46]

إلى إخوتي وأخواتي،
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إلى صديقاتي،
أنتم النور في لحظات العتمة، والدعم في ساعات الانكسار،
جزاكن الله عني كل خير.
﴿وَمَا تَوْفِيقِي إِلَّا بِاللَّهِ﴾

[هود: 88]

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أحبكم في الله.

Abstract

The German cockroach is a persistent indoor pest known for its resistance to conventional insecticides. This study explored the insecticidal potential of essential oils derived from *Allium sativum* L. and *Artemisia herba-alba*, both individually and in combination, against adult *Blattella germanica* L. A total of 540 adult cockroaches were exposed to inhalation treatments with three increasing concentrations of essential oils: 30% (C1), 15% (C2), and 5% (C3), from *Allium sativum* L. and *Artemisia herba-alba*. Each group included 30 male and 30 female individuals. Our findings show that the insecticidal activity of *Artemisia herba-alba* essential oil varied significantly between male and female *Blattella germanica* L. In males, the oil demonstrated strong toxicity, with the highest concentration (C1) causing 96% mortality over six days. Mortality remained relatively high even at lower concentrations, reaching 76% at C2 and 86% at C3. In contrast, females exhibited greater resistance. The same high concentration (C1) led to only 53% mortality, while the intermediate concentration (C2) caused a lower mortality rate of 23%. At the lowest concentration (C3), no mortality was observed. Additionally, the synergistic formulation of *Artemisia herba-alba* and *Allium sativum* L. essential oils demonstrated exceptional efficacy, inducing complete mortality (100%) in both male and female *Blattella germanica* L. within 24 hours across all tested concentrations (C1, C2, and C3). These findings highlight the potent bioactivity of *Allium sativum* L. and *Artemisia herba-alba* essential oil, supporting their potential as effective, eco-friendly alternatives to synthetic insecticides in pest management strategies.

Keywords: *Allium sativum* L. ; *Artemisia herba -alba*; *Blattella germanica*; Essential oil

Résumé

La blatte germanique est un nuisible domestique persistant, connu pour sa résistance aux insecticides conventionnels. Cette étude a exploré le potentiel insecticide des huiles essentielles dérivées d'*Allium sativum* L. et *Artemisia herba-alba*, utilisées seules ou en combinaison, contre les adultes de *Blattella germanica* L. Un total de 540 blattes adultes ont été exposées à des traitements par inhalation avec trois concentrations croissantes d'huiles essentielles : 30 % (C1), 15 % (C2) et 5 % (C3), extraite d'*Allium sativum* et *Artemisia herba-alba*. Chaque groupe comprenait 30 mâles et 30 femelles.

Nos résultats montrent que l'activité insecticide de l'huile essentielle d'*Artemisia herba-alba* variait significativement entre les mâles et les femelles de *Blattella germanica* L. Chez les mâles, l'huile a démontré une toxicité élevée, la concentration la plus forte (C1) provoquant 96 % de mortalité en six jours. La mortalité est restée relativement élevée aux concentrations plus faibles, atteignant 76 % à C2 et 86 % à C3. En revanche, les femelles ont montré une plus grande résistance. À la même concentration élevée (C1), la mortalité n'était que de 53 %, tandis que la concentration intermédiaire (C2) a causé un taux de mortalité plus faible de 23 %. À la concentration la plus faible (C3), aucune mortalité n'a été observée. De plus, la formulation synergique des huiles essentielles d'*Artemisia herba-alba* et d'*Allium sativum* L. a montré une efficacité exceptionnelle, induisant une mortalité complète (100 %) chez les mâles et les femelles de *Blattella germanica* L. en 24 heures, et ce, pour toutes les concentrations testées (C1, C2 et C3). Ces résultats mettent en évidence la forte bioactivité des huiles essentielles d'*Allium sativum* L. et d'*Artemisia herba-alba*, soutenant leur potentiel en tant qu'alternatives efficaces et écologiques aux insecticides synthétiques dans les stratégies de lutte contre les insectes nuisibles.

Mots-clés: *Allium sativum* L. ; *Artemisia herba-alba*; *Blattella germanica*; Huile essentielle.

ملخص

يعد الصرصور الألماني. *Blattella germanica* L من الآفات الحشرية والمعروفة بمقاومتها للمبيدات التقليدية. وبناءً على ذلك، تهدف هذه الدراسة إلى استكشاف الفعالية الحشرية للزيوت الأساسية المستخلصة من *Allium sativum* L (الثوم) و *Artemisia herba-alba* (الشيح الأبيض)، سواء بشكل منفرد أو عند مزجهما، ضد البالغين من الصرصور الألماني. وعلى هذا الأساس تم تعريض ما مجموعه 540 صرصوراً بالغاً لمعاملة بالاستنشاق باستخدام ثلاث تراكيز متزايدة من الزيوت الأساسية: 30(C1) %، و 15(C2) %، و 5(C3) %، من الثوم والشيح الأبيض. وضم كل مجموعة 30 ذكراً و 30 أنثى. ومن خلال التحليل الدقيق للنتائج تبين أن الفعالية الحشرية لزيوت *Artemisia herba-alba* الأساسية اختلفت بشكل ملحوظ بين ذكور وإناث *Blattella germanica* ففي الذكور، أظهر الزيت سمية قوية، حيث تسببت أعلى جرعة (C1) بنسبة وفاة بلغت 96% خلال ستة أيام. ومن المثير للاهتمام أن نسبة الوفاة ظلت مرتفعة حتى عند التراكيز المنخفضة، إذ بلغت 76% عند C2 و 86% عند C3. في المقابل، أبدت الإناث مقاومة أكبر، حيث تسببت نفس الجرعة العالية (C1) بنسبة وفاة لم تتجاوز 53%، بينما أدت الجرعة المتوسطة (C2) إلى وفاة 23% فقط، ولم تُسجل أي وفاة عند أدنى تركيز (C3). وما يلفت الانتباه أيضاً، أظهرت التركيبة التآزرية لزيوتي *Artemisia herba-alba* و *Allium sativum* L فعالية استثنائية، إذ تسببت في وفاة تامة (100%) لكل من الذكور والإناث من *Blattella germanica* خلال 24 ساعة، عبر جميع التراكيز المختبرة C1، C2، C3. وتجدر الإشارة إلى أن هذه النتائج الفعالية البيولوجية القوية لزيوت *Artemisia herba-alba* و *Allium sativum* L، مما يعزز مكانتهما كبدايل واعدة، فعالة وصديقة للبيئة، عن المبيدات الحشرية الاصطناعية في استراتيجيات مكافحة الآفات.

الكلمات المفتاح : *Allium sativum* L، *Artemisia herba-alba*، *Blattella germanica* L، زيت أساسي.

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General introduction

Introduction

Insects (phylum Arthropoda, class Insecta) represent the most diverse and numerous group of animals on Earth, with over a million species formally described and many more yet to be classified (Stork, 2018). Their abundance and adaptability have allowed them to colonize nearly every terrestrial habitat. Functionally, they are critical to ecological stability through roles such as pollinators, decomposers, and natural enemies of crop pests (Gullan & Cranston, 2014).

Despite these ecological benefits, some insect species have become major urban and public health threats. Among them, the German cockroach (*Blattella germanica*) L. is one of the most persistent and globally distributed indoor pests (Rust *et al.*, 1995). Belonging to the family Ectobiidae, it typically measures 13 to 16 mm in length and is light brown with two dark stripes on the pronotum. Although it possesses wings, it rarely flies. Instead, it uses rapid movement to escape threats and locate food. It thrives in warm, humid environments with abundant food and water, especially in kitchens, bathrooms, and storage areas (Rust *et al.*, 1995). Its strong tendency to hide in narrow, confined spaces makes it difficult to detect and control.

B. germanica is more than a household nuisance. It is a mechanical vector for numerous pathogenic microorganisms, including *Escherichia coli*, *Salmonella* spp., and *Staphylococcus aureus*, all of which can be transferred to food surfaces and utensils (Salehzadeh *et al.*, 2007). These bacteria are associated with serious gastrointestinal diseases in humans. Moreover, the cockroach produces allergens through its feces, saliva, and cast-off skins, which can trigger or exacerbate asthma and allergic reactions (Salehzadeh *et al.*, 2007). These health effects are especially significant in densely populated urban areas and in vulnerable groups such as children, the elderly, and individuals with respiratory conditions (Sohn and Kim, 2012).

Over the years, chemical insecticides such as pyrethroids, organophosphates, and carbamates have been extensively used for controlling *B. germanica*. However, the species has developed significant resistance due to repeated exposure (Limoe *et al.*, 2012).

As a result, traditional chemical control strategies are becoming increasingly ineffective and unsustainable. The growing concern over insecticide resistance, coupled with the environmental and health risks associated with synthetic chemicals, has driven interest in alternative pest management strategies (Siddiqui *et al.*, 2023). One promising direction is the use of plant-derived compounds, particularly essential oils, as natural insecticides. These

botanical extracts are biodegradable, generally less toxic to non-target organisms, and can act on multiple physiological targets in insects, which reduces the risk of resistance development (Isman, 2006).

Many plants produce secondary metabolites as chemical defenses against herbivores and insects. When extracted and applied in concentrated form, these compounds can have potent insecticidal, repellent, or growth-inhibiting effects (Isman, 2006).

Artemisia herba-alba (white wormwood) and *Allium sativum* L. (Garlic) are two such plants with well-documented medicinal and pesticidal properties. *A. herba-alba*, native to arid and semi-arid regions of North Africa and the Middle East, contains essential oil components such as camphor, thujone, and cineole (Derwich *et al.*, 2009; Douiri *et al.*, 2013).

These constituents are neurotoxic to insects and act by disrupting neurotransmission in the central nervous system, leading to paralysis and mortality (Jankowska *et al.*, 2017).

A. sativum, widely cultivated around the world, is rich in sulfur-containing compounds like allicin, ajoene, and diallyl disulfide. These bioactives impair insect feeding behavior, interfere with enzyme function, and inhibit reproduction, offering broad-spectrum control of both agricultural and public health pests (Park *et al.*, 2017).

Despite the promising biological activity of these essential oils, there is limited research on their specific toxicological effects against *B. germanica*. Investigating how these oils affect cockroach physiology, behavior, and mortality is critical for understanding their potential role in pest control (Oladipupo, 2022).

This study focuses on analyzing the toxicological effects of essential oils extracted from *Artemisia herba-alba* and *Allium sativum* L. on the German cockroach *Blattella germanica* L. The goal is to assess their insecticidal potential and determine whether these plant-based compounds could be viable tools in reducing reliance on synthetic chemicals in cockroach control strategies.

This dissertation is organized into several main sections, including an introduction that outlines the general background of the subject, followed by a detailed methodology used to achieve the study's objectives. The results are then presented, followed by a discussion. The work concludes with a summary of the findings and suggests potential directions for future research in this field.

Materials and methods

1. Materials and methods

1.2 Animal material

Blattella germanica L. were manually collected from various locations in Khenchela Province, Algeria. They were reared in transparent, well-ventilated plastic containers (20 cm × 9 cm) (Fig. 1). To ensure pesticide-free conditions, the cockroaches were kept for one year without exposure. Each container contained paper egg cartons for shelter. They were fed dog food, and water was provided using cotton soaked in water inside plastic test tubes. Rearing conditions were maintained at room temperature with a 12-hour light/dark cycle.



Figure 1. Rearing of *Blattella germanica* L. (Personal photo, 2025).

1.3 Plant material

The underground part of *Allium sativum* L. and the aerial part of *Artemisia herba-alba* were collected from Khenchela Province, Algeria. The plants were then shade-dried at room temperature for two weeks.



Figure 2. a. *Artemisia herba _alba* aerial part, b. *Allium sativum*. L. underground part, (personal photo, 2025).

1.4 Extraction of essential oils

Essential oils were extracted from 3000 grams of dried plant material using steam distillation for three hours. A separatory funnel was then used to isolate the oil from the water. The purified oils were stored in airtight glass vials at 4–5°C until biological testing. The extraction yield was calculated based on the dry weight of each sample.



Figure 3. Extraction equipment Hydro steam distillation apparatus

1.5 Bioassay

To assess insect mortality, different concentrations were prepared based on an initial concentration setting experiment. Bioassays were conducted using three increasing concentrations of essential oils (5%, 15%, and 30%) from both plants, dissolved in dimethyl sulfoxide (DMSO). A 0.1 ml volume of each concentration was applied to a small cotton ball and placed in Petri dishes. Control insects were maintained under the same conditions without essential oils. Each concentration was tested in triplicate, with 10 insects per replicate. The number of surviving insects was recorded daily until the end of the exposure period.

5. Statistical analysis

5.1. Calculating plant yield post-extraction

To determine the yield of essential oil from the plants, our procedure begins with accurately measuring the raw plant material in grams. The extraction process is then carried out to obtain the essential oil. Once the extraction is complete, the collected essential oil is weighed in grams to quantify the yield.

Ultimately, the yield is determined by applying the following formula to calculate the percentage:

$$\text{Yield (\%)} = [\text{Weight of extracted essential oil} / \text{Weight of raw plant material used}] \times 100$$

5.2 Calculation of corrected mortality

The XLSTAT software was used to perform the statistics. The percentage of observed mortality is corrected using Abbott's formula (1925), which allows for the elimination of natural

mortality. The formula for calculating corrected mortality is:

Corrected Mortality (%) = [Number of survivors in the control group - Number of survivors in the treated group / Number of survivors in the control group] * 100

The normalized data are subjected to one-way analysis of variance (ANOVA), followed by concentration ranking using the Tukey test.

Results

6. Results

6.1. Effect of *Artemisia herba-alba* essential oil on male German cockroaches

During the exposure of male cockroaches to various concentrations (C1, C2, and C3) of *Artemisia herba alba* essential oil, mortality rates consistently increased. At the C1 concentration, mortality reached 96% by the end of the treatment period (Fig. 4). At C2, mortality reached 76% within six days, while at C3, it rose to 86% over the same duration.

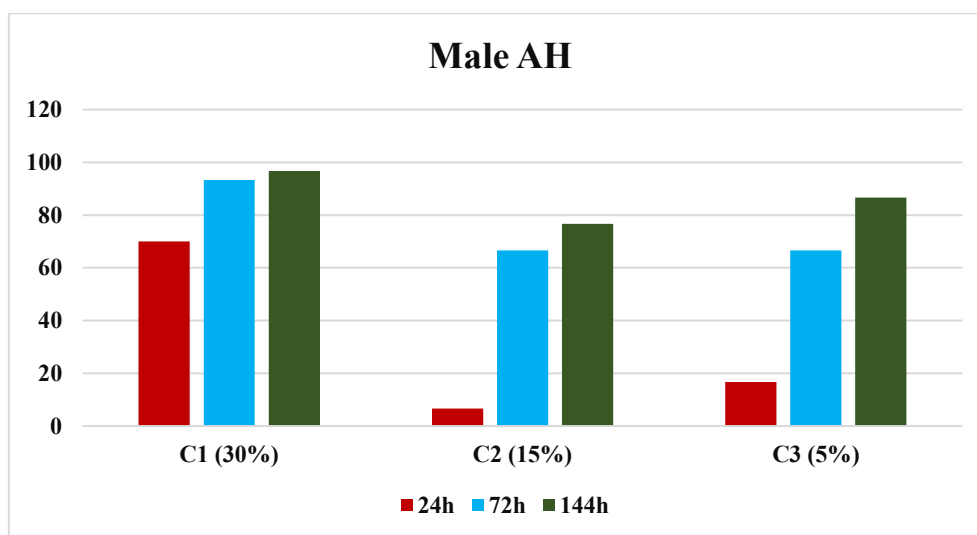


Figure 4. Mortality rate of adult Male German cockroaches exposed to *Artemisia herba-alba* essential oil extract

6.2. Effect of *Artemisia herba -alba* essential oil on female German cockroaches

Treatment of female cockroaches with different concentrations of *Artemisia herba-alba* essential oil showed variable mortality outcomes. At the C1 concentration, mortality reached 53% after six days. In contrast, no mortality was observed at the C3 concentration. At C2, a mortality rate of 23% was recorded after six days (Fig. 5).

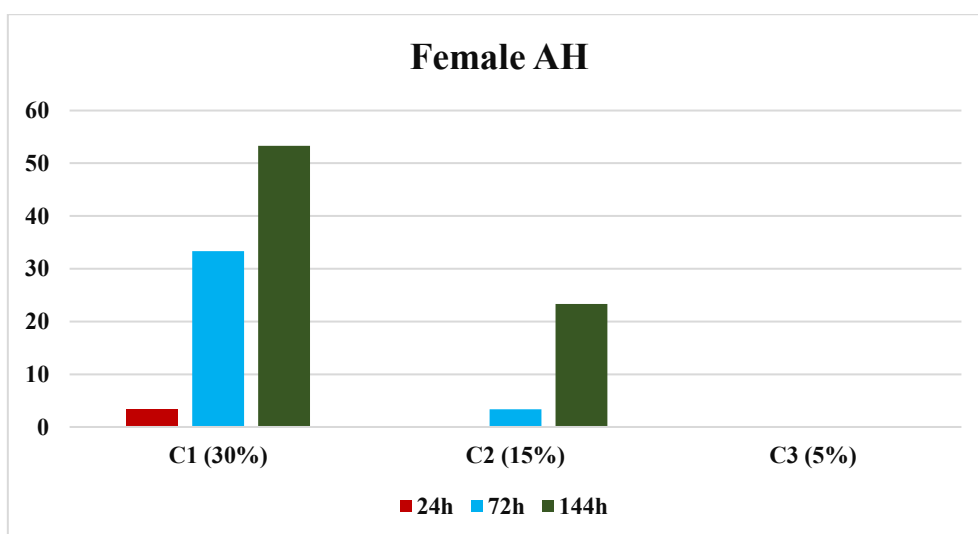


Figure 5. Mortality rate of adult female German cockroaches exposed to *Artemisia herba-alba* essential oil extract

6.3. Effect of *Allium sativum* L. essential oil on male German cockroaches

Throughout the treatment of male cockroaches to *Allium sativum* L. essential oil at three concentrations, C1 (30%), C2 (15%), and C3 (5%), complete mortality (100%) was recorded within the first 24 hours. Mortality occurred rapidly and consistently, even at low concentrations (Fig 6).

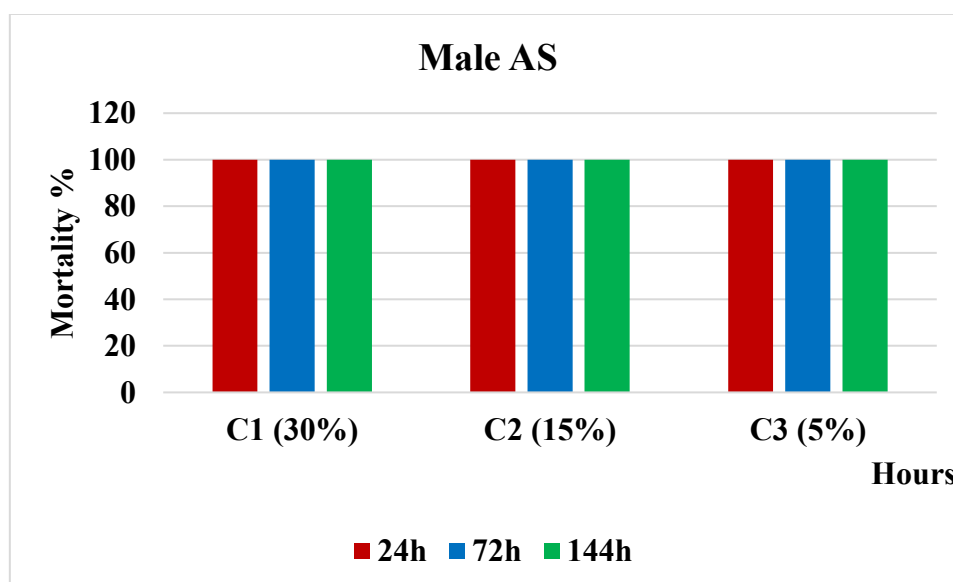


Figure 6. Mortality rate of adult male German cockroach exposed to *Allium sativum* L. essential oil extract

6.4 Effect of *Allium sativum* L. essential oil on female German cockroaches

Upon exposure of female cockroaches to *Allium sativum* L. . essential oil at three concentrations: C1 (30%), C2 (15%), and C3 (5%). At all concentrations, complete mortality (100%) was recorded within the first 24 hours. The effect was both rapid and reliable, even at minimal concentration (Fig 7).

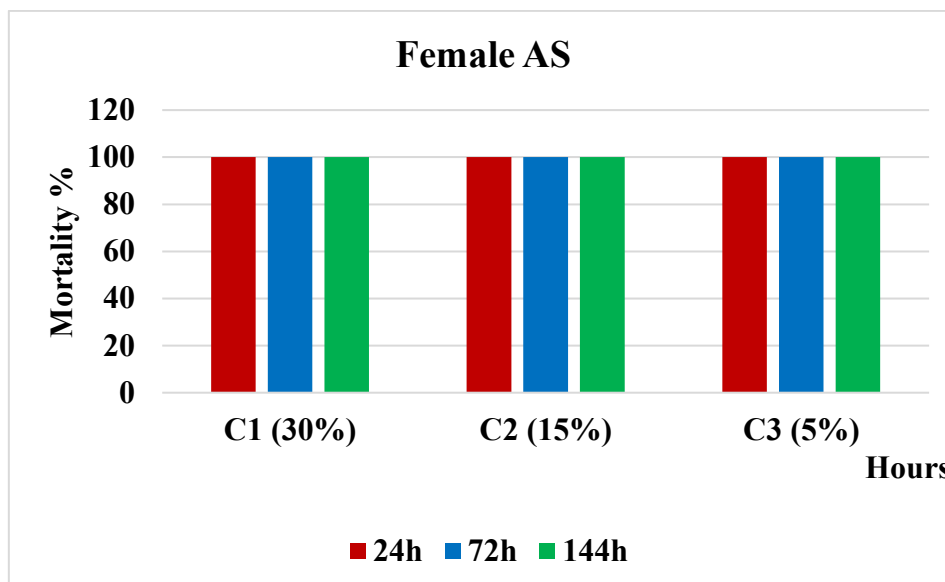


Figure 7. Mortality rate of adult female German cockroach exposed to *Allium sativum* L. essential oil extract

6.5. Synergistic effects of *Artemisia* and *Allium* essential oils on male cockroaches

The results in figure 8 shows that after exposed of male cockroaches to the mixture of *Artemisia herba -alba* with *Allium sativum* L. essential oils at three concentrations: C1 (30%), C2 (15%), and C3 (5%). Complete mortality (100%) was observed at all concentrations within the first 24 hours. The mortality was rapid and consistent effect at small concentrations.

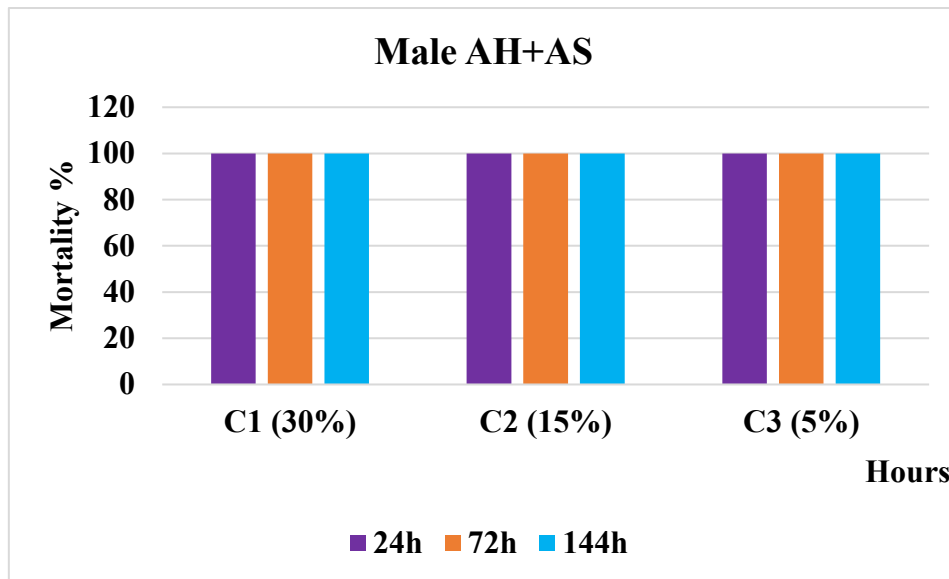


Figure 8. Mortality rate of adult male German cockroaches exposed to mixing *artemisia herba -alba* and *Allium sativum* L. essential oils extract

6.6. Synergistic effects of *Artemisia* and *Allium* essential oils on female cockroaches

The finding presented in figure 9 show that female cockroaches exposed to mixture of *Artemisia herba-alba* with *Allium sativum* L. essential oils at three concentrations: C1 (30%), C2 (15%), and C3 (5%), exhibited complete mortality (100%) within the first 24 hours across all treatments. A fast and uniform mortality response was observed, including at the lowest concentration tested (Fig 8).

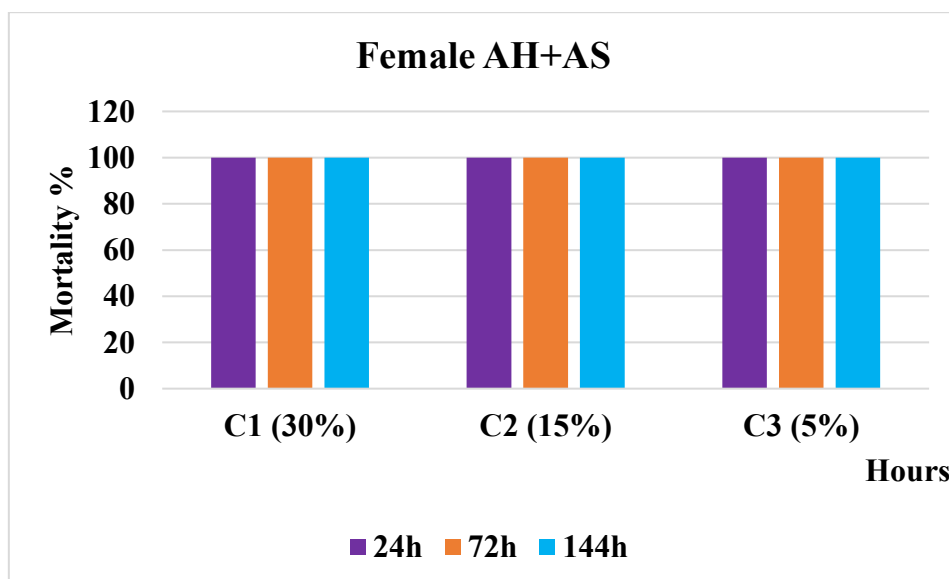


Figure 9. Mortality rate of adult female German cockroaches exposed to mixing *Artemisia herba- alba* and *Allium sativum* L. essential oil extract.

Discussion

7. Discussion

Cockroaches are among the most resilient and globally distributed insects (Dingha *et al.*, 2013). Their presence in homes, restaurants, and warehouses is not only unsettling but also poses significant health and hygiene risks (Ifeanyi and Olawumi, 2015). The German cockroach, in particular, is a known vector of disease and allergens, and contributes to economic loss, aesthetic degradation, and psychological stress (Robinson, 2005). This study aims to evaluate the toxic and insecticidal effects of *Artemisia herba-alba* and *Allium sativum* L. essential oils against adult *Blattella germanica* L.

Our results show a strong response to *Artemisia herba-alba* essential oil in adult male *Blattella germanica* L. The highest concentration (C1) resulted in 96% mortality by the end of the treatment, while C2 and C3 produced 86% and 76% mortality, respectively, over six days. This confirms the strong insecticidal potential of *A. herba-alba*. On the other hand, the mortality of female *Blattella germanica* L. exposed to *Artemisia herba-alba* essential oil showed an unexpected pattern. The highest concentration (C1) caused a moderate mortality rate of 53% after six days, while the lowest concentration (C3) caused no mortality. The intermediate concentration (C2) resulted in 23% mortality. This irregular concentration response suggests a potential tolerance or resistance mechanism in females at lower concentrations or possible behavioral avoidance reducing exposure at C3.

The data are consistent with previous study attributing the oil's toxicity against two major pests of stored products: *Tribolium castaneum* and *Sitophilus zeamais*. (coleoptera) The study employed contact and fumigant bioassays to assess toxicity. The results indicated significant mortality rates in both insect species, suggesting that *Artemisia herba-alba* essential oil could serve as an effective natural alternative to chemical insecticides for preserving stored products (Amara *et al.*, 2024). In a study conducted by Ouguirti *et al.* (2021), fifty-four compounds were identified, accounting for 94.1% of the total essential oil extracted from *Artemisia herba-alba* leaves. The primary constituents were alpha-thujone (48.0%), beta-thujone (13.4%), and camphor (13.1%). Bouaziz *et al.* (2025) found that the essential oil of *Artemisia herba-alba* has a strong and effective impact against the *Culex pipiens* L. mosquito. northern house mosquito significantly reducing reproductive capacity, fertility, and larval egg hatching. The resulting nerve poisoning can lead to either immediate death or prolonged paralysis before fatality (Kaoutar Abdelali *et al.*, 2023). Similarly, a study by Bouzeraa *et al.* (2018) demonstrated the potent insecticidal activity of *Artemisia herba-alba* essential oil against two insect species, *Plodia interpunctella* and *Ephestia kuehniella*. (Lepidoptera) The oil showed a stronger toxic effect on the larvae of *P. interpunctella*, causing significant toxicity to both

species. Another study was conducted to evaluate the efficacy of *Artemisia herba-alba* essential oil against third-instar larvae and adults of the khapra beetle *Trogoderma granarium*. (Coleoptera) The oil induced a high, nearly complete mortality rate in both developmental stages (Al-Ghadban, 2019).

Additionally, the exposure of both male and female *Blattella germanica* L. to *Allium sativum* L. essential oil resulted in complete mortality (100%) at all tested concentrations (C1, C2, and C3) within 24 hours. This rapid lethality across sexes and concentration highlights the exceptional potency of *A. sativum* L. as an insecticidal agent. These results suggest that even at the lowest concentration (5%), the bioactive compounds in garlic essential oil probably are highly effective in disrupting vital physiological systems in *B. germanica* L. through neurotoxic or metabolic interference. The insecticidal action of essential oils primarily stems from their neurotoxic effects, which involve multiple mechanisms. These include acetylcholine esterase (AChE) inhibition (Yeom *et al.*, 2012). Furthermore, according to Zhao *et al.* (2013), the key neurotoxic effects include hyperactivity followed by hyperarousal, leading to rapid immobilization. Furthermore, Rattan (2010) highlights that essential oils and their constituents interfere with biochemical processes, particularly disrupting the insect endocrine system. These compounds may act as neurotoxins or insect growth regulators, affecting normal morphogenesis. Giuliano *et al.* (2024) developed a 15% garlic essential oil nanoemulsion that showed effective larvicidal and antifeedant activity against *Spodoptera littoralis* larvae Lepidoptera, supporting the use of plant-based pesticides as sustainable alternatives to synthetic chemicals.

In the present study, the combination of *Artemisia herba-alba* and *Allium sativum* L. essential oils produced complete mortality (100%) in both male and female *Blattella germanica* L. within 24 hours across all tested concentrations (C1, C2, and C3). This outcome demonstrates a strong synergistic or additive effect between the two oils, resulting in rapid and total lethality even at the lowest concentration (5%). The increased effectiveness is likely due to the combined action of bioactive compounds in both oils, especially garlic oil, which alone caused complete mortality in male and female *Blattella germanica* L. within 24 hours. *A. sativum* L. is rich in organosulfur compounds like allicin, while *A. herba-alba* contains monoterpenes such as cineole and camphor (El-Saber Batiha *et al.*, 2020; Mohsen and Ali, 2009). Together, these constituents may target multiple physiological pathways in the insect, overwhelming its detoxification and defense systems. Additionally, the essential oil of *Artemisia herba -alba* demonstrated strong insecticidal activity against *Ephestia kuehniella*, leading to a significant reduction in both egg laying and hatch rate (Amel *et al.*, 2017). Another study on the larvae and

adults of *Tribolium confusum* coleoptera. revealed that the essential oil of *Artemisia herba-alba* exhibited moderate toxicity against both stages after 24 hours (Hafsia *et al.*, 2023). In further research, Modaferi *et al.* (2025) the nano-formulations of *A. sativum* L. essential oil displayed varying effectiveness against the immature stages of *Planococcus citri*. Hemiptera. In a preliminary trial with a high active ingredient concentration (2.5%), nano- emulsions produced through high-energy methods demonstrated complete efficacy, achieving 100% mortality. Moreover, Chaubey (2016) reported that *A. sativum* L. oil exhibited strong feeding deterrent activity against *Sitophilus oryzae* L. adults. Coleoptera. Exposure to sublethal concentrations of *A. sativum* L. oil significantly suppressed oviposition and inhibited acetylcholinesterase activity in a concentration-dependent manner. In a study conducted by (Plata-Rueda *et al.*, 2017), the LC50 and LC90 values of garlic essential oil, along with its active compounds diallyl disulfide and diallyl trisulfide, were evaluated for their toxic effects on *Tenebrio molitor* L. (coleoptera)larvae and adults. The treatment induced several toxicity symptoms, including gradual paralysis, reduced feeding activity, and regurgitation. Additionally, necrotic damage was observed in larvae, pupae, and adults within the treated areas, particularly affecting the mouthparts, thorax, legs, and abdomen.

*Conclusion
and
Perspectives*

Conclusion

The results of this study clearly indicate that the research objectives were successfully achieved. The findings demonstrate the insecticidal efficacy of essential oils extracted from *Artemisia herba-alba* (white wormwood) and *Allium sativum* L. (garlic), particularly in their ability to control adult *Blattella germanica* L. (German cockroaches). This toxicity was systematically evaluated in both male and female cockroaches.

Our results emphasize the importance of exploring and developing new formulations of essential oils derived from plants such as wormwood and garlic, given their proven efficacy in pest control, in addition to being environmentally friendly and safe for public health. Therefore, we hope that this study will serve as a foundation for promoting the adoption of biological and natural solutions in pest management, especially in residential and agricultural settings, due to their sustainable and long-term safety benefits compared to harmful chemical alternatives.

Perspectives

To broaden the scope of this research and enhance its findings, it is recommended that future studies delve deeper into various aspects of the insect's behavior and its response to essential oils. Key research directions include Investigating the effects of essential oils on different life stages of *Blattella germanica* L. such as eggs and nymphs, to determine their efficacy throughout the insect's developmental cycle.

- Exploring the potential development of resistance by exposing multiple successive generations of the insect to essential oil formulations, thereby providing a clearer understanding of the long-term effectiveness of natural biopesticides under repeated exposure.
- Evaluating the performance of essential oils under varying environmental conditions, including different temperatures, humidity levels, and surface types, in order to assess their efficacy in more realistic settings.
- Conducting field or semi-field experiments to validate the practical applicability of laboratory findings in natural environments, which would enhance the reliability of real-world recommendations.
- Analyzing the chemical composition of essential oils to identify the active compounds responsible for the observed insecticidal effects, thus paving the way for the development of more targeted and efficient formulations.

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