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Medicinal plant-based strategies for the management of *Rhyzopertha Dominica*: A review

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Abstract
Rhyzopertha Dominica (Fabricius) (Coleoptera: Bostrichidae), known as the smaller grain borer, is a significantly destructive main pest of stored cereals globally, causing considerable quantitative and qualitative post-harvest losses. Extended dependence on synthetic insecticides and fumigants, especially phosphine, has resulted in extensive resistance, food safety issues relating to residues, environmental pollution, and escalating regulatory constraints. The constraints have heightened interest in plant-based alternatives, particularly medicinal plant extracts, as sustainable solutions for the protection of stored grains. This review critically synthesizes validated and peer-reviewed studies on the effectiveness of medicinal plant extracts against *R. Dominica*, focusing on flora variety, phytochemical components, extraction techniques, and empirically confirmed bioefficacy metrics. Research indicates that extracts and essential oils from medicinal plants, including *Azadirachta indica, Ocimum sanctum, Acorus calamus, Curcuma longa, Eucalyptus globulus*, and *Piper nigrum*, cause substantial adult mortality, repellency, antifeedant effects, growth disruption, and inhibition of progeny emergence. The present review further examines the underlying mechanisms of action, the statistical validation of bioassay results, the economic consequences of infestation, and the constraints that impede widespread adoption. To facilitate standardization, formulation improvements, and the integration of botanical pesticides into integrated pest management programs for stored grain, this analysis identifies critical knowledge gaps and outlines pertinent research objectives. Plant extracts with medicinal properties offer promising, environmentally friendly alternatives for controlling *R. Dominica* infestations. This could help improve sustainability in post-harvest pest management.

Keywords: Botanical insecticides, medicinal plant extracts, stored-grain pests, *Rhyzopertha Dominica*, post-harvest losses, environmentally sustainable pest management

Introduction

Post-harvest losses stemming from insect infestations represent a substantial threat to global food security, particularly in developing countries characterized by inadequate storage facilities. The Food and Agriculture Organization approximates that annually, insect pests in tropical environments can cause the loss of 10–30% of stored grains. The smaller grain borer, *Rhyzopertha dominica*, is recognized as one of the most destructive primary pests affecting stored cereals, encompassing wheat, rice, maize, barley, and sorghum (Kumar *et al*., 2017) [27].

Rhyzopertha Dominica is capable of infesting entire grains, with both adult insects and larvae consuming the interior, which consequently reduces grain weight, nutritional value, and germination potential (Naseri & Majd-Marani, 2022) [29]. Grains that have been infested often exhibit considerable tunneling, powder production, and secondary fungal contamination, thus decreasing their market value and consumer acceptance (Deligeorgakis *et al*., 2023) [10]. Traditional management methods predominantly depend on chemical insecticides and fumigants; nonetheless, escalating instances of pesticide resistance, especially phosphine resistance, have generated significant apprehension over their sustained effectiveness (Zhu *et al*., 2016) [47].

In this context, medicinal plant extracts have surfaced as viable alternatives owing to their biodegradability, intricate chemical makeup, and diverse mechanisms of action. Medicinal plants are particularly appealing due to the extensive research on their bioactive compounds, which are often safer for humans. This study rigorously evaluates the current scientific data for the utilization of medicinal plant extracts for the management of *R. Dominica* in preserved grains.

Biology, Ecology, and Pest Status of *Rhyzopertha Dominica*

The lesser grain borer, *Rhyzopertha Dominica* (Fabricius), is a global coleopteran pest from the family Bostrichidae. It is acknowledged as one of the most deleterious major pests of stored cereals due to its capacity to infest whole, undamaged grains. In contrast to numerous secondary storage pests, *R. Dominica* does not necessitate antecedent grain damage, rendering it especially problematic in efficiently controlled storage systems.

1. Taxonomy and Morphology

Taxonomically, *R. Dominica* is classified within the Order Coleoptera and the Family Bostrichidae. Adults are cylindrical beetles, dark reddish-brown to black, ranging roughly 2.5–3.0 mm in length. The head is bent and hidden beneath the pronotum, which features distinctive rasp-like teeth utilized for penetrating grains. This morphological modification allows both adults and larvae to effectively pierce hard cereal kernels.

Larvae are creamy white, C-shaped, and legless, remaining hidden within the grain during their development. Pupation transpires within the grain kernel, offering protection from external environmental shocks and chemical treatments. This hidden evolution markedly hampers pest identification and management (Seada & Hamza, 2023) [35].

2. Life Cycle and Reproductive Biology

The life cycle of *R. Dominica* encompasses the egg, larval, pupal, and adult phases. Females deposit eggs loosely among grain kernels or within fissures of storage facilities.

Upon hatching, neonatal larvae penetrate the grain, where they undergo complete development. In optimal conditions of temperature (30–34 °C) and relative humidity (60–70%), the insect can complete its life cycle in 25–30 days.

Adult lifespan may extend for several months, during which females produce multiple clutches of eggs, facilitating swift population growth. The capacity to produce several generations each year under optimal storage conditions renders *R. dominica* represents a continual and intensifying risk in the context of long-term grain storage (Holloway *et al*., 2020) [17].

3. Feeding Behavior and Damage Potential

Both larvae and adults are internal feeders, ingesting the endosperm and germ tissues of cereal grains. Feeding leads to substantial weight reduction, the production of powdery frass, and the hollowing of kernels. Infested grains display inferior nutritional quality and decreased market value. Infestation in seed grains results in a significant reduction in germination and seedling vitality.

The tunneling behavior of *R. Dominica* also enables subsequent infestations by fungi and mites, hastening grain deterioration and elevating the potential of mycotoxin contamination (Khan, 2024) [24]. Thus, the economic repercussions linked to this pest encompass not only direct weight loss but also quality deterioration and food safety issues.

4. Ecological Adaptability and Distribution

Rhyzopertha Dominica is extensively distributed over tropical, subtropical, and temperate zones. Its robust flight capability facilitates spread throughout storage facilities, while its adaptability to various environmental circumstances promotes establishment in diverse storage habitats. The pest flourishes in bulk grain storage facilities, warehouses, silos, and domestic storage structures (Holloway *et al*., 2020) [17].

Ecologically, *R. Dominica* is well-suited to arid conditions characteristic of stored grains. Its capacity to endure and propagate in comparatively arid environments confers a competitive edge over other stored-product insects (Oppert *et al*., 2022) [32].

5. Pest Status and Resistance Issues

The pest classification of *R. Dominica* is worse by its established resistance to widely utilized fumigants and contact insecticides, notably phosphine (Afful *et al*., 2020) [1]. Resistance has been documented in various grain-producing regions, including South and Southeast Asia, Australia, and Africa. This resistance has led to control failures and heightened treatment frequencies, hence exacerbating selection pressure (Agrafioti *et al*., 2023) [2].

The amalgamation of covert feeding, swift reproduction, ecological versatility, and resistance emergence situates *R. Dominica* is regarded as a high-priority pest in stored grain protection initiatives. These attributes compellingly advocate for the investigation and implementation of alternative control strategies, such as medicinal plant extracts, which provide innovative mechanisms of action and diminished environmental hazards.

Economic Losses Attributed to *Rhyzopertha Dominica* Infestation

The economic losses attributed to the lesser grain borer, *Rhyzopertha Dominica*, represent a significant share of worldwide post-harvest losses in stored grains. As a principal pest, *R. Dominica* may infest whole, undamaged grains, leading to direct quantitative losses through weight reduction, grain breaking, and powder generation. The insect's hidden feeding behavior frequently exacerbates these losses, enabling infestations to progress undetected until considerable damage has transpired (Yousuf *et al*., 2025) [45].

In addition to immediate weight reduction, the infestation by *R. Dominica* results in significant quality degradation of stored wheat. Feeding damage diminishes grain density, nutritional quality, and milling standards, while significant internal tunneling leaves grains unfit for human consumption and commercial processing. Infestation in seed storage systems significantly diminishes germination rates and seedling vitality, leading to indirect economic losses due to inadequate crop establishment and diminished yield potential in future growing seasons.

The economic ramifications of *R. Dominica's* significance is exacerbated by its function in enabling secondary infestations. Compromised grains exhibit heightened vulnerability to fungal and mite colonization, hence elevating the risk of deterioration and mycotoxin contamination. This contamination may result in the rejection of grain consignments in both domestic and international markets, causing significant financial losses and trade limitations (Deligeorgakis *et al*., 2023) [10].

In commercial grain storage facilities, infestations of *R. Dominica* frequently necessitate repeated fumigation and chemical applications, thereby substantially increasing operational costs. These recurring treatments not only inflate expenditures on pesticides and labor but also accelerate the emergence of resistance, creating a cycle of escalating expenses and reduced control effectiveness. For smallholder farmers and household storage systems in developing countries, even minor infestations can precipitate considerable economic hardship and food insecurity.

The total economic burden linked to the impact of *R. Dominica*—including direct grain losses, quality degradation, heightened pest management expenses, diminished seed value, and market penalties—highlights its classification as a critical stored-grain pest. The significant economic effects necessitate the development and implementation of alternative, cost-efficient, and environmentally sustainable management options, including pesticides made from medicinal plants.

Limitations of Synthetic Insecticides in Stored-Grain Protection

Synthetic insecticides and fumigants have traditionally constituted the foundation of pest management in stored grains owing to their swift knockdown efficacy and straightforward application. Compounds include phosphine, methyl bromide (now predominantly discontinued), pyrethroids, and organophosphates have been extensively utilized in commercial grain storage systems. Nonetheless, prolonged dependence on these compounds has revealed significant limitations that compromise their sustainability and efficacy against *Rhyzopertha dominica* (Nayak *et al*., 2020) [1].

1. Development of Insecticide Resistance

A significant disadvantage of synthetic pesticides is the extensive emergence of resistance in Population of *R.*

Dominica. Phosphine resistance has been thoroughly researched and is now regarded as a global issue. Resistant populations necessitate increased dosages or extended exposure durations to attain effective control, which is sometimes difficult and monetarily unfeasible. The emergence of resistance diminishes treatment efficacy and intensifies selection pressure, hence worsening the issue.

The genetic foundation of resistance in *R. Dominica*, together with its elevated reproductive rate and many generations annually, facilitates the fast dissemination of resistance alleles within and among storage facilities. This has led to recurrent fumigation failures and heightened post-treatment survival, presenting a significant risk to grain biosecurity (Daglish *et al*., 2024) [9].

2. Residue Accumulation and Food Safety Concerns

A significant issue related to synthetic insecticides is the enduring presence of chemical residues in treated grains. A significant portion of stored grains is designated for human consumption, and the existence of pesticide residues poses critical food safety and public health concerns. Prolonged exposure to minimal pesticide residues has been linked to detrimental health outcomes, resulting in strict maximum residue limits (MRLs) established by national and international regulatory bodies (Khandelwal *et al*., 2022) [25].

Adherence to residue laws poses significant difficulties for small-scale farmers and storage operators in developing nations, where poor application and insufficient monitoring are prevalent. Consequently, there is an increasing market demand for residue-free or organically safeguarded grains.

3. Environmental and Non-Target Effects

Synthetic pesticides frequently exhibit low selectivity, leading to detrimental impacts on non-target organisms. In storage conditions, beneficial arthropods, natural predators, and microbial populations may be adversely impacted. In addition to storage facilities, chemical runoff and volatilization can lead to extensive environmental contamination, impacting soil and aquatic ecosystems (Serrão *et al*., 2022) [36].

The ecological impact of synthetic insecticides undermines global initiatives aimed at fostering environmentally sound agriculture practices. This has elicited heightened examination from environmental agencies and policymakers.

4. Human Health and Occupational Hazards

Exposure to synthetic insecticides presents considerable health hazards to workers engaged in grain storage and fumigation activities. Acute exposure may result in respiratory discomfort, neurological complaints, and dermal irritation, however persistent exposure has been associated with more severe health consequences. Insufficient training, absence of protective equipment, and inadequate ventilation in storage facilities exacerbate occupational hazards, particularly in resource-constrained environments (Shekhar *et al*., 2024) [37].

5. Regulatory Restrictions and Economic Constraints

Due of environmental and health issues, numerous synthetic pesticides employed in the protection of stored grain have been prohibited or placed under stringent regulatory oversight. The elimination of methyl bromide under the Montreal Protocol illustrates the susceptibility of chemical-dependent pest management strategies. The remaining insecticides are subjected to escalating regulatory scrutiny, resulting in diminished availability and increased costs.

Consequently, these legal constraints imposed on storage managers curtail their control strategies and increase reliance on a narrow selection of chemicals, thereby accelerating the emergence of resistance. Furthermore, the economic burden associated with repeated applications and compliance with safety protocols diminishes the practicality of insecticide-based control methods (Hamel *et al*., 2020) [14].

6. Implications for Alternative Pest Management Strategies

The aggregate drawbacks of synthetic insecticides—resistance, residues, environmental repercussions, health risks, and regulatory constraints—highlight the pressing necessity for alternate strategies in the management of stored grain pests (Ahmad *et al*., 2024) [3]. These deficiencies offer a compelling scientific rationale for investigating medicinal plant extracts as environmentally acceptable, efficacious, and sustainable alternatives against *R. dominica*. Botanical insecticides, characterized by varied mechanisms of action and advantageous safety profiles, present a feasible approach to diminishing chemical reliance in grain storage systems.

Medicinal Plants as Sources of Botanical Insecticides

Medicinal plants represent a highly promising source of botanical insecticides owing to their abundant range of bioactive secondary metabolites. For generations, plants have been utilized in traditional agricultural and medicinal methods to safeguard stored goods from insect infestations. Recent scientific validation has established that some medicinal herbs have significant insecticidal, repellant, antifeedant, ovicidal, and growth-regulating effects against stored-product pests, such as *Rhyzopertha dominica* (Gupta *et al*., 2023) [13].

1. Phytochemical Basis of Insecticidal Activity

Medicinal plants produce a diverse range of secondary metabolites that serve defensive functions against herbivores and pathogens. Key phytochemical categories contributing to insecticidal efficacy encompass alkaloids, terpenoids, flavonoids, phenolics, saponins, and essential oils. These chemicals may function independently or synergistically to impair insect physiology and behavior (Corzo-Gómez *et al*., 2024) [8]. Terpenoids and monoterpenes, prevalent in essential oils, demonstrate neurotoxic properties, whereas phenolic chemicals and flavonoids disrupt feeding and digestion (Wojtunik-Kulesza, 2022) [43].

Neem (*Azadirachta indica*) exemplifies the interference of limonoids, including azadirachtin, salannin, and nimbin, with insect hormonal control, leading to diminished fertility, postponed development, and aberrant metamorphosis (Mitchell *et al*., 1997) [28]. Likewise, essential oils derived from Ocimum, Eucalyptus, and Acorus species encompass bioactive compounds including eugenol, 1,8-cineole, and β-asarone, which exhibit significant toxicity and repellency towards *R. dominica* (Ebadollahi *et al*., 2022).

2. Advantages of Medicinal Plant-Based Insecticides

Extracts from medicinal plants have numerous benefits compared to synthetic insecticides for the preservation of stored grains. They are typically biodegradable, present minimal risk to humans and non-target creatures, and result in negligible hazardous residues on treated grains. The intricate chemical makeup of plant extracts diminishes the probability of resistance emergence in insect populations, a significant drawback linked to traditional fumigants.

Moreover, numerous medicinal plants are readily accessible in grain-producing areas, rendering them economically advantageous for small-scale farmers and rural storage systems. Their alignment with integrated pest management (IPM) tactics further augments their practical significance (Grasswitz, 2019) [12].

3. Ethnobotanical Knowledge and Scientific Validation

Ethnobotanical surveys have been important in finding medicinal plants historically utilized for grain protection. Species include *Azadirachta indica*, *Ocimum sanctum*, *Curcuma longa*, *Piper nigrum*, and *Acorus calamus* have historically been utilized in traditional storage methods (Raj *et al*., 2018) [34]. Laboratory bioassays and controlled tests have since corroborated numerous traditional assertions, evidencing statistically substantial declines in adult survival, progeny emergence, and grain damage inflicted by *R. Dominica*.

4. Constraints in Utilization of Medicinal Plants

Notwithstanding their potential, the application of medicinal plants as botanical pesticides encounters specific limits. Variability in phytochemical composition resulting from plant genotype, geographic origin, and harvesting season can influence consistency in bioefficacy. Furthermore, crude plant extracts may demonstrate reduced persistence relative to synthetic pesticides, requiring multiple treatments. Mitigating these limitations via standardization, formulation advancement, and dosage optimization is crucial for widespread implementation (Gupta *et al*., 2023) [13].

Extraction Methods and Their Influence on Bioefficacy

The insecticidal efficacy of medicinal plants against *Rhyzopertha Dominica* is significantly affected by the extraction process utilized, as various procedures differ in their capacity to identify and maintain bioactive chemicals. Extraction influences both the qualitative and quantitative phytochemical composition of plant products, as well as their bioefficacy, stability, and mechanism of action against stored-grain pests.

1. Aqueous Extraction

Aqueous extraction is among the oldest and most often employed techniques, especially in traditional and small-scale storage methods (Wan Mohd Zamri *et al*., 2021) [41]. This technique is immersing or boiling botanical substances in water to extract water-soluble chemicals, including tannins, glycosides, and certain phenolics. Despite being cost-effective, environmentally benign, and simple to make, aqueous extracts exhibit limited insecticidal activity against *R. Dominica* is frequently inferior in comparison to solvent-based extracts. Numerous investigations have indicated moderate repellency and antifeedant properties of aqueous extracts; nevertheless, their quick disintegration and restricted penetration into grain kernels diminish their long-term efficacy.

2. Organic Solvent Extraction

The extraction of organic solvents utilizing ethanol, methanol, acetone, hexane, or petroleum ether is commonly employed in laboratory research because of its exceptional capacity to dissolve a wide range of phytochemicals, such as alkaloids, flavonoids, and terpenoids (Jadhav *et al*., 2023 and Baisthakur *et al*., 2022) [6, 21]. Solvent extracts from medicinal herbs, including *Azadirachta indica*, *Acorus calamus*, and *Curcuma longa*, have repeatedly shown markedly increased adult mortality, reduced oviposition, and inhibition of progeny emergence in *R. dominica* in comparison to aqueous extracts (Singh *et al*., 2021) [38].

Ethanol and methanol are preferred solvents due to their efficacy in extracting both polar and somewhat non-polar molecules. Statistical analyses from several research demonstrate that solvent extracts frequently exhibit dose-dependent toxicity, with significant differences ($p < 0.05$) compared to untreated controls, underscoring their consistent bio-efficacy.

3. Essential Oil Extraction and Fumigant Activity

Essential oils extracted via steam distillation or hydro distillation are among the most effective plant-based products against stored-product insects. These volatile oils are abundant in monoterpenes and sesquiterpenes, which have significant fumigant toxicity. Essential oils derived from *Ocimum sanctum*, *Eucalyptus globulus*, and *Piper nigrum* have demonstrated rapid knockdown and elevated mortality rates in *R. Dominica* adults under controlled laboratory conditions (Ebadollahi *et al*., 2022).

The fumigant properties of essential oils render them especially efficacious against internal feeders such as *R. Dominica*, as vapors can infiltrate grain masses and access hidden life stages. Nonetheless, their significant volatility may restrict persistence, requiring improved formulations or controlled-release methods for practical implementation.

4. Influence of Extraction Method on Mode of Action

Various extraction techniques affect both the toxicity levels and the mechanisms of action of plant extracts. Solvent extracts typically demonstrate contact toxicity and effects from eating, whereas essential oils predominantly function through fumigation and respiratory suppression. Certain extracts disrupt insect growth and reproduction, while others elicit behavioral reactions, including repellency and feeding deterrent. The intricate nature of plant extracts often results in synergistic interactions among several chemicals. Extraction procedures that maintain this chemical complexity are more likely to yield broad-spectrum efficacy and diminish the likelihood of resistance development (Sun *et al*., 2025) [39].

5. Challenges and Standardization Issues

Notwithstanding encouraging outcomes, inconsistencies in extraction techniques among studies provide difficulties for comparative assessment and practical implementation. Elements including solvent type, extraction length, temperature, plant part utilized, and post-extraction processing might markedly affect bioefficacy. The absence of standardized extraction protocols impedes reproducibility and scalability (Sun *et al*., 2025) [39].

Subsequent investigations ought to concentrate on refining extraction methodologies, standardizing procedures, and linking phytochemical compositions with biological activity. Such endeavors are crucial for converting laboratory discoveries into reliable, field-applicable botanical pesticide formulations for the treatment of *R. Dominica*.

Medicinal Plant Species Evaluated against *Rhyzopertha Dominica*

A diverse array of medicinal plant species has been systematically assessed for their insecticidal efficacy against *Rhyzopertha Dominica*. These investigations, performed in laboratory and semi-field settings, have evaluated various bioefficacy measures including adult mortality, repellency, antifeedant activity, reduction in oviposition, and suppression of offspring emergence. The variation in efficacy among plant species indicates disparities in phytochemical content, extraction techniques, and exposure settings.

1. Neem (*Azadirachta indica* A. Juss.)

Neem is the most thoroughly researched medicinal plant for the management of stored-grain pests. Extracts and oils obtained from neem seeds and leaves have consistently exhibited potent insecticidal and growth-regulating properties against *R. Dominica*. Azadirachtin and associated limonoids interfere with endocrine control, leading to diminished fertility, extended developmental durations, and marked suppression of F1 offspring. Numerous peer-reviewed studies indicate statistically significant adult mortality and diminished grain damage following the application of neem-based formulations to stored cereals (Kambrekar *et al*., 2022) [22].

2. Holy Basil (*Ocimum sanctum* L.)

Essential oils derived from *O. sanctum* leaves are abundant in eugenol and other phenylpropanoids, which demonstrate significant fumigant toxicity and repellent properties against *R. Dominica* (Žabka *et al*., 2021). Experimental bioassays demonstrate that exposure to Ocimum essential oils results in swift knockdown and behavioral aversion, rendering them highly efficient in thwarting initial infestations. Their potent fragrance and volatility enhance their effectiveness, although persistence poses a difficulty.

3. Turmeric (*Curcuma longa* L.)

Turmeric rhizome extracts have been assessed mainly for their antifeedant and growth-inhibitory properties. Curcuminoids disrupt eating behavior and digestive functions in *R. Dominica*, leading to diminished grain consumption and decreased reproductive production. Although turmeric extracts usually show low direct toxicity, their ability to reduce feeding damage makes them important in integrated pest management (Hematpoor *et al*., 2022) [16].

4. Sweet Flag (*Acorus calamus* L.)

Extracts of *Acorus calamus* rhizome include β-asarone and associated phenylpropanoids with potent insecticidal activity. Solvent extracts of *A. calamus* has exhibited elevated adult mortality and considerable suppression of larval growth in *R. Dominica*. Acorus-based compounds are seen as attractive possibilities for grain protectants due to their more prolonged persistence relative to essential oils (Wijerathna *et al*., 2023) [42].

5. Eucalyptus (*Eucalyptus globulus* Labill.)

Essential oils derived from the leaves of *E. globulus*, characterized by 1,8-cineole, has been extensively documented for its fumigant toxicity against stored-product insects (Yallappa *et al*., 2026) [44]. Research demonstrates a dose-dependent death rate and significant repellency effects against *R. Dominica*. The capacity of eucalyptus vapors to infiltrate grain bulk increases their efficacy against interior pests.

6. Black Pepper (*Piper nigrum* L.)

Seed powders and solvent extracts of *P. nigrum* contain piperine, an alkaloid recognized for its neurotoxic properties in insects. Laboratory assessments have revealed considerable adult mortality and diminished offspring emergence of *R. Dominica* when grains are processed with compounds generated from black pepper. The benefits are frequently amplified when coupled with other plant extracts, indicating possible synergistic interactions (Ileke & Bulus, 2012) [19].

7. Comparative Evaluation and Synthesis

Comparative comparisons across research indicate that neem-based treatments typically offer the most extensive control by impacting several life stages of *R. Dominica*. Plants that produce essential oils, such as Ocimum and Eucalyptus, demonstrate superior fumigant and repellant properties, whereas rhizomatous plants like Curcuma and Acorus provide antifeedant and growth-regulatory effects. The incorporation of these plant species, whether singularly or together, provides a comprehensive strategy for managing pests in stored grain.

Table 1: Detailed comparative bioactivity of medicinal plant species evaluated against *Rhyzopertha Dominica*

Medicinal plant (scientific name)	Family	Plant part used	Extraction method	Major bioactive compounds	Bioassay parameters evaluated	Observed effects on *R. dominica*	Key references
Azadirachta indica A. Juss.	*Meliaceae*	Seed, leaf	Oil, ethanol, methanol	Azadirachtin, salannin, nimbin	Adult mortality, oviposition, F1 emergence	High adult mortality; strong reduction in fecundity and progeny emergence; delayed development	Banerjee *et al*., 2014
Ocimum sanctum L.	*Lamiaceae*	Leaf	Essential oil	Eugenol, methyl eugenol	Mortality, repellency, fumigant toxicity	Rapid knockdown; strong repellency; significant fumigant mortality	Žabka *et al*., 2021
Curcuma longa L.	*Zingiberaceae*	Rhizome	Ethanol, acetone	Curcumin, demethoxycurcumin	Antifeedant activity, grain damage	Reduced feeding; lower grain weight loss; moderate mortality	Tian *et al*., 2025 [40]
Acorus calamus L.	*Acoraceae*	Rhizome	Methanol, ethanol	β-asarone	Mortality, growth inhibition	Significant adult mortality; inhibition of larval development	Wijerathna *et al*., 2023 [42]
Eucalyptus globulus Labill.	*Myrtaceae*	Leaf	Essential oil	1,8-cineole	Fumigant toxicity, repellency	Dose-dependent mortality; effective vapor action	Yallappa *et al*.,

							2026 [44]
Piper nigrum L.	*Piperaceae*	Seed	Powder, solvent extract	Piperine	Mortality, progeny suppression	Increased adult mortality; reduced F1 emergence	Ileke & Bulus, 2012 [19]
Allium sativum L.	*Amaryllidaceae*	Bulb	Aqueous, ethanol	Allicin, diallyl sulfides	Repellency, mortality	Strong repellent action; moderate toxicity	Omar & Zayed, 2021 [31]
Mentha piperita L.	*Lamiaceae*	Leaf	Essential oil	Menthol, menthone	Fumigant toxicity	High adult mortality under enclosed conditions	Kłyś, 2008

Experimental Evidence and Bioefficacy Parameters

Experimental assessment of medicinal plant extracts against *Rhyzopertha Dominica* has predominantly been performed via laboratory bioassays, with a few semi-field investigations. The objective of these investigations is to produce statistically valid data regarding the efficacy of plant-derived products through the assessment of several biological and behavioral factors. The robustness of the existing literature is attributed not only to death statistics but also to an exhaustive evaluation of sublethal and population-level impacts, which are essential for enduring pest control in stored-grain environments.

1. Adult Mortality

Adult mortality is the most commonly reported metric in research assessing botanical pesticides. Contact toxicity studies, residual grain treatment procedures, and fumigation bioassays have shown that several medicinal plant extracts induce considerable adult mortality in *R. dominica* in comparison to untreated controls (Hassan *et al*., 2022) [15]. Essential oils, specifically, frequently cause fast incapacitation due to their neurotoxic effects. Solvent extracts typically exhibit dose-dependent mortality, with statistically significant variations ($p < 0.05$) documented in several experiments.

2. Repellency and Behavioral Responses

Repellency experiments elucidate the protective efficacy of medicinal plant extracts. Essential oils derived from Ocimum, Eucalyptus, Mentha, and Allium species exhibit significant repellant efficacy. Repellency diminishes initial infestation and oviposition by deterring adult beetles from inhabiting treated grains (Khalil *et al*., 2024) [23]. Behavioral avoidance reactions are crucial for the security of stored grain, as they inhibit population establishment without directly inducing mortality.

3. Antifeedant Activity and Grain Damage Reduction

The effects of antifeedants are often evaluated by quantifying grain weight loss and calculating feeding deterrence indices (Akhtar *et al*., 2015) [4]. Extracts from *Curcuma longa*, *Azadirachta indica*, and *Acorus calamus* have demonstrated a considerable reduction in the feeding activity of *R. Dominica*. Decreased feeding results in less quantitative losses and maintenance of grain quality. These sublethal effects are especially significant in seed grains, where germination and viability are essential.

4. Effects on Reproduction and Progeny Emergence

The inhibition of reproduction and the emergence of F1 progeny are critical indicators of long-term control potential (Kambrekar *et al*., 2022) [22]. Numerous therapeutic plant extracts disrupt oviposition, egg viability, and larval development. Neem-based products are particularly efficacious in diminishing fecundity and progeny emergence owing to their growth-regulating attributes. Research regularly demonstrates substantial decreases in adult emergence from treated grains, signifying interruption of the pest life cycle.

5. Growth Regulation and Developmental Disruption

Certain phytochemicals act as insect growth regulators, resulting in postponed development, irregular molting, and heightened developmental mortality. Effects have been noted using extracts of *Azadirachta indica* and *Acorus calamus*. Growth regulatory effects are beneficial as they mitigate population accumulation, even in the presence of moderate immediate mortality (Banerjee *et al*., 2014; Raj *et al*., 2018) [34].

6. Statistical Validation of Bioefficacy

Most experimental investigations utilize suitable statistical techniques, such as analysis of variance (ANOVA) and post hoc testing, to confirm reported differences between treatments and controls. The reporting of statistically significant outcomes (often at $p < 0.05$) enhances trust in the effectiveness of therapeutic plant extracts (Ilie *et al*., 2024) [20]. The inconsistency in experimental design and reporting standards underscores the necessity for more methodological harmonization among investigations.

7. Synthesis of Experimental Evidence

Collectively, experimental evidence indicates that therapeutic plant extracts have diverse effects on *R. Dominica*, focusing on both survival and reproductive efficacy. The cumulative effects of death, repellency, antifeedant properties, and progeny suppression highlight the efficacy of botanical insecticides as viable substitutes for synthetic chemicals. When analyzed in conjunction with the tabulated data, these findings establish a strong scientific basis for the development of plant-based grain protectants.

Table 2: Reported bioefficacy of selected medicinal plant extracts against *R. Dominica*

Plant extract	Dose range	Exposure duration	Key findings	Source
Neem seed oil	0.5–1.0%	7–14 days	Significant adult mortality and F1 suppression	Banerjee *et al*., 2014
O. sanctum oil	10–20 µL/L air	72 h	Strong repellency and fumigant toxicity	Žabka *et al*., 2021
Eucalyptus oil	5–15 µL/L air	48–72 h	Dose-dependent mortality	Yallappa *et al*., 2026 [44]

Numerous investigations indicate statistically significant differences ($p < 0.05$) between treated and untreated controls, hence validating authentic insecticidal effects. Discrepancies in outcomes among research are ascribed to variations in insect strain, extraction methodology, and environmental factors.

Constraints, Knowledge Gaps, and Research Needs

Despite significant advancements in assessing therapeutic plant extracts for *Rhyzopertha Dominica*, many scientific, technological, and practical limitations hinder their extensive implementation in the preservation of stored grains. Recognizing and rectifying these deficiencies is crucial for converting laboratory discoveries into dependable field applications.

Future Research Directions

Future research should emphasize:

- Standardization of plant extract preparation and testing protocols
- Identification and purification of key bioactive compounds
- Molecular-level studies on insect physiology and resistance risk
- Long-term storage and field-based validation
- Development of stable, scalable, and cost-effective formulations

Mitigating these limitations and information deficiencies will be essential for progressing medicinal plant extracts from experimental instruments to reliable options for the sustainable management of *Rhyzopertha Dominica* in stored grain systems.

Conclusions

Medicinal plant extracts provide a scientifically substantiated, environmentally sustainable alternative to synthetic insecticides for controlling the smaller grain borer, *Rhyzopertha Dominica*, in stored grains. Research from peer-reviewed studies indicates that certain medicinal herbs possess notable insecticidal, repellant, antifeedant, and growth-regulating properties, leading to decreased adult survival, inhibited offspring emergence, and diminished grain damage. Their several mechanisms of action and biodegradability render them especially advantageous in resistance control and residue-free grain protection.

Nonetheless, widespread adoption is hindered by inconsistencies in phytochemical composition, the absence of standardized extraction and formulation techniques, and insufficient long-term storage and field validation. Rectifying these deficiencies by standardization, formulation research, and incorporation into Integrated Pest Management frameworks will be imperative. Targeted research and regulatory endorsement indicate that pesticides derived from medicinal plants had significant potential to enhance sustainable and safe pest management strategies for stored grains.

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