International Research Journal of Biological Sciences ______________________________ ISSN 2278-3202
Vol. **14(2),** 46-61, May **(2025)** *Int. Res. J. Biological Sci.*

Review Paper

Reasons led to reconsideration of botanicals as stored grain insect pest control agents

Vasudha Lingampally[1*], V.R. Solanki[2] and S. Sabita Raja[1]
[1]Department of Zoology, Nizam College, Osmania University, Hyderabad, Telangana, India
[2]Department of Zoology, University College of Science, Saifabad, Osmania University, Hyderabad, Telangana, India
vasudhav.lingampally@gmail.com

Available online at : www.isca.in, www.isca.me
Received 10th November 2024, revised 14th February 2025, accepted 6th April 2025

Abstract

Ensuring the safety of food grains poses a significant and pressing challenge for grain handling organizations and experts in stored product entomology worldwide. Insects are universally recognised as the primary adversaries of stored grains, as they not only cause direct damage but also create an environment conducive to secondary infestations, primarily by fungal pathogens. Synthetic insecticides and fumigants have demonstrated higher efficacy in managing insect pests that affect stored grains. However, their widespread and indiscriminate use over many years, aimed at reducing post-harvest losses and preserving grain quality, has resulted in several adverse outcomes. These include the development of genetic resistance in pest species, lingering residues in stored grains, safety hazards during handling, pollution of storage environments, health concerns for humans, and detrimental impacts on the environment, thereby jeopardising the sustainability of ecosystems. These undesirable consequences have driven researchers to seek safer, efficient, and nontoxic grain protectants. Natural products derived from plants are increasingly gaining recognition as promising bio rational substitutes for synthetic insecticides in the control of postharvest insect pests. There has been a growing interest in various regions across the globe in investigating botanicals as a new approach to safeguarding grains. This review primarily focuses on the reasons that have sparked renewed scientific curiosity in utilising botanicals as stored grain insect pest control agents. It explores botanicals as an ecofriendly alternative to synthetic insecticides for stored grain insect pest management and provides an overview on the use of botanicals as stored grain insect pest control agents. This review also summarises the obstacles, constraints linked to the commercialization of botanicals as grain protectants.

Keywords: Botanicals, Stored grain insect pests, Postharvest losses, Grain protectants, Synthetic insecticides, Insecticide resistance, Integrated pest management, Pest control agents.

Introduction

Ensuring the safety of food grains stands as a paramount challenge faced by global grain handling organizations and experts in stored product entomology. Preserving food grains deserves equal attention as their efficient production. It is supported by the fact that "post-harvest losses are directly proportional to the backwardness of a nation". Prevention of food grain losses in developing countries could greatly reduce or eliminate the need to import food grains[1,2].. Grains must be stored between harvests to ensure a steady supply throughout the year and to maintain their quality until needed. It is estimated that 60-80% of grain produced in tropics is stored at the farm level[3].

Grain storage often results in both quantitative and qualitative losses due to physical, chemical, and biological factors, particularly pests like insects, rodents, birds, and microorganisms[4,5]. Poor storage facilities and insect pest damage during storage, transportation, and shipping are major concerns, across the world[6] especially in developing countries[7,8]. Insect pests cause significant destruction of stored food grains globally, leading to substantial losses in crop production for farmers[9]. Post-harvest losses resulting from insects remain a huge challenge[10,11]. Insects are considered the most significant pests of stored grain worldwide, as they not only cause direct damage but also generate conditions conducive to secondary infestation by rot organisms, primarily fungi[12,13].

Post-harvest losses, mainly caused by storage pests, is a major threat to global food security and lead to significant economic implications. In developed countries, these losses account for up to 9%, while in developing nations, they can reach as high as 20%[14]. A World Bank study highlights that approximately 12-16 million tonnes of food grains are lost annually due to storage pests, a quantity sufficient to feed nearly one-third of the global population[15]. India, being the second-largest producer of food grains with an average annual production of 250 million tonnes, faces substantial post-harvest losses. It is estimated that 11-15% of the total production, amounting to 27.5 to 37.5 million metric tonnes per year, is lost due to various factors[16]. These losses translate to over 50 billion INR (exceeding $1 billion) annually[17], with insect-related losses alone contributing around 17 billion INR ($364 million)[18]. Such post-harvest grain losses in India could potentially feed 70-100 million people, approximately one-third of the country's poor population[19,20].

While advances in production technology have led to a consistent increase in grain production, inadequate storage practices have resulted in significant grain losses. The presence of insect pests in stored grain is a major concern as they inflict substantial damage on agricultural produce held in storage. In fact, their impact on stored grains post-harvest is often comparable to the damage caused by crop pests during the growing season. On a global scale, annual grain losses due to insect damage following harvest are estimated to range between 10% and 40%[21-23]. The financial impact caused by the feeding activities of pest insects, including larvae and adults, amounts to billions of dollars each year[24,25]. In India, insect pests are responsible for a loss of approximately 6.5% of stored grain[26,27].

Once infestation is established pest insects cause gradual and progressive damage that leads to loss in weight, nutritional, organoleptic, and aesthetic quality of stored grains. Apart from the percentage losses incurred from the grain they feed on, insect pests also render large quantities useless by contaminating grains with their droppings, webs, and odours. Their biochemical activities could lead to generation of heat that may eventually result in hot spot in bulk grain storage, leading to the caking of grains[13]. Damaged grains may become inedible, unusable and in the case of seed, the germination capacity may be impaired[28]. Spoilage of food grains caused by heat and moisture from insect infestations encourage molds, bacteria and this not only reduces grain quality and quantity but can pose health risks[29,30]. Allergies are widespread hazards associated with insect infestation of food materials[31].

Insect pests play a significant role in the loss of stored grains, causing economic damage worth millions of dollars each year. This poses a serious threat to the food security programme of any nation, especially in developing countries, where agricultural produce is largely stored by farmers with limited resources[32,33]. Studies suggest that over 20,000 species of field and storage pests are responsible for destroying nearly one-third of the global food production annually, valued at over $100 billion. The highest proportion of these losses, about 43%, is reported in developing countries[24,34] because they lack modern storage methods[14,35].

Losses in temperate regions of the world due to insect damage can be expected to be lower than in the tropics and subtropics. The occurrence and number of stored grain insect pests are directly related to geographical and climatic conditions[36]. The tropics and subtropics provide optimum conditions for pest multiplication and losses tend to increase[37,38]. The quantitative and qualitative damage to stored grains and grain products from the insect pests amount to 20–30% in the tropical zone and 5–10% in the temperate zone[39-41].

Global food production must increase by 70% to sustain a population projected to reach 10 billion by 2050. In India, the population has been growing at an annual rate of 1.8% and was expected to reach 1.3 billion by 2020. To meet the food demand associated with this growth, the country would need an additional 2 million tonnes of food grains every year[42]. The highest food grain production in India, 259.32 million tonnes, was recorded in 2010-2011. However, 20-25% of this yield was lost due to damage caused by stored grain pests[43,44]. Such damaged grains exhibit reduced nutritional content, lower germination rates, decreased weight, and diminished market value[45].

The presence of stored grain insect pests poses a significant agricultural challenge, resulting in substantial economic setbacks for warehouse operators, the milling industry, and small-scale farmers worldwide. Mitigating post-harvest losses caused by these insects is not only essential for preserving food grain supplies but also for enhancing overall production efficiency. Thus, safeguarding grains and agricultural produce from insect damage during storage is essential.

Control of stored grain insect pest infestation by synthetic insecticides and insecticide resistance problem

Several methods are used in controlling insect pests in stored grain including physical (smoking, heating), cultural (drying of grains, airtight storage), biological (male insect sterilization, natural enemies, resistant grain varieties) and chemical (synthetic and natural products). Since 1950s synthetic insecticides have been used intensively in developed and transitional countries[46] in grain facilities to control stored product insect pests. Synthetic insecticides have become easy weapons for controlling insect pests because they are highly effective, rapid in curative action, adaptable to most situations and flexible in meeting with changing agronomic and ecological conditions[13]. They were widely accepted by the farmers, agri-industries and grain handlers due to their uniform and rapid effectiveness ease of shipment, storage, application and often relatively long term persistence[27]. Thus, synthetic pesticides were immediately embraced due to their effectiveness and efficacy in managing serious pests[47].

Globally, two main chemical methods are used to manage insect pests in stored grains: fumigation and the use of contact insecticides for grain protection[48-50]. Fumigation is considered one of the most effective techniques, where insect pests are exposed to a toxic gaseous environment created by applying a fumigant. The fumes from these fumigants enter insects through their spiracles, traveling through their tracheal system and interact with their haemolymph. Over time, various synthetic fumigants have been used to control insect pests in stored grains. Common fumigants include carbon disulphide, carbon tetrachloride, ethylene dichloride, ethylene oxide, methyl bromide, chloropicrin, trichloroethylene, sulphur dioxide, methyl formate, and trichloroacetonitrile. For fumigating empty storage facilities, a mixture of ethylene dichloride and carbon tetrachloride in a 3:1 ratio is often used to target eggs, larvae, and adult insect stages of stored pests[6]. Therefore, safeguarding of stored grains largely depends on chemical control methods, particularly the use of protectant insecticides and fumigants[13].

In recent times, there has been a gradual increase in the resistance of stored product insects to fumigation methods, resulting in a significant decline in the availability of effective fumigants for insect pest control. Presently, only two fumigants remain in use, methyl bromide and phosphine. It is suspected that methyl bromide may leave behind residues that can be harmful to warm-blooded animals[51]. Further, the utilization of methyl bromide is being restricted and phased out in accordance with the Montreal Protocol due to its detrimental impact on ozone depletion[52].

Phosphine is currently the primary fumigant used globally to protect stored grains and other stored commodities from insect pests[53-55]. Its widespread adoption can be attributed to its affordability, ease of application, low residue levels, and compatibility with various storage systems and commodities[56-59]. While phosphine has long been an effective tool for managing stored product insects, its excessive and uncontrolled use has led to the development of resistant insect populations[60,61]. Reports of resistance have become increasingly concerning, with several species of grain pests exhibiting resistance in different regions worldwide[62-64]. In some cases, this has resulted in fumigation failures[65]. A global survey by the Food and Agriculture Organization (FAO) in 1972-73, revealed resistance in stored grain pests across 33 of the 82 countries surveyed, affecting 82 of the 849 insect populations tested[66].Insect resistance to fumigants used in grain storage remains a significant issue worldwide[67].

Contact insecticides applied directly to grains or storage facilities, such as malathion, chlorpyrifos, and deltamethrin, are used to protect against infestations for extended periods. However, various pests in stored grains have shown resistance to these insecticides. Some of these contact insecticides have lost their effectiveness due to widespread resistance among insect populations. Currently, 122 pest species have developed resistance to malathion[68,69]. Resistance to this insecticide has been observed globally and remains stable in natural populations, even without continued insecticide exposure[70]. The rise of cross resistance and multi resistance in insect strains of many important insect species is an alarming issue worldwide[71,27].

The rising issue of insecticide resistance presents a significant challenge to the protection of stored grains. To date, more than 500 insect species have been documented to develop resistance to one or more insecticides, with 12 species showing resistance to nearly all insecticides. The spread of resistant insect strains through global trade poses the challenges we are bound to face with pests targeting stored products[72]. The widespread, prolonged, and uncontrolled use of synthetic insecticides has created a strong selection pressure, leading to changes in the genetic makeup of pest populations. Individuals with natural resistance have survived synthetic insecticide treatments, allowing them to pass on resistant traits to subsequent generations[73]. Over time, this has resulted in a significant increase in the proportion of insect populations resistant to insecticides, resurgence of stored product insect pests[74], compelling the use of double and triple application rates, increased marketing costs with reduced benefits[72] making them unavailable to small farmers, particularly in underdeveloped and developing countries[75]. Consequently, the effectiveness of chemical control has declined in recent decades due to the emergence of resistance in insect pests[76].

The failure of synthetic insecticides to effectively control pests, leading to resistance and subsequent food losses, results in annual global economic damage amounting to billions of dollars[77]. Insect pest resistance to insecticides has thus emerged as one of the key constraints to continued successful post-harvest protection of the grain and is threatening the economic viability of the stored grain protection industry.

Adverse effects of synthetic insecticides as grain protectants

Synthetic insecticides played a prominent role in decreasing post-harvest losses due to insect pests[78]. Although effective, their widespread, extensive and injudicious use for decades has reduced the biodiversity of agro ecosystems, provoking their instability and caused harmful effects such as evolution of resistant strains, primary pest resurgence, secondary pest outbreaks, conversion of innocuous species to pests, direct toxicity to non-target beneficial fauna, disruption of natural biological control and pollination, residual effects on stored grain, handling hazards, pollution of storage environment, human health issues and deleterious effects on the environment endangering the sustainability of ecosystems[79-83].

Most of the synthetic insecticides currently in use leave behind long-lasting residues that are challenging to eliminate during grain processing[84]. These persistent insecticides also accumulate themselves at various concentrations in different levels of ecosystems leading to bioconcentration, biomagnification and are found to be carcinogenic and mutagenic in action[85]. Therefore, the excessive and enthusiastic utilization of synthetic insecticides for controlling insect pests in stored grain has led to a range of adverse consequences that were not anticipated when these chemicals were first introduced.

Reliance on synthetic chemical insecticides resulted in many serious drawbacks[86]. The synthetic insecticides possess inherent toxicities that endanger the health of the warehouse operators, consumers, and the environment[87]. Constituent compounds of synthetic insecticides have been linked to chronic human health issues, either through exposure or consumption[88,89]. Studies suggest these insecticides may contribute to cancer development through non-genotoxic mechanisms, including promotion, peroxisome proliferation, hormone disruption, or by influencing the carcinogenic process in ways that can alter the genome and enhance the growth of neoplastic cells[90,91]. These insecticides are known to induce oxidative stress as part of their toxic effects, leading to the production of free radicals and changes in antioxidant or oxygen-free radical scavenging enzymes[92]. Oxidative stress can result in DNA damage, which is associated with malignancies and other disorders[93].

Certain insecticides can have harmful effects on the nervous, immune, endocrine, renal, respiratory, and reproductive systems in both men and women[91]. Exposure during foetal development can lead to congenital disorders, genetic diseases, DNA damage, and hormonal imbalances in the foetus[94]. The World Health Organization (WHO) estimates that 3 million cases of pesticide poisoning occur annually, resulting in over 250,000 deaths, primarily due to improper handling, application, or intentional poisoning[91]. Agricultural workers and consumers are at risk of adverse health effects from insecticide residues, and their breakdown products, particularly due to inadequate registration, poor storage, and misuse[95]. As such, the use of synthetic insecticides presents significant risks to human health.

These well documented ecotoxocological, environmental and social consequences led to increasingly stringent environmental regulation of synthetic insecticides[96]. Recent regulations have led to a reduction in the availability of synthetic insecticides for pest management in agriculture and storage facilities[97]. This decline is primarily due to the increasing resistance to these chemicals and their deregistration, driven by growing awareness of their environmental and human health impacts. In response, there has been a shift towards ecologically based practices[98]. Moreover, rising consumer concerns regarding the safety of food treated with synthetic insecticides have contributed to a gradual abandonment of their use for controlling post-harvest bio-deterioration[99,100]. Therefore, the existing approach to rely exclusively on synthetic insecticides to control post-harvest insect pests needs to be redesigned[97].

The adverse impacts of synthetic pesticides have spurred a demand for a safer and ecologically conscious alternative. There is an imminent demand for a novel methodology capable of significantly reducing the utilization of synthetic insecticides. The emerging pest control agents must adhere to a completely distinct set of criteria. They must exhibit specificity towards pests, lack any adverse effects on plant health, pose no harm to mammals and beneficial organisms, be biodegradable, environmentally sustainable, less susceptible to pest resistance, relatively cost-effective, and locally available. In this context, botanicals have been championed as efficacious substitutes for synthetic chemical insecticides in the management of stored grain insect pests. Increasing awareness of the risks linked to widespread synthetic insecticide use has sparked a renewed interest in plant-based pest control agents[101] because of their fewer ecological side effects[102,103].

Botanicals as an ecofriendly alternative to synthetic insecticides for stored grain insect pest management

The increasing potential risks associated with the use of synthetic insecticides raised doubt about their use as grain protectants in the future. To combat increasing pressure of insecticide resistance in insect pests and to reduce the insecticide residue in the treated stored grain the researchers are compelled to find safer, effective, alternative nontoxic grain protectants. Recently in different parts of the world attention has been given towards exploration of novel classes of insect pest control agents with alternative modes of action, environmentally benign, toxicologically safe, more selective and can replace or minimize the use of synthetic insecticides. As plant secondary metabolites, botanicals present an appealing and ecofriendly option for pest control[104]. The use of plant-based pest management has a long history, until technological advancements led to the development of synthetic pesticides[105].The reliance on plant-based natural products gradually declined, but with growing concerns about the risks posed by synthetic pesticides to human health and the environment, there has been a resurgence in interest in this natural and ecofriendly alternative[106].

Plants, as nature’s chemical factories, produce a range of bioactive compounds primarily designed to defend against insect pests[107,108]. Scientific literature confirms that plant secondary metabolites known as botanicals play a key role in plant interactions with other species, primarily by defending against pests. These compounds represent a vast reservoir of chemical structures with pesticidal properties[109]. Various plant species serve as a valuable source of secondary metabolites, which hold immense potential for development as insecticides[110]. Despite this potential, their use as insecticides remains largely unexplored. Botanical insecticides offer distinct advantages over synthetic insecticides, including rapid breakdown by sunlight, moisture, or detoxifying enzymes, reduced phytotoxicity, and high target specificity. These attributes make botanical insecticides an attractive and sustainable option for insect pest management. Higher plants produce a wide variety of secondary metabolites, such as phenolics, terpenes, alkaloids, lignans, and their glycosides. Thus, these bioactive compounds apart from playing a vital role in the plant's defense system also serve as promising structural prototypes for designing lead molecules, which can serve as innovative insect pest control agents. Natural compounds with anti-insect properties present less risk to the environment than synthetic insecticides[111]. In this context, botanicals with anti-insect properties are gaining attention.

Natural plant-derived products are emerging as promising bio-rational alternatives to synthetic insecticides for managing post-harvest insect pests[112-114]. The significance of botanicals with anti-insect properties lies in their effectiveness, biodegradability, diverse mechanisms of action, minimal toxicity, and the availability of raw materials[103,115]. As byproducts of metabolic processes shaped by species co evolution, botanicals offer several environmental benefits[116]. Research has shown that botanicals are not only highly effective and more biodegradable but also less likely to cause environmental contamination and demonstrate a lower potential for resistance, making them a viable substitute for synthetic pesticides[117,118]. In various regions across the globe, there has been a growing focus on the exploration of botanical resources as a novel avenue for safeguarding grains. Currently, botanical insecticides make up just 1% of the global insecticide market[119,120]. The botanical pesticide market is expected to experience an annual growth rate of 10%, while synthetic chemical insecticides are projected to see a more modest increase of 1-2%[121]. The expectation is that botanicals will find their place in agriculture primarily as supplements to synthetic insecticides or as essential components of pesticide rotation strategies. This application will help in slowing down the emergence of resistance[122].

Botanicals play a crucial role in managing pests of post-harvest produce[107,123,124]. Historically, people relied on botanicals to control pests before turning to other pesticides. Botanicals have a historical record of being employed for the management of agricultural pests in ancient civilizations such as China, Egypt, Greece, and India dating back over two millennia[107]. The agricultural industry's growing fascination with natural plant-based products has driven extensive research into the chemical composition of different plant families[125]. Approximately 200 plant species have been identified as effective against pests that target stored products. These species are distributed across 96 different plant families, with the Asteraceae and Lamiaceae families being the most represented[126,127].

Plant-derived botanicals exhibit the potential to influence various aspects of insect biology, including their behaviour, morphology, physiology, and metabolic processes[107,128,129]. These effects can manifest in different ways, such as inhibiting growth, preventing egg-laying, exhibiting ovicidal properties, and triggering mechanisms that hamper growth[130-133]. The anti-insect properties of botanicals are linked to the bioactive compounds they contain. These compounds, which include unique structural motifs found in secondary metabolites such as alkaloids, essential oils (e.g., terpenes), flavonoids, phenolics, phytosterols, polyketides, and resins, contribute to their potent insecticidal activity[134,125].

Secondary metabolites have been recognized as promising candidates for their potential use as biopesticides[135]. Remarkably, more than 2000 plant species are recognized for their pesticidal attributes, effectively combating a range of stored grain pests[136]. Various scholarly sources have also outlined diverse plant-derived products, each exhibiting a distinctive level of effectiveness against these pests [137,138]. These plant-derived botanicals, are commonly administered in various forms, including aqueous or solvent extracts, powders, slurries, volatiles, oils, or as shredded components[139,140].

In post-harvest pest control, farmers have long relied on plant-based protection agents, particularly for grain storage. The use of plant insecticides against pests by Ancient Romans were documented as early as 400 B.C.[141]. In ancient Rome, granaries frequently underwent fumigation using a variety of aromatic plants, such as rosemary, myrrh, and juniper. Additionally, aromatic plants were strategically placed near the entrances of these granaries. Consequently, individuals gained knowledge about the deterrent properties of aromatic botanical substances[142]. To this day, the conventional practice of employing botanicals for safeguarding field crops and preserving stored produce remains widespread and valuable among subsistence and transitioning farmers[143].

Before the Second World War, natural insecticides such as pyrethrum, rotenone, and nicotine accounted for at least 20% of the commercial insecticide market[144]. Several scientific publications offer insightful information on the varieties of plants utilized across different regions worldwide for the protection of stored products[127,145-147]. In East Africa, specifically in countries like Kenya and Tanzania, various botanical substances are commonly employed as grain protectants. These botanicals are from plants such as *Ocimum*spp., *Eugenia aromatica*, *Bascia* spp., *Tagetes* spp., *Tephrosia vogelis*, *Azadirachta indica* (neem), *Eucalyptus* spp., and *Lantana camara*[148].

India possesses an abundant diversity of plants that can be utilized as botanical pesticides, offering an effective alternative to chemical pesticides. India, being a tropical country, serves as a rich source of various secondary metabolites suitable for formulating different botanical pesticides. Botanical pesticides are derived from either the entire plant or specific plant parts, whether fresh or dried, and they contain active ingredients capable of combating insects and pathogens[126]. In India, there is an extensive tradition of utilising more than 450 botanical derivatives in agricultural practices, with neem being one of the most extensively researched trees. Neem has been found to have insecticidal properties in nearly all parts of the tree. The practice of using neem leaves and powdered neem kernels to manage pests in stored grains has a long history in India[148].

Nowadays, *Azardirachta indica* based pesticides have gained significant popularity due to their biodegradability, minimal residual presence, low toxicity to non-target organisms, cost-effectiveness, and ready accessibility. In India, neem-based products have proven efficacy in combatting a wide array of pests, spanning crop fields and the protection of stored grains such as rice, wheat, corn, legumes, potato, tomato, and more[149].

Both leaves and fruit of neem plant known to have bitter taste exhibit anti-insect properties[150]. The pesticidal effectiveness of crude or commercially available pesticides derived from neem tree seeds, twigs, and stem barks has been documented against more than 700 pests and disease causing pathogens. This property has been ascribed to their secondary metabolites, specifically triterpenoids and nonterpenoids[151,152].

The anti-insect properties of neem (*Azadirachta indica*) are extensively studied, and indeed attributed to a group of natural compounds known as limonoids (triterpenoids). Among these limonoids, azadirachtin A is considered the most active and prominent compound responsible for the insecticidal properties of neem. However, it is important to note that other limonoids present in neem extracts may also contribute to the overall efficacy of neem-based insecticides[153-155]. Further, these additional limonoids may play a role in preventing the development of resistance to azadirachtin A[156]. Azadirachtin is a versatile insecticide known for its broad-spectrum effectiveness. It functions as an antifeedant, interferes with insect development, and functions as a sterilizing agent, making it suitable for controlling a broad range of insect pests related to agriculture, including species from the orders Coleoptera, Hymenoptera, Diptera, Orthoptera, and Isoptera. Recognized as one of the most effective insecticides, it targets over 550 insect species. Azadirachtin is distinguished by its remarkable selectivity, exhibiting low toxicity to mammals[157], and is easily degradable, non-mutagenic, and safe for non-target and beneficial organisms[158].

In trials conducted for storage applications, the use of ground neem plant material demonstrated effective and consistent control of coleopteran pests. Azadirachtin exhibits antifeedant properties, acts as a growth regulator, hinders oviposition, and serves as a sterilizing agent. Currently, neem-based commercial products are marketed under various names, including Neem Gold, Neemazal, Econeem, Neemark, Neemcure, and Azatin. These formulations are widely available across many countries, such as the United States, India, Germany, and several Latin American countries [159-163].

Pyrethrum, an age-old and non-hazardous insecticide derived from the desiccated flower buds of *Chrysanthemum* species, found applications in the early 19th century. Comprising four compounds - pyrethrins I and II, as well as cinerins I and II, pyrethrum stands out as one of the safest insecticides in use, posing minimal toxicity to most mammals. Pyrethrins disrupt normal nerve functioning. To date, the widely employed botanical insecticides for preserving stored commodities are pyrethrins[127]. Sabadilla, also known as "cevadilla," is derived from the seeds of the tropical sabadilla lily (*Schoenocaulon officinale*), native to Central and South America. Its primary active ingredient is an alkaloid called veratrine, which is marketed under trade names such as "Red Devil" and "Natural Guard." Recognized as one of the least toxic botanical insecticides, sabadilla has an oral LD50 ranging between 4000 and 5000 mg/kg. Its mechanism of action involves disrupting the membranes of neuron cells, leading to reduced nerve activity, paralysis, and ultimately, the death of the target pest.Rotenone, a natural compound, is derived from plant species such as *Derris*, *Lonchocarpus*, *Tephrosia*, and *Mundulea*. It functions as both a contact and ingestion agent with repellent properties. Rotenone's mechanism of action involves disrupting electron transport at the mitochondrial level, which prevents the phosphorylation of ADP to ATP, effectively halting insect metabolism[165]. Extracted from *Tephrosia*, rotenone has been employed as an insecticide for over a century[165]. In storage pest management, ground leaf material from *Tephrosia* has proven effective in controlling coleopteran pests[167-169].

Tobacco's insecticidal effects are due to nicotine and related alkaloids. While nicotine-based pesticides have a rich historical background, their application has decreased over time due to their high toxicity to humans [107]. The insecticidal properties of tobacco can be attributed to nicotine and its associated alkaloids. Nicotine-based pesticides have a rich historical background, but their utilization is declining due to their significant toxicity to humans[107]. Nicotine acts as a biodegradable contact insecticide. It works by imitating acetylcholine, binding to its receptor on the post-synaptic membrane. The efficacy of ground tobacco leaves was documented with an efficacy of 100% against cowpea weevils[170,171].

Botanical pesticides even in their crude form have been demonstrated to possess insecticidal properties [172]. Researchers tested the effectiveness of extracts from *Nicotiana tabacum*, *Sinapsis arvensis*, and *Cardariadraba* against *Trogoderma granarium* and found them to be effective in reducing pest populations in stored wheat grains[173]. Extracts from *Pegaum harmala*, *Ajuga iva*, *Aristolochiabaetica*, and *Raphanus raphanistrum* exhibited insecticidal activity against *Triboliumcastaneum.* These extracts worked by disrupting the developmental cycles of the insects and inhibiting the production of F1 progenies[174].

In storage scenarios, ground bitter leaf plant material was employed for the management of coleopteran storage pests. The insecticidal effect of garlic cloves is linked to sulphur-containing compounds produced through the enzymatic breakdown of allicin. Research have shown that garlic extracts exhibit anti-insect properties against a range of pests, including coleopteran, dipteran, lepidopteran, and hemipteran species[175]. Storing grains with sweet flag (*Acorus calamus*) powder can effectively prevent insect infestation for up to six months. This successful protection is attributed to the potent and repellant odour emitted by sweet flag, which deters various storage pests from infesting the grains[120].

Processes for insect repellent and insecticide products of plant origin have also been patented[176]. Over the past few decades, there has been extensive exploration of the effectiveness of botanicals utilized in traditional pest management through research trials. Numerous aromatic plants, widely utilized as culinary herbs and spices, along with their essential oils, have gained scientific interest for their potential as botanical insecticides to prevent storage losses of post-harvest produce[177]. More specifically, numerous farmer surveys have brought to light the utilization of a diverse array of botanicals for insect pest control. For instance, in Northern Malawi, farmers employ 10 different botanicals, while in Zambia, 7 are used[178]. In the Lake Victoria basin in Uganda, the count reaches 34 [179], and in one district of Tamil Nadu State in India, farmers rely on 11 botanicals for this purpose[180].

Insecticidal sesquiterpene lactones targeting coleopteran pests have been successfully extracted from bitter leaf[181]. Clove basil essential oil and several of its components also demonstrated insecticidal and repellent properties effective against coleopteran pests[175]. Carvone, a monoterpene extracted from the essential oil of *Carum carvi*, is marketed as a non-toxic botanical pesticide under the brand name 'TALENT.' This compound is effective in preventing potato tubers from sprouting during storage and protects them from bacterial decay, while being safe for mammals. Additionally, the monoterpenoid α-pinene, the primary component of marigold tree essential oil, has shown insecticidal and repellent effects against coleopteran pests that affect stored products. The sesquiterpene lactones found in tree marigold also have demonstrated toxicity against the coleopteran species *Callosobruchus maculatus*[181,175].

Capsaicin, the primary compound responsible for the spiciness of chili peppers, is a key ingredient in many commercially available insecticide formulations. It possesses both repellent and insecticidal properties. Ground chili pepper fruits have demonstrated effective control over the cowpea weevil *Callosobruchus maculatus*, making chili pepper a potent solution for killing and deterring various species of weevils that infest stored grains. Furthermore, an essential oil component found in Siam weed, the monoterpenoid α-pinene, exhibits insecticidal and repellent activities against storage pests of the order coleoptera. Coumarins, which are significant secondary metabolites present in the mother of cocoa, as well as limonoids in China berry, have been well-documented for their insecticidal properties against storage pests belonging to the orders Coleoptera and Lepidoptera. In addition to these, ground moringa leaves have also proven effective in controlling coleopteran storage pests[175].

Rosmarinus officinalis (rosemary), an herb native to Mediterranean region exhibits insecticidal properties [182]. The phytochemicals existing in its oil showed anti-insect properties against the stored product insects, *Trogoderma granarium* and *Tribolium castaneum*[183]. *Piper nigrum* (Black pepper) and *Mentha piperita* (Pepper mint) exhibited promising insecticidal activity against *Corcyra cephalonica* (rice moth), and *Sitophilus oryzae* (rice weevil) which are economically significant stored product pests causing severe damage to grains and products in storage. The anti-insect properties of these plants is due to the presence compounds, menthol, limonene, cineole and isomenthone in pepper mint while α and β pinene, limonene and caryophyllene in black pepper[184].

The wide range of bioactive compounds found in plants can disrupt insect nervous system, inhibit growth, impair reproduction, deter, or kill pests with minimal harm to non-target species and the environment. Sourcing can be done by identifying plants with insecticidal properties, utilizing traditional knowledge, and optimizing extraction methods. Advances in bioprospecting and green chemistry can pave the way for more potent botanical insect pest control agents, reducing dependence on synthetic insecticides and supporting integrated insect pest management.

Major challenges and constraints to the utilization of botanicals as insect pest control agents

Botanical pesticides emerge as a captivating alternative for safeguarding agricultural produce, offering reduced environmental and health hazards. Despite the substantial research conducted across global laboratories and the exponential growth of scientific literature elucidating the pesticide attributes of botanicals, it is rather astonishing that the marketplace has seen a scanty emergence of pest control products rooted in vast plant resource. In spite their merits in eco-friendly pest management, the adoption and utilization of botanical pesticides remain limited, signaling challenges in their acceptance. Various factors hinder the utilization of botanicals as insect pest control agents constraining their broad use and practical implementation.

The commercialization of botanicals as grain protectants faces a unique set of challenges and constraints, primarily related to their effectiveness, safety, regulatory approval, and market acceptance. Overcoming these obstacles will require continued research, investment, education, and collaboration among stakeholders in agriculture and pest management industries. The prevalent challenges hindering their adoption and utilization in the pursuit of sustainable pest management are –

Limited Efficacy: Botanical grain protectants may not be as effective as synthetic chemical pesticides in providing long term protection against a wide range of stored grain pests. This limitation can discourage their adoption by grain storage facilities.

Variability in Active Ingredients: The variability in active ingredients is a common challenge with botanical pesticides because these products often rely on complex mixtures of plant extracts. Factors like plant species, growth conditions, and extraction methods can result in variations in the concentration and composition of active compounds. This variability can make it challenging to predict and control the pesticide's efficacy, requiring thorough research and quality control measures to ensure consistent performance in pest management.

Pest Resistance: Just as pests can develop resistance to synthetic pesticides, they can also develop resistance to botanicals over time. This resistance can reduce the effectiveness of botanical grain protectants and necessitate the development of alternative solutions.

Shorter Residual Activity: Botanicals often have shorter residual activity compared to synthetic chemicals. As a result, grain may require more frequent treatments with botanicals, which can increase operational costs and labour.

Storage and Stability: Some botanical insecticides are less stable and may require special storage conditions to maintain their efficacy. Challenges related to the stability and storage of botanical insecticides include their susceptibility to degradation over time, sensitivity to environmental factors such as temperature, humidity, and the need for proper packaging to prevent moisture ingress or exposure to light, which can diminish their effectiveness. Finding solutions to these issues is essential to ensure the longterm viability and efficacy of botanical based protectants in grain storage. Innovations in encapsulation technologies and formulation strategies are a key to extending the shelf life of botanical insecticides. This can add complexity to their commercialization and increase costs.

Regulatory Approval: Botanical insecticides may face regulatory challenges in terms of registration and approval. Regulatory agencies may require extensive testing to ensure their safety and efficacy, which can be costly and time-consuming**.**

Quality Control and Standardization: The challenge of quality control and standardization in botanical insecticides arises from the inherent variability in plant-based ingredients. Ensuring consistent potency and effectiveness across different batches of botanical products can be difficult due to variations in plant sourcing, growing conditions, and extraction methods. Establishing effective quality control measures and standardized manufacturing processes are essential to overcome these issues and provide reliable and effective botanical grain protectants to safeguard grain.

Limited Research and Development Funding: Limited research and development funding for botanical insecticides in grain storage hinders the exploration of their full potential. Unlike synthetic counterparts, botanical insecticides may not receive the same level of investment and attention. This limitation restricts the discovery of new botanical solutions, development of innovative formulations, and comprehensive field trials, hindering progress in enhancing their efficacy and ensuring their suitability for longterm use in grain protection. Increased funding and support are essential to harness the sustainable and ecofriendly advantages of botanical grain protectants in the context of storage of agricultural produce.

Commercialization challenges: Commercialization of botanical pest control agents faces economic impediments, including high production costs and limited market demand. To overcome these hurdles, innovative approaches such as efficient extraction methods, sustainable sourcing, and effective marketing strategies are required.

Compatibility with Integrated Pest Management (IPM): Integrating botanical grain protectants into an IPM program can be challenging due to their variable effectiveness. Finding the right balance between different pest management methods is crucial.

Information Dissemination: A scattered landscape of knowledge and information about botanicals for pest control further obstructs their integration into grain storage practices. A comprehensive, centralized repository of research findings and best practices can catalyze the dissemination of knowledge, thus facilitating their adoption.

Education and Training: Many stakeholders in the grain industry may not be familiar with the use of botanicals as grain protectants or may lack knowledge about their proper application. The training programs and resources are to be provided to warehouse operators and agricultural professionals to enhance their understanding of botanical pesticide benefits, proper application methods, and potential limitations. Such education and awareness campaigns may play a crucial role in successful adoption of botanicals in grain storage.

Market Competition: While botanical pesticides offer ecofriendly alternatives, they face competition from well established synthetic pesticides. Pesticide companies face challenges around efficacy, regulatory compliance, and pricing as they seek market entry. With consumer and regulatory preferences increasingly favouring sustainability, botanical insecticides have a growing opportunity to capture a larger market share, if they can effectively navigate these competitive challenges.

Policy Support: Promote policies that encourage the adoption of ecofriendly pest control methods, such as subsidies or tax incentives for using botanical alternatives. This would support their widespread use in post-harvest produce protection.

A plethora of challenges, in the pursuit of commercially applying plant based pesticides also encompass the procurement of ample plant material, the need for rigorous standardization and enhancement of botanical formulations, safeguarding intellectual property through patents, and navigating the intricate terrain of regulatory approvals[185]. Further, there is a vital need to transform these plant-derived products into commercially viable forms that are readily accessible to farmers and grain merchants[186]. Thus, to harness the full potential of botanicals, in advancing sustainable agriculture which predominantly revolves around precision targeting, environmental safety, and biodegradability[187,188], numerous hurdles must be surmounted, and uncertainties must be addressed. While these limitations appear conquerable, they present challenges for both the scientific and economic development sectors. Continued research efforts are required to yield more refined formulations exhibiting increased efficacy. These advancements may ultimately offer environmentally sustainable alternatives, supplanting the use of conventional insecticides that raise environmental concerns, in the field of stored grain pest control. Overcoming these challenges and uncertainties could reveal a valuable resource that has the potential to significantly benefit the protection of agricultural produce worldwide.

Conclusion

The future prospect of botanicals as stored grain protectants is promising due to their ecofriendly and sustainable nature. Various botanicals with anti-insect properties have been tested against stored grain pests, showing their potential to protect grains while reducing dependence on synthetic insecticides. Botanicals offer a promising alternative to develop innovative, targeted molecules for sustainable insect pest management in stored grain. To unlock the potential, government support is essential. Direct grants, tax incentives, and subsidies for institutions and private companies focused on green chemistry can accelerate scientific efforts toward sustainable agricultural practices. A comprehensive strategy is needed to address regulatory issues, improve efficacy, and shelf life, increase public awareness and enhance commercial viability. By supporting scientists with proper resources, simplifying regulatory pathways, researchers can unlock the full potential of botanicals, setting the stage for a new era of sustainable and effective grain preservation.

References

1. Ashfaq, M., Griffith, G., and Parton, K. (2001). Welfare Effects of Government Interventions in the Wheat Economy of Pakistan. *Pak. J. Agric. Econ*., 4(1), 25-33.

2. Vasudha lingampally, V. R. Solanki, Amarjit Kaur and S. Sabita Raja (2013). Effect of Andrographolide on The Protein Content of *TriboliumConfusum* (Duval). *Int. J. Pure Appl. Zool.*, 1(1), 70-79.

3. Golob, P., Dales, M., Fidgen, A., Evans, J. and Gudrups, I. (1999). The Use of Spices and Medicinals as Bioactive Protectants for Grains. FAO, Rome, Italy. ISBN 92-5-104294-2.

4. Osuji, F. N. C. (1985). Ouline of stored products. Entomology for the tropics. First Edition. Fourth Dimension Publishers, Enugu, Nigeria.

5. Lale N (2002). Stored product Entomology and Acarology. Mole Publications, Maiduguri. pp. 264.

6. R.K. Upadhyay and S. Ahmad (2011). Management Strategies for Control of Stored Grain Insect Pests in Farmer Stores and Public Warehouses. *World J. Agric. Sci.*, 7(5), 527-549.

7. Talukder, F.A., Islam, M.S., Hossain, M.S., Rahman, M.A. and Alam, M.N. (2004). Toxicity effects of botanicals and synthetic insecticides on *Triboliumcastaneum* (Herbst) and *Rhyzoperthadominica* (F.). Bang. *J. Env. Sci*., 10(2), 365–367.

8. Dubey, N. K., Srivastava, B. and Kumar, A. (2008). Current status of plant products as botanical pesticides in storage pest management. *J. Biopest*., 1(2), 182–186.

9. Jilani, G., (1984). Use of Botanical Materials for Protection of Stored Food Grains against Insect Pest - A Review. Research Planning Workshop on Botanical pest control project, IRRI, Los Danos, pp 6-10.

10. Tefera, T., Kanampiu, F., Groote, H.D., Hellin, J., Mugo, S., Kimenju, S., Beyene, Y., Boddupalli, P., Shiferaw, B. and Banziger, M. (2010). The metal silo: an effective grain storage technology for reducing post-harvest insect and pathogen losses in maize while improving smallholder farmers' food security in developing countries. *Crop Prot*., 30, 240-245.

11. Charles A.O. Midega, Alice W. Murage, Jimmy O. Pittchar and Zeyaur R. Khan (2016). Managing storage pests of maize: Farmers' knowledge, perceptions and practices in western Kenya. *Crop Protection*, 90,142-149.

12. O. A. Oke and S. Muniru (2001). Fungi associated with stored rice grains and their implications. *Nigerian Journal of Research and Review of Scientific*, 2, 6–9.

13. Vasudha Lingampally, V. R.Solanki and Sabita Raja Sangam (2013). Terpenoids-Effective agents for the control of *Triboliumconfusum*. LAP Lambert Academic Publishing, Germany. ISBN: 10: 3659442860 / ISBN 13: 9783659442865.

14. Phillips T.W. and Throne J.E. (2010). Bio-rational Approaches to Managing Stored Product. *Annual Review of Entomology*, 55,375-397.

15. Sharon M., Abirami C.V. and Alagusundaram K. (2014). Grain storage management in India. *Journal of Post-Harvest Technology*, 2(1),12-24.

16. Basavaraja, H., Mahajanashetti, S.B. and Udagatti, N. C. (2007). Economic analysis of post-harvest losses in food grains in India: A case study of Karnataka. *Agricultural Economics Research Review*, 20, 117-126.

17. M. Nagpal and A. Kumar. (2012). Grain losses in India and government policies. *Quality Assurance and Safety of Crops & Foods*, 4(3), 143.

18. Boxall, R. A. (2001). Post-harvest losses to insects - a world overview. *International Biodeterioration and Biodegradation*, 48(1-4),137-152.

19. Singh, P. K. (2010). A decentralized and holistic approach for grain management in India. *Current Science*, 99 (9), 1179-1180.

20. P.P. Said and V.V. Pashte (2015). Botanicals: The Protectants of Stored Grains Pests. *Trends in Biosciences*, 8(15), 3750-3755.

21. Raja N., Abert S., Ignacimuthu S. and Dorn S. (2001). Effect of plant volatile oils in protecting stored cowpea *Vigna unguiculata* (L.) Walpers against *Callosobruchus maculatus* (F.) (Coleoptera: Bruchdae) infestation. *J. stored prod. Res*., 37, 127-132.

22. Matthews G.A. (1993). Insecticide application in the stores. In Matthews, G.A. and Hislop, E.C. (eds.). Application technology for crop protection. CAB, London. pp. 305-315.

23. Rajashekar Y., Gunasekaran N. and Shivanandappa T. (20104). Insecticidal activity of the root extract of *Decalepishamiltonii* against stored-product insect pests and its application in grain protection. *J Food Sci Technol*., 7, 310–314.

24. Jacobson M. (1982). The potential role of natural product chemistry research in Heliothis management. In: Proceedings of International Workshop on Heliothis Management: Patacheru, Andrapradesh, India. pp 233-240.

25. S Ramya and R Jayakumararaj (2009). Antifeedant Activity of Selected Ethno-botanicals used by Tribals of Vattal Hills on *Helicoverpaarmigera* (Hübner). *Journal of Pharmacy Research*, 2(8), 1414-1418.

26. Raju P (1984). The staggering storage losses - causes and extent. *Pesticide*, 18, 35-37.

27. Talukder, F. (2009). Pesticide Resistance in Stored-Product Insects and Alternative Biorational Management: A Brief Review. *Journal of Agricultural and Marine Sciences*, 14, 9–15.

28. Obeng-Ofori, D. (2008). Management of Stored Product Arthropods Pest. In: Cornelius E. W. and Obeng-ofori, D. (eds), Postharvest Science and Technology, college of agriculture and consumer services, University of Ghana, Legon, Accra, pp 92-146.

29. Evans, D.E. (1987). Stored Products., in A.J. Burn, T.H. Coaker and P.C. Jepson (eds.). International Pest Management, Academic Press, London. pp. 425 – 461.

30. Pederson, J.R. (1992). Insects In: Storage of cereal grains and their products (Editor: D. B. Sauer), American Association of cereal chemists, Minnesota, USA, pp 615. ISBN: 978-0-913250-74-7

31. Phillips, J. K., and Burkholder, W. E. (1984). Health hazards of insects and mites in food. In Insect Management for Food Storage and Processing (F. J. Bauer, Ed.), American Association of cereal chemists, Minnesota. USA. pp. 280–293.

32. Ismaila U., A. S. Gana, N. M. Tswanya and D. Dogara (2010). Cereals production in Nigeria: Problems, constraints and opportunities for betterment. *African Journal of Agricultural Research*, 5(12), 1341-1350.

33. Balami D. H., I. Ogboru and D. M. Talba (2011). The Cereal Economy in Nigeria and the Sub- Regional Dimension. A Publication of Social Science Study Group (SSSG), Benue State University, Makurdi. SSSG Series 29, 1-71. ISBN:9785033856, 9789785033854

34. Ahmed SA. and Grainage M. (1986). Potential of neem tree for pest control and rural development. *Economic Botany*, 40, 201-209.

35. Nopsa, J.F.H., Daglish, G.J., Hagstrum, D.W., Leslie, J.F., Phillips, T.W., Scoglio, C., Thomas-Sharma, S., Walter, G.H. and Garrett, K.A. (2015). Ecological networks in stored grain: key post-harvest nodes for emerging pests, pathogens, and mycotoxins. *Bioscience*, 65,985-1002.

36. Lal S., Srivastava B. P. (1985). Insect pests of stored wheat of Madhya Pradesh (India). *Journal of Entomological Research*, 9, 141–148.

37. Shazali, M.E.H. (1987). Problems of food grain storage in the Sudan with particular reference to insects. Workshop on storage and preservation on food grains. Khartoum, Sudan.

38. Harein, P.K. and Davis, R. (1992). Control of stored – grain insects. In: storage of cereal grains and their products. Editor: Sauer, D.B. Fourth edition. American Association of cereal chemists, Minnesota. USA. ISBN: 978-0-913250-74-7

39. Shaaya E, Kostjukovaki M, Eilberg J and Sukprakarn C (1997). Plant oil as fumigants and contact insecticides for the control of stored-product insects. *J Stored Prod Res*., 33,7-15.

40. Murli Manohar Kiradoo and Meera Srivastav (2010). A comparative study on the efficacy of two lamiaceae plants on egg - laying performance by the pulse beetle Callosobruchus chinensis Linn. (Coleoptera :Bruchidae). Journal of Biopesticides., 3(3), 590 – 595.

41. S. Rajendran and V. Sriranjini (2008). Plant products as fumigants for stored-product insect control. *Journal of Stored Products Research*, 44(2), 126–135.

42. Paroda, R.S. and P. Kumar. (2000). Food production and demand situations in South Asia. *Agricultural Economics Research Review*., 13(4), 1-25.

43. Y. Rajashekar and T. Shivanandappa, (2011). Novel natural insecticide molecule for grain protection, in Stored Products Protection. M.O. Carvalho, P. G. Fields, C. S. Adler et al., Eds., Proceedings of the 10th International Working Conference on Stored Product Protection, JuliusK¨uhn- Archiv 425, pp. 913–917.

44. Vandana Singh (2016). Phytochemical based pesticides as Grain Protectants. *International Journal of Scientific and Research Publications*, 6(6), 468-469.

45. Tadele Tefera, Stephen Mugo and Paddy Likhayo (2011). Effects of insect population density and storage time on grain damage and weight loss in maize due to the maize weevil *Sitophilus zeamais* and the larger grain borer *Prostephanus truncates*. *African Journal of Agricultural Research*, 6(10), 2249-2254.

46. FAO (2013). Statistical yearbook of the Food and Agricultural Organization of the United Nations. Food and Agriculture Organization of the United Nations. http://www.fao.org/docrep/018/i3107e/i3107e01.pdf. Accessed 26 January 2017

47. N. Raja (2014). Botanicals: Sources for eco-friendly biopesticides. *J. Biofertil. Biopestic*., 5, Article No. e122. https://doi.org/10.4172/2155-6202.1000e122

48. White NDG (1995). Insect, mites and insecticides in stored grain ecosystems. In: Stored grain ecosystem (Edited by Jayas, D. S.; White, N. D. G. and Muir, W. E.), Marcel Dekker, NY., USA. pp. 123-168.

49. I. O. Udo (2011). Potentials of Zanthoxylum xanthoxyloides (LAM.) for the control of stored product insect pest. *Journal of Stored Products and Postharvest Research*, 2(3),40-44.

50. Kostyukovsky, M., Trostanetsky, A., and Quinn, E. (2016). Novel approaches for integrated grain storage management. *Israel Journal of Plant Sciences*, 63(1), 7–16.

51. Dansi, L., F.L. Vanvelser and C.A.V. Heuden. (1984). Methyl bromide: Carcinogenic effects in the rat fore stomach. *Toxicology and Applied Pharmacology*, 72,262-271.

52. Benhalima, H., M.Q. Chaudhry, K.A. Mills and N.R. Price. (2004). Phosphine resistance in stored-product insects collected from various grain storage facilities. *Morocco Journal of Stored Products Research*, 40,241-249.

53. Daglish, G. J. (2004). Effect of exposure period on degree of dominance of phosphine resistance in adults of *Rhyzoperthadominica* (Coleoptera: Bostrychidae) and Sitophilus oryzae (Coleoptera: Curculionidae). *Pest Management Science*, 60(8), 822-826.

54. Collins, P. J., G.J. Daglish, H. Pavic, and R.A. Kopittke. (2005). Response of Mixed-Age Cultures of Phosphine-Resistant and Susceptible Strains of Lesser Grain Borer, *Rhyzoperthadominica*, to Phosphine at a Range of Concentrations and Exposure Periods. *Journal of Stored Products Research*, 41(4), 373-385.

55. Wang, D., P.J. Collins and X. Gao (2006). Optimising indoor phosphine fumigation of paddy rice bagstacks under sheeting for control of resistant insects. *Journal of Stored Products Research*, 42, 207-217.

56. Chaudhry, M.Q. (2000). Phosphine resistance: a growing threat to an ideal fumigant. *Pesticide Outlook*, 11, 88-91.

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

58. Nayak, M.K. and P.J. Collins (2008). Influence of concentration, temperature and humidity on the toxicity of phosphine to the strongly phosphine resistant psocid Liposcelis bostry-chophila Badonnel (Psocoptera: Liposcelididae). *Pest Manag. Sci*., 64, 971-976.

59. Akhlaq Ahmad, Mubarik Ahmed, Noorullah, Qazi Mehmood Ali, Muhammad Abbas and Saqib Arif (2013). Monitoring of Resistance Against Phosphine in Stored Grain Insect Pests in Sindh Middle-East. *Journal of Scientific Research*, 16(11), 1501-1507.

60. Bell, C.H. (2000). Fumigation in the 21st century. *Crop Protection*, 19, 563-569.

61. Pimentel, M.A.G., L.R.D'A. Faroni, M.R. Tótola and R.N.C. Guedes (2007). Phosphine resistance, respiration rate and fitness consequences in stored-product insects. *Pest Management Science*, 63, 876-881.

62. Srivastava, J.L. (1980). Pesticide residue in food grains and pest resistance to pesticides. *Bulletin of Grain Technology*, 18, 65-76.

63. Zettler, J.L. (1990). Phosphine resistance in stored product insects in the United States. In Proceedings of the 5th International Working Conference on Stored-Product Protection (Edited by Fleurat-Lessard F. and Ducom P.). *Bordeaux*. France. pp: 1041-1049.

64. Emery, R.N., M.K. Nayak and J.C. Holloway (2011). Lessons learned from phosphine resistance monitoring in Australia. *Stewart Posthar*, 7, 1-8.

65. Chaudhry, M.Q. (1997). A review of the mechanism involved in the action of phosphine as an insecticide and phosphine resistance in stored-product insects. *Pesticide Science*, 49,213-228.

66. Champ, B.R. and C.E. Dyte (1976). Report of the FAO Global Survey of Pesticide Susceptibility of Stored Pests. *FAO, Rome*. pp: 297.

67. Marco Aurélio Guerra Pimentel, Lêda Rita D' Antonino Faroni, Maurílio Duarte Batista and Felipe Humberto da Silva (2008). Resistance of stored-product insects to phosphine. *Pesq. agropec. bras*, (43)12,1671-1676.

68. Sayaboc, P.D. and M.A. Acda. (1990). Resistance of the major coleopterous pests of stored grain to malathion and pirimiphosmethyl. *Philippine Entomologist*, 8,653--660.

69. Zettler, J.L. and G.W. Cuperus. (1990). Pesticide resistance in *Tribolium castaneum* (Coleoptera: Tenebrionidae) and

Rhyzopertha dominica (Coleoptera: Bostrichidae) in wheat. *Journal of Economic Entomology*, 83,1677--1681.

70. Arnaud, L. and E. Haubruge. (2002). resistance enhances male reproductive success in a beetle. *Evolution*, 56,2435-2444.

71. Dyte, C.E. and D. Halliday (1985). Problems of development of resistance to phosphine by insect pests of stored grains. *Bulletin, Organization Europeenne et Mediterraneenne pour la Protection des Plantes*, 15, 51-57.

72. Talukder, F.A. (2006). Products as Potential Stored Product Insect Management Agents-A Mini Review. *Emirates Journal of Agricultural Science*, 18, 17-32.

73. Amerika Singh and O.P. Sharma (2004). Integrated Pest Management for Sustainable Agriculture Proceedings 11, Integrated Pest Management in Indian Agriculture.

74. Brower, J. H., Smith, L., Vail, P. V., Flinn, P. W. (1995). Biological control. In: Subramanyam, B., Hagstrum, D.W. (Eds.), Integrated Management of Insects in Stored Products. Marcel Dekker, New York, pp. 223-286.

75. Anand Prakash and Jagadiswari Rao (1996). Botanical Pesticides In Agriculture. Taylor & Francis Inc. ISBN: 9780873718257.

76. Shelton, A. M., Robertson, J. L., Tang, J. D., Pérez, C., Eigenbrode, S. D., Preisler, H. K., Wilsey, W. T., and Cooley, R. J. (1993). Resistance of diamondback moth (Lepidoptera: Plutellidae) to *Bacillus thuringiensis* subspecies in the field. *Journal of Economic Entomology*, 86, 697-705.

77. Elzen G.W. and Hardee D.D. (2003). United State Department of Agricultural Research on managing insect resistance to insecticides. *Pest Manag Sci*., 59, 770-776.

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

79. Brown, A. W. A. (1978). Ecology of Pesticides. Wiley, New York. pp 525.

80. Hayes Jr., J. B., Laws Jr. and E. R. (1991). Handbook of Pesticide Toxicology. Academic Press, San Diego, 1: 496.

81. Forget G., Goodman T. and de Villiers A (eds) (1993). Impact of pesticide use on health in developing countries. Int Dev Res Centre, Ottawa, pp 335.

82. Perry, A. S., Yamamoto, I., Ishaaya, I., and Perry, R. Y. (2013). Insecticides in agriculture and environment: retrospects and prospects. Springer Science & Business Media.

83. Jeyasankar, A. and Jesudasan, R.W.A. (2005). Insecticidal properties of novel botanicals against a few lepidopteran pests. *Pestology*, 29,42-44.

84. Kabungo, D.A., S. Mkoga and M.A. Shetto (1998). On farm evaluation of Botanicals insecticides for the control of storage insect pests on maize. Wheat and Beans in Matamba and Bulongwa Divisions of Makete District. Report, pp:4-6.

85. Vasudha Lingampally, V.R. Solanki, Amarjit Kaur and S. Sabita Raja (2013). Andrographolide - an effective insect growth regulator of plant origin against Triboliumconfusum (duval). *International Journal of Current Research*, 5(1), 022-026.

86. Lee, B., W. Choi, S. Lee and B. Park. (2001). Fumigant toxicity of essential oils and their constituent compounds towards the rice weevil, Sitophilus oryzae. *Crop Prot*., 20, 317-320.

87. Vasudha Lingampally, V.R. Solanki and S. Sabita Raja (2012). Induction of ovarian dysfunction in Triboliumconfusum by solasodine. *Indian Journal of Fundamental and Applied Life Sciences*, 2(2), 160-163.

88. C.A. Damalas and S.D. Koutroubas (2016). Farmers' exposure to pesticides: toxicity types and ways of prevention. *Toxics*, 1,1–10.

89. K.A. Kumari, K.N.R. Kumar and C.N. Rao (2014). Adverse effects of chemical fertilizers and pesticides on human health and environment. *J. Chem. Pharm. Res*., 3,150–151.

90. Hodgson E. and Levi P. E. (1996). Pesticides: an important but underused model for the environmental health sciences. *Environmental Health Perspectives*, 104, 97–106.

91. Stoytcheva M. (2011). Pesticides in the Modern World – Effects of Pesticides Exposure. Croatia, InTech.

92. Banerjee BD, Seth V, Bhattacharya A, Pasha ST and Chakraborty AK (1999). Biochemical effects of some pesticides on lipid peroxidation and freeradical scavengers. *Toxicol Lett*., 107, 33–47.

93. Akash Sabarwal Kumar Kumar and Rana P. Singh (2018). Hazardous effects of chemical pesticides on human health– Cancer and other associated disorders. *Environmental Toxicology and Pharmacology*, 63,103-114.

94. Asghar U., Malik M.F. and Javed A. (2016). Pesticide Exposure and Human Health: A Review. *J. Ecosys. Ecograph*, S5: 005. DOI: 10.4172/2157-7625.S5-005

95. Eddleston M, Karalliedde L, Buckley N, Fernando R, Hutchinson G, Isbister G, Konradsen F, Murray D, Piola JC, Senanayake N, Sheriff R, Singh S, Siwach SB and Smit L (2002). Pesticide poisoning in the developing world—a minimum pesticides list. *Lancet*, 360,1163–1167.

96. Pavela, R., Sajfrtova, M., Sovova, H., Barnet, M., Karban, J. (2010). The insecticidal activity of Tanacetum parthenium (L.) Schultz Bip. extracts obtained by supercritical fluid extraction and hydrodistillation. *Industrial Crops and Products*, 31, 449–454.

97. Franck E. Dayan, Charles L. Cantrell, Stephen O. Duke (2009). Natural products in crop protection. *Bioorganic & Medicinal Chemistry*, 17, 4022–4034.

98. Blankson W. Amoabeng, Anne C. Johnson and Geoff MGurr (2019). Natural enemy enhancement and botanical insecticide source: a review of dual use companion plants. *Applied Entomology and Zoology*, 54,1-19.

99. Smith A.G. and Gangolli S.D. (2002). Organochlorine chemicals in seafood: occurrence and health concerns. *Food and Chemical Toxicology*, 40, 767–779.

100. Walker K. and Lynch M. (2007). Contributions of Anopheles larval control to malaria suppression in tropical Africa: review of achievements and potential. *Medical and Vet¬erinary Entomology*, 21, 2–21.

101. Vasudha Lingampally, V. R. Solanki, Vidya Jayaram, Amarjit Kaur and S. Sabita Raja (2012). Betulinic acid: A potent insect growth regulator from Ziziphus jujuba against Triboliumconfusum [Duval]. *Asian Journal of Plant Science and Research*, 2(2), 198-206.

102. Khater, H.F. (2012). Prospects of Botanical Biopesticides in Insect Pest Management. *Pharmacologia*, 3, 641-656.

103. Vasudha Lingampally, V.R. Solanki, D.L. Anuradha and S. Sabita Raja (2014). Effect of Solasodine against Last Instar Larvae of Triboliumconfusum. *Journal of Entomology and Zoology Studies*, 2(3), 118-120.

104. McLaren, J.S. (1986). Biologically active substances from higher plants: Status and future potential. *Pesticide Science*, 17, 559–578.

105. I. Mahmood, S.R. Imadi, K. Shazadi, A. Gul and K.R. Hakeem (2016). Effects of pesticides on environment. in: Plant, Soil and Microbes, Springer, Cham, pp. 253–269.

106. Mehdi Nikkhah, Maryam Hashemi, Mohammad B. Habibi Najafi and Reza Farhoosh (2017). Synergistic effects of some essential oils against fungal spoilage on pear fruit. *International Journal of Food Microbiology*, 257, 285-294.

107. M.B. Isman (2006). Botanical insecticides, deterrents, and repellents in modern agriculture and an increasingly regulated world. *Annu. Rev. Entomol*., 51, 45–66.

108. M.E. Maffei, J. Gertsch, G. Appendino (2011). Plant volatiles: production, function and pharmacology. *Nat. Prod. Rep*., 28, 1359–1380.

109. Klocke, J.A. (1987). Natural plant compounds useful in insect control. *American Chemical Society Series*., 296, 396–415.

110. P.W. Green, A.P. Davis, A.A. Cosse and F.E. Vega (2015). Can coffee chemical compounds and insecticidal plants be harnessed for control of major coffee pests?. *J. Agric. Food Chem*., 63, 9427–9434.

111. John Lydon and Stephen O. Duke (1989). Pesticide effects on secondary metabolism of higher plants. *Pesticide Science*, (25) 4, 361-373.

112. Nakanishi K. (1977). In natural products and the protection of plants. Marini-Bettolo, G.B., ed., Elsevier, New York. pp. 185-210.

113. Balandrin MF, Klocke JA, Wurtele ES, Bollinger WH. (1985). Natural plant chemicals: Sources of industrial and medicinal materials. *Science*, 228, 1154-1160.

114. Isman MB, Matsuura H, Mackinnon S, Durst T,Towers GH and Arnason JT. (1996). Phytochemistry of the Meliaceae: So many terpenoids, so few insecticides. *Recent Adv. Phytochem*., 30, 155-178.

115. G.S. Neeraj, A. Kumar , S. Ram and V. Kumar (2017). Evaluation of nematicidal activity of ethanolic extracts of medicinal plants to Meloidogyne incognita (kofoid and white) chitwood under lab conditions. *Int. J. Pure Appl. Biosci*.,1,827–831.

116. Regnault-Roger C (2005c). New insecticides of plan origin for the third millenium?. In: Regnault-Roger C., Philogene ` BJR, Vincent C, eds. Biopesticides of Plant Origin. Paris, Lavoisier, and Andover, UK, Intercept. pp. 17–35.

117. Hermawan W., S. Nakajima, R.Tsukuda, K. Fujisaki and F. Nakasuji. (1997). Isolation of an antifeedant compound from Andrographis paniculata (Acanthaceae) against the diamondback moth, Plutellaxylostella (Lepidoptera: Yponomeutidae). *Applied Entomology and Zoology*, 32,551-559.

118. Talukder, F.A. and T. Miyata. (2002). In vivo and in vitro toxicities of pithraj and neem against rice green leafhopper (Nephotettixcincticeps Uhler). *Zeitschriftfür Pflanzenkrankheiten und Pflanzenschutz*, 109, 543-550.

119. Rozman V, Kalinovic I and Korunic Z. (2007). Toxicity of naturally occurring compounds of Lamiaceae and Lauraceae to three stored-product insects. *J Stored Prod Res*., 43, 349-355.

120. Ashwin Trivedi, Natasha Nayak and Jitendra Kumar (2018). Recent advances and review on use of botanicals from medicinal and aromatic plants in stored grain pest management. *Journal of Entomology and Zoology Studies*, 6(3), 295-300.

121. Ryšánek, P. Hall, F.R. and Menn, J.J. (1999). Biopesticides: Use and Delivery. *Biologia Plantarum*, 42, 566.

122. A Jeyasankar (2017). Phytochemicals: As Alternate to Chemical Pesticides for Insects Pest Management. *Current Trends in Biomedical Engineering & Biosciences*, Juniper Publishers Inc., 4(1), pp 3-4.

123. Kokwaro, J.O. (1976). Medicinal Plants of East Africa. East African Literature Bureau, Nairobi.Weaver, D.K., Subramanyam, Bh. (2000). Botanicals. In: Subramanyam, Bh., Hagstrum, D.W. (Eds), Alternatives to Pesticides in

Stored-Product IPM. Kluwer Academic Publishers, Boston, USA. pp. 303-320.

124. Grzywacz D., Stevenson P.C., Mushobozi W.L., Belmain S. and Wilson K. (2014). The use of indigenous ecological resources for pest control in Africa. *Food Security*, 6, 71–86.

125. Geraldin M.W. Lengai, James W. Muthomi, Ernest R. Mbega (2020). Phytochemical activity and role of botanical pesticides in pest management for sustainable agricultural crop production. *Scientific African*, 7, e00239, https://doi.org/10.1016/j.sciaf.2019.e00239.

126. Prakash, A., and J. Rao. (1997). Botanical pesticides in agriculture. CRC Press, Boca Raton, FL.

127. Weaver, D.K. and Subramanyam, Bh. (2000). Botanicals. In: Subramanyam, Bh., Hagstrum, D.W. (Eds), Alternatives to Pesticides in Stored-Product IPM. Kluwer Academic Publishers, Boston, USA. pp. 303-320.

128. Rattan, R.S. (2010). Mechanism of action of insecticidal secondary metabolites of plant origin. *Crop Prot*., 29, 913–920.

129. Pavela, R. (2016). History, presence and perspective of using plant extracts as commercial botanical insecticides and farm products for protection against insects—A review. *Plant Prot. Sci*., 52, 229–241.

130. Peixoto, M.G.; Bacci, L.; Fitzgerald Blank, A.; Araújo, A.P.A.; Alves, P.B.; Silva, J.H.S.; Santos, A.A.; Oliveira, A.P.; da Costa, A.S.; Arrigoni-Blank, M.d.F. (2015). Toxicity and repellency of essential oils of Lippia alba chemotypes and their major monoterpenes against stored grain insects. *Ind. Crops Prod*., 71, 31–36.

131. Cao, J.Q.; Guo, S.S.; Wang, Y.; Pang, X.; Geng, Z.F.; Du, S.S. (2018). Toxicity and repellency of essential oil from Evodia lenticellata Huang fruits and its major monoterpenes against three stored-product insects. *Ecotoxicol. Environ. Saf*., 60, 342–348.

132. Tandon, S. and Ak, M. (2018). Insecticidal and growth inhibitory activity of essential oils of Boenninghauseniaalbiflora and Teucrium quadrifarium against Spilarctiaobliqua. *Biochem. Syst. Ecol*., 81, 70–73.

133. Khan, H.A.A. (2021). Toxicity, repellent and oviposition deterrent effects of select essential oils against the house fly Musca domestica. *J. Asia-Pac. Entomol*., 24, 15–20.

134. Ahmad, W.; Singh, S. and Kumar, S. (2017). Phytochemical screening and antimicrobial study of Euphorbia hirta extracts. *J. Med. Plants Stud*., 5, 183–186.

135. Y. Rajashekar, L.J. Rao and T. Shivanandappa (2012). Decaleside: a new class of natural insecticide targeting tarsal gustatory sites. *Naturwissenschaften*., 99, 843–852.

136. S. Rajendran, V. Sriranjini (2008). Plant products as fumigants for stored-product insect control. *J. Stored Prod. Res*., 44, 126–135.

137. Y. Rajashekar, H.V. Kumar, K.V. Ravindra and N. Bakthavatsalam (2013). Isolation and characterization of biofumigant from leaves of Lantana camara for control of stored grain insect pests. *Ind. Crop. Prod*., 51, 224-228.

138. Y. Rajashekar, K.V. Ravindra, N. Bakthavatsalam (2014). Leaves of *Lantana camara* Linn. (Verbenaceae) as a potential insecticide for the management of three species of stored grain insect pests. *J. Food Sci. Technol*., 51, 3494–3499.

139. Rajashekar, Y., Bakthavatsalam, N. and Shivanandappa, T. (2012). Botanicals as Grain Protectants. *Psyche, Article* ID: 646740. http://dx.doi.org/10.1155/2012/646740

140. Y. Rajashekar, N. Tonsing, T. Shantibala, J.R. Manjunath (2016). 2, 3-Dimethylmaleic anhydride (3, 4-Dimethyl-2, 5-furandione) a plant derived insecticidal molecule from *Colocasia esculenta* var. *esculenta* (L.). *Schott Sci. Rep*., 6:20546.doi: 10.1038/srep20546.

141. Franck E. Dayan, Charles L. Cantrell, Stephen O. Duke (2009). Natural products in crop protection. *Bioorganic & Medicinal Chemistry*, 17, 4022–4034.

142. Dubey N.K. (2011). Natural Products in Pest Management. London, CAB International.

143. Belmain, S. and Stevenson, P. (2001). Ethnobotanicals in Ghana: Reviving and Modernizing Age-Old Farmer, Practice. *Pesticide Outlook*, 12, 233-238.

144. Isman, M. B. (1994). Botanical insecticides. *Pesticide Outlook*, June 1994. pp 26-31.

145. Golob, P., Webley, D.J. (1980). The use of plants and minerals as traditional protectants of stored products. *Report Tropical Product Institute*, G138.

146. Golob, P., Dales, M., Fidgen, A., Evans, J., Gudrups, I. (1999). The Use of Spices and Medicinals as Bioactive Protectants for Grains. FAO, Rome, Italy.

147. Obeng-Ofori, D. (2007). The use of botanicals by resource poor farmers in Africa and Asia for the protection of stored agricultural products. *Stewart Postharvest Review*, 6, 1-8.

148. Saxena, R.C., Dixit, O.P. and Harshan, V. (1992). Insecticidal action of Lantana camara against Callosobruchus chinensis (Coleoptera: Bruchidae). *Journal of Stored Product Research*, 28, 279-281.

149. Mondal Debashri and Mondal Tama (2012). A Review on efficacy of Azadirachta indica A. Juss based biopesticides: An Indian perspective. *Research Journal of Recent Sciences*, 1(3), 94-99.

150. Bajwa, A.A. and Ahmad, A. (2012). Potential Applications of Neem Based Products as Biopesticides. *The Health*, 3,116-120.

151. Finar, I.L. (1986). Stereochemistry and the chemistry of natural products. Organic chemistry. Vol. 2. Longman Publishers England. pp. 696-761.

152. Hellpap, S. and Dreyer, M. (1995). The smallholders' neem products in the neem tree: Source of unique natural products for Integrated Pest Management, Medicine, Industry and other purposes; H. Schmutterer Weinhein, Germany. pp. 3-6.

153. Isman MB, Koul O, Luczynski A and Kaminski J (1990). Insecticidal and antifeedant bioactivities of neem oils and their relationship to azadirachtin content. *J Agric Food Chem*., 38(6), 1406.

154. Lynn OML (2010). Effects of Azadirachtin and neem-based formulations for the control of sweetpotato whitefly and root-knot nematode. *J Korean Soc Appl Biol Chem*., 53(5), 598.

155. Boursier CM, Bosco D, Coulibaly A and Negre M (2011). Are traditional neem extract preparations as efficient as a commercial formulation of azadirachtin A?. *Crop Prot*, 30(3), 318.

156. Feng, R., and Isman, M. B. (1995). Selection for resistance to azadirachtin in the green peach aphid, Myzus persicae. *Experientia*, 51(8), 831–833.

157. Mordue, A. J., Morgan, E.D., and Nisbet, A. J. (2010). Azadirachtin, a naturalproduct in insect control. in Insect Control: Biological and synthetic agents, edsL. I. Gilbert and S. S. Gill (Elsevier; Academic), 185–203.

158. Kilani-Morakchi S, Morakchi-Goudjil H and Sifi K (2021). Azadirachtin-Based Insecticide: Overview, Risk Assessments, and Future Directions. Front. Agron., 3:676208.

159. Kossou DK (1989). Evaluation des differentsproduits du neem Azadirachta indica A. Juss pour le controle de Sitophilus zeamais Motsch sur le maisen post-récolte. *Int J Trop Insect* Sci., 10(03), 365.

160. Boeke SJ, Baumgart IR, van Loon JJA, van Huis A, Dicke M, Kossou DK (2004b). Toxicity and repellence of African plants traditionally used for the protection of stored cowpea against Callosobruchus maculatus. *J Stored Prod Res*., 40(4), 423.

161. Ilesanmi JO and Gungula DT (2010). Preservation of cowpea (Vigna unguiculata (L.) Walp) grains against cowpea bruchids (Callosobruchus maculatus) using neem and moringa seed oils. *Int J Agron*., (2), 1.

162. Ileke KD, Oni MO (2011). Toxicity of some plant powders to maize weevil, Sitophilus zeamais (Motschulsky) [Coleoptera: Curculiondae] on stored wheat grains (Triticum aestivum). *Afr J Agric Res*., 6(13), 3043.

163. Kemabonta KA, Falodu BB (2013). Bioefficacy of three plant products as post-harvest grain protectants against Sitophilus oryzae Linnaeus (Coleoptera: Curculionidae) on stored wheat (Triticum aestivum). *Int J Sci Nat*., 4(2), 259.

164. Ahmad T, Haile A, Ermias A, Etbarek R, Habteab S, Teklai S (2015). Ecofriendly approaches for management of bruchid beetle Callosobruchus chinensis (Coleoptera: Bruchidae) infesting faba bean and cowpea under laboratory conditions. *J Stored Prod Postharvest Res*., 6(3),25.

165. R.C. Gupta (2014). Rotenone. Editor(s): Philip Wexler, Encyclopedia of Toxicology (Third Edition), Academic Press, pp. 185-187. ISBN 9780123864550,

166. Isman M.B. (2008). Botanical insecticides: for richer, for poorer. *Pest Manag Sci*, 64(1), 8.

167. Ogendo JO, Belmain SR, Deng AL, Walker DJ (2003). Comparison of toxic and repellent effects of Lantana camara L. with Tephrosia vogelii Hook and a synthetic pesticide against Sitophilus zeamaisMotschulsky (Coleoptera: Curculionidae) in stored maize grain. *Int J Trop Insect Sci*., 23(02), 127.

168. Mkenda PA, Stevenson PC, Ndakidemi P, Farman DI, Belmain SR (2015). Contact and fumigant toxicity of five pesticidal plants against Callosobruchus maculatus (Coleoptera : Chrysomelidae) in stored cowpea (Vigna unguiculata). *Int J Trop Insect Sci*., 35(04), 172.

169. Stevenson PC, Kite GC, Lewis GP, Forest F, Nyirenda SP, Belmain SR, Sileshi GW, Veitch NC (2012). Distinct chemotypes of Tephrosia vogelii and implications for their use in pest control and soil enrichment. *Phytochem*., 78, 135.

170. Boeke SJ, Baumgart IR, van Loon JJA, van Huis A, Dicke M and Kossou DK (2004). Toxicity and repellence of African plants traditionally used for the protection of stored cowpea against Callosobruchus maculatus. *J Stored Prod Res*., 40(4), 423.

171. Longe OO (2016). Evaluating the efficacy of some plant powders on the bean weevil [Callosobruchus maculatus (fabricius) (Coleoptera: Bruchidae)] affecting stored cowpea seeds (Vigna unguiculata). *Asian J Sci Technol*., 7(2),2486

172. S. Ali, S.M.H. Muhammad, A. Muneer, H. Faisal, F. Muhammad, H. Dilbar, S. Muhammad and G. Abdul (2014). Insecticidal activity of turmeric (Curcuma longa) and garlic (Allium sativum) extracts against red flour beetle, Triboliumcastaneum: a safe alternative to insecticides in stored commodities. *J. Entomol. Zool. Stud*., 3, 201-205.

173. A.G. Sarmamy, H. Hashim, A. Sulayman (2011). Insecticidal effects of some aqueous plant extracts on the control of Khapra Trogoderma granarium. Evert Proceedings of the International Conference on Chemicals, Biological, and Environmental Sciences (ICCEBS-December, 2011), pp. 55-70.

174. Jbilou, R., Ennabili, A. and Sayaha, F. (2006). Insecticidal activity of four medicinal plant extracts against Tribolium castaneum (Herbst) (Coleoptera: Tenebrionidae). *African Journal of Biotechnology*, 5(10), 936-940.

175. Julien Dougoud, Stefan Toepfer, Melanie Bateman and Wade H. Jenner (2019). Efficacy of homemade botanical insecticides based on traditional knowledge. A review. *Agronomy for Sustainable Development*, 39, 37.

176. Suresh Walia, Supradip Saha and Virendra S. Rana (2014). Phytochemical Pesticides. D. Singh (ed.). Advances in Plant Biopesticides, Springer India. DOI 10.1007/978-81-322-2006-0_15

177. Showket. A Dar; Nisar. A. Dar; Mudasir. A. Bhat andMudasir. H. Bhat (2014). Prospects, Utilization and Challenges of Botanical Pesticides in Sustainable Agriculture. *International Journal of Molecular Biology & Biochemistry*, 2(1), 1-14.

178. Nyirenda SP, Sileshi GW, Belmain SR, Kamanula JF, Mvumi BM, Sola P, Nyirenda GKC and Stevenson PC (2011). Farmers' ethno-ecological knowledge of vegetable pests and pesticidal plant use in Northern Malawi and Eastern Zambia. *Afr J Agric Res*., 6(2), 41–49.

179. Kamatenesi-Mugisha M, Buyungo JP, Egwang P, Vudriko P, Gakunga JN, Deng A, Ogendo J, Mihale JM (2012). Evaluation of the biosafety of selected botanical pesticide plants used by subsistence farmers around the Lake Victoria basin. In: Ethnobotany and health Proceedings of the cluster workshop, Lake Victoria Research Institute, Uganda, pp 45–57.

180. Kiruba S, Jeeva S, Kanagappan M, Stalin IS and Das SSM (2008). Ethnic storage strategies adopted by farmers of Tirunelveli district of Tamil Nadu, Southern Peninsular India. *J Agric Technol*., 4(1), 1.

181. Green PWC, Belmain SR, Ndakidemi PA, Farrell IW and Stevenson PC (2017). Insecticidal activity of Tithonia diversifolia and Vernonia amygdalina. *Ind Crop Prod*., 110, 15.

182. Borrás-Linares, I., Stojanović, Z., Quirantes-Piné, D., Arráez-Román, R., Švarc-Gajić, J., Fernández-Gutiérrez, A. and Segura-Carretero, A. (2014). Rosmarinus Officinalis Leaves as a Natural Source of Bioactive Compounds. *Int J Mol Sci*., 15, 20585-20606.

183. Alvaroz, M.R., Heralde, F. and Quiming, N. (2016). Screening for Larvicidal Activity of Ethanolic and Aqueous Extracts of Selected Plants against Aedes aegypti and Aedes albopictus Larvae. *J Coast Life Med*., 4(2), 143-147.

184. Erdogan, P., Yildirium, A. and Sever, B. (2012). Effects of Five Different Plant Extracts on the Two Spotted Mite Tetranychus urticate Koch (Arachnida: Tetranychidae). Pshyche.

185. Isman, M.B. (2005). Problems and opportunities for the commercialization of botanical insecticides. In C. Regnault-Roger, B.J.R. Philog‘ene and C. Vincent (eds.), Biopesticides of Plant Origin, Lavoisier, Paris. pp. 283–291.

186. Lale, N. E. S. (1995). An overview of the use of plant products in the management of stored product Coleoptera in the tropics. *Postharvest News and Information*, 6, 69-75.

187. Bisen, K., Keswani, C., Patel, J.S., Sarma, B.K., Singh, H.B. (2016). Trichoderma spp.: Efficient Inducers of Systemic Resistance in Plants. In: Choudhary, D.K., Varma, A. (eds) Microbial-mediated Induced Systemic Resistance in Plants. Springer, Singapore.

188. Kumar, S. and Singh, A. (2015). Biopesticides: present status and the future prospects. *Journal of Fertilizers and Pesticides*, 6, e129.