



## NATURALLY OCCURRING BOTANICAL EXTRACTS FOR THE MANAGEMENT OF STORAGE WEEVIL INFESTATION: A REVIEW

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### ABSTRACT

Post-harvest grain losses caused by storage weevils remain a major constraint to food security in many developing countries. Species of *Sitophilus*, particularly *S. oryzae*, *S. zeamais*, and *S. linearis*, inflict extensive damage during storage due to their concealed larval development, rapid reproductive cycles, and strong adaptation to storage environments. The limitations and health concerns associated with synthetic insecticides have stimulated renewed interest in plant-derived pest management. This review synthesizes current knowledge on the biology and ecology of storage weevils, the phytochemical basis of botanical insecticides and the efficacy of plant extracts in grain protection. Key phytochemicals including alkaloids, terpenoids, phenolics, and Saponins were identified. Their diverse mechanism includes insecticidal, repellent, fumigant, and growth-inhibitory regulation and synergistic enhancement. Botanicals such as *Azadirachta indica*, *Ocimum basilicum*, *Zingiber officinale*, *Curcuma longa*, *Allium sativum*, and *Eucalyptus spp.* demonstrate significant activity against *Sitophilus* species, with effectiveness influenced by extraction solvent, concentration, and exposure duration. While plant-based pesticides offer safe, environmentally compatible alternatives to chemical insecticides. Overall, botanical extracts hold strong potential for sustainable, integrated management of storage weevils and improved post-harvest grain security.

**Keywords:** *Sitophilus oryzae*, *Sitophilus zeamais*, *Sitophilus linearis*, Alkaloids, Insecticide

### INTRODUCTION

Post-harvest losses are one of the major causes of food insecurity in the developing world. In Africa, at the farm level, producers store their grains for three purposes: for consumption until the next harvest, as seed for planting in the next season and for selling when prices become favorable.

In many developing countries, traditional grain-storage methods and structures are commonly used but often fail to prevent deterioration of stored products (Mataka *et al.*, 2025). Among the key constraints to improving food security in Africa are losses resulting from poor post-harvest management of grains (Charles *et al.*, 2016). The average grain losses due to storage pests is about 12% of the total grain produced in some case the losses could be rise to 50% (Gabriel *et al.*, 2006). Deterioration of stored grains results from the interactions of several factors such as physical, chemical and biological variables existing the overall chains from production to consumptions. However, deterioration of grain due to infestations of insects, mites, and fungi is the main post-harvest factor affecting the nutritional quality and marketability of stored grain (Dubale *et al.*, 2012). Grain storage pests are major concerns for farmers worldwide especially in developing countries because large percentage of the crop may be lost to storages pests. Prior to any pest control interventions, it is vital to assess the pest status and extent of losses that have occurred or likely to occur during storage (Togola *et al.*, 2015).

Historically, plants possessing biologically active ingredients have been successfully utilized to control crop pests and human diseases (Thiruppathi *et al.*, 2010). Many plants, such as pyrethrum, tobacco, neem, sabadilla and ryania have been identified as sources of effective botanical pesticides (Shabana *et al.*, 2017). These plant-derived pesticides manage insect pests and plant pathogens like nematodes, fungi, bacteria and viruses (Waziri *et al.*, 2015). However, with the advent of synthetic pesticides, their use declined due to the immediate effectiveness of synthetic chemicals in managing severe crop diseases (Raja *et al.*, 2014). Nonetheless, recent concerns over the negative impacts of chemical pesticides on community health and safety of surroundings have revived interest in plant-



based pest control methods (Mohammad and Yakasai, 2017). The global trend now favors food production with the use of non-toxic natural plant substances. Dangerous chemical deposits in foods and augmented consumer alertness of food safety have led to bans on specific chemicals used in agriculture, boosting the popularity of plant-based pesticides in organic farming (Karani *et al.*, 2017). Constant usage of chemical pesticides has caused contamination, health threats and loss of biodiversity, while adopting plant-based pesticides fosters a healthy environment and sustainable agriculture (Shabana *et al.*, 2017). The study provide update on the efficacy of naturally occurring plant extracts as environmentally safe, cost-effective alternatives for the management of storage weevils in stored grain.

### **Plant-Derived Pest Management**

Plant-derived pest management is rooted in the chemical ecology of plants, which produce a wide variety of **secondary metabolites** including alkaloids, terpenoids, flavonoids, phenolics, tannins, saponins, and glycosides primarily as defense mechanisms against herbivores, pathogens, and environmental stresses. These compounds have attracted scientific attention because many possess insecticidal, repellent, antifeedant, fumigant, oviposition-deterrent, or growth-regulating properties (Isman *et al.*, 2006). In post-harvest protection, plant-derived products may be applied as **powders, oils, solvent extracts, or essential oils**, each with distinct chemical composition and potency (Pavela *et al.*, 2016). Their performance is often attributed to complex mixtures of phytochemicals which in combination exert multiple modes of action, reducing the likelihood of insects developing resistance compared to single-molecule synthetic insecticides (Regnault-Roger *et al.*, 2012).

Historically, botanical materials have been central to grain preservation in traditional agricultural systems. Farmers across Africa and Asia, for example, applied powdered leaves, seeds, ash, or aromatic plant parts to stored cereals to deter weevils and beetles (Boeke *et al.*, 2004). Modern scientific evaluations have validated many of these traditional practices: species such as *Azadirachta indica*, *Ocimum basilicum*, *Zingiber officinale*, *Curcuma longa*, *Allium sativum* and *Eucalyptus spp.* have demonstrated significant activity against storage pests such as *S. oryzae* and *S. zeamais* through toxicity, repellency, or inhibition of oviposition (Nerio *et al.*, 2010).

### ***Azadirachta indica* (Linn)**

*Azadirachta indica*, commonly known as neem, is one of the most widely studied botanical insecticides due to its broad-spectrum activity and eco-friendly nature. Neem seed and leaf extracts rich in bioactive compounds such as azadirachtin and other limonoids, have demonstrated significant insecticidal effects against a variety of insect pests including stored-product pests like *Tribolium castaneum* and *Sitophilus* spp. The primary modes of action includes antifeedant effects, growth regulation, and sterilization achieved by disrupting insect hormonal systems, and interfering with molting and reproduction (Aliyu *et al.*, 2023). Laboratory studies have shown that ethanolic neem leaf extracts cause high mortality in adult beetles and reduce progeny emergence when applied to stored grains. However,

The effectiveness of neem depends on seed storage time, extraction technique, and concentration, with aged seeds typically showing decreased potency (Saleem *et al.*, 2024). Despite these limitations, neem remains a valuable component of integrated pest management programs, offering biodegradability, low mammalian toxicity, and multiple modes of action that reduce the risk of pest resistance.

### ***OCIMUM BASILICUM***

*Ocimum basilicum* (basil) is a medicinal and aromatic plant whose essential oils (EO) have shown strong insecticidal, fumigant, and repellent properties against stored-product pests. Major constituents of basil EO, including estragole and linalool, are responsible for neurotoxic effects on insects, as well as behavioral repellency that reduces feeding and oviposition (Lima *et al.*, 2016). Laboratory bioassays show that basil essential oil is strongly toxic to *Sitophilus oryzae*, *Tribolium castaneum*, and *Acanthoscelides obtectus*, producing up to 100% adult mortality at sufficient concentrations and suppressing offspring emergence (Pavela and Benelli, 2016). Although highly effective, the use of basil EO in stored grains requires consideration of potential odor transfer to commodities and careful handling due to its concentrated volatile compounds. Overall, basil EO is a promising botanical for fumigant or repellent applications in stored-product pest management.



### *EUCALYPTUS SPP.*

Essential oils from Eucalyptus species, particularly *Eucalyptus globulus*, are effective botanical insecticides with fumigant and contact toxicity against several stored-product pests. The major active component, 1,8-cineole (eucalyptol), along with  $\alpha$ -pinene and limonene contributes to neurotoxic and respiratory-disrupting effects that cause rapid mortality in pests such as *Sitophilus oryzae*, *S. granarius*, and *Tribolium castaneum* (Bekhechi *et al.*, 2008). Studies have shown that eucalyptus EO can achieve complete mortality in weevils under laboratory conditions, both by direct contact and fumigant exposure, and can also serve as a repellent (Pathipati and Ko, 2016). The volatility of eucalyptus EO ensures quick action, though it can reduce persistence in storage unless incorporated into controlled-release formulations. Eucalyptus EO is considered safe, biodegradable, and effective in integrated pest management, making it a valuable option for reducing reliance on synthetic fumigants in grain storage systems (Bekhechi *et al.*, 2008).

### *Zingiber officinale*

Ginger is well-known for its insecticidal and repellent properties, primarily due to its rich content of bioactive compounds such as gingerol, shogaol, zingerone, and essential oils. These compounds exhibit toxic, repellent, and growth-inhibitory effects on a variety of insect pests. Studies have shown that ginger extracts can cause mortality, feeding deterrence, and reproductive inhibition in insects such as weevils, mosquitoes, aphids, and stored-product pests. Oladimeji *et al.* (2020) reported that ethanolic extracts of ginger significantly reduced the survival of *Sitophilus zeamais* by interfering with their feeding and causing contact toxicity. Similarly, Singh and Prakash (2012) found that ginger essential oil acts as a natural insecticide and repellent against *Aedes aegypti*, the mosquito vector of dengue, by disrupting their nervous system functions. The insecticidal potential of ginger is attributed to its ability to inhibit enzymes involved in insect metabolism, interfere with neurotransmission, and damage insect cell membranes (Isman *et al.*, 2006). These properties make ginger a promising eco-friendly alternative to synthetic pesticides for managing insect pests in agriculture and storage systems. Different scientists have reported the antifungal (Hasan *et al.*, 2005), antimicrobial and insecticidal properties of ginger (Ukeh *et al.*, 2008).

### *Curcuma longa* (Turmeric)

Turmeric has been found effective in controlling certain agricultural and animal pests due to the presence of a variety of bioactive constituents that interfere with insect behavior and growth. Its products have been found active as insect repellents and insecticidal agents. Turmeric possesses significant **insecticidal and repellent properties**, largely due to the presence of **curcumin, turmerone, ar-turmerone, and essential oils**. These bioactive compounds have been found to exhibit toxic, antifeedant, growth-inhibitory, and repellent effects against a wide range of insect pests. Studies have demonstrated that turmeric powder and extracts are effective against stored-product pests such as **weevils, beetles, and moths** primarily by interfering with insect feeding, reproduction, and survival. Rajashekar *et al.* (2014) reported that turmeric powder showed strong repellency and contact toxicity against *Tribolium castaneum* (red flour beetle) and *Sitophilus oryzae* (rice weevil), making it a potential botanical pesticide for stored grains. Pandey *et al.* (2018) found that turmeric essential oil exhibited larvicidal and repellent activities against *Aedes aegypti* mosquitoes, disrupting their nervous system and causing mortality. The insecticidal action of turmeric is often attributed to its ability to inhibit insect acetylcholinesterase, disrupt enzyme activity, damage insect cuticles and digestive systems (Isman *et al.*, 2006). These properties make turmeric a promising natural alternative to synthetic chemical pesticides for sustainable pest management.

Rhizomes of *Curcuma longa* were tested for repellency against adult stored-product insects (*Tribolium castaneum*, *Sitophilus granarius*, and *Rhyzopertha dominica*); the powder showed effectiveness specifically against *S. granarius* and *R. dominica* (Kumar *et al.*, 2021). Moreover, studies report that mixing turmeric powder with mustard oil can protect milled rice from *Sitophilus oryzae* infestation (Kumar *et al.*, 2020). Likewise, dust from rhizomes was shown to be effective against store-grain pests such as lesser grain borer (*Rhyzopertha dominica*) (Chander *et al.*, 2003). In particular, turmeric powder provided 63.2% suppression of progeny of the test insect at 0.5% level (Chander *et al.*, 2003). Also, there was complete mortality of adult insects on milled rice treated with 6 ml oil plus



1 - 4 g of turmeric powder (Chander *et al.*, 2003), whereas mustard oil in various combinations with turmeric powder suppressed the progeny by more than 92%. Chander *et al.* (2000) observed that turmeric extracts showed some repellency on *Tribolium castaneum*, *Oryzaephilus surinamensis* and *Cryptolestes ferrugineus*.

#### **Allium sativum**

Garlic (*Allium sativum*) is widely recognized for its insecticidal and repellent properties, mainly due to its rich content of organosulfur compounds such as allicin, diallyl disulfide, diallyl trisulfide, and ajoene. These bioactive compounds have been shown to exhibit broad-spectrum activity against various insect pests by acting as repellents, contact toxins, feeding deterrents, and growth inhibitors. Singh *et al.* (2017) reported that garlic extract significantly reduced the infestation of *Sitophilus oryzae* (rice weevil) in stored grains, both by killing the insects and deterring their feeding activity. Similarly, Ghosh and Devi (2012) demonstrated that garlic essential oil has strong larvicidal and adulticidal effects against mosquitoes (*Anopheles stephensi* and *Culex quinquefasciatus*) by disrupting their physiological processes. The mechanism of action of garlic includes inhibition of acetylcholinesterase, interference with insect neurotransmission, oxidative stress induction, and disruption of the insect's cuticle integrity and metabolism (Isman *et al.*, 2006). Garlic is also effective in protecting plants from leaf miners, aphids, and other field pests, making it a promising natural alternative to synthetic pesticides in both pre- and post-harvest pest management.

The increasing interest in plant-based pest management is also driven by concerns over the negative impacts of synthetic insecticides: development of resistance, chemical residues in food, environmental contamination, and human toxicity (Aktar *et al.*, 2009). Botanicals often degrade more rapidly in the environment, leaving fewer harmful residues, and many are considered safe for humans when used appropriately. Additionally, they offer advantages of **renewability** and **local availability**, especially in rural communities where commercial pesticides may be unaffordable or restricted. Essential oils rich in monoterpenes and sesquiterpenes such as eugenol, citronellal, linalool, thymol, and  $\alpha$ -pinene have shown particularly strong fumigant and repellent properties against storage weevils and bruchids (Nerio *et al.*, 2010).

Despite these benefits, several limitations challenge the widespread adoption of botanicals. **Variability in potency** can arise due to plant genotype, maturity, soil conditions, extraction method, season of harvest, and storage of plant materials (Pavela *et al.*, 2015). The **stability of active compounds** is another major concern; essential oils are volatile and prone to degradation when exposed to heat, oxygen, or light (Regnault-Roger *et al.*, 2012). These fluctuations complicate standardization and quality control, making it difficult to produce consistent commercial formulations. Additionally, extraction processes can be labor-intensive or costly, and some botanicals may require high application rates to achieve effects comparable to synthetic pesticides (Isman *et al.*, 2020). Addressing these challenges requires improved formulation technologies such as nanoemulsions, microencapsulation, and carrier-based delivery systems—that enhance stability and prolong activity (Benelli *et al.*, 2018). Overall, plant-derived pest management represents a promising, environmentally compatible alternative for controlling storage weevils. With continued advancements in formulation science, phytochemical characterization, and field validation, botanical insecticides have the potential to play a central role in future post-harvest protection strategies, especially within the context of sustainable agriculture and food safety.

#### **Phytochemical Constituents of Insecticidal Plants**

Phytochemical constituents are fundamental to the insecticidal activity of botanically derived extracts because these secondary metabolites directly influence toxicity, repellency, and feeding inhibition in storage pests.

#### **Alkaloids**

Alkaloids are nitrogen-containing secondary metabolites known for their potent bioactivity against insects. Their insecticidal effects primarily arise from interference with the insect nervous system. Many alkaloids inhibit acetylcholinesterase (AChE) or disrupt neurotransmission pathways, leading to impaired neural signalling, paralysis, and eventually death. Due to these neurotoxic



properties, alkaloids contribute significantly to the toxicity and repellency of plant-derived insecticidal extracts used in managing storage pests such as *Sitophilus* species (Isman *et al.*, 2006).

### Terpenoids

Terpenoids play a crucial role in botanical pest control due to their volatility and fumigant action. Monoterpenes—such as 1,8-cineole, limonene, citronellal, and  $\alpha$ -pinene—exhibit strong repellent and neurotoxic effects, influencing insect behavior and physiology. These compounds disrupt insect hormonal and endocrine systems, impair respiration, and alter neuromodulation, making them effective agents against stored-product pests. Terpenoids are especially valued for their rapid action and low persistence in the environment (Nerio *et al.*, 2010).

### Phenolics

Phenolic compounds, including flavonoids, tannins, and phenolic acids, serve as critical plant defenses and contribute to the antifeedant and growth-inhibitory properties of botanical insecticides. These metabolites can inhibit digestive enzymes such as amylases and proteases, reducing nutrient absorption in insects. Additionally, phenolics can induce oxidative stress through the generation of reactive oxygen species (ROS), which negatively affects insect survival, reproduction, and development. Their multifunctional mode of action makes phenolics pivotal in reducing the feeding efficiency and fitness of storage pests (Simmonds *et al.*, 2003).

### Saponins

Saponins are glycosides with both hydrophobic and hydrophilic components, enabling them to interact with and disrupt insect cell membranes. Their ability to form complexes with sterols leads to membrane leakage, reduced nutrient assimilation, and morphological damage to midgut tissues. This results in decreased feeding activity, growth retardation, and increased mortality. Saponins therefore contribute significantly to the insecticidal and growth-regulatory activity of plant extracts (Francis *et al.*, 2002).

**Table 1:** Phytochemical Compounds with Documented Biopesticidal Activity against Insect Pest

Phytochemical Compound	Plant species	Mode of Action	Target Insect Pests	Reference
Azadirachtin	<i>Azadirachta indica</i> (Neem)	Antifeedant, growth inhibitor, disrupts molting hormones	Grain weevils ( <i>Sitophilus spp.</i> ), aphids, caterpillars	Isman (2006)
Pyrethrin	<i>Chrysanthemum cinerariifolium</i>	Neurotoxic, disrupts sodium channels	Mosquitoes, beetles, moths	Casida and Quistad (1995)
Rotenone	<i>Derris spp.</i> , <i>Lonchocarpus spp.</i>	Mitochondrial electron transport inhibitor	Leaf beetles, aphids	Isman (2006)
Nicotine	<i>Nicotiana tabacum</i> (Tobacco)	Acetylcholine receptor agonist	Aphids, caterpillars, thrips	Ware and Whitacre (2004)
Allicin	<i>Allium sativum</i> (Garlic)	Broad-spectrum insecticidal, inhibits enzymes	Aphids, spider mites, armyworms	Chowdhury <i>et al.</i> , (2013)
Eugenol	<i>Syzygium aromaticum</i> (Clove)	Neurotoxic, disrupts sensory function	Houseflies, stored product pests	Pavela (2015)
Limonene	<i>Citrus sinensis</i> (Orange peel)	Fumigant, neurotoxic	Rice weevil ( <i>Sitophilus oryzae</i> ), ants	Regnault-Roger <i>et al.</i> , (2012)
Camphor	<i>Cinnamomum camphora</i>	Repellent, neurotoxic	Mosquitoes, cockroaches	Nerio <i>et al.</i> , (2010)

### Plant Extracts Used in the Management of Storage Weevils

A wide range of botanicals have been demonstrated to possess strong insecticidal properties against storage pests, particularly weevils of the genus *Sitophilus*. For instance, several East African plants including *Clausena anisata*, *Maesa lanceolata*, and *Croton macrostachyus* have shown exceptional bioactivity, with crude extracts producing 95–98% mortality of *Sitophilus zeamais* within



28 days and *C. anisata* completely suppressing F<sub>1</sub> progeny emergence, highlighting the significance of Rutaceae-derived metabolites in grain protection (Gindaba *et al.*, 2024). Essential oils from *Litsea cubeba* fruits also exhibit potent repellent, fumigant, and contact toxicity against *S. zeamais*, effects attributed to dominant monoterpenes such as citral and limonene (Xiong *et al.*, 2014). Similarly, *Gnidia kaussiana* root extracts particularly the non-polar hexane fraction show strong insecticidal activity against the storage beetle *Callosobruchus maculatus*, with evidence suggesting that diterpenoids and terpenoid esters contribute to toxicity and egg inhibition (Nukenine *et al.*, 2010). In addition, *Azadirachta indica* (neem) remains one of the most extensively studied botanicals in post-harvest pest management; neem seed oil, kernel extracts, and azadirachtin-rich fractions have consistently shown ovicidal, antifeedant, and growth-disrupting effects on species such as *S. zeamais* and *S. oryzae* (Ofuya *et al.*, 2006). Other food-grade botanicals such as *Allium sativum* (garlic) and *Ocimum gratissimum* (scent leaf) have also demonstrated utility in low-technology grain protection systems, with powder mixtures significantly reducing infestation and adult emergence of *C. maculatus* in stored cowpea (Ekeh *et al.*, 2013). More broadly, several common spices and aromatic leaves—including *Piper guineense*, neem leaf powders, and *Ocimum* species have been shown to suppress *S. zeamais* adult survival and reduce progeny production, supporting the expanding use of readily available plant materials in smallholder grain protection programs (Ajayi *et al.*, 2003). Collectively, these studies underscore the strong potential of diverse botanicals ranging from essential oils to crude powders to serve as eco-friendly, indigenous alternatives for managing storage weevils.

#### **Solvent Extraction Methods and Efficiency**

Solvent extraction methods play a crucial role in determining the types and quantities of phytochemicals recovered from plant materials, which in turn strongly influence the insecticidal efficacy of botanical preparations. In the study by (Gindaba *et al.*, 2024), a sequential solvent extraction approach was employed using petroleum ether, chloroform, acetone, methanol, and water to partition phytochemicals of varying polarity from the powdered plant material before bioassays against *Sitophilus zeamais*; the authors reported that non-polar and moderately polar fractions exhibited the highest insecticidal activity, demonstrating the selective enrichment of bioactive constituents through solvent choice. Similarly, research on *Litsea cubeba* fruit oil has shown that liquid-liquid fractionation into hexane, ethyl acetate, chloroform, and aqueous fractions produces extracts with markedly different bioactivities hexane and ethyl acetate fractions showed stronger contact toxicity and fumigant effects, whereas polar fractions tended to show weaker bioactivity indicating that monoterpenes and other non-polar compounds are likely responsible for most insecticidal actions (Xiong *et al.*, 2014).

Extraction method and solvent polarity strongly affect activity, as shown in the fractionation of *Litsea cubeba* oil, where non-polar fractions exhibited stronger contact toxicity while polar fractions contributed to fumigant and repellent effects (Xiong *et al.*, 2014). Finally, the physical form of the botanical product influences both potency and practicality: essential oils are typically more toxic but require specialized extraction, whereas crude leaf powders are cheaper, more accessible for smallholder farmers, and still effective when used at appropriate dosages (Odeyemi *et al.*, 2000). Together, these findings underscore that the effectiveness of plant-based insecticidal products depends not only on the plant species used but also on the extraction technique, solvent polarity, and fractionation process, all of which determine the specific phytochemical profiles responsible for storage pest control.

#### **Modes of Action of Plant Extracts on Storage Weevils**

Plant extracts exert their insecticidal activities against storage weevils through several interrelated mechanisms that act on different life stages. Contact toxicity is one of the primary modes of action, especially when powders or essential oils are applied directly to grain, allowing active phytochemicals to penetrate the insect cuticle, disrupt physiological processes, and ultimately cause mortality (Isman *et al.*, 2006). Many essential oils also exhibit strong fumigant toxicity due to their high content of volatile terpenoids, which diffuse through the grain headspace and kill insects without physical contact an attribute particularly useful for targeting pests such as *Sitophilus zeamais* hidden inside kernels (Nerio *et al.*, 2010).

Repellency is another important mode of action, with aromatic botanicals such as *Ocimum* species and *Litsea cubeba* producing volatile constituents that deter adult weevils from colonizing



treated grain, reducing oviposition and feeding (Xiong *et al.*, 2014). Some plant extracts also inhibit oviposition or suppress progeny development; *Clausena anisata* extract completely inhibited F<sub>1</sub> emergence of *S. zeamais* in the study by (Gindaba *et al.*, 2024), suggesting interference with egg viability or larval development. In addition, many plant secondary metabolites including alkaloids, terpenoids, flavonoids, and Saponins act as antifeedants or growth disruptors by impairing hormone regulation, digestive enzyme function, or nutrient absorption (War *et al.*, 2012). Synergistic effects between multiple compounds are also reported; combinations of *Allium sativum* (garlic) and *Ocimum gratissimum* powders exhibit stronger bioactivity against *Callosobruchus maculatus* than either plant alone, supporting the value of multi-component botanical mixtures (Ekeh *et al.*, 2013). Plant species differ markedly in potency, with powders of neem, basil, *Chromolaena*, *Tithonia*, and *Piper guineense* reducing *S. zeamais* infestation (Adedire *et al.*, 2003).

Plant-based extracts are increasingly recognized as promising alternatives to synthetic insecticides for the management of storage weevils, which are major pests of stored grains worldwide. These botanical extracts possess a diverse array of bioactive compounds that target storage weevils through multiple mechanisms, enhancing their effectiveness while reducing the risk of resistance development (Isman, 2006). Below are the principal modes of action by which plant extracts affect storage weevils:

#### **Neurotoxic effect**

Many plant extracts contain compounds that interrupt the nervous system of insects thereby disrupting nerve impulse transmission, blocking ion channels, or affecting neurotransmitter function. For instance, pyrethrins from *Chrysanthemum cinerariifolium* act by interfering with sodium channel function, leading to rapid paralysis and death of weevils. Similarly, Alkaloids like nicotine from *Nicotiana tabacum* bind to acetylcholine receptors as agonists, producing excessive stimulation that can lead to impaired nerve signal transmission (Changeux and Taly, 2022; Ware and Whitacre, 2004).

#### **Antifeedant and repellent activity**

Some plant extracts deter feeding behavior by affecting taste receptors or creating aversive responses or repel storage weevils, reducing their impact on stored products. Azadirachtin, a limonoid from neem (*Azadirachta indica*), is a well-known antifeedant that disrupts feeding and oviposition in weevils. Essential oils such as eugenol (from clove) and limonene (from citrus peel) also exhibit strong repellent properties, making grains less attractive to pests (Isman, 2006; Pavela, 2015).

#### **Growth regulation and developmental disruption**

Certain phytochemicals act as insect growth regulators, interfering with hormonal pathways responsible for molting and development. Azadirachtin, for example, disrupts the action of ecdysone (the molting hormone). **Limonoids** interfere with chitin synthesis resulting in abnormal development or failure to molt, ultimately reducing weevil populations (Isman, 2006).

#### **Respiratory inhibition**

Some plant-derived compounds such as quinones and rotenone inhibit cellular respiration in insect pests. Rotenone, isolated from *Derris* spp., interferes with the mitochondrial electron transport chain, impeding energy production and causing mortality in storage weevils (Isman, 2006).

#### **Enzyme inhibition**

Phytochemicals such as allicin from garlic (*Allium sativum*) and various phenolic compounds can inhibit key metabolic enzymes involved in digestion, detoxification, or metabolism in insects. **Protease, Cytochrome P450 and Acetylcholinesterase inhibitors** prevent protein digestion, reduce detoxification capacity and disrupt nerve function leading to reduced vitality and increased susceptibility to environmental stresses (Chowdhury *et al.*, 2013).



**Table 2: Modes of Action of Plant Extracts against Storage Weevils**

Plant Species (Source)	Phytochemical Compound	Mode of Action	Target Insect Pest	Reference
<i>Azadirachta indica</i> (Neem)	Azadirachtin	Antifeedant, growth regulator, disruption	Rice weevil ( <i>S. oryzae</i> )	Isman (2006)
<i>Chrysanthemum cinerariifolium</i>	Pyrethrin	Neurotoxic, sodium channel disruption	Maize weevil ( <i>S. zeamais</i> )	Casida and Quistad (1995)
<i>Derris spp.</i>	Rotenone	Respiratory inhibitor (mitochondrial electron chain)	Rice weevil ( <i>S. oryzae</i> )	Isman (2006)
<i>Citrus sinensis</i> (Orange Peel)	Limonene	Fumigant, repellent, neurotoxic	Rice weevil ( <i>S. oryzae</i> )	Regnault-Roger <i>et al.</i> , (2012)
<i>Syzygium aromaticum</i> (Clove)	Eugenol	Neurotoxic, contact toxicity, sensory disruption	Granary weevil ( <i>S. granarius</i> )	Pavela (2015)
<i>Allium sativum</i> (Garlic)	Allicin	Enzyme inhibition, repellent	Rice weevil ( <i>S. oryzae</i> )	Chowdhury <i>et al.</i> , (2013)
<i>Cinnamomum camphora</i> (Camphor)	Camphor	Repellent, neurotoxic	Maize weevil ( <i>S. zeamais</i> )	Nerio <i>et al.</i> , (2010)
<i>Nicotiana tabacum</i> (Tobacco)	Nicotine	Neurotoxic, acetylcholine receptor agonist	Rice weevil ( <i>S. oryzae</i> )	Ware and Whitacre (2004)

### Physical and ovicidal activity

Some plant extracts also work through physical means, such as blocking spiracles (breathing pores), affects mating behavior, egg development, or fertility through hormonal disruption or direct toxicity to reproductive organs or disrupting the integrity of the insect cuticle, leading to desiccation and death. For instance, **Phytoecdysones** mimic insect hormones and disrupt reproduction, **Steroids** interfere with sex pheromone production while alkaloids cause ovarian dysfunction thereby reducing the viability of weevil eggs and limiting population growth (Regnault-Roger *et al.*, 2012).

### Economic Values

Biopesticides play a significant economic role by reducing health-related expenses from pesticide poisoning, improving market access, and supporting sustainable agricultural growth. The use of botanical and microbial biopesticides such as neem-based formulations has been shown to reduce pest damage and increase marketable yield, thereby improving farmers' income while minimizing losses associated with synthetic-pesticide residues especially in export commodities like sesame, cocoa, and ginger (Ayilara *et al.*, 2023). Globally, countries such as India, Brazil, and the United States have demonstrated that large-scale adoption of biopesticides stimulates agribusiness growth, supports local manufacturing, and creates employment in formulation, distribution, and extension services. Brazil recorded one of the fastest-growing bioinput markets worldwide following targeted investment and regulatory support (FAO, 2020). For Nigeria, the economic potential of biopesticides is further enhanced by abundant raw plant materials and the opportunity for import substitution, reducing reliance on costly synthetic pesticides and conserving foreign exchange (Ashaolu *et al.*, 2022). Additionally, biopesticides help countries avoid the hidden economic costs of environmental contamination, loss of biodiversity, and public health burdens associated with chemical pesticides, costs that often outweigh any short-term savings from conventional agrochemicals (Chowdhury *et al.*, 2013).

The global biopesticides market is large and growing (estimates USD 6–8 billion in 2024 with projected double-digit CAGR through the 2020s), representing a substantial and expanding economic sector for manufacturers, distributors, and service providers (grandviewresearch.com).

Switching from synthetic pesticides to biopesticides cuts external costs linked to applicator and consumer health, water/soil contamination, and biodiversity loss—costs that peer-reviewed analyses and life-cycle studies (Li *et al.*, 2023). Use of lower-toxicity products reduces spending on medical treatment, environmental cleanup, and regulatory non-compliance fines. FAO programs highlight



operational and regulatory benefits when biopesticides replace hazardous pesticides (FAO, 2020). Growing consumer preference for residue-free, sustainable produce supports price premiums and market access (organic and sustainable supply chains), increasing farm revenues where biopesticides help meet certification requirements (grandviewresearch.com). Local production/formulation of plant-based biopesticides creates value chains and jobs at community scale.

## CONCLUSION AND RECOMMENDATION

Comparative research on plant-based treatments further indicates that efficacy is concentration and time-dependent, with higher doses and longer exposures producing greater mortality. Plant extracts offer a compelling, more sustainable alternative to synthetic pesticides for managing storage weevils such as *Sitophilus oryzae* and *S. zeamais*. A variety of botanicals (*Azadirachta indica*, *Ocimum basilicum*, *Zingiber officinale*, *Curcuma longa*, *Allium sativum*, and *Eucalyptus spp*) have demonstrated insecticidal, repellent, or growth-inhibitory effects in laboratory studies. Their efficacy depends heavily on extraction method, concentration, and exposure time. The complex modes of action, natural origin, and lower environmental impact of botanical extracts make them valuable tools for integrated pest management in grain storage. However, challenges such as standardization, formulation, stability, and large-scale adoption must be addressed.

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