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Minimizing post-harvest losses against coleoptera species: A review

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Abstract

This review focuses on the principal coleopteran beetles that cause post-harvest losses and the use of only botanical pesticides to control them. Food loss prevention during postharvest storage is critical for economic reasons. Integrated pest management, which includes the use of chemical (contact/residual) insecticides and fumigants, is now a generally recognised pest control technique, including postharvest infestation treatment. Because of the residue problem and health concerns to consumers, the use of synthetic chemical pesticides is either prohibited or restricted. Given the foregoing, there is a demand for plants that can serve as viable replacements to presently employed insecticides since they contain a large number of bioactive chemicals. According to the literature, the plant might be used to develop novel pesticides. As a result, insecticidal chemicals originating from plants have a lot of promise. The current state of botanical insecticides as grain protectants, as well as their method of action, are the subjects of this research.

Keywords: Botanical insecticides, coleopteran, post-harvest treatment, stored grains

Introduction

Beetles belong to the Coleoptera order of insects. The name "coleoptera" comes from the Greek words keleos, which means "sheath," and pteron, which means "wing." The term comes from the fact that most beetles have two pairs of wings, with the front pair, known as the "elytra," hardening and thickening into a sheath-like or shell-like protection for the rear pair and the beetle's back half. Coleoptera contains more species than any other order, accounting for over a quarter of all known living forms [1-3]. Beetles account for over 40% of all documented insect species (approximately 400,000 species) [4], and new species are found on a regular basis. There are particular species that are adapted to practically every kind of diet. Scarabaeidae is the world's biggest insect family, with about 30000 different species [5]. Coleoptera may be found in practically every natural environment, including vegetative foliage, such as trees and their bark, flowers, leaves, and underground near roots, as well as inside plants, such as galls and tissue, even dead or rotting ones [6]. Phytophagous beetles live in or on plants, wood, fungi, and a range of stored items, such as grains, tobacco, and dried fruits, in both their larval and adult phases. The beetle is a pest since many of the plants are vital for agriculture, forestry, and domestic usage [7]. Beetles are not simply pests; they may also be useful by reducing pest numbers. The ladybug (or ladybird) is one of the greatest and most well-known examples (family Coccinellidae). Aphid colonies are fed by both larvae and adults. Other ladybugs eat mealybugs and scale insects. They may graze on tiny caterpillars, immature plant bugs, honeydew, and nectar if typical food supplies are lacking [8]. The coleopterans have more species than any other order, accounting for over a quarter of all animal life forms [9]. There are around 4, 50,000 species of beetles, accounting for over 40% of all known insects [10]. The categorization of such a huge number of species presents unique challenges. Around 75% of beetle species are polyphagous in both their larval and adult stages, living in or on plants, wood, and a range of stored items [11-12]. Beetles can be regarded pests since many of these plants are essential for agriculture, forestry, and domestic usage, and some of them cause severe harm, including direct and indirect costs [13]. Several research workers have conducted investigations on various coleopteran families [14-15]. Pest issues have existed since the dawn of agriculture. Humans came into battle with phytophagous insects as soon as the area was cleansed of natural flora and substituted with a single variety of food plant [16-17]. Insect pest concerns in agriculture have been reported to be as ancient as agriculture itself [18]. However, during the last century, rapidly increasing population necessitated intensification of agriculture through irrigation facility expansion, introduction of high yielding varieties (HYVs), and increased application of agrochemicals, which increased land production while also increasing production lost to insect pests [19-20]. In India, traditionally, crops were planted exclusively during the monsoon season, with winter serving as a closed season for both crops and pests [21-22]. Insect pests harm crop plants by eating on them or by ovipositing on them. Some insect pest species are monophagous, meaning they only eat on plants of a single species [18-23]. Although there is typically one phytophagous bug species for every kind of green plant. The majority of insect orders are phytophagous, although over half of insect species are [21]. The assessment of agricultural losses owing to pests has been a challenging and controversial topic [24]. Pest-related agricultural losses are significant in both developed and developing nations [12]. Losses in North America, Europe, and Japan are estimated to be between 10 and 30 percent, but losses in underdeveloped countries are much greater [11-15]. Insect pests are predicted to inflict 336.6 billion rupees in yearly losses to key field crops and stored food grains [22]. As a result, it is critical to reduce pest-related losses by using effective pest control measures. Efforts have been made in this review to comprehend some of the world's biggest crop pests, particularly coleopteran beetles. Insect infestation during storage of food grains is a severe concern, especially in underdeveloped nations [25-26]. Insect losses include not only direct kernel eating, but also the build-up of exuviae, webbing, and cadavers. High amounts of insect detritus may cause grain to become unsuitable for human consumption, as well as a loss of food commodities in terms of both quality and quantity. Changes in the storage environment caused by insect infestations may result in warm, wet "hotspots" that provide ideal conditions for storage fungus, resulting in further losses. More than 20,000 species of field and store pests are thought to damage around one-third of the world's food output, worth more than $100 billion yearly [27-28], with the poor world suffering the greatest losses (43 percent). Insect pests can cause 20-30% quantitative and qualitative damage to stored grains and grain products in tropical zones and 5-10% in temperate zones [29]. For the past several years, India's food grain output surpassed 250 million tonnes, with roughly 20-25 percent of food grains destroyed by stored grain insect pests. Entomologists all across the world have long sought to effectively manage and remove stored grain pests from food commodities. The Indian subcontinent's major pests of stored grain and pulses are divided into two groups: primary pests, which are capable of penetrating and infesting intact kernels of grain and developing immature stages within the kernel, and secondary pests, which cannot infest the whole grain but feed on broken kernels, debris, high moisture weed seeds, and grain damaged by primary pests. The juvenile stages of secondary pest species are usually located outside of the grain. It's a common misconception that secondary intruders can't start an infestation. The important primary pests are the rice weevil, *Sitophilus oryzae* (L.), granary weevil, *Sitophilus granaries* (L.), (Coleoptera: Curculionidae), lesser grain borer, *Rhyzopertha dominica* (F.), (Coleoptera: Bostrichidae), Khapra beetle, *Trogoderma granarium* (Everts), (Coleoptera: Dermestidae), and the pulse beetle *Callosobruchus chinensis* (L.) (Coleoptera: Bruchidae). The secondary pests are rust-red flour beetle, Tribolium cas- taneum (Herbst), (Coleoptera: Tenebrionidae), rusty grain beetle, Cryptolestes ferrugineus (L.), (Coleoptera: Cucujidae), sawtoothed grain beetle, *Oryzaephilus surinamensis* (L.), (Coleoptera: Silvanidae), mites, (Acarina: Tetranychidae) Liposcelis corrodens, and (Psocoptera: Liposcelidae). Table 1 provides a detailed summary of the principal beetle pests of agricultural crops, including their name, host plant, distributions, cause of damage, and pest characteristics.

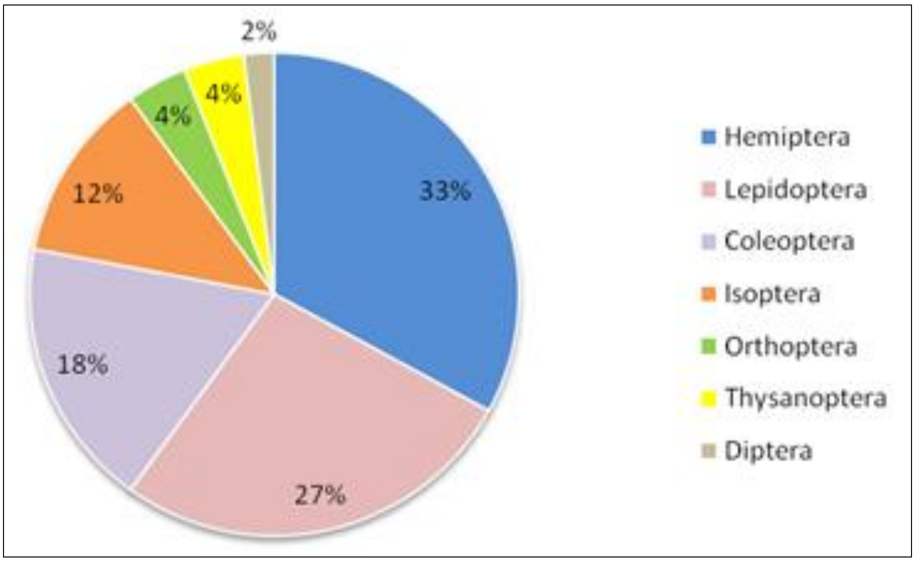


Fig 1: Insect Pest Percentage in different region of India

Table 1: List of major stored grain insect pest of coleoptera sp.in different regions of India

Insect pest	Host grain	Indian region
Rice Weevil		
Sitophilus oryzae	Rice, wheat	East region
Sitophilus granarius	Rice. Wheat, maize	East region

Khapra Beetle		
Trogoderma granarium	Rice, maize, pulse, wheat	West region
Trogoderma glabrum	Rice, maize, pulse, wheat	
Lesser Grain Borrer		
Rhyzopertha dominica	Maize, Rice, Wheat	West region
Flour beetle		
Tribolium castanum	Damage grain	West region
Tribolium confusum	Damage grain	
Pulse beetle		
Callosobruchus chinensis	Whole pulse grain, beans	South region
Callosobruchus maculatus	Whole pulse grain, beans	
Angonmois grain moth		
Sitotroga cerealella	Maize, Jowar, wheat. barley	North Region
Rice Moth		
Corcyra cephlonica	Rice, Whole cereals, pulse	South region
Maize Weevil		
Sitophilus zeamais	Wheat flour, peanut	North Region

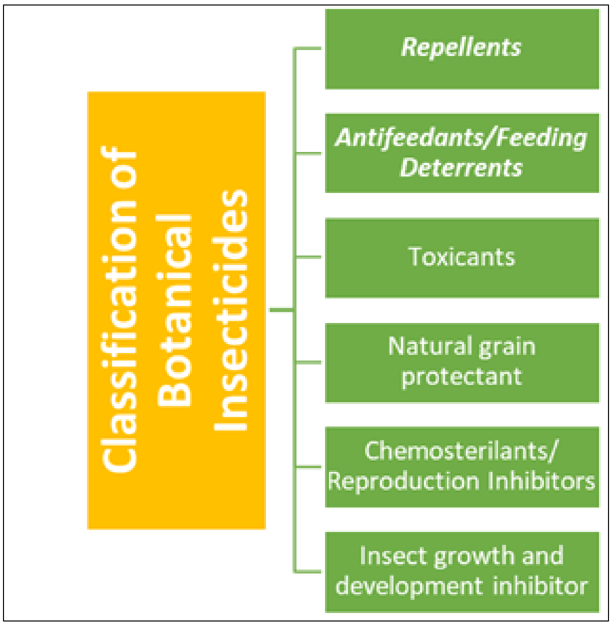
Pesticides for infestation control and their side effects

Synthetic pesticides have been widely employed in grain facilities to control stored product insect pests since the 1950s. Fumigants like methyl bromide, phosphine, cyanogens, ethyl formate, or sulfuryl fluoride destroy all stages of stored product insects in a commodity or storage building quickly. Fumigation is still one of the most efficient ways to prevent insect pests from destroying stored goods. However, pests acquire resistance, not preserved items, and fumigation resistance is slowly increasing. In Australia and India, phosphine resistance is so great that it might lead to control failures. Methyl bromide has been discovered as a major cause to ozone depletion, and it has been prohibited in wealthy countries, with developing countries agreeing to reduce consumption by 20% by 2005 and phase it out by 2015. Malathion, chlorpyrifos, and deltamethrin are contact insecticides that are sprayed directly on grain or storage structures to protect them against infection for several months. Insecticide resistance is becoming more common in the protection of stored goods. At least 500 insect and mite species have been shown to be resistant to one or more pesticides. Pesticide resistance to protect grain and other stored foods is prevalent, affecting all pesticide classes and the majority of important pests. Because of significant insect population resistance, several contact pesticides have become ineffective. Malathion resistance is common in Canada, the United States, and Australia. Insecticide resistance was discovered in stored product pests, including cyclodienes, chlorpyrifos, cyanophos, carbamates, carbaryl, cypermethrin, dichlorodiphenyltrichloroethane, deltamethrin, diazinon, dichlorovos, ethylene bromide, ethyl formate organophosphates, permethrin, pyrethrins, and propoxur. Chemical pesticides are effective, but their continued use has resulted in residual toxicity, environmental pollution, and an unfavourable effect on food, in addition to human side effects. Their indiscriminate usage has resulted in the development of resistant strains as well as the accumulation of harmful residues on food grains used for human consumption, posing health risks. Several pesticides have been prohibited or limited in their usage as a result of these issues.

Botanicals as a synthetic pesticide alternative

The demand for effective biodegradable pesticides with better selectivity has grown in response to the growing issues of pesticide resistance and residue, as well as pollution of the biosphere, connected with the widespread use of broad-spectrum synthetic pesticides. This increased awareness has sparked global interest in the development of alternative techniques, including the discovery of novel pesticides. Newer pesticides, on the other hand, will have to fulfil wholly different requirements. They must be pest-specific, non-phytotoxic, mammalian-safe, environmentally benign, less susceptible to pesticide resistance, comparably less costly, and locally available. This has prompted a re-evaluation of century-old traditions of preserving stored goods using plant-derived compounds that have been shown to repel insects [29]. Plant-derived compounds degrade more quickly, are less prone to pollute the environment, and may be less hazardous to animals. There are several plant chemicals that are extremely poisonous. As a result, researchers are currently looking for new classes of naturally occurring pesticides that may be compatible with contemporary pest management methods [26]. Pesticides have been used to safeguard crop yield since prehistoric times. Farmers in Egypt and India mixed the grain with fire ashes. False hellebore (Veratrum album) was employed as a rodenticide by the ancient Romans, and the Chinese are credited with finding the insecticidal capabilities of Derris species, while pyrethrum was used as an insecticide in Persia and China [28]. Locally accessible plants are now widely employed to safeguard stored items against pest infestation in many regions of the world. Neem leaves and seed were employed by Indian farmers to combat stored grain pests. Cowpeas are traditionally threshed and then combined with sieved ash and stored in mud granaries or clay jars in northern Cameroon. Traditional stored grain protectants in eastern Africa include the leaves of the wild plant *Ocimum* suave and the cloves of Eugenia aromatic. In Rwanda, farmers store edible beans in traditional closed structures (imboho), and full leaves of *Ocimum canum* are commonly added to the stored food to minimise insect damage. Food grains like rice and wheat are traditionally kept in various south Asian nations by combining them with 2% turmeric powder. Oils have also been used to control pests in stored goods for centuries. For millennia, botanical pesticides including pyrethrum, derris, nicotine, citronella oil, and other plant extracts have been utilised. Oilseeds are produced by more than 150 kinds of forest and roadside trees in India, and have been utilised for illumination, medicinal uses, and insecticides since ancient times. Turmeric, garlic, Vitex negundo, gliricidia, castor, Aristolochia, ginger, Agave americana, custard apple, Datura, Calotropis, Ipomoea, and coriander are some of the other extensively utilised botanicals for agricultural pest management and repellence. Talukder [29] has identified 43 plant species as insect repellents, 21 as insect feeding deterrents, 47 as insect toxicants, 37 as grain protectants, 27 as insect reproduction inhibitors, and 7 as insect growth and development inhibitors. Psyche-potential and anti-ovipositional characteristics were found with eighteen species against *Sitophilus oryzae*.

Classification of botanical insecticides



Jacobson [27] categorised plant components into six classes based on physiological effects on insects: repellents, feeding deterrents/anti-feed ants, toxicants, growth retardants, chemo-sterilants, and attractants. Since the 1980s, there has been a greater emphasis on the toxicants and grain protectants that affect the action of essential oils, extracts, and their components.

4.1 Repellents

The repellents are appealing compounds because they provide protection with low environmental effect by triggering olfactory or other receptors to drive insect pests away from treated materials. Plant-based repellents are deemed safe in pest management, reducing pesticide residue and ensuring the safety of humans, food, and the environment [25, 29]. Plant extracts, powders, and essential oils from several bioactive plants have been found to be insect repellant against stored grain pests [25]. For example, The essential oil of Artemisia annua, was shown repellent to *Tribolium castaneum* and *Callosobruchus* maculates.

4.2 Antifeedants/Feeding Deterrents

Antifeedants, sometimes known as "feeding deterrents," are compounds that prevent or interrupt insect eating by making the treated materials unappealing or unpleasant to insects. Glycosides of steroidal alkaloids, aromatic steroids, hydroxylated steroid meliantriol, triterpene hemiacetal, and other naturally occurring antifeedants have been identified [27]. Spodoptera litura synergism, or cumulative actions of a mixture of monoterpenoids from essential oils against Spodoptera litura larvae, has been documented. The root bark of Dictamnus dasycarpus was found to provide strong feeding deterrent against two stored-product insects in a study of many therapeutic plants.

4.3 Toxicants

Despite increased study devoted to the creation of synthetic insecticides, research on novel plant-based toxicants has not decreased in recent years. Many plant products are harmful to stored product insects, according to reports from throughout the world. Plant extracts from 50 different wild plant species in southeastern Spain were screened for insecticidal activity against *Tribolium castaneum* by Pascual-Villalobos and Robledo and four species, Anabasis hispanica, Senecio lopezii, Bellardia trixago, and Asphodelus fistulosus, were found to be promising. Methylene allyl disulfide and diallyl trisulfide, two primary components of the essential oil of garlic, Allium sativum, were shown to be powerful toxicants and fumigants against Sitophilus zeamais and *Tribolium castaneum*. Nicotine, an active component of Nicotiana tabacum, is a potent organic poison that operates as a contact-stomach toxin with insecticidal characteristics, according to Rahman. Of course, this chemical is extremely harmful to humans. Anise, cumin, eucalyptus, oregano, and rosemary essential oil vapours were also identified as fumigants, causing 100 percent death of Tribolium confusum and Ephestia kuehniella eggs. Oils, extracts, and bioactive components from many *Ocimum* species have been shown to have insecticidal properties against a variety of insect species. Table 2 is a list of numerous recognised toxicants of plant origin that have been found to be useful in the management of stored-product insect pests.

4.4 Natural Grain Protectants

Plant products have been employed as natural protectants of stored grains since ancient times. Leaf, bark, seed powder, or oil extracts of plants, when combined with stored grains, lower oviposition rates and limit adult emergence of stored product insects, as well as seed damage rates. The most promising natural grain protectants were found in the plant groups Annonaceae, Asteraceae, Canellaceae, Labiatae, Meliaceae, and Rutaceae. The most well-known example is the Indian neem plant, which has been used to protect stored grain against infection using various elements such as leaves, crushed seeds, powdered fruits, oil, and so on [25]. At a rate of 1 to 2 percent kernel powder or oil, neem oil and kernel powder provided good grain protection against stored grain insect pests such as *Sitophilus oryzae*, Tribolium cataneum, *Rhyzopertha dominica*, and *Callosobruchus chinensis*. For 180–330 days, neem oil adhering to grain develops a homogeneous layer around the grains, protecting them against storage pests. Dried leaves of Azadirachta indica were blended with stored grains for insect protection, according to Yadava and Bhatnagar. Azadirachtin is an active component found in the neem plant that protects grains from insect infestation. Decalepis hamiltonii root powder extracts were used with stored grains for protection against several stored grain insect pests. Wheat was protected for up to 9 months by 18 species without impairing seed germination. Plant leaves and allelochemicals such as azadirachtin, nicotine, and rotenone have traditionally been utilised as grain protectants in regions of eastern Africa [29]. Rauvolfia serpentina, *Acorus calamus*, and Mesua ferrea powders are used to protect grains against *Rhyzopertha dominica*. Only 16 plants were identified as grain protectants in a survey conducted in Ghana's northern semiarid areas. In Africa, the grain-protectant potential of several plant derivatives, particularly plant oils, against key stored-product pests was also discovered to be highly promising, reducing the dangers associated with pesticide use. In northern Cameroon, the essential oils of Xylopia aethiopica, Vepris heterophylla, and Luppia rugosa are used to preserve stored grains from insect pests. To protect grains against *Callosobruchus* maculatus, citrus peel components were used. Coconut oil was reported to be effective against *Callosobruchus chinensis* when administered at 1% to Vigna radiata (green gramme) throughout a six-month storage period. Menthol formulations were utilised to protect pulse grain from *Callosobruchus chinensis* assault. Spinosad, a naturally occurring insecticide derived from the actinomycete Saccharopolyspora spinosa, has a high efficacy, a broad insect pest spectrum, low mammalian toxicity, and a minimal environmental profile, making it one of the most effective stored-grain insecticides currently available.

4.5 Chemosterilants/Reproduction Inhibitors
Plant components, oil, extracts, and powder combined with grain were found to lower insect oviposition, egg hatchability, postembryonic development, and progeny production. The reproduction inhibitory properties of 43 plant species have been found against stored product insects. Plant compounds, such as essential oils, have also been shown to cause insect egg death. Many insect repellents are found in ground plant parts, extracts, oils, and vapour.

4.6 Insect Growth and Development Inhibitors
Plant extracts had a negative impact on insect growth and development, reducing larval pupal and adult weight, lengthening larval and pupal durations, and reducing pupal recovery and adult eclosion. According to Rajasekaran and Kumaraswami, grains coated with plant extracts entirely stopped *Sitophilus oryzae* from growing. Plant derivatives also diminish larval and pupae survival rates, as well as adult emergence. Plant compounds also prevented the development of eggs and juvenile stages inside grain kernels. The crude extract significantly slowed larval growth, produced cuticle melanization, and caused high mortality in adults.

Botanical insecticides properties
The botanical insecticides that have primarily been used and are commercially available include ryania, rotenone, pyrethrin, nicotine, azadirachtin, and sabadilla (Tables 2 and 3).

Table 2: List of natural insecticides and toxicity

Natural insecticides	Insect toxicity*	Mammalian toxicity Oral (rat) LD_{50} (mg/kg b.w.)
Anethole	C, S	2090
β-asarone	C, S	275
Azadirachtin	IGR, R	13000
Carvacrol	C	810
1,8-Cineole	C, F	2480
Cinnamaldehyde	C	1160
Cuminic aldehyde	C, S	1390
Eugenol	C, F	500
Nicotine	C	50
Pyrethrin I and II	C, S	1200
Rotenone	S	350
Ryania	C, S	750
Sabadilla	C, S	5000
Spinosad	C	3738

*C: contact, S: stomach poison, F: fumigant, IGR: insect growth regulator, and R: repellent.

1. Ryania
The active ingredients in ryania come from the roots and woody stems of the Trinidadian plant Ryania speciosa. Ryania has a mild toxicity in mammals, with a median fatal dosage (LD_{50}) of 750 mg/kg, and acts as a stomach and contact poison. Among the botanical insecticides, it has a long residual action. This botanical pesticide works by binding to the calcium channels in the sarcoplasmic reticulum, which affects muscles. Calcium ions pour into the cells, and the cells die extremely quickly. Ryania is most effective against caterpillars (such as the codling moth and maize earworm), but it is also effective against a variety of insects and mites, including the potato beetle, lace bugs, aphids, and squash bug.

2. Rotenone
Rotenone is extracted from the roots of two legumes native to the East Indies, Malaya, and South America: Lonchocarpus sp. and Derris sp. Rotenone is a moderately toxic plant pesticide with a lethal dose for animals of 132 mg/kg. Rotenone, in fact, is more hazardous to animals than carbaryl and malathion, two extensively used synthetic pesticides. Rotenone is also very harmful to fish. This natural pesticide has a contact and stomach poisoning effect. Rotenone is a slower-acting botanical pesticide than most others, requiring several days to kill bugs, although pests cease eating practically immediately. In the presence of air and sunshine, it quickly degrades. Rotenone inhibits respiration by interfering with electron transport on complex I. Rotenone has a wide range of insect and mite pest activities, including leaf-feeding beetles, caterpillars, lice, mosquitoes, ticks, fleas, and fire ants.

3. Pyrethrin/Pyrethrum
Pyrethrin I and II extracted from the seeds or flowers of *Chrysanthemum cinerariaefolium*, a plant native to Africa, Ecuador, and Kenya. Pyrethrin is not poisonous to mammals. Cats, on the other hand, are extremely sensitive

to pyrethrin poisoning. Pyrethrin's LD50 ranges from 1200 to 1,500 mg/kg. Pyrethrin is a fast-acting pesticide that provides practically rapid "knockdown" of insects after treatment. It functions as a contact poison as well as a stomach poison. Because the substance has a brief residual activity and degrades fast in sunshine, air, and moisture, it may be necessary to apply it frequently. Pyrethrin can be utilised up to harvest because there is no need to wait for food crops to mature before applying it. Pyrethrin kills insects by disrupting the sodium and potassium ion-exchange mechanism in insect neurons, which prevents nerve impulses from being sent normally. Flies, fleas, beetles, and spider mites are among the insects and mites that are affected by pyrethrin.

4. Nicotine

Nicotine, derived from Nicotiana tabacum, is one of the botanical insecticides that is hazardous to animals, having an LD50 of 50 to 60 mg/kg. Humans are highly vulnerable to it. Nicotine is a contact poison because it is a fast-acting nerve toxin. It kills insects (and people) by binding to receptors at nerve synapses (junctures) and mimicking acetylcholine (Ach) at nerve-muscle junctions in the central nervous system. Nicotine sprays have the potential to hurt or kill certain plant species, such as roses. Aphids, thrips, leafhoppers, and spider mites are among the soft-bodied insects and mites that are particularly susceptible to nicotine. Nicotine resistance is common in caterpillars.

5 Azadirachtin

Azadirachtin derived from the Azadirachta indica tree, which found in India and Africa. With an LD50 of 13,000 mg/kg, azadirachtin has the lowest mammalian toxicity of all commercial botanical pesticides. When applied to the leaves of plants, azadirachtin has "some" systemic action. Beneficial insects and mites are usually unaffected by the substance. Azadirachtin is a feeding deterrent, insect growth regulator, repellant, and sterilant with the potential to impede oviposition. Stored grain pests, aphids, caterpillars, and mealybugs are all attracted to the substance.

6. Sabadilla

Sabadilla is derived from the seeds of the Venezuelan shrub Schoenocaulon officinale. With a mammalian LD_{50} of 5,000 mg/kg, sabadilla is one among the least lethal registered plant insecticides. Sabadilla is a gastrointestinal toxin and a contact toxicant. The substance has low residual action and dissolves swiftly in sunshine and moisture, similar to other botanical insecticides (rainfall). Sabadilla causes loss of nerve function, paralysis, and death by damaging nerve cell membranes. It kills caterpillars, leafhoppers, thrips, stink bugs, and squash bugs.

7. Avermectins

Avermectins are macrocyclic lactones derived from the actinomycete Streptomyces avermitilis, with a fatal dose of 50 percent in the 10–11.3 mg/kg range for rats. This chemical is particularly effective against agricultural pests, with lethal concentrations of 90% (LC90) in the range of 0.02 ppm for mites, and has relatively low toxicity for stored product pests. It works against domestic animal intestinal parasites. In insects and mites, avermectins prevent GABA from being released at the neuromuscular junction. After exposure, visible activity such as eating and egg laying ceases quickly, but death may take many days.

8. Spinosads

Spinosad is a combination of spinosyn A and spinosyn D that was first isolated from Saccharopolyspora spinosa, a soil Actinomycete. Spinosad is effective against a wide variety of caterpillars, leaf miners, and foliage-feeding insects. Spinosyns have a unique method of action, principally targeting binding sites on nicotinic acetylcholine receptors that are different from those targeted by conventional insecticides, resulting in acetylcholine neurotransmission disruption.

9. Asarone

Asarone is a natural insecticide derived from the *Acorus calamus* L. plant. This compound has fumigant and contact toxicity against adults of *Sitophilus oryzae*, Lasioderma serricorne, and *Callosobruchus chinensis*. Some investigations have found that the compounds have carcinogenic and mutagenic properties *in vivo* and *in vitro*. In vitro, this chemical also causes structural chromosomal aberration in human cells. The chemical is unsuitable for grain treatment because of its mammalian toxicity

Table 3: List of insecticidal active principles of plants

Plant species	Common name of plant species	Active principle	Insect toxicity	Insect species	References
Annona reticulate	Custard apple	Anonaine	Contact	*Callosobruchus chinensis*	[30]
Azadirachta indica	Neem	Azadirachtin	Contact: IGR	*Stored grain pests, aphids*	[31]
Foeniculum vulgare	Common fennel	E-Anethole	Contact	*Sitophilus oryzae, Callosobruchus chinensi*	[32]
Acorus calamus	Sweet-flag	β-Asarone	Contact	*Stored grain pests*	[51]
Acorus gramineus	Grassy-leaved sweet flag	Z-Asarone	Contact	*Sitophilus zeamais*	[34]
Chamaecyparis obtuse	Hinoki cypress	Bornyl acetate	Contact	*Sitophilus oryzae*	[35]
Ocimum kilimandscharicum	Camphor basil	Camphor	Contact	*Sitophilus oryzae*	[36]
Baccharis salicifolia	Mule fat	(+)-3-Carene	Contact	*Tribolium castaneum Sitophilus oryzae*	[36]
Thujopsis dolabrata	Hiba	Carvacrol	Contact; fumigant	*Sitophilus oryzae, Callosobruchus chinensis*	[37]
Carum carvi	Caraway	Carvone	Contact	*Rhyzopertha dominica*	[38]
Cinnamomum aromaticum	Cassia	Cinnamaldehyde	Contact	*Tribolium castaneum, Sitophilus zeamais*	[39]

Conyza dioscoridi	Argentine fleabane	Dioctyl hexanedioate	Contact	*Tribolium castaneum, Sitophilus oryzae*	[40]
Citrus	*Lemon*	Eugenol	Fumigant	*Sitophilus oryzae*	[41]
Foeniculum vulgare	Common fennel	Estragole	Contact	*Lasioderma serricorne, Sitophilus oryzae*	[42]
Foeniculum vulgare	Common fennel	(+)-Fenchone	Contact	*Sitophilus oryzae Lasioderma serricorne*	[42]
Chenopodium ambrosioides	Mexican tea	Hexa decane	Contact	*Tribolium castaneum, Sitophilus granaries*	[43]
Convolvulus arvensis	Bindweed	Hexadecanoic acid	Contact	*Sitophilus oryzae, Rhyzopertha dominica*	[43]
Ocimum canum Sims	Hoary basil	Linalool	Fumigant	*Tribolium castaneum, Sitophilus granaries*	[44]
Citrus	*Lemon*	Limonene	Contact	*Tribolium castaneum*	[45]
Baccharis salicifolia	Mule fat	(−)-Limonene	Contact; fumigant	*Tribolium castaneum*	[42]
Nicotiana tabacum	Tobacco	Nicotine	Contact	*Mites, aphids, thrips, leafhopper*	[46]
Tanacetum cinerariaefolium	Dalmatian chrysanthemum	Pyrethrin I and II	Contact; stomach poison	*Stored grain pests, crop pests*	[47]
Baccharis salicifolia	Mule fat	β-Pinene	Contact	*Tribolium castaneum*	[35]
Baccharis salicifolia	Mule fat	α-Pinene	Fumigant	*Tribolium castaneum*	[45]
Lonchocarpus sp.	Lancepod	Rotenone	Contact; stomach poison	*Crop pests, lace bugs, Sitophilus oryzae*	[48]
Ryania speciosa	Synonym	Ryania	Contact; stomach poison	Potato beetle, aphids, lace bugs, stored grain pests	[49]
Schoenocaulon officinale	Sabadilla	Sabadilla	Contact; stomach poison	Stinks, thrips, squash bugs, leaf hoppers, caterpillars	[50]

Challenges to the Utilization of Botanicals Pesticides

Secondary metabolites found in many plant species are effective against a variety of insect species. Not only are certain of the plants (such as neem trees) of great significance as sources of phytochemicals for grain/crop protection that is more ecologically friendly. Phytochemical compounds can boost rural farmers' income while also improving food safety and quality.

Botanicals can help manage many of the world's damaging pests and illnesses, as well as minimise erosion, desertification, deforestation, and possibly even lower human population by functioning as spermaticicide (although many cultures and faiths will consider this a huge negative consequence). Although the applications of botanical pesticides appear to be nearly limitless, many specifics remain unclear. Before their full potential can be achieved, numerous hurdles must be conquered and many doubts must be cleared. These obstacles may appear insurmountable, yet they pose intriguing challenges to the scientific and economic development community. Solving the following challenges and uncertainties might result in a significant new resource that benefits much of the globe. These obstacles include:

1. Lack of knowledge and understanding of the effectiveness of botanicals in pest management. Because of their sluggish action and lack of quick knockdown impact, plant-derived treatments (both "home-made" and commercial ones) continue to be questioned for their efficacy.
2. Genetic variability of plant species in various environments.
3. Natural product registration and patenting are challenging, and botanical pesticide products are not standardised.
4. Economic risks arising from seasonal seed supply, the perennial character of most botanical trees, and variations in potency with respect to regional constraints.
5. Because there is no way to automate the act of collecting, storing, or managing the seeds, leaves, or flowers from some perennial trees; handling challenges.
6. When exposed to direct sunshine, the active components become unstable; Commercial pesticide dealers use strong promotion to compete with synthetic pesticides, and commercially produced botanicals are more expensive and less commonly available than synthetic insecticides.
7. Although advantageous in certain ways, quick deterioration necessitates more accurate scheduling or more frequent applications. Some botanicals lack data on their usefulness and long-term (chronic) mammalian toxicity, and tolerances have yet to be established for others.

Summary and Conclusion

Several writers have studied the insecticidal (grain-protecting) capabilities of plant products against a variety of stored-product insect pests. The findings clearly suggest that grain protection solutions may be developed with less synthetic chemical pesticide use. The key advantages of botanical pesticides are that they are environmentally friendly, easily biodegradable, and harmless to nontarget creatures, and that many plant-derived natural insecticides may be made with locally accessible raw ingredients. Numerous plant insecticides have been investigated in the laboratory.

The focus of research should not only be on their efficacy, but also on mammalian toxicity, insect mechanism of action, seed germination, nutritional quality, seedling development, and chemical stability. Plant-based pesticides might be used to produce innovative compounds with extremely specific targets for long-term insect pest control in stored grains.

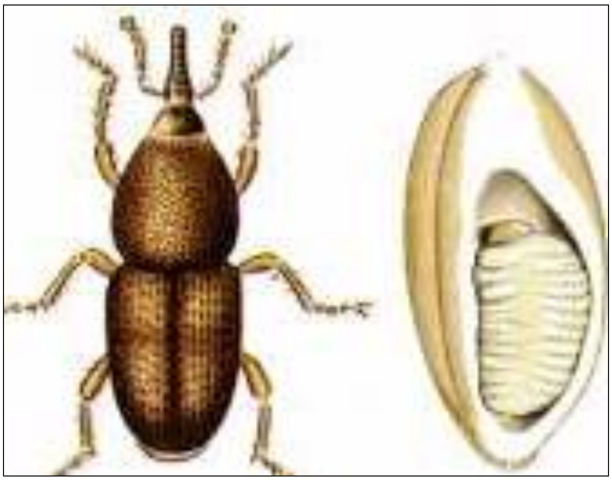


Fig 2: Rice Weevil *Sitophilus oryzae* (L) (=*Calandra oryzae* L.)

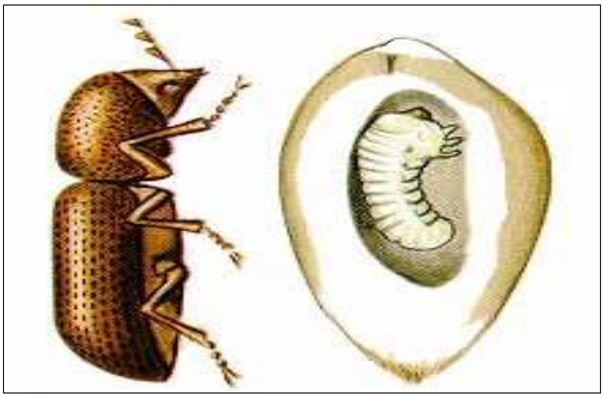


Fig 3: Lesser Grain Borer *Rhizopertha dominica* (F.)

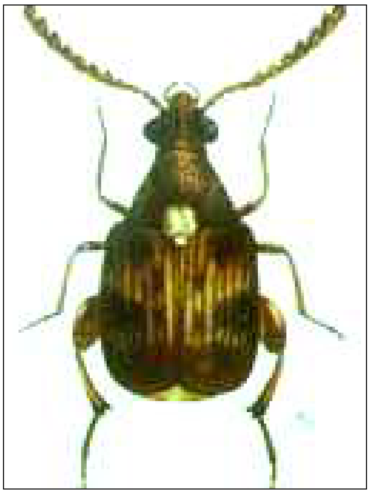


Fig 4: Pulse beetles: *Callosobruchus chinensis* (L.) and *C.maculatus* (F.)

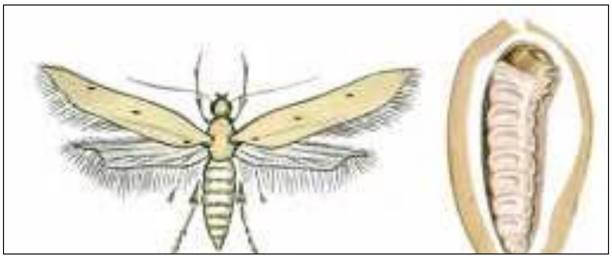


Fig 5: Angoumois Grain Moth *Sitotroga cerealella*

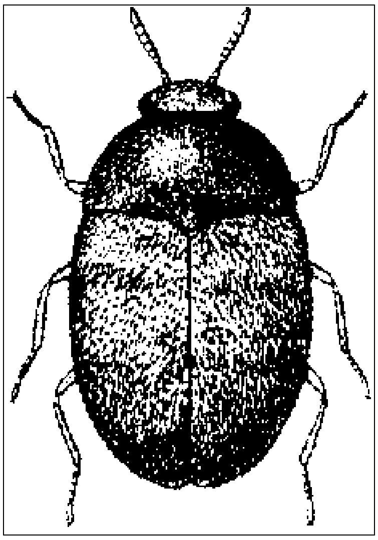


Fig 6: Khapra Beetle *Trogoderma granarium*

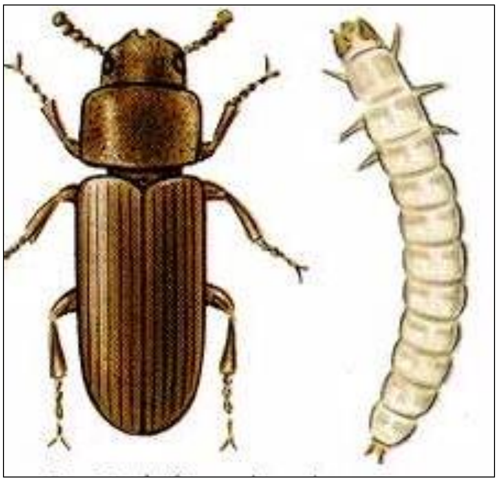


Fig 7: Red Flour Beetle *Tribolium castaneum* (Herbst)

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