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Use of biorational insecticides for the management of storage insect pests: A review

Uso de insecticidas biorracionales para el manejo de plagas de insectos de almacenamiento: Una revisión

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Abstract

Pests of various species cause havoc on storage grains, resulting in both qualitative and quantitative grain losses. Insect pests feed stored grains and reduce the weight, nutritional content, and germination of these grains. Contamination, odor, mold, and heat damage are also caused by infestations, decreasing the grain's quality and rendering it unfit for human or animal consumption. Commercial grain buyers might choose between refusing to accept insect-infested grain or paying a reduced price for it. Various pest management practices have been tried. The emergence of insecticidal and fungicidal resistance, as well as damage to non-target organisms and acute and chronic effects on humans and the environment have necessitated the use of biorational methods over chemical control of storage-product pests. The term biorational refers to several products that are relatively non-toxic and have few environmental adverse effects. Biorational techniques, such as the use of microbials, pheromones, and food attractants, natural enemies, botanicals, and biological control, were used as alternatives to chemical pesticides for suppressing and controlling storage-product pests. To ensure food security and agricultural sustainability, the use of such biorational chemicals is unavoidable.

Keywords: *grain infestation, microbials, pheromones, botanicals, natural enemies*

Resumen

Las plagas de varias especies causan estragos en los granos almacenados, lo que resulta en pérdidas de granos tanto cualitativas como cuantitativas. Las plagas de insectos alimentan los granos almacenados y reducen el peso, el contenido nutricional y la germinación de estos granos. La contaminación, el olor, el moho y el daño por calor también son causados por infestaciones, lo que disminuye la calidad del grano y lo vuelve inadecuado para el consumo humano o animal. Los compradores comerciales de granos pueden elegir entre negarse a aceptar granos infestados de insectos o pagar un precio reducido por ellos. Se han probado varias prácticas de manejo de plagas. La aparición de resistencia a insecticidas y fungicidas, así como el daño a organismos no objetivo y los efectos agudos y crónicos en humanos y el medio ambiente han requerido el uso de métodos biorracionales sobre el control químico de plagas de productos almacenados. El término biorracional se refiere a varios productos que son relativamente no tóxicos y tienen pocos efectos ambientales

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adversos. Las técnicas biorracionales, como el uso de microbios, feromonas y atrayentes alimentarios, enemigos naturales, productos botánicos y control biológico, se utilizaron como alternativas a los plaguicidas químicos para suprimir y controlar las plagas de productos almacenados. Para garantizar la seguridad alimentaria y la sostenibilidad agrícola, el uso de estos productos químicos biorracionales es inevitable.

Palabras clave: *infestación de granos, microbios, feromonas, botánicos, enemigos naturales*

INTRODUCTION

Agro-based enterprises support the most of the world's population, both directly and indirectly. Pests attack crops at all stages of development, from early vegetative to flowering, fruiting, and harvest. Even after harvest, a large range of pest groups, including bacteria, fungus, insects, rodents, and birds, continues to damage these commodities. Storage pests are pests that cause damage to stored commodities, lowering their nutritional and economic worth, and more than 20,000 species of field and storage pests harm around one-third of worldwide food production worth more than $100 billion per year (Shukla & Toke, 2013). According to Yankanchi et al. (2014), tropical storage-grain insects cause 20-30% qualitative and quantitative grain loss, while temperate storage-grain insects cause 5-10%. Several of pest management methods have been tried, with some issues regarding their effectiveness and effects rose each time. In comparison to other pest categories, cereals have a greater interaction with insect pests. Chemical insecticides have been used to control a number of stored products (Arthur & Rogers, 2003), but due to scale limitations or lack of appropriate chemical control, interest in biological control techniques is growing, for instance, the parasitoid beetles are used to manage stored product beetles (Schöller et al., 2006). On a commercial basis, several biological pest management techniques are available and the biocontrol measures used are in stored grains and goods.

Storage-product pests have caused damage to stored products, not only by destroying the product and rendering it unfit for consumption but also by causing a significant economic loss. According to Hagstrum & Flinn (1995), such insect pests can have a significant economic impact on stored grains and processed products. These insects do not require a significant amount of food, since a food accumulation on cracks and crevices, inside machinery, and under the floor is sufficient (Campbell et al., 2004). It is also challenging for humans to clean and handle such waste. Chemical pesticides can serve as a check, but they are not a long-term solution because various insect pests may develop resistance to them (Subramanyam & Hagstrum, 1995). Pesticide use in agriculture has caused health issues, environmental issues, yield loss owing to non-target chemical application, which has resulted in pesticide-induced pest resurgence, and finally a financial load on farmers (Koirala et al., 2009). Farmers are affected by headache, eye burning, skin irritation, teary eyes, weakness, and other ailments and discomforts because of pesticide application (Atreya, 2012). Pesticide exposure also causes acute diseases such headaches, skin irritation, respiratory and throat discomfort (Yassin, 2002). Long-term pesticide exposure causes major health problems like cancer, endocrine disruption, and neurological consequences (Reigart & Roberts, 1999). Similarly, long-term low-dose pesticide exposure has been associated with health problems such as immune suppression, hormone disruption, decreased memory, reproductive abnormalities, and cancer (Gupta, 2004).

Storage-grain pests cause economic losses as well as a reduction in the nutritional value of stored products, rendering them unfit for consumption (Padin et al., 2002). Pest-related losses have been estimated to reach around 9% in developed countries and up to 20% in developing countries (Phillips & Throne, 2010). Developed countries have various infrastructures, a scientific environment for evaluation, and systematic policies in place to deal with the damage that such pests can cause. For pests of stored products, biological control measures may be more effective than chemical pesticides because they can be hidden inside the storage room behind sacs, machinery, holes, and other places difficult to access, and chemical control is difficult to implement. Many biological control techniques have been used to control stored bulk grains. The ability of parasitic wasps such as *Theocolax elegans* and *Anisopteromalus calandrae* to effectively suppress and control various pest populations in bulk grain storage is one example (Scholler & Flinn, 2000). Species such as *Beauveria bassiana*, *Nosema* spp. Vuillemin, *Mattesia* spp., and *Metarhizium anisopliae* have been examined and evaluated. However, only limited testing of such organisms has been done (Brower et al., 1995). Similarly, the bacterium *Bacillus thuringiensis* (Bt.) has been employed as a grain- protectant in the United States, and it has been used to suppress Indian meal moth larvae in India (Brower et al., 1995). Stored grain pests face similar issues from lepidopteran pests, which have been targeted with different biocontrol agents. The bacterium *B. thuringiensis* is useful in controlling lepidopteran larvae that have been attacking stored grains, but resistance has also been reported (McGaughey & Beeman, 1988). Granulosis virus, which is available on a commercial scale in the market, has been used to control the moth on stored products such as nuts and fruits, particularly dry fruits (Vail, 1991).

Physical control (inert dust, ionizing radiation, light and sound), thermal control (low temperature control, high temperature disinfection), ionization, and fumigation are the methods used to control storage-grain pests in addition to bio control approaches. In North America and Africa, inert dusts have been proven to be efficient in controlling various storage insects (Fields & Muir, 1996). Calcium was added to Diatomaceous Earth (DE), which is made up of the fossilized remains of diatoms. Using ionizing radiation to control storage-grain pests can be an effective and environmentally benign method. Low temperatures also reduce feeding behavior and fertility, as well as storage pest survival (Longstaf & Evans, 1983). Phosphine and methyl bromide are two typical fumigants used for storage pest management, according to Rajendran & Sriranjini (2008). Poor countries are still falling behind due to a lack of awareness and concern about the storage grain pests and the extent of their damage. Synthetic insecticides and fumigants are important chemical control strategies for stored-grain insects (Zettler & Arthur, 2000; Benhalima et al., 2004). However, the usage of such chemical pesticides harms consumers' health and the environment while also increasing insecticidal resistance. The use of biological approaches poses little to no risk to the environment (Edde, 2012). The objective of this review paper was to gather information on biorational insecticides for managing the storage insect pests.

Storage Pests

Major insect pests of stored grains include lesser grain borer (*Rhyzopertha dominica*), rice weevil (*Sitophilus oryzae*), khapra beetle (*Trogoderma granarium*), rust red flour beetle (*Tribolium castaneum*), long headed flour beetle (*Latheticus oryzae*), saw toothed beetle (*Oryzaephilus surinamensis*), rice moth (*Corcyra cephalonica*), almond moth (*Cadra cautella*), Angoumois grain moth (*Sitotroga cerealella*), pulse beetles (*Callosobruchus chinensis*, *C. maculates, C. analis*) (Ahmad et al., 2021). The non-insect pests include rodents, mites and fungi. *Aspergillus* and *Penicillium* are common fungi that cause damage to crops in both the storage and field. According to the hypothesis, during storage and microbial growth, the microbes use the carbohydrate and oil deposits, causing a loss of those elements and negatively affecting germination capacity (Mohapatra et al., 2017). Fungi can damage grain quality in various ways. According to (Multon, 1988), such fungi are responsible for lowering the baking quality of wheat grain. Also, fungi produce the toxic metabolites, known as mycotoxins, such as aflatoxins, fusariotoxins, ochratoxins, fumonisins, trichothecenes, deoxynivalenol zearalenone, citrinin, patulin, Alternariatoxins and moniliformin (Mohapatra et al., 2017). The cumulative effect of all storage pests is what causes damage to the stored grains and other products. Insects are the most serious hazard to stored products, mainly grains. Indeed, they interact and associate with the crop at an early stage, causing damage both during crop standing and storage. Hundreds of bug species are responsible for the infestation of stored products. Some of the storage grains pests along with their hosts are listed in Table 1.

Table 1: List of pests of stored grains

Common name	Pest	Host
Rice moth	*Corcyra cephalonica*	N/A
Lesser grain borer	*Rhyzopertha dominica*	N/A
Pulse beetle	*Callosobruchus chinensis C. maculates*	Pulses, bean and grain
Tamarind/groundnut bruchid	*Caryedon serratus*	Groundnut, tamarind and other legumes
Rice weevil	*Sitophilus oryzae, S. zeamais, S. granaries*	Rice, wheat, Sorghum, maize, barley
Khapra beetle	*Trichoderma granarium*	Cereals, groundnut and pulses
Angoumois grain moth	*Rhyzopertha dominica*	Paddy, maize and wheat
Grain moth	*Sitotroga cerealella*	Rice, wheat and maize
Potato tuber moth	*Phthorimaea operculella*	Potato
Red flour beetle	*Tribolium castaneum, T. confusum*	Broken grains, damaged grains, milled products, machinery
Long-headed flour beetle	*Latheticus oryzae*	N/A
Cigarette beetle	*Lasioderma serricorne*	Wheat flour, cereal bran, groundnut, chillies, cocoa beans, spices, turmeric
Drug store beetle	*Stegobium paniceum*	Turmeric, coriander, ginger, dry vegetable and animal matter
Sweet potato weevil	*Cylas formicarius*	Sweet potato
Saw toothed grain beetle	*Cryptolestus minutas , Laemophloeus pusillus*	Dry fruits, maize, cereals and oil seeds
Red rust grain beetle	*Cryptolestes ferrugineus*	N/A
Flat grain beetle	*Cryptolestes pusillus*	N/A

Source: Ahmed (1983)

Rodents, particularly mice and rats, have a greater impact on the quality of stored grains. Storage structures, electrical installations, and a water pipe have all been reported to be damaged (Smith, 1995). House mice (*Mus musculus*), brown rats (*Rattus norvegicus*), and black rats (*Rattus rattus*) affect field and stored-grain in many ways (Table 2). The nature, behavior, and habitat of these rats have all been widely investigated (Lund, 1994). *Citellus* spp., *Tamias* spp., *Xerus* spp., *Funiscurus* spp., and *Halosciurus* spp. are some of the other ground or tree squirrels that eat stored grains (Smith, 1995).

Loss Assessment

Several storage pests, including insects, mites, fungi, and rodents, can cause grain loss. Insect consumption of grains or products includes not only direct kernel consumption but also the accumulation of detritus, leaving the product unfit for human consumption. They also cause harm to grains by poking holes in them for oviposition. Insect pests caused a 12% loss before harvest and 36% loss after the harvest of grains. Insect-related losses have been estimated to be between 5 and 10%, with up to 30% in the tropics (Ahmad et al.,

Table 2: Important rodent species damaging stored grains

Rodent species	Common name	Habitat
Rattus rattus	House rat	Rural and urban residential places
Bandicota indica	Large bandicoot rat	Rural environment
Rattus meltada	Soft furred field cat	Crop fields and grassland
Mus musculus	House mouse	Warehouse and godowns
Mus booduga	Field mouse	Crop fields
Bandicota bengalensis	Indian mole rat	Stores, warehouses and crop fields
Tatera indica	Indian gerbil	Crop fields and grassland

Source: (Indian Grain Storage and Management and Research Institute, 2021; Tobin & Fall, 2004)

2021). This has resulted in an annual loss of $200 million in net storage crop value in the United States (Weaver & Petroff, 2004). The pulse beetle (*C. chinensis* L.) has caused massive qualitative and quantitative losses. Pest damage caused a quantitative loss (a decrease in the weight of stored grains), a qualitative loss (a decrease in size, an unappealing shape, and the accumulation of pest wastes), and a reduction in seed viability. Psocid pests are annoyance and a concern for godowns and storage facilities (Kleih & Pike, 1995). They have been found to cause an apparent grain degradation and loss (about 3% in a storage period of 6 months). *Prostephanus truncatus* is a severe corn pest in East and West Africa, causing more damage to unhusked corn (Group for Assistance on Systems Relating to Grains After Harvest, 1987). Mite is a lesser-known but more serious issue to storage products. They feed on germ section of stored grains and release storage fungus and bacteria, according to Fleurat-Lessard (1988). *Aspergillus halophilicus, A. restrictus, A. glaucus, A. candidus, A. ochraceus*, and *A. flavus* are some fungi that damage the grain germ and cause discoloration (Hall & Harman, 1991). *C. maculatus* (Fab.) (Coleoptera: Bruchidae) is a significant pest of cowpea that causes greater damage. The indication of insect- infested stored products is given in Table 3.

Biorational management

Microbials

Various types of microbials or microbial pesticides have been employed to reduce the effect of different storage grain pests, mainly insects. Spinosad, a popular bacterial pesticide, is made from the metabolites of an Actinomycete bacterium called *Saccharopolyspora spinosa*. The bacterial pesticide was used to effectively manage stored wheat grains that lost weight owing to insects (Flinn et al., 2004). When exposed to UV rays from the sun, spinosad loses its insecticidal properties within a week, making it difficult to use in open fields. However, it has been reported that it can retain its insecticidal activity for up to 12 months when stored away from sunlight, making it beneficial in the control of the smaller grain borer (*R. dominica* F.) and the Red flour beetle (*T. castaneum* Herbst). The application of 1mg of spinosad per kg of wheat under stored conditions provided complete control and progeny suppression of the F1 in grain beetle (*Cryptolestes pusillus* Schonherr), the confused flour beetle (*T. confusum*), and the rusty grain beetle (*Cryptolestes ferrugineus* Stephens) (Fang et al., 2002).

Pheromones

Pheromones are chemicals released or excreted by individual organisms that cause responses in other members of the same species. Mass trapping and mating disruption techniques and pheromones have been successfully used in pest management. In fields, many pheromone baited traps can be employed to catch newly emerged moth males and reduce the number of males available for mating. Pheromones are typically seen to be safer and more environmentally friendly than conventional pesticides because

Table 3: Indication of insect-infested stored products

Indication	Commodities	Insects
Pupal cases sticking to shells and gunny bags	Groundnuts in shells	*Caryedon serratus*
Eggs on grain surface	Pulses (whole)	*Callosobruchus* spp.
Webbing or silken strands	whole and milled cereals	*Corcyra cephalonica, Plodia interpunctella*
	Oilseed/oilcakes	*Ephestia cautella, Plodia interpunctella*.
	Dry fruits	*E. cautella*
	Tree nuts	*E. cautella*
Exit holes	Wheat, rice, maize	*Rhyzopertha dominica, Sitophilus* spp.
	Paddy	*Sitotroga cerealella*
	Pulses(whole)	*Callosobruchus* spp.

Source: Rajendran (1999)

they exist naturally, may target specific pest species, have low acute toxicity to vertebrates, and are usually volatile compounds that do not leave harmful residues (Dang et al., 2016). Pheromone monitoring traps help focus and narrow down the investigation to certain locations. We can detect and locate stored- product pests (SPPs) population via pheromone monitoring before they can cause major product damage. They function as hormones outside the body of the creature that secretes them, influencing the organism that receives them (Trematerra, 2011). According to Phillips et al. (2000), about 20 different species of stored-product insects have slow-release formulations of pheromone lures in monitoring traps. Pheromones are used by the Indian meal moth (*Plodia interpunctella)*, the cigarette beetle (*Lasioderma serricorne* F.; Coleoptera: Anobiidae), the Red and Confused flour beetles (*T. castaneum* and *T. confusum* Jacquelin du Val, respectively), and the Warehouse beetle (*Trogoderma variabile* Ballion; Coleoptera: Dermestidae). The placement of the pheromones is critical for them to act efficiently. In an experiment, responding beetles were suffocated after passing through a corrugation tunnel to the cup of oil (Barak & Burkholder, 1985). According to Nansen et al. (2004), male *P. interpunctella* were attracted to pheromone-baited traps on flat landing sites.

Natural Enemies for stored-product pest

The application or release of any natural enemy depends on the history of the pest and background knowledge. Before releasing any natural enemy for control, important aspects such as understanding of its lifecycle, behavior, feeding mode, etc, are critical. Some natural enemies or predators kill their prey right after an attack, whereas others require a close biosystemic connection to do so (Hagstrum & Subramanyam, 2006). The former is classified as a generalist, whereas the latter is classified as a specialist. The pirate warehouse bug (*Xylocoris flavipes*) is a generalist that feeds on the eggs and larvae of insects that feed on stored products (Arbogast, 1975). The Histerid beetle (*Teretriosoma nigrescens*), which feeds on beetles, is another example (Rees, 1985). Such beetles feed on various families of hazardous beetles, protect stored grains and products from pest damage. Egg parasitoids of *Trichogramma* spp. westwood are one of the possible generalist parasitoids employed widely in the investigation of its potential on field crops (Wajnberg & Hassan, 1994). The use of the parasitoid *Theocolax elegans*, and other different pests such as the Weevil (*Sitophilus* spp.), Lesser grain borer (*R. dominica*), Drugstore beetle (*Stegobium paniceum*), Cowpea weevil (*Callosobruchus* spp.), and Angoumois grain moth (*S. cerealella*) have been effectively suppressed (Flinn & Hagstrum, 2001; Flinn, 1998). The type of natural enemy to be used, as well as how it should be handled and implemented, is determined in part by the storage situation because the pest complex for numerous species is encountered while considering storage pest control (Press et al., 1982).

Botanicals

Botanicals are plant-derived chemical compounds that are employed as insect repellents, deterrents for feeding and oviposition, and disruptions of insect pest biochemistry, physiology, and behavior. Several spice crops, such as chilli, garlic, turmeric, ginger, and botanicals, such as neem, bakaino, century plant, undi, China berry, and lac tree, have been used successfully to control insect pests (Shukla et al., 2007). According to Srinivasan (2008), several plant items have been successfully evaluated with satisfactory results as preventatives against various stored-grain insect pests. Pigeon pea was tested for 8 months against pulse beetle damage with neem seed oil at 10 mL/Kg, mahua oil at 10 mL/kg and a mass fraction of 4 % of neem seed kernel, all of which were found to be repellent and powerful oviposition inhibitors (Singal & Chouhan, 1997). For the control of coleopteran insect pests on stored grains, essential oils were proven to be a satisfactory alternative to chemical insecticides (Pérez et al., 2010). Kiruba et al. (2008) reported that *C. chinensis* (L.) oviposition and F1 emergence were suppressed on red gram treated with 2 mL/kg ginger grass oil. Similarly, when essential oils of *Cymbopogon citratus*

(Stapf) and *Cymbopogon nardus* (Rendle) were applied to rice grains (*Oryza sativa* L.) for the control of Cowpea bruchid (*C. maculatus* (F.)), oviposition and F1 emergence were delayed compared to a control study (Paranagama et al., 2003). Garlic (*Allium sativum*) has been found to resist *T. castaneum*, and its oil proved effective in killing *T. castaneum* and *S. zeamais* (Ho, 1995). Turmeric (*Curcuma longa*) repels various insects, when 2 % turmeric powder is added to rice and wheat, it kills a variety of storage pests (Jilani & Su, 1983). Neem (*Azadirachta indica*) has pesticide properties in almost every part of the plant, with the seed kernel being the most potent. *T. granarium* can be controlled with neem products, while the pulse weevil can be controlled using 0.5 % neem oil as a surface protectant (Ketkar, 1987). The oil of the lac tree (*Schleichera trijuga*) is used as a surface protectant against the pulse weevil, and the extract is used as a repellent and insecticidal against *S. zeamais* adults and *T. castaneum* eggs (Ketkar, 1987). Teotia & Tewari (1971) suggested that China berry (*Melia azedarach*) leaf and drupe powders (1 % and 4 %), respectively, protect wheat against *S. cerealella*. The list of spices and botanicals used to control storage product pests is given in Table 4.

Biological Control

Biological control of storage-product pests includes a variety of entomopathogenic fungi, nematodes, bacteria, predators, parasitoids, and wasps. These biological control agents are commercially available only when scaled up for organic synthesis, according to Weaver & Petroff (2004). Entomopathogenic fungi (EPF) are a viable commercial treatment against a range of insects in open field conditions, such as termites, among other biological control approaches (Rath, 2000). Unfortunately, little progress has been made in terms of commercial availability while in storage. Conidia of the entomopathogenic fungi have been used in dry or mixed form (with rice grain) against stored-grain insects (Kaur et al., 2014). Sedehi et al. (2014) conducted an experiment with different isolates that resulted in moderate to high mortality at various phases (immature stage and adult stage). The conidia of *B. bassiana* were suspended in a mixture of corn oil and mineral oil and applied to *S. zeamais*, with the oil suspension formulation having more efficacy among the three formulations. According to Batta et al. (2010), liquid formulations of entomopathogenic fungus were successful in controlling *S. granarius, R. dominica, S. oryzae*,

Table 4: List of spices and botanicals used to control storage pests

Scientific name	Common name	Effect on storage pest	References
Spices			
Syzygium aromaticum	Clove tree	Repels *T. castaneum*. Repels a number of grain insects	Grainge & Ahmed (1988)
Zingiber officinale	Ginger	Causes adult mortality in *C. chinensis* and repels *T. castaneum*	Ho (1995)
Piper nigrum	Black pepper	Inhibit development of F1 of *Callosobruchus chinensis*	Morallo-Rejesus et al. (1990)
Allium sativum	Garlic	Repels *Tribolium castaneum*. Oil kills *T. castaneum* and *Sitophilus zeamais* Strong repellent for *T. castaneum* and *S.zeamais*	Ho (1995)
Curcuma longa	Turmeric	Repels a number of stored insects. A 2% powder mix with rice and wheat can protect from storage pests	Jilani & Su, (1983)
Botanicals			
Calophyllum Inophyllum	Undi	Oil used as surface protectant against pulse weevils	Ketkar, (1987)
Vitex negundo	Indian privet	Leaves have insecticidal property against stored-grain pests	Ahmed & Koppel (1987)
Agave americana	Century plant,	Leaves are used against stored pests	Grainge & Ahmed (1988)

and *T. molitor*. Entomopathogenic nematodes acts as endoparasites of storage pests (Gaugler et al., 2002) that were found to be a successful biocontrol option (Kaya & Gaugler, 1993). Though entomopathogenic nematodes have not been studied much for storage pest management, they do have some qualities that make them a good biocontrol option. They are not harmful to vertebrates and several species are commercially available (Bathon, 1996; Grewal, 2002). Tolerance to various pesticides (Koppenhöfer et al., 2000), a wide host range (Capinera & Epsky, 1992), and active host finding capacity are all important characteristics of such nematodes (Lewis & Campbell, 2002). They have been used as biocontrol agents against a variety of storage-grain insects. They are used to control Pyralidae and Curculionidae (Shannag & Capinera, 2000) and storage insects (Shapiro & McCoy, 2000). Morris (1985) proved that nematodes can effectively suppress storage product insects such as *T. molitor* L. and *Ephestia kuehniella* Zeller.

Anthocorid bugs have efficiently controlled *C. cephalonica* as well as other insect pests such as thrips, aphids, and mealy bugs, in cropping systems in Sub-Saharan Africa and the Mediterranean region (Zhang *et al*., 2012; Efe & Cakmak, 2013; Wang et al., 2014). A predatory bug, *X. flavipes,* is one of the most important biological control agents used against stored-grain pests such as moths, mites, and bruchids (Rahman et al., 2009). *Blaptostethus pallescens*, a biocontrol agent, has efficiently reduced the eggs and larvae of lepidopteran pests, sucking pests such as mealy bugs, aphids, thrips, mites, and stored insect pests (Kaur et al., 2019). The combo of *B. bassiana* ARSEF 5500 and *M. anisopliae* ARSEF 2974 isolates had the highest mortality rate (51.66 %) among rice weevil (*S. oryzae* L.) (Dal Bello et al., 2000).

Monitoring of stored grain pests

Monitoring of stored-grain pests aids in the identification and isolation of pest populations and prevents both qualitative and quantitative losses in stored commodities. It also advises the practitioners to learn about the efficacy of a specific integrated pest management (IPM) strategy for a specific storage-product pest (Campbell et al., 2002). The type and nature of the pest, commodity, and storage methods all influence the pest monitoring technique. Some monitoring systems and techniques include bulk commodity storage, pheromone attractant, food attractant, and white painted bins. Additionally, new monitoring techniques include parasitoid stored product detection using near infrared spectroscopy and grain rotting detection using electronic nose technology. Food attractants for flour beetles (*Tribolium* spp.) as well as attractiveness to *Attagenus*, *Trogoderma*, and *Anthrenus* larvae can improve the effectiveness of pheromone traps (Burkholder & Ma, 1985). It has been used to distinguish between infested and non-infested wheat kernels in order to identify wheat internal insect pests (Dowell et al., 1998). It is also been employed in wheat to determine the difference between unparasitized and parasitized weevil larvae by wasps (Burks et al., 2000). Electronic nose technology has been employed recently for the rapid detection of grain quality by taking grain attributes such as odor and volatility into account (Magan and Evans, 2000).

CONCLUSION

Biorational pesticides can be an environmentally-friendly and long-term alternative to chemical pesticides in various ways. Natural enemies, such as predators and parasitoids, can be employed to control pests. However, prior to releasing any natural enemy, critical considerations such as understanding of its life cycle, behavior, and style of feeding must be made. Various types of microbials or microbial pesticides have been employed to reduce the impact of a variety of storage grain pests, especially insects. Botanicals, or chemical compounds produced from plants, such as *A. sativum, C. longa, M. azedarach, A. indica*, and others, can be employed as insect repellents, deterrents for feeding and oviposition, and disruptors of insect pests' biochemistry, physiology, and behavior. Pheromones, as biorational chemicals, can be an effective pest control tool for a variety of storage grain pests, particularly insects. They function as hormones outside of the body of the creature that secretes them, having an influence on the organism that receives them. Entomopathogenic fungi and nematodes can also be used as biological controls to counteract the use of chemicals. Biorational methods should be promoted, scaled up, and commercialized so that they may effectively control diseases without acquiring resistance on the one hand and recover the environment on the other.

Author contributions

Elaboration and execution, development of methodology, conception and design; editing of articles and supervision of the study have involved all authors.

Conflicts of interest

The signing authors of this research work declare that they have no potential conflict of personal or economic interest with other people or organizations that could unduly influence this manuscript.

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REFERENCES

Ahmad, R., Hassan, S., Ahmad, S., Nighat, S., Devi, Y. K., Javeed, K., Usmani, S., Ansari, M. J., Erturk, S., Alkan, M., & Hussain, B. (2021). Stored Grain Pests and Current Advances for Their Management. In Md Ahiduzzaman (Ed.), *Postharvest Technology- Recent Advances, New Perspectives and Applications*. IntechOpen. https://doi.org/10.5772/intechopen.101503

Ahmed, H. (1983). Losses incurred in stored food grains by insect pests-a review. *Pakistan Journal of Agricultural Research*, *4*(3), 198–207.

Ahmed, S., & Koppel, B. (1987). Use of neem and other botanical materials for pest control by farmers in India: summary of findings. *Natural Pesticides from the Neem Tree*, 623–626.

Arbogast, R. T. (1975). Population growth of *Xylocoris flavipes*: influence of temperature and humidity. *Environmental Entomology*, *4*(5), 825–831. https://doi.org/10.1093/ee/4.5.825

Arthur, F. H., & Rogers, T. (2002, july 22-26). *Legislative and regulatory actions affecting insect pest management for postharvest systems in the United States* [Conference]. Proceedings of the 8th International Working Conference on Stored Product Protection, York, UK, (pp. 435–438). CABI Publishing.

Atreya, K., Johnsen, F. H., & Sitaula, B. K. (2012). Health and environmental costs of pesticide use in vegetable farming in Nepal. *Environment, Development and Sustainability*, *14*(4), 477–493. https://doi.org/10.1007/s10668-011-9334-4

Barak, A. V., & Burkholder, W. E. (1985). A versatile and effective trap for detecting and monitoring stored-product Coleoptera. *Agriculture, ecosystems & environment*, *12*(3), 207–218. https://doi.org/10.1016/0167-8809(85)90112-4

Bathon, H. (1996). Impact of entomopathogenic nematodes on non-target hosts. *Biocontrol Science and Technology*, *6*(3), 421–434. https://doi.org/10.1080/09583159631398

Batta, Y., Murdoch, G., & Mansfield, S. (2010). Investigations into the formulation and efficacy of entomopathogenic fungi against larvae of yellow mealworm (*Tenebrio molitor* L., Coleoptera: Tenebrionidae). *General and Applied Entomology: The Journal of the Entomological Society of New South Wales*, *39*, 5–8.

Benhalima, H., Chaudhry, M. Q., Mills, K. A., & Price, N. R. (2004). Phosphine resistance in stored-product insects collected from various grain storage facilities in Morocco. *Journal of Stored Products Research*, *40*(3), 241–249. https://doi.org/10.1016/S0022-474X(03)00012-2

Brower, J., Smith, L., Vail, P., & Flinn, P. (1995). Biological control. In B. Subramanyam, and D. Hagstrum (Eds.), *Integrated Management of Insects in Stored Products* (pp. 223–286). New York, Marcel Dekker.

Burkholder, W. E., & Ma, M. (1985). Pheromones for monitoring and control of stored-product insects. *Annual Review of Entomology*, *30*(1), 257–272.

Burks, C. S., Dowell, F. E., & Xie, F. (2000). Measuring fig quality using near-infrared spectroscopy. *Journal of stored products Research*, *36*(3), 289–296. https://doi.org/10.1016/S0022-474X(99)00050-8

Campbell, J. F., Arthur, F. H., & Mullen, M. A. (2004). Insect management in food processing facilities. *Advances in food and nutrition research*, *48*(2), 239–295. https://doi.org/10.1016/S1043-4526(04)48005-X

Campbell, J. F., Mullen, M. A., & Dowdy, A. K. (2002). Monitoring stored-product pests in food processing plants with pheromone trapping, contour mapping, and mark-recapture. *Journal of Economic Entomology*, *95*(5), 1089–1101. https://doi.org/10.1093/jee/95.5.1089

Capinera, J. L., & Epsky, N. D. (1992). Potential for biological control of soil insects in the Caribbean basin using entomopathogenic nematodes. *Florida Entomologist*, 75, 525–532. https://doi.org/10.2307/3496134

Dal Bello, G., Padin, S., Lastra, C. L., & Fabrizio, M. (2000). Laboratory evaluation of chemical-biological control of the rice weevil (*Sitophilus oryzae* L.) in stored grains. *Journal of Stored Products Research*, *37*(1), 77–84. https://doi.org/10.1016/S0022-474X(00)00009-6

Dang, C. H., Nguyen, C. H., Im, C., & Nguyen, T. D. (2016). Synthesis and Application of Pheromones for Integrated Pest Management in Vietnam. In *Integrated Pest Management (IPM): Environmentally Sound Pest Management*. IntechOpen. https://doi.org/10.5772/63768

Dowell, F. E., Throne, J. E., & Baker, J. E. (1998). Automated nondestructive detection of internal insect infestation of wheat kernels by using near-infrared reflectance spectroscopy. *Journal of Economic Entomology*, *91*(4), 899–904. https://doi.org/10.1093/jee/91.4.899

Edde, P. A. (2012). A review of the biology and control of *Rhyzopertha dominica* (F.) the lesser grain borer. *Journal of Stored Products Research*, *48*, 1–18. https://doi.org/10.1016/j.jspr.2011.08.007

Efe, D., & Cakmak, I. (2013). Life table parameters and predation of *Orius niger* (Wolf) (Hemiptera, Anthocoridae) feeding on two different prey. *Turkish Journal of Entomology, 37*, 161–67.

Fang, L., Subramanyam, B., & Dolder, S. (2002). Persistence and efficacy of spinosad residues in farm stored wheat. *Journal of economic entomology*, *95*(5), 1102–1109. https://doi.org/10.1093/jee/95.5.1102

Fields, P. G., & Muir, W. E. (1996). Physical control. In B. Subramanyam (Eds.), *Integrated management of insects in stored products* (pp. 195–221). CRC Press. https://doi.org/10.1201/9780203750612

Fleurat-Lessard, F. (1988). Grain mites, general characteristics and consequences of their presence in stocks. In *Preservation and storage of grains, seeds and their by-products: cereals, oilseeds, pulses and* *animal feed* (pp. 409–416).

Flinn, P. W. (1998). Temperature effects on efficacy of *Choetospila elegans* (Hymenoptera: Pteromalidae) to suppress *Rhyzopertha dominica* (Coleoptera: Bostrichidae) in stored wheat. *Journal of Economic Entomology*, *91*(1), 320–323. https://doi.org/10.1093/jee/91.1.320

Flinn, P. W., & Hagstrum, D. W. (2001). Augmentative releases of parasitoid wasps in stored wheat reduces insect fragments in flour. *Journal of Stored Products Research*, *37*(2), 179–186. https://doi.org/10.1016/S0022-474X(00)00018-7

Flinn, P. W., Subramanyam, B., & Arthur, F. H. (2004). Comparison of aeration and spinosad for suppressing insects in stored wheat. *Journal of economic entomology*, *97*(4), 1465–1473. https://doi.org/10.1093/jee/97.4.1465

Group for Assistance on Systems Relating to Grains After-harvest (1987). *Larger Grain Borer.* Kent, Technical Leaflet No. I, NRI.

Randy Gaugler, & Han R. (2002). Production technology. In Gaugler Randy, & R. Han (Eds.), *Entomopathogenic nematology* (pp. 289–310).

Grainge, M., & Ahmed, S. (1988). *Handbook of plants with pest-control properties*. John Wiley & Sons Limited.

Grewal, P. (2002). Formulation and application technology. In R. Gaugler (Ed.), *Entomopathogenic Nematology* (pp. 265–287). UK, CABI Publishing, Wallingford.

Gupta, P. K. (2004). Pesticide exposure-Indian scene. *Toxicology*, *198*(1–3), 83–90. https://doi.org/10.1016/j.tox.2004.01.021

Hagstrum, D., & Flinn, P. (1995). Integrated Pest Management. In B. Subramanyam, D. Hagstrum, B. Subramanyam, & D. Hagstrum (Eds.), *Integrated Management of Insects in Stored Products* (pp. 399–408). New York, Marcel Dekker.

Hagstrum, D. W., & Subramanyam, B. (2006). Chapter-11 Biological Control. In *Fundamentals of Stored-Product Entomology* (pp. 151–156). Elsevier. https://doi.org/10.1016/B978-1-891127-50-2.50017-X

Hall, J. S., & Harman, G. E. (1991). Protection of stored legume seeds against attack by storage fungi and weevils: Mechanism of action of lipoidal and oil seed treatments. *Crop Protection*, *10*(5), 375–380. https://doi.org/10.1016/S0261-2194(06)80027-X

Ho, S. H. (1995, July). Grain quality maintenance through the use of bioactive compounds from spices. In *17th ASEAN Technical Seminar on Grain Postharvest Technology, Perak, Malaysia*, *25*, p. 27.

Indian Grain Storage and Management and Research Institute (2021). *Rodent pests*. Hapur, U.P., India. https://igmri.dfpd.gov.in/igmri/rodent-pests

Jilani, G., & Su, H. C. (1983). Laboratory studies on several plant materials as insect repellants for protection of cereal grains. *Journal of Economic Entomology*, *76*(1), 154–157. https://doi.org/10.1093/jee/76.1.154

Kaur, R., Sharma, S., Shera, P. S., & Sangha, K. S. (2019). Evaluation of anthocorid predator, *Blaptostethus pallescens* Poppius against spider mite, *Tetranychus urticae* Koch on Okra under insect net cage condition. *Journal of Biological Control*, *33*(3), 236–241.

Kaur, S., Thakur, A., & Rajput, M. (2014). A laboratory assessment of the potential of *Beauveria bassiana* (Balsamo) Vuillemin as a biocontrol agent of *Corcyra cephalonica* Stainton (Lepidoptera: Pyralidae). *Journal of Stored Products Research*, *59*, 185–189. https://doi.org/10.1016/j.jspr.2014.08.004

Kaya, H. K., & Gaugler, R. (1993). Entomopathogenic nematodes. *Annual review of entomology*, *38*(1), 181–206. https://doi.org/10.1146/annurev.en.38.010193.001145

Ketkar, C. M. (1987). Use of tree-derived nonedible oils as surface protectants for stored legumes against *Callosobruchus maculatus* and *C. chinensis*. In *Natural pesticides from the neem tree (Azadirachta indica A. Juss) and other tropical plants. Proceedings of the 3rd International Neem Conference, Nairobi, Kenya, 10-15 July, 1986*. (pp. 535–542). Deutsche Gesellschaft für Technische Zusammenarbeit.

Kiruba, S., Jeeva, S., Kanagappan, M., Stalin, S. I., & Das, S. S. M. (2008). Ethnic storage strategies adopted by farmers of Tirunelveli district of Tamil Nadu, Southern Peninsular India. *Journal of Agricultural Technology*, *4*(1), 1–10.

Kleih, U., & Pike, V. (1995). Economic assessment of psocid infestations in rice storage. *Tropical science*, *35*, 280-289.

Koirala, P., Dhakal, S., & Tamrakar, A. S. (2009). Pesticide application and food safety issue in Nepal. *Journal of Agriculture and Environment*, *10*, 128–132. https://doi.org/10.3126/aej.v10i0.2137

Koppenhöfer, A. M., Brown, I. M., Gaugler, R., Grewal, P. S., Kaya, H. K., & Klein, M. G. (2000). Synergism of entomopathogenic nematodes and imidacloprid against white grubs: greenhouse and field evaluation. *Biological control*, *19*(3), 245–251. https://doi.org/10.1006/bcon.2000.0863

Lewis, E. E., & Campbell, J. F. (2002). Entomopathogenic nematode host search strategies. *The Behavioral Ecology of Parasites*, 13–39. https://doi.org/10.1079/9780851996158.0013

Longstaff, B. C., & Evans, D. E. (1983). The demography of the rice weevil, *Sitophilus oryzae* (L.)(Coleoptera: Curculionidae), submodels of age-specific survivorship and fecundity. *Bulletin of Entomological Research*, *73*(2), 333–334. https://doi.org/10.1017/S0007485300008920

Lund, M. (1994). Rodents as commensal pests. In: A. Buckle & R. Smith (eds.), *Rodent Pests and Their Control. Buckle AP, Smith*.

Magan, N., & Evans, P. (2000). Volatiles as an indicator of fungal activity and differentiation between species, and the potential use of electronic nose technology for early detection of grain spoilage. *Journal of Stored Products Research*, *36*(4), 319–340. https://doi.org/10.1016/S0022-474X(99)00057-0

McGaughey, W. H., & Beeman, R. W. (1988). Resistance to *Bacillus thuringiensis* in colonies of Indianmeal moth and almond moth (Lepidoptera: Pyralidae). *Journal of Economic Entomology*, *81*(1), 28–33. https://doi.org/10.1093/jee/81.1.28

Mohapatra, D., Kumar, S., Kotwaliwale, N., & Singh, K. K. (2017). Critical factors responsible for fungi growth in stored food grains and non-Chemical approaches for their control. *Industrial Crops and Products*, *108*, 162–182. https://doi.org/10.1016/j.indcrop.2017.06.039

Morallo-Rejesus, B., Maini, H. A., Ohsawa, K., & Yamamoto, I. (1990). Insecticidal Actions of Several Plants to *Callosobruchus chinensis* L. In *Bruchids and Legumes: Economics, Ecology and Coevolution* (pp. 91–100). Springer, Dordrecht. https://doi.org/10.1007/978-94-009-2005-7_10

Morris, O. N. (1985). Susceptibility of 31 species of agricultural pests to entomogenous nematodes *Steinernema feltiae* and *Heterorhabditis bacteriophora*. *The Canadian Entomologist, 117*(4), 401–407. https://doi.org/10.4039/Ent117401-4

Multon, J. L. (1988). Spoilage mechanisms of grains and seeds in the postharvest ecosystem, the resulting losses and strategies for the defense of stocks. New York, Lavoisier.

Nansen, C., Phillips, T. W., & Sanders, S. (2004). Effects of height and adjacent surfaces on captures of Indianmeal moth (Lepidoptera: Pyralidae) in pheromone-baited traps. *Journal of economic entomology*, *97*(4), 1284–1290. https://doi.org/10.1093/jee/97.4.1284

Padın, S., Dal Bello, G., & Fabrizio, M. (2002). Grain loss caused by *Tribolium castaneum*, *Sitophilus oryzae* and *Acanthoscelides obtectus* in stored durum wheat and beans treated with *Beauveria bassiana*. *Journal of Stored Products Research*, *38*(1), 69–74. https://doi.org/10.1016/S0022-474X(00)00046-1

Paranagama, P. A., Abeysekera, T., Nugaliyadde, L., & Abeywickrama, K. P. (2003). Effect of the essential oils of *Cymbopogon citratus*, *C. nardus* and *Cinnamomum zeylanicum* on pest incidence and grain quality of rough rice (paddy) stored in an enclosed seed box. *Journal of Food, Agriculture and Environment, 1*(2), 134–136.

Pérez, S. G., Ramos-López, M. A., Zavala-Sánchez, M. A., & Cárdenas-Ortega, N. C. (2010). Activity of essential oils as a biorational alternative to control coleopteran insects in stored grains. *Journal of Medicinal Plants Research*, *4*(25), 2827–2835.

Phillips, T. W., & Throne, J. E. (2010). Biorational approaches to managing stored-product insects. *Annual review of entomology*, *55*, 375–397. https://doi.org/10.1146/annurev.ento.54.110807.090451

Phillips, T. W., Cogan, P. M., & Fadamiro, H. Y. (2000). Pheromones. In: B. Subramanyam & D.W. Hagstrum (eds.), *Alternatives to Pesticides in Stored-product IPM* (pp. 273–302). Springer, Boston, MA. https://doi.org/10.1007/978-1-4615-4353-4_10

Press, J. W., Cline, L. D., & Flaherty, B. R. (1982). A comparison of two parasitoids, *Bracon hebetor* (Hymenoptera: Braconidae) and *Venturia canescens* (Hymenoptera: Ichneumonidae), and a predator *Xylocoris flavipes* (Hemiptera: Anthocoridae) in Supressing residual populations of the almond moth, *Ephestia cautella* (Lepidoptera: Pyralidae). *Journal of the Kansas Entomological Society*,*55*(4), 725–728. https://www.jstor.org/stable/25084352

Rahman, M. M., Islam, W., & Ahmed, K. N. (2009). Functional response of the predator *Xylocoris flavipes* to three stored product insect pests. *International Journal of Agriculture and Biology*, *11*(3), 316–320.

Rajendran, S. (1999). Detection of insect infestation in stored food commodities. *Journal of Food Science and Technology, 36*, 283–300.

Rajendran, S., & Sriranjini, V. (2008). Plant products as fumigants for stored-product insect control. *Journal of stored products Research*, *44*(2), 126–135. https://doi.org/10.1016/j.jspr.2007.08.003

Rath, A. C. (2000). The use of entomopathogenic fungi for control of termites. *Biocontrol Science and Technology*, *10*(5), 563–581. https://doi.org/10.1080/095831500750016370

Rees, D. P. (1985). Life history of *Teretriosoma nigrescens* Lewis (Coleoptera: Histeridae) and its ability to suppress populations of *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae). *Journal of Stored Products Research*, *21*(3), 115–118. https://doi.org/10.1016/0022-474X(85)90002-5

Reigart, J. R., & Roberts, J. R. (1999). *Recognition and management of pesticide poisonings*. US Environmental Protection Agency.

Schöller, M., & Flinn, P. (2000). Parasitoids and Predators. In B. Subramanyam, & D. Hagstrum (Eds.), *Alternatives to Pesticides in Stored-Product IPM* (pp. 229–271). Massachusetts, Kluwer Academic Publishers, Norwell.

Schöller, M., & Prozell, S. (2005, November). Natural enemies to control stored-product pests in grain stores and retail stores. In *Proceedings of the International Workshop on Implementation of Biocontrol in Practice in Temperate Regions—Present and Near Future* (pp. 85–106).

Sedehi, A., Sedaghatfar, E., & Modarres-Najafabadi, S. S. (2014). Studies on effect of the *Beauveria bassiana* on eggs and larvae of *Plodia interpunctella*. *Canadian*

Journal of Basic & Applied Science, 2(02), 40–45.

Shannag, H. K., & Capinera, J. L. (2000). Interference of *Steinernema carpocapsae* (Nematoda: Steinernematidae) with *Cardiochiles diaphaniae* (Hymenoptera: Braconidae), a parasitoid of melon worm and pickleworm (Lepidoptera: Pyralidae). *Environmental Entomology*, *29*(3), 612–617. https://doi.org/10.1603/0046-225X-29.3.612

Shapiro, D. I., & McCoy, C. W. (2000). Virulence of entomopathogenic nematodes to *Diaprepes abbreviatus* (Coleoptera: Curculionidae) in the laboratory. *Journal of Economic Entomology*, *93*(4), 1090–1095. https://doi.org/10.1603/0022-0493-93.4.1090

Shukla, A., & Toke, N. R. (2013). Plant products as a potential stored product insect management agents. *Indian Journal of Research*, *2*(2), 4–6.

Shukla, R., Srivastava, B., Kumar, R., & Dubey, N. K. (2007). Potential of some botanical powders in reducing infestation of chickpea by *Callosobruchus chinensis* L. (Coleoptera: Bruchidae). *Journal of Agricultural Technology*, *3*(1), 11–19.

Singal, S. K., & Chauhan, R. (1997). Effect of some plant products and other materials on development of pulse beetle, *Callosobruchus chinensis* (L.) on stored pigeonpea, *Cajanus cajan* (L.) Millsp. *Journal of Insect Science*, *10*(2), 196–197.

Smith, R. H. (1995). Rodents and birds as invaders of stored-grain ecosystems. In: Jayas DS, White NDG, Muir WE (eds.), *Stored grain ecosystems* (pp. 289–323). Marcel Dekker, New York,, USA.

Srinivasan, G. (2008). Efficacy of certain plant oils as seed protectant against pulse beetle, *Callosobruchus chinensis* Linn. on pigeonpea. *Pesticide Research Journal*, *20*(1), 13–15.

Subramanyam, B., & Hagstrum, D. (1995). Resistance measurement and management. In B. Subramanyam, & D. Hagstrum (Eds.), *Integrated Management of Insects in Stored Products* (pp. 331–397). New York, Marcel Dekker.

Trematerra, P. (2011). Advances in the use of pheromones for stored-product protection. *Journal of Pest Science*, *85,* 285–299. https://doi.org/10.1007/s10340-011-0407-9

Teotia, T. P. S., & Tiwari, G. C. (1971). Dharek drupes and leaves as protectants against *S. cerialotta* infesting wheat seeds. *Bull Grain Technol*, *9*, 7–12.

Tobin, M. E., & Fall, M. W. (2004). Pest control: rodents. In *Agricultural Sciences, from Encyclopedia of Life Support Systems* (EOLSS). UNESCO, Eolss Publishers, Oxford ,UK.

Vail, P. V. (1991). *U.S. Patent No. 5,023,182*. Washington, DC: U.S. Patent and Trademark Office.

Wajnberg, E., & Hassan, S. (Eds.). (1994). *Biological Control with Egg Parasitoids.* Wallingford, U.K, CAB International.

Wang, S., Michaud, J. P., Tan, X. L., & Zhang, F. (2014). Comparative suitability of aphids, thrips and mites as prey for the flower bug *Orius sauteri* (Hemiptera: Anthocoridae). *European Journal of Entomology*, *111*(2), 221–226. https://doi.org/10.14411/eje.2014.031

Weaver, D. K., & Petroff, A. R. (2004). *Pest management for grain storage and fumigation*. Montana Department of Agriculture.

Yankanchi, S. R., Jadhav, A. D., & Patil, P. M. (2014). Insecticidal and repellant activities of *Clerodendrum serratum* L. leaf extract against rice weevil, *Sitophilus oryzae* L. *Asian Journal of Biological and Life Sciences*, *3*(1), 35–39.

Yassin, M. M., Mourad, T. A., & Safi, J. M.

(2002). Knowledge, attitude, practice, and toxicity symptoms associated with pesticide use among farm workers in the Gaza Strip. *Occupational and environmental medicine*, *59*(6), 387–393. http://dx.doi.org/10.1136/oem.59.6.387

Zettler, J. L., & Arthur, F. H. (2000). Chemical control of stored product insects with fumigants and residual treatments. *Crop Protection*, *19*(8-10), 577–582. https://doi.org/10.1016/S0261-2194(00)00075-2

Zhang, S. C., Zhu, F., Zheng, X. L., Lei, C. L., & Zhou, X. M. (2012). Survival and developmental characteristics of the predatory bug *Orius similis* (Hemiptera: Anthocoridae) fed on *Tetranychus cinnabarinus* (Acari: Tetranychidae) at three constant temperatures. *European Journal of Entomology*, *109*(4), 503.