OPEN ACCESS Plant Protection, 09 (04) 2025. 777-786 DOI:10.33804/pp.009.04.5887

Check for updates

Available Online at EScience Press

Plant Protection

ISSN: 2617-1287 (Online), 2617-1279 (Print)

http://esciencepress.net/journals/PP

Research Article

Toxicity and Repellent Effects of Acetonic Plant Extracts against the Lesser Grain Borer, *Rhyzopertha dominica*

Shatha I. Alqurashi

Department of Biological Science, College of Science, University of Jeddah, Jeddah, Saudi Arabia.

ARTICLE INFO

Article history

Received: 24th July, 2025

Revised: 8th October, 2025

Accepted: 10th October, 2025

Keywords

Acetonic plant extracts

Rhyzopertha dominica

Repellent test

Toxicity effects

Mortality rates

ABSTRACT

Stored grain pests cause considerable damage by feeding on stored commodities, resulting in significant qualitative and quantitative losses. Although chemical pesticides are widely used for protection, their effectiveness has been compromised by toxic residues in food, a limited range of approved compounds, and the development of resistant pest populations. Therefore, there is an urgent need for safer and more sustainable alternatives. The present study, therefore, evaluated the insecticidal and repellent efficacy of five acetonic plant extracts viz., *Ruta chalepensis*, *Artemisia judaica*, *Heliotropium bacciferum*, *Salvadora persica*, and *Moringa oleifera* against the lesser grain borer, *Rhyzopertha dominica* F. (Coleoptera: Bostrichidae). Dose-response bioassays were conducted to determine adult mortality, LC_{50} values, and repellence at various concentrations and exposure durations. An increase in extract concentration led to higher mortality and toxicity, showing clear dose- and time-dependent effects. Among the tested plants, *A. judaica* and *R. chalepensis* were the most effective, exhibiting the lowest LC_{50} values and strongest repellence. Acetonic extracts of *A. judaica*, *R. chalepensis*, and *S. persica* demonstrated particularly significant insecticidal and repellent activity against *R. dominica* adults. These findings highlight the potential of plant-derived extracts as eco-friendly alternatives to conventional synthetic pesticides. Their biodegradability, low residue levels, and reduced ecological risks make them promising candidates for incorporation into integrated pest management strategies, particularly in the context of rising insecticide resistance and growing environmental and health concerns associated with chemical control.

Corresponding Author: Shatha I Alqurashi

Email: saaqurshi@uj.edu.sa

© 2025 EScience Press. All rights reserved.

Introduction

Stored grains are highly susceptible to insect infestation during handling, storage, and transportation. Storage facilities often provide favorable environmental conditions, such as optimal temperature, humidity, and readily available food sources, for the proliferation of beetle pests (Mantzoukas et al., 2023). Since the 1960s, considerable efforts have been devoted to protecting stored grains from insect infestation (Arthur, 1996). Both larval and adult stages contribute to damage through feeding (Daglish et al., 2024), leading to significant economic losses by reducing both the quality and quantity of grains (Rajendran and Sriranjini, 2008), and thereby diminishing their commercial value (Mantzoukas et al., 2023).

Stored grains represent one of the most essential

agricultural commodities, serving as staple food sources for humans and feed for livestock (Sarwar, 2013). Consequently, the management of insect infestations remains a major concern for the food processing industry, particularly in industrialized nations that enforce strict regulations on insect contamination in food products (Guru et al., 2022).

Among the major insect pests associated with stored grains, *Rhyzopertha dominica* (Fabricius) (Coleoptera: Bostrichidae), commonly known as the lesser grain borer, is recognized as one of the most destructive species, especially in tropical and temperate regions (Edde, 2012). Although wheat is its primary host, it can also infest other cereals and pulses, including maize, rice, oats, and beans (Kavallieratos et al., 2012). Other significant beetle pests include the rice weevil *Sitophilus oryzae* (Coleoptera: Curculionidae), the saw-toothed grain beetle *Oryzaephilus surinamensis*, and the red flour beetle *Tribolium castaneum* (Coleoptera: Tenebrionidae). Infestations by these pests often spread vertically through the grain mass, from the top to the bottom or vice versa, a process termed "vertical infestation" (Martins et al., 2012; Asiry et al., 2022). Such infestation dynamics highlight the urgent need for effective and sustainable grain protection strategies. Increasing attention is now being directed toward biological control approaches, which can minimize dependence on chemical insecticides.

The reproductive capacity and feeding behavior of *R. dominica* significantly contribute to its pest status. A single female can oviposit between 200 and 500 eggs on grain surfaces, either singly or in clusters (Deshwal et al., 2018). Upon hatching, the larvae bore into the kernels and feed on vital components such as the germ and endosperm, resulting in substantial weight loss and quality deterioration (Arthur et al., 2012). Due to its concealed endophytic feeding habit, the larval stage is largely inaccessible to direct control, making adults the primary target for intervention.

Management efforts have included physical control methods such as exposure to high or low temperatures; however, these techniques are often labor-intensive, costly, and not completely effective (Fields and White, 2002). Chemical insecticides remain the predominant means of control (Hamel et al., 2020), but their use raises several concerns, including toxic residues in food, a limited range of approved active ingredients (mainly pyrethroids and phosphine), and the development of resistant pest populations (Leskovac and Petrović, 2023). Synthetic insecticides, including pyrethroids, carbamates, organophosphates, and organochlorines, are commonly used in stored-grain pest management. Nevertheless, these chemicals can adversely affect grain quality, cause unpleasant odours, pose risks to human health, and contribute to environmental pollution. Many of these compounds have been banned or placed under strict regulation in several countries because of their potential ecological and toxicological impacts (Tapondjou et al., 2002).

These limitations have intensified interest in developing alternative strategies, particularly those based on plant-derived bioactive compounds. Botanical insecticides are considered safer and more environmentally sustainable, as they often exhibit species-specific selectivity, biodegrade into non-toxic residues, and are compatible with Integrated Pest Management (IPM) programs (Sutherland et al., 2002; Akinkurolere et al., 2006; Zibaee and Stoytcheva, 2011).

Following this approach, numerous studies have demonstrated the insecticidal efficacy of plant-derived extracts against both field and stored-product pests (Alvi et al., 2018; Asiry et al., 2022; Ahmady et al., 2024). For instance, extracts of *Azadirachta indica* L. (neem) (Sapindales: Meliaceae) exhibit significant toxicity against the khapra beetle *Trogoderma granarium* Everts (Coleoptera: Bostrichidae) (Mahmoud et al., 2015). Similarly, *Calotropis procera* Aiton (Apocynaceae), *Solenostemma argel* Hayne (Asclepiadaceae), and *Datura stramonium* L. (Solanaceae) have shown strong insecticidal activity against adult saw-toothed grain beetles (Yousif and Taha, 2016). *Ruta chalepensis* essential oil has also been reported to exhibit toxic and repellent effects against *Tribolium confusum* Duval (Coleoptera: Tenebrionidae), with repellence increasing with exposure duration (Abdellaoui et al., 2018). In addition, both leaf and seed extracts of *R. chalepensis* have been found to be toxic and repellent to *T. granarium* and *R. dominica* under laboratory conditions (Alvi et al., 2018). Beyond stored-product insects, *M. oleifera* L. seed and root extracts have been reported to significantly reduce field pests such as *Megalurothrips sjostedti*, *Aphis craccivora*, and *Maruca vitrata*, while also decreasing postharvest infestations of *Callosobruchus maculatus* (Frank et al., 2013). Moreover, *Heliotropium curassavicum* extracts have demonstrated rodenticidal properties, highlighting their broader applicability within IPM frameworks (Eldidamony et al., 2020).

The Area Preference Method (APM) is a well-established bioassay for assessing insect behavioral responses under controlled laboratory conditions (Bougherra et al., 2015; Nazurah et al., 2022). It is widely used to evaluate the repellence or attraction of insects to chemical or botanical compounds. However, limited studies have examined the behavioral responses of specific pests such as *R. dominica* to plant extracts using APM. In this study, APM was employed to assess the behavioral responses of *R. dominica* adults to various plant extracts, thereby confirming their bioactivity and potential utility in stored-grain pest management.

Although several studies have investigated the insecticidal properties of medicinal plants, few have comparatively evaluated the acetonic extracts of multiple botanicals against *R. dominica* under laboratory conditions. The inclusion of *H. bacciferum* and *S. persica* in the current study provides novel evidence of their bioactivity, while the comparative evaluation of five plant species offers valuable understandings for IPM development.

To address this knowledge gap, the present study investigated alternative, effective, and environmentally safe botanical insecticides against the adult stage of *R. dominica*. The toxicity and repellence of five medicinal plant extracts viz., *R. chalepensis* L. (Rutaceae: Sapindales), *A. judaica* L. (Asteraceae: Asterales), *H. bacciferum* F. (Boraginaceae: Boraginales), *S. persica* L. (Salvadoraceae: Brassicales), and *M. oleifera* L. (Moringaceae: Brassicales) were evaluated using the APM method under laboratory conditions. These plant species were selected based on previous evidence of their insecticidal or repellent activity and their potential applicability in stored-product protection. By incorporating both well-studied and less-explored botanicals, this research contributes to a more comprehensive understanding of their behavioral effects on *R. dominica* and advances sustainable pest management strategies.

Materials and Methods

Rearing of *R. dominica*

The lesser grain borer was obtained from an established laboratory culture maintained in the Laboratory of Plant Protection, Department of Arid Land Agriculture, King Abdulaziz University. The culture was maintained on fresh wheat grains under controlled environmental conditions of 28 ± 2°C and 75 ± 5% relative humidity. The insects were reared in glass jars (21.5 × 11 cm; 1.5 L capacity) containing fresh wheat grains. The openings of the jars were covered with muslin cloth to allow ventilation while preventing insect escape. Since the toxicity bioassays were conducted on adult beetles, the cultures were maintained until a sufficient number of adults were available for testing.

Preparation and plant extraction

Fresh aerial parts of *A. judaica*, *R. chalepensis*, *H. bacciferum*, *S. persica*, and *M. oleifera* were collected from various locations within the central region of Saudi Arabia. These plants were naturally grown and had not been treated with pesticides. The identification of plant species was confirmed by taxonomists from the Department of Arid Land Agriculture, Faculty of Meteorology, Environment, and Arid Land Agriculture, King Abdulaziz University.

The collected plant materials were air-dried under dark conditions for three weeks, then ground separately into fine powders, sieved through a 1 mm mesh, and stored in airtight plastic containers at 4°C until use. Acetone extracts of each species were prepared using a cold extraction method. For each plant species, 100 g of powdered material was soaked in 500 ml of acetone in a sealed extraction bottle. The mixture was intermittently stirred with a glass rod and left to stand for 72 h. The resulting mixture was filtered through a double layer of Whatman No. 1 filter paper, and the solvent was evaporated using a rotary evaporator at 30-40°C at a rotation speed of 3-6 rpm for 8 h. The concentrated extracts were further air-dried to remove any residual solvent. From each stock extract, test solutions of 200, 300, 400, and 500 ppm concentrations were prepared for subsequent bioassays.

Plants extract treatments and adult mortality of *R. dominica*

Fifty grams of wheat grains were weighed and placed into 250 ml plastic containers. Subsequently, 1 ml of each plant extract at concentrations of 200, 300, 400, and 500 ppm was added to separate containers. The grains were thoroughly mixed and left for 1 h to allow complete evaporation of the volatile solvent. The control treatment consisted of 1 ml of distilled water only.

Forty adults of *R. dominica* were introduced into each container. Four replicates were prepared for each concentration, including the untreated control. The experiment was arranged in a Randomized Complete Block Design (RCBD). Adult mortality was observed and recorded at 2, 4, and 6 days after treatment.

In preliminary trials, acetone-treated grains (without plant extract) were compared with distilled-water-treated and untreated grains, and no mortality or behavioral changes were observed in *R. dominica* adults. Therefore, distilled water was used as the control in all subsequent experiments.

Repellence test using the APM

The repellence assay was conducted using the APM as described by Talukder and Howse (1994) and Kundu et al. (2007). Petri dishes (90 mm in diameter) were divided into two equal sections: one treated and one untreated. Filter paper discs (Whatman No. 40) were cut into two equal halves. Approximately 1 ml of the test solution at each plant extract concentration was applied to one half using a micropipette. The treated halves were air-dried and then joined to the untreated halves with cellophane tape along the midline to allow free insect movement between the two sections (Figure 1).

Each assembled filter paper was placed inside a Petri dish, and twenty newly emerged adults of *R. dominica* were released at the center. The dishes were covered to prevent insect escape. Each concentration of every plant extract was tested in triplicate. The number of insects present on each half of the filter paper was recorded at two-hour intervals. The percentage repellence (PR) was calculated according to the method described by Jilani et al. (1988).

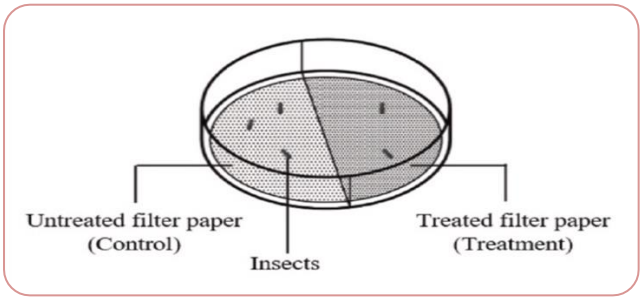


Figure 1. Schematic representation of the APM adapted from Parichanon et al. (2025).

Data analyses

Adult mortality percentages for *R. dominica* were calculated using the following formula:

$$\text{Mortality Percentage} = \frac{\text{Number of dead adults}}{\text{Total number of adults}} \times 100$$

Observed mortality data were corrected for control mortality using Abbott's formula (Abbott, 1925). Data normality was assessed using the Shapiro-Wilk test. A *p*-value < 0.05 was considered statistically significant. Subsequently, the data were analyzed using a one-way repeated measures ANOVA to evaluate the effects of time (2, 4, and 6 days), concentrations of the five plant extracts, and their interactions. Interaction effects between time and treatment were examined, and post hoc comparisons were performed using Duncan's Multiple Range Test (DMRT).

The LC_{50} and LC_{90} values (the lethal concentrations required to cause 50% and 90% mortality, respectively) were estimated as described by Finney (1971). All statistical analyses were performed using IBM SPSS Statistics version 22.0 (Armonk, NY, USA). Data were presented as mean ± standard deviation (SD).

Repellency percentages obtained from the APM were calculated as follows:

$$\text{Repellency Percentage} = \frac{\text{Number of repelled adults}}{\text{Total number of adults observed}} \times 100$$

Repellency data were analyzed using one-way ANOVA, with plant extract type (five species) and tested concentration (20 experimental units) as fixed factors, to determine the most effective treatment for repelling newly emerged adults of *R. dominica*. A *p*-value < 0.05 was considered statistically significant.

Results

Effects of plant extract treatments on adult *R. dominica*

The mean mortality rates of adult *R. dominica* increased progressively across the three exposure periods (days 2, 4, and 6) for all four concentrations of the five tested plant extracts (P < 0.0001; Table 1). Toxicity increased with exposure duration, indicating enhanced potency over time (Table 2).

Among the tested extracts, *A. judaica* consistently caused the highest mortality at all concentrations and exposure periods, reaching a peak of 96.88 ± 3.15% mortality on day 6 at 500 ppm. This was followed by *R. chalepensis*, which caused 86.25 ± 2.50% mortality on the same day and at the same concentration, with significant differences observed between the two species (F = 63.9; P < 0.0001; Table 1).

A. judaica exhibited the greatest toxicity, with LC_{50} values decreasing from 157.12 ppm on day 2 to 70.53 ppm on day 6 (Table 2). In contrast, *H. bacciferum* showed the lowest mortality across all concentrations and exposure periods, with LC_{50} values consistently above 297 ppm and LC_{90} values exceeding 1999 ppm (Table 2). *S. persica* and *M. oleifera* demonstrated moderate toxicity, with *S. persica* being slightly more effective than *M. oleifera* (Table 1).

Table 1. Mean mortality (%) of the five tested groups at four concentrations over four exposure periods.

Groups	Concentrations (ppm)				Average
	200	300	400	500	mortality %
			2nd day		
A. judaica	59.38 ± 1.25[a]	65.63 ± 1.25[a]	75.00 ± 2.04[a]	83.13 ± 3.15[a]	70.78 ± 9.52[a]
R. chalepensis	53.13 ± 2.39[b]	62.50 ± 2.89[b]	73.75 ± 1.44[a]	80.00 ± 4.56[a]	67.34 ± 11.01[a]
S. persica	50.63 ± 1.25[b]	55.00 ± 2.04[c]	63.13 ± 2.39[b]	70.00 ± 2.04[b]	59.69 ± 7.90[b]
M. oleifera	47.50 ± 2.04[c]	53.13 ± 2.39[c]	58.75 ± 1.44 [c]	66.25 ± 1.44[b]	56.41 ± 7.36[b]
H. bacciferum	35.63 ± 2.39[d]	40.63 ± 1.25[d]	51.25 ± 1.44[d]	58.13 ± 2.39[c]	46.41 ± 9.26[c]
F	82.167	88.646	125.806	48.713	17.765
Significance	0.0001	0.0001	0.0001	0.0001	0.0001
			4th day		
A. judaica	68.75 ± 4.33[a]	72.50 ± 2.04[a]	81.88 ± 2.39[a]	88.13 ± 3.15[a]	77.81 ± 8.36[a]
R. chalepensis	59.38 ± 3.15[b]	66.25 ± 3.23[b]	77.50 ± 3.54[b]	83.75 ± 3.23[b]	71.72 ± 10.24[a]
S. persica	55.00 ± 2.04[c]	58.13 ± 2.39[c]	67.50 ± 2.04[c]	76.88 ± 2.39[c]	64.38 ± 9.06[b]
M. oleifera	50.00 ± 2.04[d]	58.13 ± 1.25[c]	61.88 ± 1.25[d]	70.63 ± 1.25[d]	60.16 ± 7.77[b]
H. bacciferum	38.13 ± 1.25[e]	44.38 ± 3.75[d]	54.38 ± 3.15[e]	61.25 ± 4.33[e]	49.53 ± 9.67[c]
F	66.831	62.109	74.469	48.994	22.990
Significance	0.0001	0.0001	0.0001	0.0001	0.0001
			6th day		
A. judaica	82.50 ± 2.04[a]	85.63 ± 2.39[a]	90.63 ± 1.25[a]	96.88 ± 3.15[a]	88.91 ± 5.98[a]
R. chalepensis	69.38 ± 1.25[b]	74.38 ± 3.15[b]	81.88 ± 3.15[b]	86.25 ± 2.50[b]	77.97 ± 7.14[b]
S. persica	61.25 ± 3.23[c]	63.75 ± 3.23[c]	76.25 ± 3.23[c]	81.88 ± 3.15[c]	70.78 ± 9.30[c]
M. oleifera	55.00 ± 1.00[d]	60.63 ± 1.25[c]	66.88 ± 2.39[d]	76.88 ± 3.15[d]	64.84 ± 8.63[d]
H. bacciferum	41.25 ± 2.50[e]	47.50 ± 2.04[d]	56.88 ± 2.39[e]	65.63 ± 2.39[e]	52.81 ± 9.78[e]
F	179.706	130.746	102.938	63.900	42.959
Significance	0.0001	0.0001	0.0001	0.0001	0.0001

Values are expressed as means ± standard deviation (SD). Differences among groups were analysed using one-way ANOVA followed by Duncan's Multiple Range Test (DMRT). Different letters indicate statistically significant differences ($P < 0.05$), while identical letters denote no significant difference.

Area preference bioassay

The mean repellence percentage of adult *R. dominica* increased with the rising concentrations of all tested extracts, indicating a clear dose-dependent response. Among the extracts, *A. judaica* exhibited the highest repellence, while *H. bacciferum* showed the lowest (Table 3). At 200 and 400 ppm, *A. judaica*, *R. chalepensis*, and *S. persica* demonstrated significantly higher repellence than *M. oleifera* and *H. bacciferum*, although no significant differences were observed among the three most effective extracts.

At 300 ppm, *A. judaica* exhibited the highest repellence, surpassing all other extracts. *S. persica* showed intermediate activity, which was statistically comparable to neither *A. judaica* nor *R. chalepensis*, but was significantly greater than that of *M. oleifera* and *H. bacciferum*. At 500 ppm, *A. judaica* and *R. chalepensis* achieved the highest repellence values (90.00 ± 5.00% and 85.00 ± 5.00%, respectively; Table 3). *S. persica* was less effective than these two extracts but significantly more effective than *M. oleifera* and *H. bacciferum*. Overall, *H. bacciferum* consistently exhibited the lowest repellence across all concentrations, significantly lower than that of all other extracts.

Discussion

The present study clearly demonstrated that the tested plant extracts exhibited significant toxicity and repellent activity against adult *R. dominica*. The mortality of *R. dominica* adults increased markedly with higher extract concentrations and longer exposure durations, indicating a strong dose- and time-dependent effect. Among all evaluated species, *A. judaica* and *R. chalepensis* were the most effective, producing the highest mortality rates and lowest LC_{50} values. In addition to their toxic effects, *A. judaica*, followed by *R. chalepensis* and *S. persica*, displayed strong repellent properties against *R. dominica* adults. Therefore, medicinal plant extracts represent promising alternatives to synthetic insecticides for the management of stored-grain infestations, as they are readily available, environmentally safe, and require minimal formulation for direct application.

Table 2. Lethal concentrations (LC_{50} and LC_{90}) of five plant extracts against adult *R. dominica* after 2, 4, and 6 days of exposure.

Plant extracts	Assay times (days)	Slope	LC50 (Fiducial limits)	LC90 (Fiducial limits)	χ^2	P
A. judaica	2	1.75	157.12 (94.93-198.59)	850.72 (628.27-1671.52)	2.831	0.999
	4	1.677	111.94 (48.67-157.26)	650.09 (503.72-1184.86)	4.997	0.986
	6	1.892	70.53 (13.10-114.31)	335.47 (285.27-419.30)	7.356	0.920
R. chalepensis	2	1.931	189.57 (136.59-225.79)	873.94 (658.16-1552.74)	2.979	0.999
	4	1.872	158.93 (101.57-197.99)	768.83 (589.52-1339.35)	4.160	0.994
	6	1.461	95.40 (27.88-145.97)	718.99 (528.16-1694.07)	2.837	0.999
S. persica	2	1.265	210.17 (120.80-260.82)	2166.75 (1111.97-17833.16)	1.739	1.000
	4	1.470	183.30 (107.93-229.32)	1364.50 (852.11-4714.51)	3.709	0.997
	6	1.596	147.03 (77.96-192.28)	934.26 (659.22-2190.28)	5.382	0.980
M. oleifera	2	1.166	239.64 (144.99-293.85)	3008.93 (1331.82-54828.74)	1.260	1.000
	4	1.271	206.02 (116.70-256.64)	2098.22 (1090.36-16374.64)	1.136	1.000
	6	1.426	176.45 (97.61-224.10)	1397.43 (857.47-5307.73)	2.943	0.999
H. bacciferum	2	1.473	382.58 (328.15-478.78)	2835.46 (1439.64-16674.03)	1.752	1.000
	4	1.497	337.37 (286.28-400.90)	2423.09 (1922.39-11919.28)	2.834	0.999
	6	1.548	297.33 (244.92-344.45)	1999.93 (1149.46-7812.24)	2.117	1.000

Lethal concentrations (LC_{50}: concentration required to kill 50% of the population; LC_{90}: concentration required to kill 90% of the population) of five medicinal plant extracts were determined against adult *R. dominica* after 2, 4, and 6 days of exposure. Lower LC values indicate higher toxicity (greater potency) of the extract. The slope represents the rate at which mortality increases with concentration. Chi-square (χ^2) and P-values indicate the goodness of fit of the probit model, with $P > 0.05$ signifying a good fit (i.e., no significant difference between observed and expected values).

Table 3. Percentage repellence of different extracts against adult *R. dominica* at various concentrations.

Groups	Concentrations				Repellence test average %
	200	300	400	500	
A. judaica	71.67 ± 2.89^{a}	76.67 ± 2.89 ^{a}	80.00 ± 5.00 ^{a}	90.00 ± 5.00 ^{a}	79.58 ± 7.82^{a}
R. chalepensis	65.00 ± 5.00 ^{a}	66.67 ± 2.89^{b}	73.33 ± 5.77 ^{a}	85.00 ± 5.00 ^{a}	72.50 ± 9.17^{b}
S. persica	65.00 ± 5.00 ^{a}	71.67 ± 2.89 ^{a,b}	73.33 ± 2.89 ^{a}	75.00 ± 0.00^{b}	71.25 ± 4.83^{b}
M. oleifera	50.00 ± 5.00^{b}	55.00 ± 5.00^{c}	60.00 ± 5.00^{b}	65.00 ± 0.00^{c}	57.50 ± 6.91^{c}
H. bacciferum	38.33 ± 7.64^{c}	46.67 ± 2.89^{d}	51.67 ± 2.89^{c}	56.67 ± 2.89^{d}	48.33 ± 8.07^{d}
F	19.471	38.929	19.917	48.786	34.033
Significance	0.0001	0.0001	0.0001	0.0001	0.0001

Values are expressed as mean ± standard deviation (SD). Comparisons among groups were performed using one-way ANOVA followed by Duncan's Multiple Range Test (DMRT). Different letters indicate statistically significant differences at $P < 0.05$, while the same letters denote no significant difference.

Although chemical insecticides and fumigants remain the most widely used methods for managing stored-grain insects, their long-term effectiveness has been severely constrained by the development of resistance in target populations (Zettler and Cuperus, 1990; Collins et al., 2002; Lorini et al., 2007). Consequently, biological control agents such as entomopathogenic fungi (EPF) have gained attention, with species like *Beauveria bassiana* and *Metarhizium anisopliae* demonstrating promising pathogenicity against major beetle pests under laboratory conditions (Mantzoukas et al., 2023). However, their performance in actual storage environments is often limited by factors such as low humidity, temperature fluctuations, and poor persistence on grain surfaces, leading to inconsistent field efficacy and relatively slow insecticidal action (Meikle et al., 2001; Stathers et al., 2002).

In contrast, plant-derived extracts are a more immediate and practical alternative. The botanicals *A. judaica*, *R. chalepensis*, *S. persica*, *M. oleifera*, and *H. bacciferum* have shown strong toxic and repellent activities against *R. dominica* and other storage beetles, even at low concentrations. Moreover, these extracts are widely available, biodegradable, and

environmentally benign, making them more practical and sustainable than EPF for incorporation into eco-friendly pest management strategies.

Acetonic extracts from diverse plant species show a clear dose-response relationship against *R. dominica* (Abubakar et al., 2021), with increasing extract concentrations resulting in higher mortality and enhanced toxicity indices. Similarly, studies on *T. confusum* larvae revealed that medicinal plant extracts significantly inhibited larval growth, highlighting their efficacy as potential biocontrol agents (Ahmady et al., 2024). These findings confirm that plant-derived insecticides exert strong insecticidal effects that substantially reduce insect survival. Their activity is likely due to bioactive phytochemicals that interfere with key physiological and metabolic processes in insects.

The pronounced toxicity of *A. judaica* and *R. chalepensis* may be attributed to their high content of alkaloids, glycosides, volatile oils, and terpenoids, compounds known to disrupt normal metabolic and physiological functions (Ali et al., 2000; Onyilagha et al., 2004; Marwat et al., 2012; Albeshri et al., 2021). These results are consistent with earlier reports indicating that alkaloids, terpenes, and flavonoids in botanical extracts adversely affect the growth, feeding, and survival of grain-infesting beetles (Jbilou et al., 2006). The strong toxic effects observed in this study further support the potential of these medicinal plants as effective botanical protectants against *R. dominica* adults when applied at suitable concentrations.

The present findings corroborate previous studies by providing comparative laboratory evidence on five plant extracts, confirming that *A. judaica* and *R. chalepensis* are among the most potent candidates. These results form the foundation for future semi-field and storage-scale experiments to validate their practical efficacy under real storage conditions.

In the current study, crude acetonic extracts were used to evaluate the biological activity of different plant species; therefore, the specific bioactive constituents were not identified. The observed variations in toxicity and repellence among the extracts may be attributed to differences in their phytochemical composition. Future research should include chromatographic and spectroscopic analyses (e.g., GC-MS or HPLC) to identify and quantify the active components responsible for these effects, thereby enhancing our understanding of their insecticidal mechanisms.

In addition to toxicity, the plant extracts exhibited strong repellent activity against *R. dominica* adults. Repellence increased significantly with both concentration and exposure duration, with *A. judaica* showing the highest repellent effect, followed by *R. chalepensis* and *S. persica*. This dual action, killing and repelling insects, is particularly valuable, as it reduces infestation pressure by deterring beetles from colonizing grain stores while simultaneously suppressing existing populations.

Additional findings, including high repellence (up to 93.33%), marked biochemical alterations (reductions in glycogen, protein, and nucleic acids), and inhibition of F_1 progeny, indicate that toxicity generally increased with both concentration and exposure time (ranging from 16 h to 21 days) (Upadhyay, 2013). Several studies have emphasized the significance of repellence (Alvi et al., 2018), noting that *Rhazya stricta* and *S. persica* exhibit strong repellent effects against *R. dominica* and *Trogoderma granarium*. Similarly, Asiry et al. (2022) reported potent insecticidal and repellent activities from *R. stricta* extracts, supporting the potential of certain plant species as effective biocontrol agents. Although previous studies differ in plant species, extraction methods, and reporting metrics, their collective evidence supports a consistent dose-dependent increase in toxicity indicators against *R. dominica*.

The combined insecticidal and repellent properties of these medicinal plant extracts support their potential use as eco-friendly alternatives to chemical insecticides. The effectiveness of *A. judaica*, *R. chalepensis*, and *S. persica* against *R. dominica* aligns with findings from related studies on other stored-product pests, where similar species produced high mortality and repellence (Abdel-Sattar et al., 2010). Considering the growing concerns over insecticide resistance and environmental contamination, such botanical extracts may provide sustainable, safe, and effective options for future grain protection strategies. However, further research is needed to evaluate their persistence, residual activity, and large-scale applicability under real storage conditions to ensure their suitability for integration into sustainable Integrated Pest Management (IPM) programs.

Conclusion

This study investigated the potential of natural, locally available medicinal plant extracts as eco-friendly alternatives to synthetic insecticides for the management of stored-grain pests. The results demonstrated that acetonic extracts of *A. judaica*, *R.*

chalepensis, and *S. persica* possessed significant insecticidal and repellent activities against *R. dominica* adults. Mortality increased in a dose- and time-dependent manner, with *A. judaica* and *R. chalepensis* being the most effective, as reflected by their low LC_{50} values and strong repellence. These findings suggest that such botanicals could serve as promising substitutes for synthetic insecticides in stored-grain protection.

Plant extracts are considered eco-friendly because they degrade rapidly in the environment, leave minimal residues, and pose low ecological risk. Their bioactivity is attributed to diverse phytochemicals such as alkaloids, glycosides, terpenoids, and volatile oils, which disrupt the metabolic and physiological functions of insects. Future work should aim to isolate and characterize these active compounds, assess their persistence under storage conditions, and develop optimized formulations for large-scale application.

Authors' Contributions

SIA designed the study, prepared the materials, conducted the experiments, collected and analyzed the data, and wrote the manuscript.

Research Funding

This research did not receive any grant from funding agencies.

Conflict of Interest

The authors declare no conflict of interest.

Sustainable Development Goals Targeted

SDG 2: Zero Hunger
SDG 12: Responsible Consumption and Production
SDG 15: Life on Land

References

Abbott, W.S., 1925. A method of computing the effectiveness of an insecticide. Journal of Economic Entomology 18, 265-267.

Abdellaoui, K., Acheuk, F., Miladi, M., Boughattas, I., Omri, G., 2018. Phytochemistry, biochemical and insecticidal activities of *Ruta chalepensis* essential oils on *Tribolium confusum*. Agriculture and Forestry 64, 31-45.

Abdel-Sattar, E.A., Zaitoun, A.M.A., Farag, M.A., El Gayed, S.H., Harraz, F.M., 2010. Chemical composition, insecticidal and insect repellent activity of *Schinus molle* L. leaf and fruit essential oils against *Trogoderma granarium* and *Tribolium castaneum*. Natural Product Research 24, 226-235.

Abubakar, R., Suleiman, M., Wagini, N.H., 2021. Phytochemical and insecticidal properties of some botanical extracts against the lesser grain borer, *Rhyzopertha dominica* F. (Coleoptera: Bostrichidae). Journal of Entomology and Zoology Studies 9, 1-7.

Ahmady, A., Moahid, A.J., Mukhles, M.R., Andar, F., Ahmadi, A.J., 2024. Efficacy of some plant extracts against stored-product pest red flour beetle, *Tribolium confusum* (Jacquelin Du Val) (Coleoptera: Tenebrionidae) adults. International Journal of Current Science Research and Review 7, 1-8.

Akinkurolere, R.O., Adedire, C.O., Odeyemi, O.O., 2006. Laboratory evaluation of the toxic properties of forest anchomanes, *Anchomanes difformis* against pulse beetle *Callosobruchus maculatus* (Coleoptera: Bruchidae). Insect Science 13, 25-29.

Albeshri, A., Baeshen, N.A., Bouback, T., Aljaddawi, A.A., 2021. A review of *Rhazya stricta* Decne phytochemistry, bioactivities, pharmacological activities, toxicity, and folkloric medicinal uses. Plants 10, 1-25.

Ali, B.H., Al-Qarawi, A.A., Bashir, A.K., Tanira, M.O.M., 2000. Phytochemistry, pharmacology and toxicity of *Rhazya stricta* Decne: A review. Phytotherapy Research 14, 229-234.

Alvi, A.M., Iqbal, N., Bashir, M.A., Rehmani, M.I.A., Ullah, Z., Latif, A., Saeed, Q., 2018. Efficacy of *Rhazya stricta* leaf and seed extracts against *Rhyzopertha dominica* and *Trogoderma granarium*. Kuwait Journal of Science 45, 1-8.

Arthur, F.H., 1996. Grain protectants: Current status and prospects for the future. Journal of Stored Products Research 32, 293-302.

Arthur, F.H., Ondier, G.O., Siebenmorgen, T.J., 2012. Impact of *Rhyzopertha dominica* (F.) on quality parameters of milled rice. Journal of Stored Products Research 48, 137-142.

Asiry, K.A., Almasoudi, N.M., Zaitoun, A.A., 2022. Insecticidal and repellent actions of methanolic extracts from five medicinal plants against the saw-toothed grain beetle *Oryzaephilus surinamensis* (Linn.) (Coleoptera: Silvanidae). Revista de la Sociedad Entomologica Argentina 81, 41-51.

Bougherra, H.H., Bedini, S., Flamini, G., Cosci, F.,

Belhamel, K., Conti, B., 2015. *Pistacia lentiscus* essential oil has repellent effect against three major insect pests of pasta. Industrial Crops and Products 63, 249-255.

Collins, P.J., Daglish, G.J., Bengston, M., Lambkin, T.M., Pavic, H., 2002. Genetics of resistance to phosphine in *Rhyzopertha dominica* (Coleoptera: Bostrichidae). Journal of Economic Entomology 95, 862-869.

Daglish, G.J., Jagadeesan, R., Burrill, P.R., May, P.D., Wade, A.J., Nayak, M.K., 2024. Potential of flavesone as a grain protectant: Long-term efficacy and residues for controlling the lesser grain borer, *Rhyzopertha dominica* (F.), in stored wheat. Journal of Stored Products Research 109, 102467.

Deshwal, R., Gupta, P.K., Vaibhav, V., Kumar, N., Kumar, A., 2018. Biology of lesser grain borer (*Rhyzopertha dominica* Fab.), under different temperature and humidity at laboratory condition. Journal of Entomology and Zoology Studies 6, 364-368.

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

Eldidamony, A.M., Moustafa, G.G., Mead, H.M.I., El-Shafiey, S.N., Abdelhafez, A., 2020. New insight on *Heliotropium curassavicum* L. extracts as a rodenticide. Journal of Environmental Science and Toxicology 14, 1-10.

Fields, P.G., White, N.D.G., 2002. Alternatives to methyl bromide treatments for stored-product and quarantine insects. Annual Review of Entomology 47, 331-359.

Finney, D.J., 1971. Probit analysis, third ed. Cambridge University Press, Cambridge, UK.

Frank, O.O., Agu, C.M., Ahuchaogu, C.E., 2013. Potentiality of *Moringa oleifera* Lam. extracts in the control of some field-store insect pests of cowpea. International Journal of Agricultural Science 4, 3537-3542.

Guru, P.N., Mridula, D., Dukare, A.S., Ghodki, B.M., Paschapur, A.U., Samal, I., Nikhil Raj, M., Padala, V.K., Rajashekhar, M., Subbanna, A.R.N.S., 2022. A comprehensive review on advances in storage pest management: Current scenario and future prospects. Frontiers in Sustainable Food Systems 6, 1-20.

Hamel, D., Rozman, V., Liška, A., 2020. Storage of cereals in warehouses with or without pesticides. Insects 11, 1-16.

Jbilou, R., Ennabili, A., Sayah, F., 2006. Insecticidal activity of four medicinal plant extracts against *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae). African Journal of Biotechnology 5, 936-940.

Jilani, G., Saxena, R.C., Rueda, B.P., 1988. Repellent and growth-inhibiting effects of turmeric oil, sweetflag oil, neem oil, and "Margosan-O" on red flour beetle (Coleoptera: Tenebrionidae). Journal of Economic Entomology 81, 1226-1230.

Kavallieratos, N.G., Athanassiou, C.G., Arthur, F.H., Throne, J.E., 2012. Lesser grain borers, *Rhyzopertha dominica*, select rough rice kernels with cracked hulls for reproduction. Journal of Insect Science 12, 38.

Kundu, B.R., Ara, R., Begum, M.M., Sarker, Z.I., 2007. Effect of Bishkatali, *Polygonum hydropiper* L. plant extracts against the red flour beetle, *Tribolium castaneum* Herbst. University Journal of Zoology, Rajshahi University 26, 93-97.

Leskovac, A., Petrović, S., 2023. Pesticide use and degradation strategies: Food safety, challenges and perspectives. Foods 12, 1-17.

Lorini, I., Collins, P.J., Daglish, G.J., Nayak, M.K., Pavic, H., 2007. Detection and characterisation of strong resistance to phosphine in Brazilian *Rhyzopertha dominica* (F.) (Coleoptera: Bostrychidae). Pest Management Science 63, 358-364.

Mahmoud, A.K., Bedawi, S.M., Satti, A.A., 2015. Efficacy of some botanical extracts in the control of khapra beetle (*Trogoderma granarium*). Journal of Science 5, 213-217.

Mantzoukas, S., Lagogiannis, I., Kitsiou, F., Eliopoulos, P.A., 2023. Entomopathogenic action of wild fungal strains against stored product beetle pests. Insects 14, 1-11.

Martins, C.H.Z., Freir, M.G.M., Parra, J.R.P., Macedo, M.L.R., 2012. Physiological and biochemical effects of an aqueous extract of *Koelreuteria paniculata* (Laxm.) seeds on Anticarsia (Lepidoptera: Noctuidae). Brazilian Journal of Entomology 56, 81-93.

Marwat, S.K., Fazal-ur-Rehman, Usman, K., Shah, S.S., Anwar, N., Ullah, I., 2012. A review of phytochemistry, bioactivities and ethnomedicinal uses of *Rhazya stricta* Decne (Apocynaceae). African Journal of Microbiology Research 6,

1629-1641.

Meikle, W.G., Cherry, A.J., Holst, N., Hounna, B., Markham, R.H., 2001. The effects of an entomopathogenic fungus, *Beauveria bassiana* (Balsamo) Vuillemin (Hyphomycetes), on *Prostephanus truncatus* (Horn) (Col.: Bostrichidae), *Sitophilus zeamais* Motschulsky (Col.: Curculionidae), and grain losses in stored maize in the Benin Republic. Journal of Invertebrate Pathology 77, 198-205.

Nazurah, R.N.F., Noranizan, M.A., Nor-Khaizura, M.A.R., Nur Hanani, Z.A., 2022. The potential of chitosan-based film with curry leaf essential oil as natural insect-repellent food packaging. Food Packaging and Shelf Life 34, 100993.

Onyilagha, J.C., Lazorko, J., Gruber, M.Y., Soroka, J.J., Erlandson, M.A., 2004. Effect of flavonoids on feeding preference and development of the crucifer pest *Mamestra configurata* Walker. Journal of Chemical Ecology 30, 109-124.

Parichanon, P., Ascrizzi, R., Echeverría, M.C., Farina, P., Pieracci, Y., Flamini, G., Semprucci, F., Guidi, L., Grassi, E., Gogou, T.I., Ortega-Andrade, S., Conti, B., 2025. The aromatic plant essential oils and their hormetic effect on *Rhyzopertha dominica* (Coleoptera: Bostrichidae). Crop Protection 194, 107235.

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

Sarwar, H., 2013. The importance of cereals (Poaceae: Gramineae) nutrition in human health: A review. Journal of Cereals and Oilseeds 4, 32-35.

Stathers, T.E., Žďárková, E., Wakefield, M., Lukas, J., Hubert, J., 2002. Entomopathogenic fungi in grain storage - any lessons for Europe from elsewhere? Journal of Stored Products Research 38, 305-313.

Sutherland, J.P., Baharally, V., Permaul, D., 2002. Use of the botanical insecticide, neem to control the small rice stinkbug *Oebalus poecilus* (Dallas, 1851) (Hemiptera: Pentatomidae) in Guyana. Entomotropica 17, 97-101.

Talukder, F.A., Howse, P.E., 1994. Laboratory evaluation of toxic and repellent properties of the pithraj tree, *Aphanamixis polystachya* Wall & Parker, against *Sitophilus oryzae* (L.). International Journal of Pest Management 40, 274-279.

Tapondjou, L.A., Adler, C., Bouda, H., Fontem, D.A., 2002. Efficacy of powder and essential oil from *Chenopodium ambrosioides* leaves as post-harvest grain protectants against six stored-product beetles. Journal of Stored Products Research 38, 395-402.

Upadhyay, R.K., 2013. *Capparis decidua* induced toxicity, biochemical and enzymatic alterations in *Rhyzopertha dominica* (Fabr.) (Coleoptera: Bostrichidae). International Journal of Biological Sciences 5, 1-12.

Yousif, R.E., Taha, A.K., 2016. Evaluation of some plant extracts against adults of the saw-toothed grain beetle, *Oryzaephilus surinamensis* (Linn.) (Coleoptera: Silvanidae). Universal Journal of Agricultural Research 4, 170-174.

Zettler, L.J., Cuperus, G.W., 1990. Pesticide resistance in *Tribolium castaneum* (Coleoptera: Tenebrionidae) and *Rhyzopertha dominica* (Coleoptera: Bostrichidae) in wheat. Journal of Economic Entomology 83, 1677-1681.

Zibaee, A., Stoytcheva, M., 2011. Botanical insecticides and their effects on insect biochemistry and immunity. Pesticides in the Modern World - Pests Control and Pesticides Exposure and Toxicity Assessment 1, 55-68.